Original Research Paper

Volume - 11 | Issue - 03 | March - 2021 | PRINT ISSN No. 2249 - 555X | DOI : 10.36106/ijar

Physical Education

UNDERSTANDING THE THEORETICAL MECHANISMS BEHIND PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION THROUGH THE EXPERIMENTAL STUDIES ON BRAIN

Manabendra Majhi*	Research Scholar, Exercise and Sport Science Laboratory,Department of Physical Education and Sport Science,Visva- Bharati (Central University),Santiniketan,Zip code-731235,India. *Corresponding Author
Samiran Mondal	Professor, Exercise and Sport Science Laboratory,Department of Physical Education and Sport Science,Visva- Bharati (Central University),Santiniketan,Zip code 731235,India.
Sridip Chatterjee	Assistant Professor, Department of Physical Education, Jadavpur University,Kolkata, India.
Deepeshwer Singh	Associate Professor, S-VYASA Yoga University, Bangalore, India.

ABSTRACT **Background:** Four theoretical mechanisms: Autogenic inhibition, Reciprocal inhibition, Stress relaxation, and Gate control theory tried to explain Proprioceptive Neuromuscular Facilitation (PNF) stretching with a common activation area in the brain. However, the experimental supports regarding PNF and Brain functions are very limited. **Purpose of the Study:** The study aimed was to identify empirical research regarding PNF, which supports the theoretical mechanisms mainly, the brain functions. **Methods:** To compile data sources and data extraction in relation to its participants, interventions, comparisons, outcomes and study design, screen, collaborate, and synthesize the items PRISMA guideline was followed. A total of six papers identified following the strict exclusion and inclusion criteria. **Result:** Within the five brain and PNF related studies, four studies measured brain activity using electrophysiological methods, and one study observed motor evoked potentials, and another study measured Brain-Derived Neurotrophic Factor (BDNF). Three studies were randomized control trial. However the sample size, method structure, and statistical applications were also the limitation of these studies. **Finding:** PNF stretching may activate both the right and left hemispheres; sensory cortex; motor and pre motor cortex; working memory and; increase BDNF level which may develop brain plasticity. **Conclusion:** After PNF stretching, the activation of Central Nervous System (CNS) especially the brain areas, has been corroborated with the findings of the reported experimental studies.

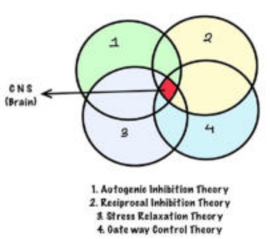
KEYWORDS : Cortex; Sensory Cortex; Motor Cortex; Pre motor Cortex; Memory Cortex; Brain Chemicals.

Introduction:

Movement is a fundamental neuromuscular activity of rhythmical progression, resulting in a change of position, pace, posture and place**.** The sensory cortex, motor cortex, pre-motor cortex and supplementary motor area in the different lobe of the brain are mainly responsible to initiate, execute, feedback and control of movements in the human body. It is a long standing evident and obvious fact that movement produce by skeletal muscle positively influence our brain function. Movement is also an essential modality to execute daily living activities including household activities, walking, sitting, lying, running, driving and also task specific activities. The movement is also essential for neurocognitive functions of human being. If they lose any functional capacity in the limbs for that, one has to understand the mechanisms involved in the execution of movement for example- brain and neural activity is very important in regaining lost functional ability (Moreira et al.2017; Costa et al, 2017).

PNF stretching was first developed as a method of physical therapy and rehabilitation. It is an established neuromuscular rehabilitation process for muscular injury and illness, circulo-respiratory disorders and especially for neurological impairment. The muscles, tendons, and joint receptors are involved in this process (Powers and Howley, 2018; Hindle et al., 2012). Scientists hypothesized four theories on PNF mechanisms that are the autogenic inhibition (Sharman et al, 2006), the reciprocal inhibition (Rowlands et al.2003), the stress relaxation (Sharman et al, 2006), and the gate way control theory (Konoza, 2018; Mazzullo,1978). All the theories are emphasizing central nervous system control, especially in the brain over PNF stretching (Fig.1).

Figure 1: Central Nervous System (CNS) and four PNF Theories overlapping area.



Existing research evidence reported that PNF stretching might increase physical fitness: strength (Sanavi et al.2013; Nogueira et al, 2010); endurance (Gomes et al.,2010); flexibility (Ruas et al.,2018; Ramachandran et al. 2018; Lim, 2018; Lempke et al.2018; Ferber et al,2002;), and Balance (Szafraniee et al.2018; Ghram et al. 2016). PNF stretching may also improve sports performance**:** Football (Derbachew et al.2019; Oliveira et al.2018; Jordan et al.2012); Basketball (Naderifar et al.2018); Athletics (Kaya, 2018).

In the management of rehabilitation PNF stretching widely used throughout the world: for chronic low back pain (Areeudomwong and Buttagat, 2019; Kofotolis and Kellis.2006); shoulder rehabilitation (Tedla and Sangadala, 2019; Lee, 2015; Ravichandran and Balamurugan.2020) and spinal cord injury (Crnkovic et al.2018).

PNF proved its importance for stroke rehabilitation (Kim and Kim, 2018; Chaturvedi et al.2017); Hemiplegic condition (Ali et al. 2015; Kumar et al.2012;); and myofascial pain syndrome (Lee et al. 2013). Further, PNF plays a vital role in human physiological process, including circulatory (Ha et al.2017; Krima and Falak,2016; Silva et al,2013; Hurtado et al. 2011; Gultekin et al.2006); and respiratory functions (Souza et al.2020; Ptaszkowska et al.2019; Ashtankar and Kazi,2019).

PNF on neurology (Kaya et al.2018; Smedes et al.2018; Marek et al. 2005); and brain function research was gaining momentum recently (Chaturvedi et al. 2018; Costa et al.2017; Moreira et al. 2017; Lial et al. 2017; Shimura and Kasai.2002; Nakamura and Kosaka,1986). Hindle et al. (2012) rightly pointed out that there is a little empirical evidence to support four theoretical mechanisms of PNF techniques and suggested for further research. Recently, International PNF Association in their website and others (Smedes et al. 2016) suggested that evident-base practice approach for PNF.

