The Proprioceptive Neuromuscular Facilitation-concept;

the state of the evidence, a narrative review.

This is an Accepted Manuscript of an article published by Taylor & Francis in ***Physical Therapy Reviews*** *on August 7, 2016, available online:* http://www.tandfonline.com/10.1080/10833196.2016.1216764

To cite this article: Fred Smedes, Marianne Heidmann, Carsten Schäfer, Nicola Fischer & Agnieszka Stępień (2016): The proprioceptive neuromuscular facilitation concept; the state of the evidence, a narrative review, Physical Therapy Reviews, DOI: 10.1080/10833196.2016.1216764

Authors:

1. Fred Smedes, MSc. PT, MT. Saxion, University of applied sciences, Department of Physical Therapy, Enschede, the Netherlands. Practice for physical therapy "ten Berge", Losser, the Netherlands. E-mail: f.smedes@saxion.nl

2. Marianne Heidmann, MSc. PT. Diploma European University- Study Centre BFW Mainz, Department for medical professions. Private Practice for Physical Therapy, Germany. E-mail: mheidmann@arcor.de

3. Carsten Schäfer, MSc. PT. Physiotherapy Practice Killwies, Hilzingen, Germany. Zurich University of applied Science, Zurich, Switzerland. E-mail: pnfcarsten@hotmail.com

4. Nicola Fischer, MSc. PT. S-R-H, School for Physical Therapy, Karlsruhe, Germany. Practice for Physical Therapy, Ettlingen, Germany. E-mail: fischer-nico@web.de

5. Agnieszka Stępień, PhD. PT. Józef Piłsudski University of Physical Education, Department of Rehabilitation, Warsaw, Poland. E-mail: fp.agnieszka@wp.pl

Corresponding author: Fred Smedes, f.smedes@saxion.nl , Post-box 70.000, 7500 KB

Enschede, the Netherlands. Tel **31 (0)6 12 37 94 34.

Acknowledgement: We like to express our gratitude to Mr. Stephen G. Schmidt for guidance and advice in linguistic matters.

Abstract.

Introduction: The Proprioceptive Neuromuscular Facilitation concept (PNF-concept) is a widely used rehabilitation concept, and is in many countries part of the undergraduate curriculum of physiotherapy education. It is also offered in postgraduate training worldwide. The modern physiotherapist is confronted with the application of evidence-based practice; therefore the aim of this review is to summarize the available evidence for this rehabilitation concept.

Method: A search was completed using Pubmed, ScienceDirect, PEDro, Cochrane library and the International PNF Association (IPNFA) website. An evidence-based practice approach has been promoted in the field of physiotherapy since the early 1990's, hence we limited the search from 1990 until 2014.

Major findings: Seventy-four sources that were found were categorized in: A) PNF philosophy, B) PNF basic principles and procedures, C) PNF techniques in rehabilitation. In the reviewed publications, a variety of indications and subject populations were identified including: neurological, musculoskeletal, pulmonary, geriatric, and mixed disorders. The publications varied in type and quality, ranging from case studies, clinical trials, randomized controlled trials (RCTs), and reviews. This variety of publications, treatment indications and outcome measures in the publications warranted a narrative review

Discussion and conclusion: The scope and diversity of articles in the review make it difficult to study the PNF-concept in a methodical way, since different components of a comprehensive rehabilitation approach may act as confounders when measuring the effects of one specific part of the approach. There is a substantial body of research which supports the use of PNF as a comprehensive rehabilitation concept. The literature also describes that the PNF-concept is applied in clinical practice in a variety of populations and indications, however efficacy for specific indications and populations requires further investigation.

Keywords: ***Proprioceptive neuromuscular facilitation; PNF; Motor learning; Physical therapy; Clinical Rehabilitation.***

Background

Proprioceptive Neuromuscular Facilitation (PNF) is a rehabilitation approach or concept which is widely used by physiotherapists and forms part of the physiotherapy curriculum in many countries.[1] The concept of PNF was originally developed by Dr Herman Kabat and Margaret (Maggie) Knott for rehabilitation purposes.[2] In the decades following, the concept evolved to a complete rehabilitation approach for a variety of indications of neurological and musculoskeletal origin. The works of Dr Kabat and Maggie Knott was encouraged by the Kaiser Foundation Rehabilitation Center (KFRC, Vallejo, California, USA).[2] The International PNF Association (IPNFA) is an organization which aims to foster development and continued clinical practice of the PNF-concept as successor of Dr Kabat and Maggie Knott.[3] The IPNFA defined the PNF philosophy in five subheadings: 1) positive approach; 2) functional approach; 3) mobilize reserves; 4) treating the whole person; 5) use of motor learning and motor control principles.[3]

Treating with a positive approach (1), involves selecting therapeutic activities which the patient has the potential to successfully complete. This allows the patient to experience success in at least some part of the therapeutic activities. In this way the mental engagement in therapy is enhanced (e.g. locus of control, feeling of achievement, motivation etc.). Interventions are often performed first indirectly on stronger (healthier) parts of the body prior to more impaired areas in order to irradiate to the weaker parts of the body.[4] In this way the patient is treated as a whole person (4), both physically and mentally. The reserve potentials of the patient are triggered through irradiation and the demand of the selected activity (3).[4] Treating in a functional context (2) is achieved by integrating real tasks from daily life. Functional task oriented treatment enhances motor learning (5).[5]

All together the PNF-concept fits in the International Classification of Functioning, Disability and Health (ICF) with its components of impairments, activity limitations, and participation restrictions in the personal and environmental context of the patient involved.[6] Today's perspective on physiotherapy practice is characterized by an approach that is evidence-based.[7] Since the 1990s, there has been a movement towards promoting evidence-based practice (EBP) within health care and health education.[8] This requires physiotherapists to reflect upon their choices of treatment concepts, methods, and techniques. The scientific basis for the PNF-concept is under-researched and evidence from large population studies is lacking.[1]

The PNF-concept is based upon three main section PNF Philosophy, PNF Basic principles and procedures, PNF techniques in rehabilitation. PNF techniques, which comprise 10 specifically defined techniques are tools to be applied within the PNF approach, not as separate concepts.[3,4,9] This is a misunderstanding frequently followed in several publications.[10-12] Despite the state of the level of evidence, the PNF concept remains a popular rehabilitation approach worldwide. Post-graduate training is offered in many different countries including Brazil, Germany, Hungary, Japan, Poland, South Korea, the USA, and others.[3] Reviews of PNF have mainly focused on so called "PNF stretching",[10-12] as a result PNF techniques can be confused with the overall PNF-concept as a comprehensive rehabilitation approach. The authors regard this as a misunderstanding of the PNF-concept as it is meant to target rehabilitation in a variety of indications.[3,9]

Voss, Jonta, and Meyers (1985) defined proprioceptive neuromuscular facilitation as: "methods of promoting or hastening the response of the neuromuscular mechanism through stimulation of the proprioceptors".[4] A lasting response of the neuromuscular mechanism is considered to be a motor learning effect, which is the key component of the PNF philosophy. The methods of promoting or hastening the response are defined within the PNF-concept as the PNF basic principles and procedures and PNF techniques.[3,4,9]

As far as the authors know, previous attempts to review the PNF literature have not thoroughly addressed the comprehensive nature of PNF as a comprehensive rehabilitation approach. The aim of this paper is to describe and explain the complexity of the PNF-concept as a rehabilitation approach from a practical clinical view. Furthermore this review seeks to categorize the available evidence into the clinical components of the PNF-concept and to discuss the implications for physical therapy.

