Journal of Bodywork & Movement Therapies 23 (2019) 622–627

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

PREVENTION & REHABILITATION: Case Report

Motor learning with the PNF-concept, an alternative to constrained induced movement therapy in a patient after a stroke; a case report

Fred Smedes [a, b, *], Leandro Giacometti da Silva [c, d]

[a] *Department of Physical Therapy, Saxion, University of Applied Sciences, Enschede, The Netherlands*
[b] *Practice for Physical Therapy: "ten Berge", Losser, The Netherlands*
[c] *Department of Physiotherapy, Universidade Luterana do Brasil, Canoas, Brazil*
[d] *Private Practice (clinic): Luthier - Innovation and Rehabilitation, Porte Alegre, Brazil*

A R T I C L E I N F O

Article history:
Received 12 October 2017
Received in revised form
12 February 2018
Accepted 26 May 2018

Keywords:
PNF
Stroke
Hemiplegic hand
Rehabilitation
CIMT

A B S T R A C T

Introduction: Over sixteen million people suffer a stroke each year. Stroke is characterized by a one-sided paresis. Upper extremity and hand function are most limited. The current view on "neuro rehabilitation" advocates a constrained induced movement therapy (CIMT) setting. This case report seeks to illustrate the clinical reasoning and the feasibility of applying an alternative approach in patients who are not accepted or not suitable for the constrained induced movement therapy.

Case description: A male patient, 68 years of age, developed impairments in his right arm and hand, such as loss of range of motion and strength besides spasticity after a stroke. This resulted in a loss of dexterity in his affected right side and in "disuse" of that arm and hand.

Patient management: A therapy was designed based upon the Proprioceptive Neuromuscular Facilitation-concept (PNF-concept) and consisting of PNF pattern exercises in a functional task setting with specified PNF-principles of facilitations and PNF-techniques for motor re-learning activities, over a period of six weeks. This resulted in clinical important improvements of wrist extension, grip strength, spasticity, dexterity and patient satisfaction with specific tasks.

Discussion and conclusion: The provided comprehensive therapy mimics CIMT and robotics. The approach addresses possibly motor learning effects, cortical reorganization and structural impairments. Proprioceptive Neuromuscular Facilitation (PNF) - diagonal movement patterns have been described as: "having beneficial effects in cortical adaptations and cortical organization resulting in motor learning effects". In cases where CIMT is difficult to apply, a specified PNF-based therapy has shown to be a feasible alternative.

1. Introduction

The World Health Organisation (WHO) describes a stroke as a "clinical syndrome characterized by a rapid development of clinical signs and symptoms of focal (sometimes global) disturbance of cerebral function, lasting more than 24 hours or leading to death" (WHO, 1978). Current epidemiological data indicate that 16.9 million people suffer a stroke each year, which represents a global incidence of 258/100,000/year, with marked differences between high- and low-income countries, and an age-adjusted incidence 1.5 times higher in men than in women (Béjot et al., 2016). The number of stroke survivors almost doubled between 1990 and 2010, and has now reached 33 million people (worldwide) (Béjot et al., 2016). In 2007 the prevalence of stroke was 191.000 cases and an incidence of 35.000 new cases per year in the Netherlands (RIVM, 2017). Stroke is the primary cause of disablement in the Netherlands. Outcomes after stroke are frequently impaired by complications, including motor handicaps, dementia, depression, fatigue, and a high risk of early re-hospitalization and institutionalization, with adverse consequences in terms of socioeconomic costs (Béjot et al., 2016).

The hemiplegic disablement as a result of a stroke is characterized by a one sided paresis in the upper and lower extremity resulting in problems with activities of daily life (ADL), such as reaching, grabbing and holding objects as well as with ambulation (Lee et al., 1999; Kwakkel et al., 1999, 2008; 2016). Upper extremity

* Corresponding author. Post-box70.000, 7500KB, Enschede, 7500, The Netherlands.
E-mail address: f.smedes@saxion.nl (F. Smedes).

https://doi.org/10.1016/j.jbmt.2018.05.003
1360-8592/

and hand function are most limited (Kwakkel et al., 1999, 2008; 2016). The current view on physiotherapeutic treatment is based upon the guidelines for patients suffering from a status after stroke, which summarize the possible interventions with supporting research and evidence. One of them is the Guideline "Stroke" from the Dutch physiotherapy association, KNGF (KNGF, 2014). An eclectic approach consisting of several different treatment methods, - concepts and - forms seems to offer the best results (KNGF, 2014). There is no evidence for one specific intervention in the rehabilitation of arm and hand function (KNGF, 2014). Within the current view of "neuro rehabilitation", task oriented training is strongly advocated in a constrained induced movement therapy (CIMT) setting (KNGF, 2014; Kwakkel et al., 2016; Wolf et al., 2006). Inclusion criteria for this task oriented CIMT training are often defined by an active wrist extension of 20° and 10° for finger extension (Lee et al., 1999; Wolf et al., 2006). Given that therapy-related gains are achieved on the basis of brain plasticity (Liepert et al., 2000; Hodics et al., 2006), this suggests the hypothesis that the provided intervention has to aim at inducing motor cortex plasticity for the tasks provided in therapy. Paresis and/or hypertonia may result in a relative immobilization, "learned non-use" and "disuse" of the arm and hand (Gracies, 2005; Wolf et al., 2006; Kwakkel et al., 2016). It is very likely that morphologic changes in muscle and joint tissue occur as a result of "disuse" and relative immobilization (Gracies, 2005). Loss of mobility, capsular adhesions and muscular contractures might be the consequences (Gracies, 2005; Pandyan et al., 2003; Malhotra et al., 2011; Lieber et al., 2004). Contractures are described as pathological changes of connective tissue which present themselves as stiffness (Pandyan et al., 2003; Malhotra et al., 2011). These changes can occur in muscle-, capsule- and joint tissue (Gracies, 2005; Pandyan et al., 2003; Malhotra et al., 2011; Lieber et al., 2004).