The present review study aimed was to identify and analyze authentic scientific experimental studies related to brain functions and PNF stretching for better understanding the theoretical mechanisms already stated by scientists.

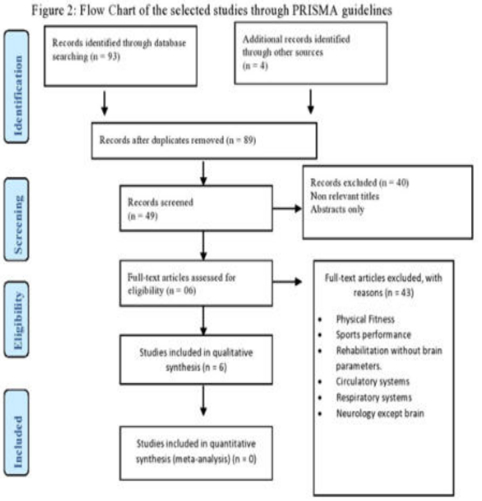
Methods:

Identification of relevant studies:
The aim of this review was to understand the brain related mechanisms of PNF stretching. The present study followed the guideline of Preferred Reporting Systematic Reviews and Meta- Analysis (PRISMA) proposed by Moher et al.2009. We used the following database to identify studies from inception to May 2020 that have examined the role of PNF stretching on brain functions: MEDLINE, PubMed, Elsevier, Archives of Budo,Web of Science, IPNFA, Biomed Central, Springer, Somatosensory and Motor research, Science Direct, PEDro, and Cochrane library. The relevant published articles were identified using the following keywords like PNF and Cortex; Sensory Cortex; Motor Cortex; Pre motor Cortex; Memory Cortex; Brain Chemicals. Only the experimental studies were extracted from various searches of related papers.

Inclusion and Exclusion Criteria:
The criteria of eligibility were included; i) The papers should be published in English language ii) The papers were accessible in online iii) Quantitative and Qualitative data of PNF stretching iv) Brain function and related aspects. The papers were considered which have published up to the month of May 2020 with no starting line. We did not set any limitations of published studies in terms of age, gender for the target groups etc. The duplicate citation papers have been excluded.

Study selection:
An assessment of eligibility was identified by the researchers. The selected literatures were downloaded with reference. The duplicate manuscripts were eliminated. The eligible titles and the abstracts were screened. Then the full text articles on PNF stretching as an intervention in different age and gender group with the brain related variables were downloaded. The inclusion and exclusion were determine after reading the full texts articles. The total records of 93 identified from search data base at the initial stage. After removed of duplicates, 89 titles and abstracts were checked for inclusion. After the eligibility check a total of 49 literatures were extracted as full texts. After examined all the full texts 43 studies were excluded. For the final qualitative synthesis six studies fulfill the criteria completely in the systematic review. Fig.2 presents the PRISMA flowchart that summarize the of the study selection process.

Figure 2: Flow Chart of the selected studies through PRISMA guidelines



Study Characteristics:
Out of six brain related studies, four studies contained the prevalence related information for brain waves. Out of four studies 3 studies are done on alpha band absolute power, and one is for beta band absolute power. One study reported on motor cortex evoked potential, and other study was on brain chemical (BDNF). Among the six studies, three studies were done in South America, and one was done in Asia on electrophysiology. Study on motor evoked potential, and Brain-Derived Neurotrophic Factor (BDNF) was done in Asia.

Findings:
After thoroughly completing the systematic review process under the PRISMA guideline, only six experimental papers were identified to meet the objectives of the study. In the following chronologically the studies were presented:

Brain Chemical: Brain-Derived Neurotropic Factor (BDNF)
Chaturvedi et al. (2018) observed Brain-Derived Neurotropic Factor (BDNF) in the serum which is responsible for neuroplasticity, before and after PNF stretching and task-specific training interventions on 90 male and female patients (age range 40-70 years) with first time stroke. The subjects were divided into two groups: PNF and task-specific training for upper and lower extremity. Both the groups received the intervention for 30 minutes twice a daily, 5days in a week for 4 weeks. After 4 weeks and 6 months serum BDNF level was measured in both the groups. They reported raised in serum BDNF level from baseline to 4 weeks and 6 months in both the groups. The PNF group showed more improvement in BDNF level. BDNF the most abundant neurotropin within the brain, it promotes neurogenesis and angiogenesis which are very effective for the development of neuroplasticity (Kurozumi et al.2004; Schabitz et al. 2007).

Cortical activity: Sensory and Motor cortex, Pre motor and Working memory Cortex
Moreira et al.(2017) investigated the differences in the electrophysiological responses triggered by PNF and shoulder flexion movements performed without the diagonal component on cortical electrical activity. They analyzed the differences by using the cortical potentials produced by the motor task before and after the execution of movements specifically through the beta band absolute power levels produced in the dorsolateral prefrontal cortex, primary motor cortex, and parietal cortex. They hypothesized that PNF diagonal upper movement would produce a greater increase in absolute beta band power than flexion in the sagittal plane alone. It was a self-control cross-sectional study conducted in a brain mapping laboratory. Thirty right-handed sedentary female participants, 21.36 $\pm$ 2.18 years mean age and with a mean of body mass index 23 $\pm$ 2.27 kg/m^2. The exclusion criteria was musculoskeletal and joint disorder in the upper limb and any kind of cardiopulmonary or neurocognitive diseases, the individuals with functional limitation in the performance of resistance movement, amputees, participants those who have used psycho active drugs or less than 8 hours slept the night before the experiment. The signals of EEG was measured by using a standard medical instrument with electrodes arranged according to the international 10-20 systems in an isolated acoustically control recording room.The participants were randomized into three groups: i). No performance of movement during the task interval (control), ii) PNF group starting with the wrist and fingers, the participant flexed the hand on the contralateral leg in order to simulate the starting position standardized by PNF, i.e., the participant performed an extension of the wrist and fingers, an extension of the elbow with flexion, abduction, and external rotation in the right upper limb; Flex, upper limb flexion, adduction and rotation, held in the sagittal plane, i.e., the hand was initially placed on the ipsilateral leg with the wrist and fingers in flexion. All the participants have received instruction from a physiotherapist, and when they performed all the movements correctly, then the EEG signals data was captured.