Method

Securing a significant amount of sources to describe and explain the philosophy and complexity of the PNF-concept as a rehabilitation approach requires a methodical search strategy. To find publications in which the PNF-concept or components of it were subject of the study, a search was completed using Pubmed, ScienceDirect, PEDro and Cochrane library. The IPNFA website was also searched. The evidence-based practice approach has been promoted since the early 1990s, hence the search was limited to items published between 1990 and 2014. The search was conducted between July and December 2014. The search terms included Proprioceptive Neuromuscular Facilitation, PNF, facilitation techniques, treatment techniques, exercise methods, exercise concepts, treatment methods, treatment concepts, rehabilitation approaches and motor learning. Secondary search terms were based upon the PNF philosophy, basic procedures and principles, and techniques as defined and described by the IPNFA (For specification see table 1). Search terms were used isolated and combined. A manual search of the reference list of relevant articles was also performed. Four researchers were involved in the search. All authors are familiar with the PNF-concept in its therapeutic application and in teaching, hence a standard screening procedure was secured.

After screening the title and the abstract, papers were included based upon the following criteria: a) PNF as a concept was a part of the publication. b) Techniques from the PNF-concept were a part of the publication. c) PNF-concept or PNF techniques were a part of the treatments for a specific indication or patient population. d) Facilitation similar to the described PNF basic principles and procedures was a part of the publication. The results were categorized into three main sections which are in concordance with the categories proposed and used by the IPNFA: A) PNF philosophy, B) PNF basic principles and procedures C) PNF techniques in rehabilitation.[3,4,9]

Major findings

The search resulted in 74 sources which were then categorized into the three sections. There were no specific studies identified in connection with motor learning terminology combined with PNF-based terminology. Therefore the rational narrative for the PNF philosophy is described with references from widely accepted standard motor learning works, such as from Shumway-Cook and Woollacott (2007)[5], Schmidt and Lee (2009)[13] and Fitts and Possner (1967)[14] supported by nine other publications. The PNF basic principles and procedures were addressed in 12 publications describing or demonstrating effects on impairments and enhancing motor learning. A variety of indications and populations treated with various PNF techniques were addressed in 50 publications. As the literature identified in the search comprised varying levels of evidence (case studies, clinical trials, RCTs, reviews) and investigated a broad range of PNF applications quantitative or qualitative systematic review was not feasible. This diversity of sources justifies a presentation of the results in a narrative type review. In the sections below the results are described within the three main categories.

PNF philosophy

As the primary aim of treatment is to help patients maximize movement efficiency and achieve their highest level of functioning, principles of motor learning have been integrated into the PNF-concept as an underlying philosophy. Motor learning is influenced by different factors such as emotion and motivation.[5,15] Meaningful tasks for the patient address these motivations and emotions, which fits into the PNF-philosophy point of "functional approach".[4,9] Variability of practice, repetition and variation enhances the effect of motor learning.[16] This variability and repetition may be achieved in functional tasks with different approaches such as blocked training or random training.[5,13] Shaping, a way of enhancing motor learning is defined as "explicit training of limb movement".[17] Shaping is incorporated into the PNF-concept by using PNF basic procedures as well as the techniques: Rhythmic Initiation, Replication, and Combination of Isotonics.[4] Practice conditions, observational practice, and self-controlled practice are emphasised when aiming for motor learning effects.[15,18,19] Focus of attention and feedback resulting in Knowledge of Results (KR) and Knowledge of Performance (KP) are other components that stimulate motor learning.[15,20-22] The stages of motor learning are defined as the cognitive, associative, and autonomous stage.[14] Depending on the underlying reason for motor impairment, different strategies for motor learning in rehabilitation are required. Motor adaptation may relate to the stages as proposed by Fitts and Posner.[23] These motor learning strategies are incorporated in the PNF philosophy.[3,9]

PNF Basic principles and procedures

The basic principles and procedures as proposed by the IPNFA have to be regarded as means of facilitation to enhance therapy effects.[3,4,9] They can be subdivided into proprioceptive, exteroceptive, and procedural stimuli (see table 1). Twelve publications have been identified describing and / or studying the effects of these stimuli (see table 2, PART A).

Modulation of muscle activity by cutaneous and muscular afferents was proposed by Sherrington in 1910.[24] Fallon, Bent, McNulty, and Macefield (2005) demonstrated the importance of *tactile stimuli* on the sole of the foot for modulation of gait and posture.[25] *Resistance* is one of the crucial drivers of increase in muscular strength.[26] Muscular adaptations that contribute to strength include hypertrophy, changes in descending neural drive, increase in motor unit firing rate, motor unit synchronisation, and alteration in agonist-antagonist co-activation.[26] Resistance can be applied in isometric, concentric, and eccentric ways, depending on the objectives and intentions of the patient, such as maintaining a position in space or moving against or with an external force.[27] PNF resisted pattern training may result in hypertrophy.[28] Kofotolis, Vrabas, Vamvakoudis, Papanikolaou, and Mandroukas (2005) demonstrated alterations in the cross sectional area of the musculus vastus lateralis ($p<0.05$) after a PNF training regimen.[28] Resisted pattern activity results in activation of contralateral homonymous muscles, often referred to as cross education[29] and in activation of synergistic muscles, referred to as *irradiation.*[9,30] Activation of contralateral lower limb muscles demonstrated excellent correlation to resistance applied to upper limb muscles, referred to as *irradiation* (intra-class correlation of 0.836 to 0.845).[31] *Approximation* is appropriate to stimulate stability and is defined as axial compression of joints.[27] The effect of *approximation* on weight bearing has been demonstrated in patients with a trans-femoral amputation, and was significantly ($p<0.05$) more effective than traditional training.[32] *Traction* has been proposed as a facilitator of movement.[4,9] Traction is defined as the elongation of a segment perpendicular to the highest point of the arc of the motion.[27] The use of patterns is one of the characteristics of the PNF concept. *Patterns* are all derived from analysis of natural physical activities such as in labour and/or in sports.[9] The activation of the nervous system seems to be easier with the use of PNF pattern compared to neutral movements in starting and executing voluntary movement. The Motor Evoked Potentials (MEP) are larger ($p<0.01$) and the electromyographic reaction time (EMG-RT) is shorter when using PNF related positions ($p<0.05$) compared to neutral positions.[33] The activation of specific scapular muscles was significantly higher when performing PNF arm patterns compared to maximum voluntary contraction of the muscles when using manual muscle testing as described by Kendall et al.[34] McMullen and Uhl (2000) stated that PNF patterns fit in "kinetic chain rehabilitation" since it applies elements of biomechanical and motor control theories in exercise techniques. By using multiple body segments in the exercises, adjacent segments can facilitate the activation of involved muscles *(irradiation*) to develop appropriate shoulder motion and function.[35] The final facet of functional rehabilitation is the inclusion of activities that mimic (athletic) function. The importance of incorporating activities such as PNF pattern exercises, when preparing an athlete for return to competition, has been pointed out, since they mimic (athletic) function.[36] *Timing* is referred to as being the order of movements or the sequences of an activity. A specific type of alteration of timing is called Timing for Emphasis.[9,27] The position of the therapist and the manner of moving is emphasized as a basic procedure: "*Body mechanics*". Body mechanics enhance the efficiency and effectiveness of the therapist, and improve the neuromuscular response of the patient.[4,9] A *summation of stimuli* is more effective to achieve activation. Regardless of age, response to multisensory input is significantly faster compared to unisensory stimuli ($p<0.01$).[37] Elderly tend to respond faster to a combination of somatosensory and *visual stimuli* while younger people tend to respond faster to a combination of somatosensory and *auditory stimuli*.[37]