Smedes et al. (2014) used successfully, in a pilot study, manual joint techniques integrated in functional task training, addressing the role-glide mechanism and capsular components and so combining mobilization of body structures and functional task training integrated in single therapy.

Proprioceptive neuromuscular facilitation (PNF) has been described as a comprehensive rehabilitation concept, promoting motor learning, motor control, strength and mobility. This comprehensive rehabilitation approach includes task oriented training with manual facilitation aiming for motor learning and motor control effects (Adlers et al., 2014; Smedes et al., 2016). An overview of the components of the PNF-concept is provided in Table 1.

Misunderstandings of the concept in research publications addressing the PNF-concept has been criticised (Smedes et al., 2016). Often, just single components are addressed without the real clinical context, for example, die application of isolated PNF stretching techniques (Hindle et al., 2012; Sharman et al., 2006), even without the use of the three dimensional muscle chain (Smedes et al., 2016).

This case report seeks to illustrate the clinical reasoning and feasibility of using the comprehensive nature of the PNF-concept. All resulting in a suitable approach for the hemiplegic hand in a patient who is not accepted or is not suitable for the advocated task oriented CIMT.

2. The case/patient characteristics

A male patient of 68years of age, suffered a stroke five months prior to the start of this case report. The stroke was a result from a left sided cerebral vascular accident (CVA) that resulted in a hemiplegic condition on the right side. The patient had no prior neurological condition; neither did he suffer from any cardiovascular disease. There is no history of arm and hand injuries. The patient encountered difficulties in ADL, in keeping his balance and in ambulation. The patient is right handed.

The initiated rehabilitation focused on improvement in balance and ambulation. The function of the hand was considered with a lower priority. Therefore the patient developed impairments in his right arm and hand (Pandyan et al., 2003; Malhotra et al., 2011; Lieber et al., 2004), such as loss of range of motion (ROM), loss of strength, increased muscle tone and spasticity (Lieber et al., 2004). This resulted in a loss of dexterity in his affected right hand and in "disuse" of that arm and hand. An informed consent, allowing the anonymous use of his data from assessment and treatment for publication, was provided by the patient.

3. Physical therapy management

3.1. Initial assessment and monitoring

General guidelines for stroke suggest using task oriented treatment within a CIMT-setting (KNGF, 2014; Kwakkel et al., 2008, 2016; Wolf et al., 2006). The patient was uncomfortable with this approach, and was more and more frustrated since positive results didn't occur. He felt more "handicapped" when his "good" arm was constrained. In these situations he felt himself bilaterally restricted.

Therefore a treatment regimen within the comprehensive nature of the PNF-concept, consisting of a functional approach with manual guided training was defined. The effectivity of this approach was monitored with measuring the ROM of active and passive wrist extension (AWE/PWE), grip strength, spasticity and dexterity. The reliability of measuring ROM with a goniometer is shown with an intraclass correlation coefficient (ICC) of 0.95 by Khamwong et al. (2010), grip strength was measured with a JAMAR handheld dynamometer (JAMAR, Sammons Preston Rolyan inc. Bolingbrook, Chicago, USA) (Peolsson et al., 2001; Mathiowetz, 2002). The "Modified Ashworth Scale" (MAS) was used for monitoring spasticity. The MAS has an ordinal 6 point scale of which, the reliability is shown with Kappa-values of 0.75–0.83 (Pandyan et al., 1999). Finally the Frenchay arm test (FAT) and the nine-hole peg test (NHPT) were administered for dexterity. The inter- and intra-tester reliability of the FAT is shown by Heller et al. (1987), with correlation coefficients between 0.83 and 0.99. The inter tester reliability of the NHPT has been established with correlation coefficients of 0.98 and 0.99 (Oxford Grice et al., 2003; Lin et al., 2010). Monitoring took place at the start of this study (T0), after six weeks of intervention (T1) and four weeks after finishing the intervention period (T2). (see Table 2).

3.2. Physical treatment and intervention

To address the patient's problems a therapy was designed consisting of PNF pattern exercises in a functional task setting (Adlers et al., 2014, p 4-11).