They observed that the absolute beta band power increases in both the right and left dorsolateral prefrontal cortex, especially in the PNF group suggest a greater need for planning movement execution in a diagonal movement, consistent with greater neural adaptations in these regions. The result also seems to indicate that PNF increased working memory activity since this function is control by the dorsolateral prefrontal cortex, which shows an increase in absolute power following PNF. They also reported the primary motor cortex demonstrated increase beta band power in the PNF group means greater control of movements and kinesthetic responses. This in turn required greater participation of the motor cortex in the movement processing and execution because of muscle recruitment and proprioceptive stimuli (Hoshi,2006).

The beta power increase also observed in the parietal cortex, suggesting that PNF requires to increase cortical activity to integrate somatosensory information related to the movement (Cabeza et al. 2008; Teixeira et al.2014). PNF appears to involve the coordination of more difficult motor sequences and requires greater muscle recruitment and articulation (Witt et al.2011). This indicate that more cognitive control and neural plastic adaptation are necessary for PNF (Sauvage et al. 2015; Zhorne, 2016). So that the motor task may be learned and perform correctly (Macdonald, 2000). PNF may have greater attention demand so that the movement performed required better coordination spatial organization (Johansen-Berg and Matthews,2002). They concluded that PNF increased dorsolateral prefrontal cortex activity which control working memory and generate greater changes in parietal cortex activity, a cortical region whose function relate to the integration of motor information.

Lial et al.(2017) investigated electrophysiological activity in the dorsolateral prefrontal cortex and superior parietal pattern. The hypothesis of this study was that the alpha band absolute power would be higher in the PNF group compared to the group that carried out the movement in the sagittal plane and PNF would promote greater neuromuscular recruitment and generate a greater stimulation of muscle and joint receptors. 30 female participants with an average age of 21.3 $\pm$ 2.1 years and with a BMI range between 18.5 and 24.99 were included in this study. They excluded women with musculoskeletal and joint disorders in the right upper limb and the presence of any circulo-respiratory and neurocognitive diseases and with functional limitations, amputation. The participants should not have used psychoactive drugs or slept less than 8 hours the night before the experiment. The volunteers were performed diagonal PNF with right upper limb flexion as well as abduction and external rotation with elbow extension and radial deviation of the wrist and fingers. The movement began with the positioning of the upper extension of the right limb, internal rotation, and adduction of the shoulder, elbow extension, wrist flexion, and then the deviation of the fingers and ulnar. The experiment was started with the participants positioned in the medial thigh contralateral position. The participants received instruction of PNF movement by an experienced trainer. Once the participants understood the PNF movement correctly, then the EEG measurement was collected. The task was carried out in a standard experimental room and the participants were sitting comfortably when the EEG signals were captured. They observed that the absolute alpha power was higher in the cortical areas of the left hemisphere compared with the right hemisphere in the PNF group. As it is directly related to motor planning processing and the level of care required for movement in the PNF diagonal as the fronto-parietal circuit participants in the joint planning of motor action. The fronto-parietal circuit is integrated to the specialization of movement. Especially in decision making processes related to motor action. (Andersen and Cui 2009; Capotosto et al. 2009; Nader et al. 2008; Cole et al. 2014). They concluded that in this context, the higher alpha absolute power behavior of the left hemisphere was expected because the task was performed only by the right upper limb. They also reported that there was a pre dominance of absolute alpha power in the central dorsolateral prefrontal cortex and superior parietal cortex.

Costa et al.(2017) investigated the effect of upper limb PNF stretching on electrophysiological signals in healthy female subjects. Thirty female participants with the age range of 18-28 years weight between 50-80 kg were recruited for this study. It was a controlled cross-sectional study that was approved by the research ethics committee. In order to ensure homogeneity, only female students were selected. The inclusion criteria were: sedentary young women, normal BMI, and should not be familiar with the basic PNF principle. The exclusion criterion was subject with musculoskeletal or upper limb joint problem, cardiopulmonary or neurocognitive illness or functional limitation and amputees. For accurate EEG recording, the subject who used psychoactive drugs and slept less than 8 hours in the night before the experiment were excluded. They divided all subjects into 3 groups with a specific task: namely A- control group, B- PNF group, C- PNF load group. The PNF group performed the flexion-abduction-external rotation movement with an extension of elbow, wrist, and fingers and radial deviation of the right upper limb. The movement starting from the right shoulder in a position of slight internal rotation with elbow extension, flexion of the wrist and fingers and ulnar deviation, with the hand resting on the medial part of the contralateral thigh; c) PNF load group performed the same movements of B group, however, with the addition of a load to the movement. The EEG signals were captured by using international 10-20 systems and 20 channels of medical instruments. The objective of the present study was to collect data on the effect of upper limb diagonal PNF in the electro-neurophysiological parameters. The hypothesis of this study was that PNF would produce an increase of the relative power (RP) in the alpha band, and that would be generated from the cerebral cortex level. In this investigation, it was observed that the relative power increase of the alpha band at both the experimental group. It is assumed that this area of the cortex remains more active because the movements activate the central nervous system generally and consequently promoting greater neuromuscular recruitment. This may be explained due to the fact that this region of the cortex, more precisely the dorsomedial prefrontal cortex, is related to working memory and serves as a guide for decision making and future motor actions.(Raschle et al.2015; Yang et al.2014; Rosario,2011; Rhyu et al.2015; Pereira and Goncalves, 2012)

Shimura and Kasai, (2002) they evaluated neurophysiological mechanism related to the PNF method on the basis of observed changes in latency and amplitude of the motor evoked potentials in the motor cortex. They investigated four healthy male subjects age range 38-43 years who gave their informed consent forms. This experiment followed the local institutional guideline and ethical standard. Motor evoked potentials (MEPS) measured with the MES-10 magnetic stimulation apparatus. They found that the motor evoked potentials amplitude was larger and its latency shorter in the PNF stretching than in the neutral position. They assumed that these results are due to the fact that the amount of sensory input coming from the periphery was greater in the PNF position than in the normal position, which induced changes in the excitability of the pyramidal tract the final motor path way (Benecke, Meyer, Gohmann, & Conrad, 1988; Day et al.,1987; Hess, Mills, & Murry, 1987; Kasai, 1989, 1992; Rothwell et al., 1987). In the PNF position sensory inputs from the periphery lead to stronger excitation of the cortical area, leading to variations in the threshold, of a number of motorneurons, which is reflected in the motor evoked potentials (Deletis V, Dimitrijevic & Sherwood,1987; Kasai et al.1992; Day et al.1987; Beneceke et al.1988; Hess et al. 1987; Hauptmann & Hummelsheim, 1996; Hummelsheim & Skrotzki,1997; Hauptmann & Neuman, 1995; Rothwell et al. 1987). They identified another possibility that the PNF position influences the cortical and the spiral activation prior to voluntary movement and consequently leads to a reduction in EMG-RT and excitability changes in the MEPS.