PNF techniques in Rehabilitation

The IPNFA defined several techniques which are in line with the description of Maggie Knott.[3,4,9] Techniques are selected to pursue specific rehabilitation objectives which can be defined within the various levels of the ICF (impairments, activity limitations, and participation restrictions). In general the techniques are described with objectives to improve impairments.[3,4,9] In the functional context the application of techniques will have an effect on disabilities by addressing impairments within the task setting. No studies were found concerning the techniques: "Stretch at beginning of range of motion", "Stretch through range of motion" and "Rhythmic Stabilization". For all other techniques a separate section is provided (see table 2, PART B).

Hold Relax (HR) and Contract Relax (CR)

To improve range of motion (ROM) and flexibility the use of HR and CR has been studied in several different settings, addressing different joints and muscles. We identified 23 studies which investigated the use of PNF stretching techniques with outcome measures in relation to ROM, muscle performance and general activities.

HR and CR in relation to Range of Motion

Godges, Matsen-Bell, Thorpe, and Shah (2003) investigated the effect of a PNF – CR treatment in a group of shoulder patients. They demonstrated a statistically significant change in ROM ($p<0.0005$) and also in overhead reach distance ($p<0.01$).[38] Decicco and Fisher (2005) studied the effect of HR and CR in shoulder ROM in overhead athletes, and concluded that they are equally effective.[39] Funk, Swank, Mikla, Fagan, and Farr (2003) found that PNF is more effective than static stretching (SS) to increase ROM of hamstrings and should be implemented after (sports) activity.[40] Wenos and Konin (2004) also concluded that HR stretching in hamstrings is more effective after an active warm up program at 70% of heart rate reserve.[41] Youdas, Haeflinger, Kreun, Holloway, Kramer, and Hollman (2010) studied the flexibility of hamstrings by applying HR techniques and found a statistically significant change in ROM ($p<0.05$). However, they could not establish a lower electromyography (EMG) activity in the hamstrings therefore concluded that ROM gains were not based upon neurophysiologic factors such as autogenic and reciprocal inhibition.[42] Feland and Marin (2004) studied the effect of the contraction intensity, and concluded that sub-maximum and maximum voluntary contraction have equally good results in increasing ROM.[43] Schuback, Hooper, and Salisburg (2004) compared self-applied and therapist applied HR techniques. Both are significant in increasing ROM.[44] Rowlands, Marginson, and Lee (2003) studied contraction time in the relaxation techniques. The conclusion was that a longer contraction time results in a larger increase of ROM.[45] In contrary the results from Bonnar, Deivert and Gould (2004) indicated that contraction time of 3 or 6 or 10 seconds is equally effective in increasing ROM.[46] Contrary to all of these findings, Davis, Ashby, Mc Cale, McQuain, and Wine (2005) concluded that PNF is not as effective as static stretching to increase ROM.[47]

HR and CR in relation to muscle performance

Carter, Kinzey, Chitwood, and Cole (2000) studied the muscle activity in terms of mean output of EMG activity after PNF stretching techniques and concluded that muscle activity decreased.[48] Church, Wiggins, Moode, and Crist (2001) performed a clinical trial on the effects of warming up procedures which included PNF stretching techniques.[49] Vertical jump was measured after the warming up procedures. Performance decreased with PNF stretching. This corresponds with the results of Marek, Cramer, Fincher, Massey, Dangelmaier, Purkayastha et al. (2005), who also found a decreased muscle performance.[50] Bradley, Olsen and Portas (2007) also measured vertical jump and found a significantly decreased performance after 10 minutes of PNF stretching ($P<0.05$) which fully recovered after 15 minutes of rest.[51]

HR and CR in elderly

Klein, Stone, Phillips, Gangi, and Hartman (2002) concluded that a PNF flexibility program in elderly improved their ROM in shoulder and ankle joints ($p<0.05$) and increased their strength in hip extension and ankle flexion and extension ($p<0.05$). This had a significant effect on the sit to stand test ($p<0.05$) as well as a clinically important improvement in the timed up and go test.[52]

HR and CR in relation to EMG

Ferber, Gravelle and Osternig (2002) concluded in a controlled trial that agonist CR is more effective than CR in increasing knee extension ROM in older adults.[53] In a second publication, they concluded in the same target group (elderly) that CR influenced ROM positively but that the EMG activity did not decrease, thus the ROM gain was not because of relaxation.[54] Moore and Kulkulka (1991) however concluded that HR results in a short phase of relaxation, the H-reflex in calf muscles was reduced by maximally one second after HR.[55] Olivo and Magee (2006) studied the CR in masticatory muscles and concluded that agonistic and antagonistic CR did not decrease EMG activity.[56]

HR and CR in reviews

Weerapong, Hume and Kolt (2004) stated in a review that the effect of stretching, including PNF stretching, was inconclusive in terms of increasing performance, but an improvement of ROM was evident.[10] Chalmers (2004) concluded in a review that ROM is clearly positively influenced by PNF stretching techniques; however there is no proof for neuromuscular relaxation.[57] Sharman, Cresswell and Riek (2006) concluded in a review that PNF stretching with the use of HR and CR techniques is the most effective means of improving ROM, particularly in the short term effects.[11] They discussed the explanation for this effect. Literature however, seems to be unclear on this matter. The proposed autogenic and reciprocal inhibition cannot be supported as the only explanation for the effect on ROM. She suggested that a change in stretch perception and stretch tolerance is a much more suitable explanation.[11]

Hindle, Whitcomb, Briggs, and Hong (2012) stated in a review that PNF stretching techniques improve both ROM and muscle performance, when applied consistently and post exercise.[12] The mechanisms that explain the effect are possibly a combination of autogenic inhibition, reciprocal inhibition, stress relaxation, and the gate control theory.[12]

Rhythmic Initiation (RI) and Combination of Isotonics (CoI)
in relation to elderly

One study was identified concerning RI and CoI. Cilento, da Nóbrega, and de Queiroz Campos (2013) applied RI and CoI in a group of elderly women and compared this to two other approaches (functional training and strengthening) and a control group. The PNF group and the functional training group both showed a statistically significant improvement in the Sit to Stand, Timed up and go and Functional reach tests ($p<0.05$.) The PNF group improved more than the strengthening group and showed similar improvements to the functional training group.[58]

Dynamic Reversals (DR) and Stabilizing Reversals (SR)
in relation to tension and strength

There were two studies identified which explored the effect of reversal of antagonist known as Dynamic Reversals (DR) or Stabilizing Reversal (SR).[59,60] Both studies found a greater tension in the antagonist after a contraction of the agonist, but the studies differed in the explanation for this phenomenon. Kamimura, Yoshioka, Ito, and Kusakabe (2009) identified a neural mechanism,[60] whilst Gabriel, Basford and An (2001) proposed altered biomechanical properties.[59]

Replication in relation to motor control and motor learning

One publication was identified in which motor control improvement as a result of a PNF-based intervention was discussed. Replication was applied while performing a scapula pattern (as muscle setting exercises) and was advocated to enhance motor control in the dynamic stabilization of the scapula in patients with shoulder dysfunction.[61]

Rehabilitation: stroke

Seven studies addressed rehabilitation of patients after a stroke. Two studies found a positive effect on gait in hemiplegic patients ($p<0.05$).[62,63] Both studied the effects of a four week PNF-based treatment, where PNF pelvic patterns were utilized. In both studies the techniques RI, DR, and CoI were applied. The demonstrated effects involved gait speed and cadence[62] as well as trunk impairment, balance, and gait.[63] Ribeiro, Britto, Oliveira, Silva, Galvio, and Lindquist (2012) compared partial bodyweight supported treadmill training to PNF in stroke patients. They concluded that both approaches resulted in an equal statistically significant improvement of gait parameters ($p<0.05$).[64] On impairment level only the PNF group improved on ROM for dorsiflexion of the ankle in swing phase.[64] Choi, Nam, Lee, and Park (2013) found that patients with hemiplegia after stroke improved on the Berg Balance Scale (BBS), in 10 meter walking speed, and in ROM of ankle dorsiflexion.[65] The improvement occurred after a program in which PNF was combined with taping. Compared to a control group with neurodevelopment treatment this PNF-based intervention resulted in more statistically significant improvement in all outcome measures ($p<0.05$).[65] These results are in contrast to the results of a study that compared treadmill training versus conventional training, defined by techniques from Bobath and PNF.[66] The conventional group was treated by therapists with additional qualification in Bobath and PNF concepts. Their conclusion was that treadmill training was more beneficial for stroke patients.[66]

Kraft, Fitts and Hammond (1992) studied the recovery of hand function by comparing electrical stimulation to PNF resistive treatment and to no treatment. The intervention groups both showed statistically significant improvements in both the Fugl-Meyer test and grip strength ($p<0.05$).[67] The PNF group improved by 18% while the electrical stimulation group improved up to 42%.[67] Duncan, Studenski, Richards, Gollub, Lai, Reker et al. (2003) found that after conclusion of the initial post stroke rehabilitation, further improvement in a structured progressive program (including PNF patterns) exceeds gains from spontaneous recovery.[68] The statistically significant improvements occurred in knee extension force, BBS, endurance, gait velocity and gait distance ($p<0.05$).[68]

Rehabilitation: musculoskeletal

Three publications were related to musculoskeletal disorders. In a group of patients with chronic low back pain, Kofotolis and Kellis (2006) concluded that PNF programs with either CoI or SR were more effective for improving lumbar ROM, muscle endurance, functional ability, and pain perception ($p<0.05$) than natural spontaneous recovery.[69] In a group of patients with cervical impairments Maicki, Trabka, Szwarczyk, Wilk-Franzcuk, and Figura (2012) concluded that a PNF-based program including the techniques CoI and SR was more effective than a manual therapy based program.[70] In both groups a significant improvement of cervical ROM and strength as well as a significant reduction in pain perception, functional limitations and disabilities of daily life was achieved. The PNF group improved more than the manual therapy group.[70]

The use of PNF patterns was studied in a clinical trial with patients suffering from a shoulder impingement. This clinical trial showed that the PNF-based intervention resulted in statistically significant improvement in the Shoulder Pain And Disability Index (SPADI)

($p<0.0001$) and in overhead reach height ($p<0.05$), which were defined as clinically important results.[71]

Rehabilitation: gait

Besides the studies that addressed gait in patients after stroke,[62,64,65] one study was identified which addressed gait in Parkinson patients.[72] This study resulted in a statistically significant improvement ($p<0.05$) of step frequency and gait speed.[72] Two studies addressed gait in patients with an amputation.[32,73] In 50 patients with a trans-femoral amputation the PNF-based treatment gains were superior ($p<0.05$) to those of the control group receiving standard gait training.[32] The outcome measures were weight bearing on amputated leg, stride length, step width, cadence and velocity.[32] In 30 patients with a trans-tibial amputation a similar result has been found.[73] In both studies the PNF group received intervention incorporating specified PNF basic principles and procedures (approximation, resistance, and pattern) and motor learning was enhanced with specified use of PNF techniques DR and SR. The control group received the same intervention without the specified PNF program.