Nakamura and Kosaka (1986) examined five patients with spinocerebellar degeneration by using EEG topography before and after PNF maneuver. They observed an increase in alpha band power in four patients after PNF maneuver. They noticed that improvement of motor function by PNF treatment in patient with normal EEG response to postural changes after PNF maneuver. The summary of the studies with PNF and Brain function is presented in Table: 1. for ready references.

Table 1: Brief summary of studies with PNF stretching and Brain function

Study reference	Population of the study	Study Design	Intervention	Comparators	Brain parameters	Conclusion
1.Moreira et al.2017	30 sedentary right handed female participants (age: 21.36 + 2.18 years) BMI- 23+ 2.27 kg/m^2	Randomized Control Trial (RCT) Experimental Pre and Post	• PNF with diagonal movement • Shoulder flexion movements performed without the diagonal component • Control group at rest	PNF vs Flexion vs Control	EEG : Beta band absolute power	PNF group: increase beta band absolute power in both hemispheres indicating greater plasticity. Thus influencing cortical organisation in more complex task.
2. Lial et al.2017	30 sedentary female participants (Age 21.3 + 2.1 years and weight 57.5 + 7.1 kg). BMI- between 18.5 and 24.99 kg/m^2 .	RCT Experimental Pre and Post RCT Experimental Pre and Post	• PNF diagonal movement pattern with right upper limb. • Flexion group performed flexion,abduction,shoulder rotation and wrist extension with fingers in the sagittal plane.. • Control group at rest	PNF vs Flexion vs Control	EEG: Absolute alpha band power	PNF group: Increase in alpha absolute power in the left dorsolateral prefrontal cortex and upper left parietal cortex to execute motor action with planning and attention.
3.Costa et al.2017	30 female participants age	RCT	• PNF group-performed diagonal	PNF vs PNF with load vs	EEG: Absolute beta	PNF group: increased alpha band

	between 18-28 years. BMI- between 18.5 and 24.9 kg/m^2		pattern with right upper limb. • PNF with load- performed same PNF exercise with load. • Control group at rest	Control.	band power.	can be considered favourable in relation to cortical behaviour.
4.Shimura and Kasai, 2002	4 healthy male participants age range between 38-43 years.	Conveniently	• PNF posture • Neutral posture	PNF vs Neutral	Motor evoked potentials	PNF group: MEPS amplitude increase MEP latency decrease due to greater sensory input and excitability of the motor cortex and a pyramidal tract, the final motor path way.
5. Nakamura and Kosoka, 1986	5 patients with spinocerebellar degeneration. Age range 36-61 years. Duration of illness range 2-9 years.	Conveniently Experimental Pre and Post	• PNF (Lower extremity) hip flexed at 90o, 30o and rotation.	Single group-self as control.	EEG: Absolute beta band power	Increase Alpha band power after PNF indicating improvement of motor function.
6.Chaturvedi et al. 2018	90 Patients with having first time stroke. Age between 40-70 years (Male- 57 and Female-33).	Conveniently two experimental designs. Group 1:PNF and Group2: Task specific training.	• PNF group: For neck, trunk, scapula and pelvis. • Task oriented exercise program for upper and lower extremity.	PNF vs Task specific	Brain Derived Neurotopic Factor (BDNF)	Increased serum BDNF in both the groups indicating enhancement of neuroplasticity, neurogenesis and angiogenesis.

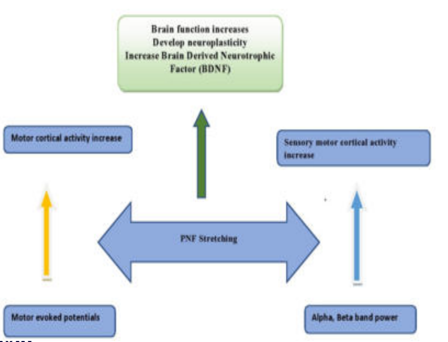
Discussion:

Already few scientists had identified theoretical mechanisms of PNF stretching that are as follows i) Autogenic inhibition theory ii) Reciprocal inhibition theory iii) Stress relaxation theory, and iv) Gate control theory. Autogenic inhibition theory golgi tendon organs activated and the action of Golgi tendon organs connected with the central nervous system. In reciprocal inhibition, the antagonist muscle activity inhibited by the motor nerve signals influence by the central nervous system. Stress relaxation theory expresses the activation of musculotendinous unit by the central nervous system. In the gate control theory, one neural stimulation allowed, and others stopped for the time being to get entry into the central nervous system.(Hindle et al.2012: Sharman et al.2006)

So, all these four theories have a common overlapping area, the central nervous system that is the spinal cord and brain activation. (Figure No. 1). PNF stretching may activate the higher cortical portion of the brain particularly sensory and motor cortex, and also the pre motor cortex area. The other associated cortical areas may influence by the PNF stretching as reported by the scientists (Shimura and Kasai, 2002; Costa et al. 2017; Lial et al.2017; Moreira et al. 2017; Nakamura and Kosaka,1986).