One study found PNF stretching to be superior over static stretching in alteration of gait pattern.[74] Hip flexion and stride length increased ($p<0.05$) and stride rate decreased ($p<0.05$), therefore the authors advocated stretching after training to alter running mechanisms.[74]

Rehabilitation: vital function and face

Four studies addressed vital function and facial expression. The effect of PNF techniques on systolic and diastolic blood pressure has been studied.[75,76] Cornelius, Jensen, and Odell (1995) found that HR techniques might increase blood pressure, mainly during the isometric contraction phase. Since improvement in ROM is already evident after one to two trials a limit of two subsequent trials of PNF stretching is advocated.[75] Pereira (2012) found that the techniques RI, DR and CoI did not increase the blood pressure levels, so it is advocated to utilize up to five repetitions of Repetition Maximum (RM), since that has been recommended for strengthening.[76]

In patients with myotonic dystrophy PNF-based breathing therapy was superior to staged basal expansion breathing exercises.[77] The effects were measured with oxygen saturation (SpO_2, increased by 2.6%), respiratory rate (declined by 30%), heart rate (dropped slightly by 4.1%) and thoraco-abdominal motion (TAM, increased by 556%).[77]

The facial profile might be considered as a part of facial aesthetics and expression.[78] Namura, Motoyoshi, Namura, and Shimizu (2008) found a direct effect ($p<0.05$) on the facial profile after application of PNF-based therapy to the facial muscles.[78]

Rehabilitation: case studies

We identified six case studies in which PNF-based physical therapy was a part of the treatment program. The case studies all used clinical reasoning to explain the choices that were made. In a case of traumatic myositis ossificans the total program which incorporated the PNF-concept, resulted in a significant improvement of ROM, decrease of pain, and returned to recreational activities.[79] In a patient with post-polio syndrome a postoperative rehabilitation for rotator cuff surgery was discussed.[80] It was argued that overuse in the upper extremities might be the result of compensation for the lack of lower extremity strength. Based upon the rare situation an individual treatment protocol was defined with dynamic incorporation of movement patterns from PNF, since these mimic functional movement. The protocol resulted in a return to independent status with excellent retention even after two years.[80] Pasiut, Banach, Longawa, and Windak (2005) used PNF-based gait training to address impaired walking ability in 4 individuals post-stroke.[81] The VICON system *(©Vicon Motion Systems Ltd. UK registered no. 1801446)* was used to measure gait parameters before and after the four week therapy program. All patients demonstrated significant improvements in gait which were retained at a three month follow-up.[81] Haemophilia, a disease with low prevalence was studied by an example of seriously disabling arthropathy of the knee as a result of recurring intra-articular bleeding.[82] A physical therapy program using RI, SR, CoI from the PNF-concept resulted in increased muscle strength (Lovett scale), decreased pain (visual analogue scale/VAS) and an improvement of nine points on the Short Physical Performance Battery Test (SPPB).[82] A female worker experienced shoulder complaints resulting from secondary impingement and gleno-humeral instability.[83] The treatment strategy which was implemented combined manual therapy and PNF-based exercise therapy using RI and CoI with specific use of the basic procedure Timing for Emphasis. This resulted in pain relief (VAS), improved joint stability (apprehension / relocation test) and return to work after five sessions.[83] The relationship between impairments and disabilities in a case 16 years after a total hip replacement was addressed with a treatment strategy of combining manual therapy and PNF-based exercise therapy.[84] After a six-week program the patient showed improvements in strength, ROM, gait speed, and gait distance.[84]

Discussion

The results demonstrate that the PNF-concept has been applied across a diverse range of patient populations and clinical problems. The literature identified yielded research from a variety of levels of evidence, ranging from case studies over clinical trials and RCTs to reviews. As the range of the literature was so broad, with substantial variance in methodology and a diverse population it was deemed most appropriate to present the findings in a narrative review. There is only one previous attempt to review the whole PNF-concept from Westwater-Wood, Adams and Kerry (2006).[1] This review did not address the complexity and philosophy of the PNF-concept as proposed and advocated by its initiators and successors of proprioceptive neuromuscular facilitation. The scope and diversity of articles demonstrate that it is very difficult to study a comprehensive rehabilitation approach, such as the PNF-concept in a methodical way, as different components of a concept can act as confounders when measuring the effects of one specific part of that concept. Case studies seem to fit the best to explain the use of the whole concept. In case studies the different components of the PNF-concept (as there are the basic procedures and principles, and the techniques) are clearly described.[82,83] Although, case studies also show that PNF was combined with other therapy strategies, such as manual therapy,[83] manual therapy combined with modalities,[80] or medication.[81] Therefore it is hard to determine and explain the main contributing therapy component for the effects from these case studies.

When studying an individual component from the PNF-concept for its specific effect, researchers have to narrow down the variability that this PNF-concept provides. The procedural execution of the PNF techniques follows methodical sequences. This means that a technique itself can be studied more easily separated from the comprehensive approach of the concept and is then less disturbed by the variations a therapist would apply in individual patient treatments. One has to consider that in such a case, research is not conducted in the way therapy is provided.

When discussing physiotherapy concepts for rehabilitation the use of the International Classification of Functioning, Disability and Health (ICF) is currently the standard to define clinical problems and set therapeutic objectives.[6] The use of the PNF-concept fits in this total approach. Considering the PNF philosophy there is similarity with Antonovsky´s salutogenesis, which refers to the analysis and reinforcement of health resources and potentials of the individual.[85] In regard to the ICF, the use of PNF patterns seem to be defensible, since they address impairments as well as disabilities. Although it is frequently advocated in publications to use PNF patterns since they mimic functional task oriented activities,[35,36] this is frequently ignored in research on the specific effects of a technique and /or specific effects on impairments. For example, in the studies of Gabriel et al. (2001) and Kamimura et al. (2009) it is clearly described that they studied the effect of reversal of antagonist on isolated isometric contractions around the elbow joint instead of in a kinetic chain like a PNF pattern.[59,60]

The effect of indirect treatment, based on irradiation can be an appropriate choice when voluntary activation of a limb is not possible. Irradiation (cross education) might have clinical relevance in rehabilitation where health conditions such as acute injuries of the extremities, post-surgical limb immobilization, and certain neurological disorders with mainly unilateral muscle weakness prevent patients from exercising one limb.[29,31]

The effects of PNF stretching techniques have been the subject of the majority of studies. These effects can be listed either in terms of ROM[10,11,57] or muscle performance.[12] While analyzing the methods we detected that the PNF stretching techniques are often studied isolated from the concept of patterns and further basic principles and procedures.[38,42,44,46,53] In the studies that focused on ROM for hamstrings, different measurement methods were used.[42,44] All studies used in this review reported positive effects on ROM from HR and CR.[38-47] Only one study indicated PNF stretching not to be as effective as static stretching.[47] Neuromuscular relaxation of the target muscles has not been consistently demonstrated, therefore the neuromuscular effect has been doubted and research to explain the effect on ROM should be encouraged.[11,57] The IPNFA defines the relaxation within the HR and CR technique as a methodical component of the technique in which the patient has to relax consciously after a voluntary contraction.[3,9] Through this methodical approach a part of the explanation for the increase of ROM might come from fascia-release aspects, such as when the combination of contraction and passive stretch influence the mobility of the different fascia layers against each other.[86] Nevertheless, further investigation is required into the mechanisms underlying the response to these PNF stretching techniques. A critical note towards the research conducted in PNF stretching is the fact that mainly healthy subjects have been studied.[39-51] Secondly the main indication for these techniques is improving ROM[3,4,9] (not specifically increasing vertical jump or other motor outputs) so research concerning motor output further confuses interpretation of the literature.