In the findings area, five out of the six identified studies were discussed. Three studies measured EEG alpha band power and one study measured EEG beta band power, and the fourth study measured peripheral neural activation by measuring EMG-RT and also the cortical activity by measuring motor cortex evoked potentials. Another study was measured brain chemical, the serum BDNF. All these five experimental studies reported that PNF stretching might activate cortical regions especially sensory-motor and pre motor cortex; and increased working memory by activating dorsolateral prefrontal cortex (Moreira et al. 2017); dorsomedial prefrontal cortex (Raschle et al.2015) and fronto-parietal circuit (Dickstein and Deutsch, 2007; Adler et al. 2008; Stoeckel et al. 2009) . The theories related to the possible PNF mechanisms of the activation of CNS, especially the brain areas has been corroborated with the findings of the above five experimental studies (Figure No.3). The above discussion also supported by the recent BDNF study (Chaturvedi et al.2018). They reported that BDNF levels increased after PNF stretching promotes neurogenesis, angiogenesis (Kurozumi et al. 2004; Schabitz et al. 2007) which may develop neuroplasticity. However, Wilkinson (1992) and Mitchell et al. (2009) challenged the theoretical mechanisms: reciprocal inhibition and autogenic inhibition theory on PNF. They collected data from surface EMG parameters. They confirmed that reciprocal inhibition and autogenic inhibition were not evident from the agonist, antagonist muscle EMG data and concluded that explanation for mechanisms of PNF stretching appears to be inadequate. Fig. 3: PNF stretching and brain function.

Figure 3: PNF stretching and brain function



Conclusion:

After reviewing the experimental papers on the effect of PNF stretching and brain function, following conclusion was drawn: i) PNF stretching can activate both the left and right cortical hemisphere ii) Sensory cortex iii) Motor cortex and pre-motor cortex area also activated iv) Working memory involved in the time of PNF stretching v) PNF stretching may develop brain plasticity by increasing BDNF. The present research team is recommending PNF stretching as a useful maneuver for different types of brain activity development and rehabilitation process. However, in the future research supporting with brain hemodynamics, structural changes and biochemical study may confirmed our conclusion and recommend strongly for implementation. Also, PNF stretching compared with Yogic stretching may add a new type of direction in the rehabilitation process and performance enhancement.

Conflict of Interest Statement:

The authors declare that this review was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Adler SS, Beckers D, Buck M (2008). *FNP in practice*. 3th ed. Germany: Editora Springer. 2: 80-89
2. Ali J, Mehrdad A, Clarice T, Ali K. (2011). The effects of a combination treatment (PNF stretching "Pre-exercise", ice massage plus static stretching-30s" post-exercise)non markers of exercise-induced muscle damage. *Australian journal of basic and applied sciences*. 5(12): 333-345
3. Ali MH, Gaikwad S and Mathew JT.(2015).A comparative study between hold relax technique and static stretching to improve gait parameter of hemiplegic stroke patients. *International journal of neurorehabilitation*. 2(4): 1000180
4. Alter JM.(2004) *Science of flexibility*. Human kinetics. Third Edition. 165-171
5. Andersen RA, Cui H.(2009). Intention, action planning, and decision making in parietal-frontal circuits. *Neuron*. 63: 568-583
6. Areeudomwong P, Buttagat V.(2019). Comparison of core stabilisation exercise and proprioceptive neuromuscular facilitation training on pain-related and neuromuscular response outcomes for chronic low back pain: a randomised controlled trial. *Malays J Med Sci*. 26(6): 77-89
7. Areeudomwong P, Buttagat V.(2019).Proprioceptive neuromuscular facilitation training improves pain-related and balance outcomes in working-age patients with chronic low back pain: a randomized controlled trial. *Brazilian journal of physical therapy*. 23(5): 428-436
8. Ashtankar AP, Kazi A. (2019). Comparative effect of proprioceptive neuromuscular facilitation (PNF) and chest physiotherapy with chest physiotherapy alone SPO2, heart rate, respiratory rate, & lung compliance in mechanically ventilated patient. *J Pharm Sci*