Muscle performance can be understood to be an effect of strengthening and hypertrophy but also to be an improvement of inter-muscular coordination or a possible motor learning effect, as required in sport performances.[28] The muscle strength can further be influenced by using specific techniques as DR and SR.[59,60] These techniques mimic specific tasks such as hand sawing (DR) or holding and carrying objects (SR) and require inter- and intra-muscular coordination.[9]

The effectiveness of PNF therapy has been studied in various settings. For motor learning and motor control effects upon functional tasks (e.g. sit to stand, functional reach, etc.), there are clear indications that elderly can benefit from a PNF-based training.[52,58] The use of different techniques in the studies of Klein et al. (2002) and Cilento et al. (2013) raise questions about the specific objectives of these techniques.[52,58] Cilento et al. (2013)[58] specifically used RI and CoI, techniques that are meant to enhance the motor learning effect and to stimulate motor planning.[4,9] Klein et al. (2002)[52] used CR, which aims to improve ROM.[4,9] In both studies however there was a significant effect on sit to stand activity. All together these techniques and basic principles and procedures seem to fit into motor learning ideas such as shaping, blocked training, feedback and focus of attention. In stroke patients the PNF-concept resulted in improved ability of “getting up” and “gait”,[62-65] not only in short term post stroke but also after conclusion of initial rehabilitation.[68] This is consistent with the findings in a RCT from Nilsson, Carlsson, Danielsson, Fugl-Meyer, Hellström, Kristensen et al. (2001),[87] they concluded that over ground gait training (like PNF can provide) is as effective as bodyweight supported treadmill training in stroke patients. The results of treatment of hand function in stroke patients as studied by Kraft et al. (1992) should be considered with caution due to participant drop-out, resulting in an intervention group only consisting of three participants.[67] Specific treatment (manual mobilization and functional task training) for impaired wrist ROM in stroke patients has a significant effect on hand function.[88] The review of Luke, Dodd and Brock (2004) dealt with treatment concepts to improve arm function in hemiplegic patients; they concluded that there was no superiority in any studied concept.[89] These results are similar to those of other studies which concluded that no specified therapy-concept is superior over another, but rather that different therapy approaches have equal justification,[90] or even that a mix of components from different approaches should be considered.[91] Ernst (1990) recommended in their review to use the most cost effective form of treatment in stroke patients.[92] It was not specified which treatment concept that would be, but it was outlined to be dependent on the setting of the patient care. Kwakkel (2006) argued that "more therapy" is beneficial compared to "less therapy" in stroke patients.[93] The definition of "more" therapy is not specified in regards to time, frequency, and /or intensity. The PNF philosophy of mobilization of reserves might be hidden in this additional therapy. A motor learning effect is a likely explanation for the effects found in the mentioned studies, which would fit within the PNF philosophy.[3,9]

In the musculoskeletal area of health care, only three smaller studies have been identified.[69-71] These three studies focused on three different issues. The outcomes from Kofotolis and Kellis (2006) and Maicki et al. (2012) fit into the general guidelines for nonspecific low back pain and nonspecific neck pain where it is advised to treat general strength, mobility and activity, rather than pain.[69,70,94] The results from Nakra, Quddus, Khan, Kumar, and Meena (2013) confirm the ideas of McMullen and Uhl (2000) who emphasized working in a kinetic chain in shoulder rehabilitation.[71,35]

The results of the studies on gait have all shown that a positive result on step frequency and gait speed was achieved. Although different patient groups have been studied, in all studies an improvement in this essential daily activity was achieved. Again, a possible part of the explanation of the effects is the motor learning component. Compared to more expensive (weight supported) treadmill training this basic exercise approach seems to be cost effective and is therefore advisable.[92]

Cornelius et al. (1995) and Pereira (2012) have concluded that PNF treatment is also safe for patients with low cardiac loadability.[75,76] Nitz and Burke (2002) concluded that PNF therapy has a basic effect on the vital pulmonary functions in pulmonary diseases.[77] In general one can state that an active rehabilitation approach increases general fitness.[95] The PNF concept is able to provide such a strategy.[52-54,58]

Conclusion

This review shows that there is a substantial body of research which supports the use of PNF as a comprehensive rehabilitation concept. The review demonstrated that PNF has been used across many different patient populations and for many different types of impairments. It has been applied safely and effectively on impairments and activities. The PNF-concept as advocated by the IPNFA addresses rehabilitation fitting within the ICF.

The efficacy of PNF for specific indications and populations however requires further investigation, since a sufficient amount of qualified well designed randomized controlled studies is lacking. Nevertheless, the studies that have been performed indicate the potential of the PNF concept. The possible motor learning results from the PNF basic principles and procedures and PNF techniques might be of interest for further research. The effect on increasing ROM has been established. This is the only area where there is clear evidence for its efficacy.

Furthermore we hope to stimulate research in physiotherapy with a focus on the use and effectiveness of the PNF-concept in various indications. It is recommended to establish well designed studies addressing the efficacy of the PNF-concept in the different areas of rehabilitation.

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Table 1: terminology within the PNF concept.

PNF philosophy	**PNF basic principles & procedures**	**PNF techniques**
Positive approach *- assessment on abilities* *- start treatment with an activity the patient can do* *- set up a patient for success* *- indirect treatment* *- no pain / respect pain*	Tactile stimulus (lumbrical grip) *	Rhythmic Initiation +
	Verbal stimulus *	Replication +
	Visual stimulus *	Combination of Isotonics +
Functional approach *- use of ICF classification* *- functionally oriented assessment and treatment* *- optimize functional level of patient* *- Evaluation of the situation, and the treatment goal.*	Optimal resistance #	Stretch through range +
	Approximation #	Stretch at beginning of range +
	Traction #	Dynamic Reversals ++
Mobilization of reserves *- active patient participation, use of irradiation* *- intensive training – repetition and variations (change of positions, activities and environment)* *- supportive training-program*	Elongation (stretch) #	Stabilizing Reversals ++
	Irradiation and reinforcement #	Rhythmic stabilization ++
	Pattern >	Hold Relax §
Treatment of total human being. *- in assessment and treatment (direct and indirect)* *- environmental and personal factors (physical, intellectual and emotional)*	Timing >	Contract Relax §
	Body mechanics >	
	Summation >	
Use of motor learning and motor control principles		

* = exteroceptive stimuli; # = proprioceptive stimuli; > = procedures; + = agonistic techniques; ++ = antagonistic techniques; § = relax techniques (PNF stretching techniques).