& Res.11(10): 3514-3518

9. Benecke R, Meyer BV, Gohmann M & Conrad B.(1988).Analysis of muscle responses elicited by transcranial stimulation of the corticospinal system in man. *Electroencephalography and Clinical Neurophysiology*. 69: 412-422
10. Bonnar BP, Deivert RG, Gould TE. (2004). The relationship between isometric contraction durations during hold-relax stretching and improvement of hamstring flexibility. *J Sports Med Phys Fitness*. 44(3): 258-61
11. Brad A. Stretching and flexibility everything you never wanted to know. Version: 1.42, last modification 98/06/10. http:// www.enteract.com/bradapp/docs/rec/stretching.
12. Cabez R, Ciaramelli E, Olson IR, Moscovitch M. (2008). Parietal cortex and episodic memory: an attentional account. *Nat. Rev. Neuroscience*. 9(8): 613-625
13. Capotosto P, Babiloni C, Romani GL, Cobertta M.(2009). Fronto-parietal cortex controls spatial attention through modulation of anticipatory alpha rhythms. *J Neuroscience*. 6: 5863-5872
14. Carter MA, Kinzey SJ, Chitwood LF and Cole JL. (2000).Proprioceptive neuromuscular facilitation decreases muscle activity during the stretch reflex in selected posterior thigh muscles. *J Sport Rehabil*. 9: 269-278
15. Chalmers G.(2004). Re-examination of the possible role of golgi tendon organ and muscle spindle reflexes in proprioceptive neuromuscular facilitation muscle stretching. *Sports Biomech*. 3(1): 159-83
16. Chaturvedi P, Singh AK, Tiwari V, Kulshreshtha D, Maurya PK, Thacker AK.(2018). Proprioceptive neuromuscular facilitation (PNF) vs. task specific training in acute stroke: the effects on neuroplasticity. *MOJ anatomy & physiology*. 5(2): 154-158
17. Chaturvedi P, Tiwari V, Singh AK, Kulshrestha D, Maurya P, Thacker AK. (2017). Effects of early proprioceptive neuromuscular facilitation exercises on functional outcome and quality of life in patients with stroke. *MGM Journal of medical sciences*. 4(3): 130-133
18. Chen YH and Chao YH. (2016). Proprioceptive neuromuscular facilitation approach for functioning muscle transfer: a case report. *Journal of novel physiotherapies*. 6(3): 1000294
19. Cole MW, Repovs G, Anticevi A. (2014). The frontoparietal control system: a central role in mental health. *Neuroscientist*. 20: 652-6
20. Costa LC, Andrade A, Lial L, Moreira R, Lima AC, Magvinier A, Lira R, Aragao A, Ulisses PH, Crespo E, Orsini M, Teixeira S, Bastos VH. (2017).Investigation of alpha band of electroencephalogram before and after a task of proprioceptive neuromuscular facilitation. *Journal of exercise rehabilitation*. 13(4): 418-424
21. Crnkovic I, Skapin B and Canjuga E. (2018).Effects of PNF technique on increasing functional activities in patients after an incomplete spinal cord injury: a case report. *Annals of physiotherapy clinics.* 1(1):1004
22. Day BL, Rothwell JC, Thompson PD, Dick JPR, Berardelli A, & Marsden CD. (1987). Motor cortex stimulation in intact man: multiple descending volleys. Brain. 110: 1191-1209
23. Deletis V, Dimitrijevic MR, & Sherwood AM. (1987). Effects of electrically induced afferent input from the human motor cortex. *Neurosurgery.* 20: 195-197
24. Derbachew A. (2019). Static, ballistic and PNF stretching exercise effects on flexibility among arba minch football players. *Journal of humanities and social science*. 24(3): 87-92
25. Dickstein R, Deutsch J. (2007). Motor imagery in physical therapist practice. *Phys Ther*. 87: 942-953
26. Feland JB, Marin HN. (2004). Effect of submaximal contraction intensity in contract-relax proprioceptive neuromuscular facilitation stretching. *Br J Sports Med*. 38: e18
27. Ferber R, Gravelle DC, and Osternig LR. (2002).Effect of proprioceptive neuromuscular facilitation stretch techniques on trained and untrained older adults. *Journal of aging and physical activity*. 10: 132-142
28. Ghram A, Damak M, Rhibi F, Marchetti PH. (2016). The contract-relax proprioceptive neuromuscular facilitation (PNF) stretching can affect the dynamic balance in healthy men. *Medical express*. 3(4):M160404
29. Godges JJ, Mattson-Bell M, Thorpe D, Shah D. (2003). The immediate effects of soft tissue mobilization with proprioceptive neuromuscular facilitation on glenohumeral external rotation and overhead reach. *J Orthop Sports Phys Ther*. 33(12): 713-8
30. Gomes TM, Simao R, Marques MC, Costa PB, and Novaes JDS. (2010). Acute effects of two different stretching methods on local muscular endurance performance. *Journal of strength and conditioning research.* 0(0): 1-8
31. Gultekin Z, Kin-Isler A and Surenkok O. (2006). Hemodynamic and lactic acid responses to proprioceptive neuromuscular facilitation exercise. *Journal of sports science and medicine*. 5: 375-380
32. Ha KJ, Lee SY, Lee H and Choi SJ. (2017). Synergistic effects of proprioceptive neuromuscular facilitation and manual lymphatic drainage in patients with mastectomy-related lymphedema. *Frontiers in physiology*. 8: 959
33. Hauptmann B, & Hummelsheim H. (1996). Facilitation of motor evoked potentials in hand extensor muscles of stroke patients: Correlation to the level of voluntary contraction. *Electroencephalography and clinical neurophysiology*. 101: 387-394
34. Hauptmann B, Skrotzki A, & Hummelsheim H. (1997). Facilitation of motor evoked potentials after repetitive voluntary hand movements depends on the type of motor activity. *Electroencephalography and clinical neurophysiology*. 357-364
35. Hess CW, Mills KR, & Murry NMF. (1987).Responses in small hand muscles from magnetic stimulation of the human brain. *Journal of Physiology (London)*. 388: 397-419
36. Hindle KB, Whitcomb TJ, Briggs WO, Hong J. (2012). Proprioceptive neuromuscular facilitation (PNF): Its mechanisms and effects of range of motion and muscular function. *Journal of human kinetics*. 31: 105-113
37. Hoshi E. (2006). Functional specialization within the dorsolateral prefrontal cortex: a review of anatomical and physiological studies of non-human primates. *Neurosci. Res*. 54(2): 73-84
38. Hummelsheim H, Hauptmann B, & Neuman S. (1995).Influence of physiotherapeutic facilitation techniques on motor evoked potentials in centrally paretic hand extensor muscles. *Electroencephalography and clinical neurophysiology*. 97: 18-27
39. Hurtado CE, Velez RR. (2011).Proprioceptive neuromuscular facilitation (PNF) and its impact on vascular function. *Colombia medica*. 42: 373-8
40. Johansen-Berg. H, Matthews PM. (2002).Attention to movement modulates activity in sensorimotor areas including primary motor cortex. *Exp. Brain Res*. 142(1): 13-24
41. Jordan JB, Korgaokar AD, Farley RS and Caputo JL. (2012). Acute effects of static and proprioceptive neuromuscular facilitation stretching on agility performance in elite youth soccer players. *International journal of exercise science*. 5(2): 97-105
42. Karima T, Falak O. (2016). Comparison of cardiovascular responses with proprioceptive neuromuscular facilitation stretching on pectorals and hamstrings with valsalva maneuver in young adults. *International archives of integrated medicine*. 3(6): 42-48
43. Kasai T, Hayes KC, Wolfe DL, & Allatt RD. (1992).Afferent conditioning of motor evoked potentials following transcranial magnetic stimulation of motor cortex in normal subjects. *Electroencephalography and clinical neurophysiology*. 85: 95-101
44. Kasai T. (1989).How descending motor commands are governed: approach by percutaneous electrical and magneto-electrical stimulation (motor evoked potential; MEP). *Japanese Journal of Sports Science.* 8: 876-884
45. Kaya F, Bicer B, Yuktasir B, Willems MET, Yildiz N. (2018).The effects of two different stretching programs on balance control and motor neuron excitability. *Journal of education and training studies*. 6(5): 85-91
46. Kaya F. (2018).Positive effects of proprioceptive neuromuscular facilitation stretching on sports performance: a review. *Journal of education and training studies*. 6(6)
47. Kim CH, Kim YN. (2018).Effects of proprioceptive neuromuscular facilitation and treadmill training on the balance and walking ability of stroke patients. *Journal of korean physical therapy.* 30(3):79-83
48. Kofotolis N, Kellis E. (2006).Effects of two 4-week proprioceptive neuromuscular facilitation programs on muscle endurance, flexibility, and functional performance in women with chronic low back pain. *Physical therapy*. 86(7): 1001-1012
49. Konoza E. (2018).The role of muscle proprioceptors in proprioceptive neuromuscular facilitation (PNF) stretching. *MUSC Health Sports Medicine*.
50. Kumar P, Moitra M. (2015).Efficacy of muscle energy technique and PNF stretching compared to conventional physiotherapy in program of hamstring flexibility in chronic nonspecific low back pain. *Indian J Physiother Occup Ther.* 9(3): 103-107
51. Kumar, Kumar S, Kaur & AJ, J. (2012).Effect of PNF technique on gait parameters and functional mobility in hemiparetic patients. *Journal of exercise science and physiotherapy*. 8(2): 67-73
52. Kurozumi K, Nakamura K, Tamiya T, et al. (2004).BDNF gene-modified mesenchymal stem cell promote functional recovery and reduce infract size in the rat middle cerebral artery occlusion model. *Mol Ther*. 9(2): 189-197
53. Lee BK. (2015).Effects of the combined PNF and deep breathing exercises on the ROM and the VAS score of a frozen shoulder patient: single case study. *Journal of exercise rehabilitation*. 11(5): 276-281
54. Lee JH, Park SJ, Na SS. (2013).The effect of proprioceptive neuromuscular facilitation therapy on pain function. *J. Phys. Ther. Sci*. 25(6): 713-716
55. Lempke L, Wilkinson R, Murray C, and Stanek J. (2018).The effectiveness of PNF versus static stretching on increasing hip-flexion range of motion. *Journal of sport rehabilitation*. 27: 289-294.
56. Lial L, Moreira R, Correia L, Andrade A, Pereira AC, Lira R, Figueiredo R, Silva-junior F, Orsini M, Ribeiro P, Velasques B, Cagy M, Teixeira S & Bastos VH. (2017).Proprioceptive neuromuscular facilitation increases alpha absolute power in the dorsolateral prefrontal cortex and superior parietal cortex. *Somatosensory & motor research*. 34(3): 204-212
57. Lim W. (2018). Optimal intensity of PNF stretching: maintaining the efficacy of stretching while ensuring its safety. *The journal of physical therapy science*. 30: 1108-1111
58. Macdonald AW, Cohen JD, Stenger VA, Carter CS. (2000).Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science*. 288(5472): 1835-1838
59. Magalhaes FEX, Junior ARDM, Meneses HTDS, Santos RPMD, Rodrigues EC, Gouveia SSV, Gouveia GPDM, Orsini M, Bastos VHDV, Machado DDCD. (2015).Comparison of the effects of hamstring stretching using proprioceptive neuromuscular facilitation with prior application of cryotherapy or ultrasound therapy. *Journal of physical therapy science*. 27(5): 1549-1553
60. Marek SM, Cramer JT, Fincher AL, Massey LL, Dangelmaier SM, Purkayastha S, Fitz KA, Culbertson JY. (2005). Acute effects of static and proprioceptive neuromuscular facilitation stretching on muscle strength and power output. *Journal of athletic training*. 40(2): 94-103
61. Mazzullo JM. (1978).The gate of pain. *Br Med J*. 2(6137): 586-587
62. Mitchell UH, Myrer JW, Hopkins JT, Hunter I, Feland JB, and Hilton SC. (2009). Neurophysiological reflex mechanisms' lack of contribution to the success of PNF stretches. *Journal of sport rehabilitation*. 18: 343-357
63. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *Preferred Reporting Items for Systematic Reviews and Meta-Analyses:* The PRISMA Statement. *PLoS Med* 6(7): e1000097. doi: 10.1371/journal.pmed1000097
64. Moreira R, Lial L, Monteiro MGT, Aragao A, David LS, Coertjens M, Silva-Junior FL, Dias G, Velasques B, Ribeiro P, Texixeira SS, Bastos VH. (2017).Diagonal movement of the upper limb produces greater adaptive plasticity than sagittal plane flexion in the shoulder. *Neuroscience Letters*. 643: 8-15
65. Morreale M, Marchione P, Pili A, Lauta A, Castiglia SF, Spallone A, Pierelli F, Giacomini P. (2016).Early versus delayed rehabilitation treatment in hemiplegic patients with ischemic stroke: proprioceptive or cognitive approach? *European journal of physical and rehabilitation medicine.* 52(1): 81-9
66. Nader S, Machado S, Cunha M, Portela C, Silva J, Velasques B, Bastos VHV, Basile LF, Cagy M, Piedade R, Riberio P. (2008).Posterior parietal cortex role in a sensorimotor task performance. *ArqNeuropsiquiatr*. 66: 341-343
67. Naderifar H, Minoonejad H, Barati AH, Lashay A. (2018).Effect of a neck proprioceptive neuromuscular facilitation training program on the body postural stability in elite female basketball players. *Journal of rehabilitation sciences and research*. 5: 41-45
68. Nakamura R and Kosaka K. (1986). Effect of proprioceptive neuromuscular facilitation on EEG activation induced by facilitating position in patients with spinocerebellar degeneration. *Tohoku J. exp. Med*. 148: 159-161
69. Nogueira CJ, Galdino LADS, Vale RGDS, Mello DBD, Dantas EHM. (2010).Acute effect of the proprioceptive neuromuscular facilitation method on vertical jump performance. *Biomedical human kinetics*. 2; 1-4
70. Oliveira LP, Vieira LHP, Aquino R, Maneehini JPV, Santiago PRP and Puggina EF. (2018). Acute effects of active, ballistic, passive, and proprioceptive neuromuscular facilitation stretching on sprint and vertical jump performance in trained young soccer players. *Journal of strength and conditioning research.* 32(8): 2199-2208
71. Powers SK & Howley ET. (2018). *Exercise physiology: Theory and application to fitness and performance*. New York, NY: McGraw-Hill Education.
72. Ptaszkowska L, Ptaszkowski K, Halski T, Taradaj J, Dymarek R, Paprocka-Borowicz M. (2019). Immediate effects of the respiratory stimulation on ventilation parameters in ischemic stroke survivors. *Medicine*. 98: 38(e17128)
73. Ramachandran S, Paul J, Senthilkumar.N, Sudhakhar S, Tamilselvi. (2018).Comparative effect of PNF stretching techniques on hamstring flexibility. *International journal of medical and exercise science.* 4(1): 443-447
74. Raschle NM, Menks WM, Fehlbaum LV, Tshomba E, Stadler C. (2015).Structural and functional alterations in right dorsomedial prefrontal and left insular cortex co-localize in adolescents with aggressive behaviour: an ALE meta-analysis. *PLoS One*. 10: e136553
75. Ravichandran H, Balamurugan J. (2020).Effect of proprioceptive neuromuscular facilitation stretch and muscle energy technique in the management of adhesive capsulitis of shoulder. *Saudi journal of sports medicine*. 15(2): 170-175
76. Rhyu HS, Kim SH, Park HS. (2015).The effects of band exercise using proprioceptive neuromuscular facilitation on muscular strength in lower extremity. *J Exerc Rehabil*. 11: 36-40
77. Rosario JL. (2011).Manual pratico de facilitacao neuromuscular proprioceptiva. *Sao Paulo: Barauna.*
78. Rothwell JC, Thompson PD, Day BL, Dick JPR, Kachi T, Cown JMA & Marsden CD. (1987). Motor cortex stimulation in intact man-general characteristics of EMG responses in different muscles. *Brain*. 110: 1173-1190