Table 2: overview of all used sources in relation to the PNF-concept (section B: PNF basic principles and procedures and section C: PNF techniques).

Study, author and year	**Type of study**	**Focus of PNF issue**	**Population**	**Outcome measure**	**Result**
PART A:		**Publications in relation to PNF basic principles and procedures**			
Fallon et al. 2001[25]	CT	Tactile stimuli	18 healthy subjects	EMG recordings of tibialis anterior, medial and lateral gastrocnemius and soleus muscle.	Tactile stimulus effects the muscle activity about the ankle which are important to control gait.
Gabriel et al. 2006[26]	Review	Resistance, motor learning		Functional strength	Resistance effects neural drive of motor units, based on motor synchronization and firing rate.
Johnson and Johnson 2002[27]	Descriptive text	Approximation, irradiation, timing			
Kofotolis et al. 2005[28]	RCT	Resistance	24 healthy males	Muscle hypertrophy	Cross sectional area m. vastus lateralis increased.
Arai et al. 2001[29]	RCT	Resistance, patterns and irradiation	6 post surgery knee patients	EMG activity contralateral limb and torque produced	PNF pattern demonstrated a 23% increase in torque in the contralateral limb, while straight activity in sagittal plane produced not over 13%.
Sato and Maruyama 2009[31]	CT	Resistance, patterns and irradiation	30 healthy males	Extension force contralateral lower limb	The extension force of the lower limbs increased significantly. Contralateral more than ipsilateral.
Yigiter et al. 2002[32]	RCT	Approximation	50 unilateral trans-femoral amputee patients	Weight bearing on amputated leg, stride length, step width, cadence and velocity	PNF-based therapy with approximation effected stance stability.
Shimura and Kasai 2002[33]	CT	Resistance and patterns	7 healthy males	Motor evoked potentials and EMG reaction time	PNF positions superior over neutral positions.
Witt et al. 2011[34]	CT	PNF Pattern	21 healthy subjects	EMG activation of scapula muscle	In PNF patterns significantly higher activation.
McMullen and Uhl 2000[35]	Descriptive text	Kinetic chain / pattern			

Myers and Lephart 2000[36]	Review	Sensory motor system / irradiation and pattern		Athletic function	PNF pattern mimic athletic function.
Mahoney et al. 2011[37]	CT	Summation of stimuli	18 “old” subjects and 18 “young” subjects	Response time to multi-sensory stimuli.	Elderly tend to respond faster to a combination of somatosensory and visual stimuli. Younger people tend to respond faster to a combination of somatosensory and auditory stimuli.
PART B:		**Publications in relation to PNF techniques in rehabilitation**			
		Studies in relation to PNF Hold Relax and Contract Relax techniques			
Godges et al. 2003[38]	RCT	CR	20 shoulder patients	ROM for external rotation + overhead reaching.	PNF group improved significantly more than control group.
Decicco and Fisher 2005[39]	RCT	HR and CR	30 healthy subjects	Difference between HR and CR on ROM	HR and CR are equal effective.
Funk et al. 2003[40]	RCT	CR vs SS	40 healthy subjects	ROM knee extension	PNF more effective then SS.
Wenos and Konin 2004[41]	CT	HR before and after warming up	24 healthy males	ROM hamstrings	HR more effective after warming up.
Youdas et al. 2010[42]	CT	HR and CR	35 healthy subjects	ROM knee extension (hamstrings)	Significant change in ROM, no lower EMG activity.
Feland and Marin 2004[43]	RCT	HR and CR and contraction intensity	72 healthy males	ROM hamstrings	Sub maximal and maximal contraction are equal effective.
Schuback et al. 2004[44]	RCT	Self-applied vs therapist applied HR	42 healthy subjects	ROM hip flexion (hamstrings)	Both procedures are significantly effective.
Rowlands et al. 2003[45]	RCT	HR and CR and contraction time	37 healthy females	ROM hamstrings	Longer contraction time results in more improvement of ROM.
Bonnar et al.2004[46]	RCT	HR and CR and contraction time	60 healthy subjects	ROM hip flexion (hamstrings)	3, 6 and 10 seconds contraction time have the same effect on ROM.
Davis et al. 2005[47]	RCT	CR (reciprocal) vs SS	19 healthy adults	ROM knee extension (hamstrings)	SS more effective than PNF.
Carter et al. 2000[48]	RCT	HR and CR	24 healthy females	Mean output of muscle performance	Muscle activity decreased directly after PNF stretching.
Church et al. 2001[49]	CT	CR	40 healthy females	Vertical jump performance	Jump height decreased after PNF stretching.
Marek et al. 2005[50]	CT	HR and CR	19 healthy subjects	Mean output of muscle performance	Muscle activity decreased directly after both, PNF and static stretching.

Bradley et al. 2007[51]	CT	HR and CR	18 healthy males	Vertical jump performance	Performance decreased after 10 minutes of stretching but was fully recovered after 15 minutes of rest.
Klein et al. 2002[52]	Prospective CT	CR (PNF flexibility in elderly)	11 elderly persons	ROM shoulder and ankle, Sit to Stand and TUGT	Significant improvement in ROM clinical important improvement in Sit to Stand and in TUGT.
Ferber et al. 2002[53]	CT	HR	32 elderly males	ROM knee extension (hamstrings)	Significant change in ROM.
Ferber et al. 2002[54]	CT	HR	26 elderly males	ROM knee extension + EMG activity from the hamstrings	Significant change in ROM, no reduction of EMG activity.
Moore and Kulkulkas 1991[55]	CT	HR	16 females	H-reflex from M. triceps surae	Short time of depressed H-reflex amplitudes.
Olivo and Magee 2006[56]	CT	CR	30 healthy subjects	EMG activity in masticatory muscles	No reduction in EMG activity.
Weerapong et al. 2004[10]	Review	HR and CR		ROM and muscle performance	ROM improves significantly, inconclusive in muscle performance.
Chalmers 2004[57]	Review	HR and CR		ROM	PNF clearly has a positive influence on ROM, relaxation unclear.
Sharman et al. 2006[11]	Review	HR and CR		ROM	PNF most effective means for increasing ROM, mechanism unclear.
Hindle et al. 2012[12]	Review	HR and CR		ROM and muscle performance	Improvement of both, ROM and muscle performance.
Studies on PNF in relation to Rhythmic Initiation and Combination of Isotonics					
Cilento et al. 2006[58]	RCT	RI and CoI (in elderly)	63 elderly females	Sit to Stand, TUGT and functional reach test	Patients improved in all more than in the control group.
Studies in relation to PNF Reversal techniques					
Gabriel et al. 2001[59]	RCT	DR and SR	26 healthy females	Muscle activity in antagonist	EMG activity of antagonist was higher after activation of agonist.
Kamimura et al. 2009[60]	CT	DR and SR	10 healthy males	Muscle activity in antagonist	EMG activity of antagonist was higher after activation of agonist.
Studies in relation to PNF in stroke patients					
Wang 1994[62]	CT	RI, DR, CoI on pelvis patterns in stroke patients	20 stroke patients	Gait speed and cadence	Speed and cadence both improved significantly.

Khanal et al. 2013[63]	RCT	RI, DR, CoI on pelvis patterns in stroke patients vs conventional physiotherapy (truncal exercises)	30 stroke patients	Trunk impairment, balance, gait speed and gait cadence	All outcome measures improved significantly more in the PNF group then in the control group.
Ribeiro et al. 2012[64]	RCT	PNF gait training and pelvis patterns vs weight supported treadmill training in stroke patients	23 stroke patients	Gait parameters	The interventions showed equal results in both groups.
Choi et al. 2013[65]	RCT	PNF + taping vs neurodevelopment treatment in stroke patients	30 stroke patients	BBS and 10 meter walking speed	PNF group improved more than control group.
Pohl et al. 2002[66]	RCT	PNF and neurodevelopment treatment vs treadmill training in stroke patients	60 stroke patients	Gait speed, gait cadence and stride length	Treadmill training improved more than PNF and neurodevelopment treatment.
Kraft et al. 1992[67]	RCT	PNF Resisted training vs electro stimulation and no treatment for wrist in stroke patients	18 stroke patients	Fugl-Meyer test and in grip strength	Electro group improved by 42% PNF by 18% no training by 0 %
Duncan et al. 2003[68]	RCT	Structured program PNF included vs spontaneous recovery in stroke patients	92 stroke patients	Knee extension force, BBS, endurance, gait velocity and gait distance	Structured program exceeds spontaneous recovery.
		Studies in relation to PNF in musculoskeletal indications			
Kofotolis and Kellis 2006[69]	RCT	DR and SR in CLBP	86 females with CLBP	Lumbar ROM, muscle endurance, functional ability and pain perception	PNF more effective then natural spontaneous recovery.
Maicki et al. 2012[70]	RCT	CoI and SR in Neck pain patients vs manual therapy	80 patients with neck pain	Cervical ROM and strength, pain perception and NDI	PNF group improved more than manual therapy group.
Nakra et al. 2013[71]	RCT	PNF-based treatment vs conventional treatment in shoulder patients	30 shoulder patients	SPADI and overhead reach height	Statistically significant and clinically important improvement in the PNF group.
		Studies in relation to PNF in gait disabilities			
Mirek et al. 2003[72]	CT	PNF gait training in Parkinson patients	3 Parkinson patients	Step frequency and gait speed	Significant improvement of both outcome measures.
Yigiter et al. 2002[32]	RCT	PNF gait training vs traditional gait training in trans-femoral amputee patients	50 unilateral trans-femoral amputee patients	Weight bearing on amputated leg, stride length, step width, cadence and velocity	PNF-based therapy was superior over traditional therapy.

Sahay et al. 2013[73]	RCT	PNF gait training vs traditional gait training in trans-tibial amputee patients	30 unilateral trans-tibial amputee patients	Weight bearing on amputated leg, stride length, step width, cadence and velocity	PNF-based therapy was superior over traditional therapy.
Caplan et al. 2009[74]	RCT	HR vs static stretching in healthy subjects.	18 rugby players	Gait pattern in stride length and stride rate	Stride length increased stride rate decreased.
		Studies in relation to PNF in vital functions			
Cornelius et al. 1995[75]	RCT	Systolic and diastolic blood pressure responses during PNF stretching	60 healthy subjects	Raise of Systolic and diastolic blood pressure	Static contraction will increase blood pressure, but less than 15 mmHg above baseline.
Pereira 2012[76]	CT	Systolic and diastolic blood pressure responses during PNF strengthening (RI, DR, CoI)	15 elderly inactive females	Raise of Systolic and diastolic blood pressure	No statistically significant effect on blood pressure.
Nitz and Burke 2002[77]	CT	PNF breathing vs basal expansion breathing	7 patients with myotonic dystrophy	Respiration rate, heart rate, (TAM) thoracal abdominal motion and SpO_2	PNF group superior: Respiration declined with 30%, heart rate by 4.1 %, SpO_2 increased by 2.6%, TAM by 556%.
Namura et al. 2008[78]	CT	Facial profile after PNF for mimics.	40 healthy subjects	Photographed facial profile for nasolabial, mentolabial and mentocervical angles	Angles changed significantly, although continued training is necessary to avoid relapse.
		PNF in case studies			
Morley and Perrault 2012[79]	Case report	Traumatic myositis ossificans in left thigh in a young sportsman. Soft tissue mobilization with HR techniques from PNF	A 13 year old male rugby player	ROM, Pain, resuming training	All significantly improved and successful resuming of training.
Carlson and Hadlock 2007[80]	Case report	Rotator cuff surgery in a post-polio patient. PNF pattern for mobilization and strengthening	A 48 year old female	Return to independent status	All achieved, also in retention test two years later.
Pasiut et al. 2005[81]	Case report	Gait training in 4 cases of stroke patients facilitated with pattern training for upper and lower limb in various positions	4 individual male stroke patients aged between 43 and 67 years	VICON measured knee and ankle joint angles in gait	All improved significantly, retentions was seen in 3 months follow up.
Luterek et al. 2009[82]	Case report	Haemophilia resulting in arthropathy of the knee, PNF with RI, SR and CoI	A 44 year old male	Strength , Pain, SPPB	Improved strength, decreased pain, 9 point improvement on the SPPB.

Smedes 2006[83]	Case report	Secondary impingement, PNF, combined with manual therapy. PNF for strengthening and functional task training	A 27 year old female	Pain, gleno-humeral stability and return to work	Final objective achieved after 5 sessions of intervention.
Smedes 2009[84]	Case report	Secondary problems 16 years after a total hip replacement with impaired gait. PNF for strengthening and functional gait training	A 62 year old female	Strength ROM, gait speed and gait distance	Clinical relevant improved was achieved after a 6 weeks treatment period.

PNF= Proprioceptive neuromuscular facilitation; RCT= randomized controlled trial; CT= clinical trial; EMG= Electromyography; ROM=- range of motion; CR= contract relax; HR= hold relax; SS= static stretching; RI= rhythmic initiation; CoI= combination of isotonics; DR= dynamic reversals, SR= stabilizing reversals; TUGT= timed up and go test; BBS= Berg balance scale; CLBP= chronic low back pain; SPADI= shoulder pain and disability index; TAM= Thoracal abdominal motion; SPPB= short physical performance battery; vs= versus.