79. Rowlands AV, Marginson F, Lee J. (2003).Chronic flexibility gains: effect of isometric contraction duration during proprioceptive neuromuscular facilitation stretching techniques. *Research quarterly for exercise and sport*. 74(1): 47-51
80. Ruas CV, McManus RT, Bentes CM and Costa PB. (2018).Acute effects of proprioceptive neuromuscular facilitation on peak torque and muscle imbalance. *Journal of functional morphology and kinesiology*. 3, 63;
81. Sanavi HM, Zafarin A and Firouzi M. (2013).The effects of MVIC durations in PNF training on stretching, endurance and flexibility of hamstring muscle. *World applied sciences journal.* 21(1): 109-112
82. Sauvage C, De Greef N, Manto M. (2015).Reorganization of large-scale cognitive networks during automation of imagination of a complex sequential movement. *J. Neuroradial*. 42(2): 115-125
83. Schabitz WR, Steigleder T, Cooper-Kuhn CM, et al. (2007).Intravenous brain-derived neurotrophic factor enhances poststroke sensorimotor recovery and stimulates neurogenesis. *Stroke.* 38(7): 2165-2672
84. Sharman MJ, Cresswell AG, Rieks. (2006).Proprioceptive neuromuscular facilitation stretching mechanisms and clinical implications. *Sports Med*. 36(11): 929-939
85. Shimura K, Kasai T. (2002).Effects of proprioceptive neuromuscular facilitation on the initiation of voluntary movement and motor evoked potentials in upper limb muscles. *Human movement science*. 21: 101-113
86. Silva GCE, Masi FD, Paixao A, Bentes CM, Sa MD, Miranda H, Simao R, Novaes J. (2013). Effects of proprioceptive neuromuscular facilitation stretching and static stretching on cardiovascular responses. *Journal of exercise physiologyonline*. 16(1): 117-125
87. Smedes F, Heidmann M, Schafer C, Fischer N & Stepien A. (2016).The proprioceptive neuromuscular facilitation-concept; the state of the evidence, a narrative review. *Physical therapy reviews.* 21(1): 17-31
88. Smedes F, Silva LGD. (2019).Motor learning with the PNF-concept, an alternative to constrained induced movement therapy in a patient after a stroke; a case report. *Journal of bodywork and movement therapies.* 23: 622-627
89. Smedes F. *Is there support for the PNF-concept?* Literature search on electronically databases, www.ipnfa.org
90. Souza RJPD, Brandao DC, Martins JV, Fernandes J, Andrade ADD. (2020).Addition of proprioceptive neuromuscular facilitation to cardiorespiratory training in patients post stroke: study protocol for a randomized controlled trial. *Trials journal-biomed central*. 21: 184: 2-9
91. Stoeckel MC, Weder B, Binkofski F, Buccino G, Shah NJ, Seitz RJ. (2009).A fronto-parietal circuit for tactile object discrimination: an event-related fMRI study. *Neurolmage*. 19: 1103-1114
92. Szafraniec R, Chromik K, Poborska A, Kawcyski A. (2018).Acute effects of contract-relax proprioceptive neuromuscular facilitation stretching of hip abductors and adductors on dynamic balance, *Peerj*. doi 10.7717/peerj. 6108
93. Tam JPH. (2019).Effect of stretching including proprioceptive neuromuscular facilitation and muscle energy techniques on injury risks: a systematic review. *Acta scientific orthopaedics*. 2(2): 09-19
94. Tedla JS, Sangadala DR. (2019).Proprioceptive neuromuscular facilitation techniques in adhesive capsulitis: a systematic review and meta-analysis. *J Musculoskeletal neuronal interact*. 19(4): 482-491
95. Teixeira S, Machado S, Velasques B. (2014).Integrative parietal cortex processes: neurological and psychiatric aspects. *J.Neurol. Sci*. 338(1-2): 12-22
96. Uzunov V. (2007).Stretching scientifically part I: myths, facts, the science. *Gym Coach*. 1: 28-32
97. Wilkinson, Andrew. (1992).Stretching the truth. A review of the literature on muscle stretching. *Australian journal of physiotherapy*. 38(4): 283-287
98. Witt D, Talbott N, Kotowaski S. (2011).Electromyographic activity of scapular muscles during diagonal patterns using elastic resistance and free weights. *The international journal of sports physical therapy.* 6(4): 322-332
99. Yang J, Yu Y, Kunita A, Huang Q, Wu J, Sawamoto N, Fukuyama H. (2014).Tactile priming modulates the activation of the fronto-parietal circuit during tactile angle match and non-match processing: an fMRI study. *Front Hum Neurosci*. 8: 926
100. Zhorne R, Dudley-javoroski S, Shields RK. (2016).Skeletal muscle activity and CNS neuro-plasticity. *Neural-Regen. Res*. 11(1): 69-70