Motor re-learning activities, verbal and tactile facilitation within the task oriented training were performed within the execution of the following PNF patterns. To address the wrist and finger motion into wrist extension the patterns; 1) Flexion/Abduction/External rotation, 2) Extension/Abduction/Internal rotation and 3) the ulnar thrust pattern were used, since they all have wrist extension as a component and they mimic functional reaching activities (Adlers et al., 2014; McMullen and Uhl, 2000; Myers and Lephart, 2000). To address grip strength the pattern "Flexion/Adduction/External rotation with elbow Flexion" was used (Adlers et al., 2014). The basic procedure of "Timing for Emphasis" was utilized to enhance the motor learning effect on wrist and finger extension and flexion (grip strength) (Adlers et al., 2014; Smedes et al., 2016; Johnson and Johnson, 2002).

Table 1
terminology within the PNF concept.

PNF philosophy	PNF basic principles & procedures for facilitation	PNF techniques for rehabilitation
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) (exteroceptive) Verbal stimulus (exteroceptive) Visual stimulus (exteroceptive)	Rhythmic Initiation (agonistic technique) Replication (agonistic technique) Combination of Isotonics (agonistic technique)
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 (proprioceptive) Approximation (proprioceptive) Traction (proprioceptive)	Stretch through range (agonistic technique) Stretch at beginning of range (agonistic technique) Dynamic Reversals (antagonistic technique)
Mobilization of reserves - active patient participation, use of irradiation - intensive training – repetition and variations (change of positions, activities and environment) - supportive training-program	Stretch (Elongation) (proprioceptive) Irradiation and reinforcement (proprioceptive) Pattern (procedural)	Stabilizing Reversals (antagonistic technique) Rhythmic stabilization (antagonistic technique) Hold Relax (relax/stretching technique)
Treatment of total human being. - in assessment and treatment (direct and indirect) - environmental and personal factors (physical, intellectual and emotional)	Timing (procedural) Body mechanics (procedural) Summation (procedural)	Contract Relax (relax/stretching technique)
Use of motor learning and motor control principles		

For achieving the sub-goals ROM, wrist extensor strength and grip strength, the PNF-techniques Rhythmic Initiation, Combination of Isotonics and Dynamic Reversals were used (Adlers et al., 2014; Smedes et al., 2016). Rhythmic Initiation is characterized by different modes of muscle activity and guidance. Defined are a passive, assisted, resisted and active phase of agonistic muscles (Adlers et al., 2014 p 34-35). Combinations of Isotonics is characterized by the different kinds of agonistic muscle contraction, being concentric, static and eccentric, mimicking activities such as lifting an object and placing it down again (Adlers et al., 2014 p 35-37). Dynamic Reversals are characterized by the successive contractions of agonist and antagonist directly after each other, similar as in using a hand saw (Adlers et al., 2014 p 37-39). All three techniques were performed in the "normal timing" of the whole pattern and all three in a "Timing for Emphasis", the emphasis focused on wrist and fingers. In this specified way, effects on body structures such as capsule and ligaments, extensor and flexor muscles of the wrist were addressed besides the specific task of grasping and holding. Timing is the facilitation of the order of sequences of a movement, while Timing for Emphasis is the facilitation of one specific sequence within the whole movement pattern (Adlers et al., 2014 p 26-27; Smedes et al., 2016; Johnson and Johnson, 2002).

The task oriented motor re-learning exercises with the specific use of PNF-patterns focused on reaching and grabbing activities used in daily life. Reaching and holding a cup, a book, a raiser, toothbrush etc. are examples of the mentioned daily activities (see Figs. 1–3).

The intervention was provided 18 times over a period of six weeks with three times a week a therapy session. Furthermore a home exercise program was provided to practice the newly learned activities and tasks.

3.3. Results

All outcome measures improved at T1 and T2. At T1 the direct effect from the intervention was monitored. At T2 the retention of the effects in a follow up after 4 weeks was monitored. The

Fig. 1. Timing for Emphasis on finger extension/opening for reaching, within the PNF-pattern: Flexion/Abduction/External rotation.

Fig. 2. Irradiation from the shoulder into wrist extension for reaching, within the PNF-pattern: Flexion/Abduction/External rotation.

Fig. 3. Timing for Emphasis on finger and wrist flexion for holding an item (e.g. a razor), within the PNF-pattern: Flexion/Adduction/External rotation with elbow Flexion.

improvements at T1 were: for the AWE 17° (from 20 to 37), for the PWE 20° (from 25 to 45), for the grip strength 3.2 kg (Kg) (from 13.5 to-16.7). The MAS improved by 2 points (from 2 down on 1) and the dexterity improved in the NHPT by 8 seconds (from 31 to 23) and in the FAT with 2 points (from 3 to 5). For a precise overview see Table 2.

Furthermore the positive results were reflected in the ADL. After six weeks of intervention the patient was able to reach, grab and hold a (coffee) cup and to shave himself with a wet-raiser. These activities were personal objectives for the patient, enabling him to participate more in social life. At T2 the dexterity measured with the FAT and the spasticity measured with the MAS stabilized, while the other outcome measures slightly improved further. The AWE with another 3°, the PWE with 5°, the grip strength with 0.3 Kg and the dexterity measured with the NHPT with another 2 seconds.

4. Discussion

4.1. Clinical reasoning

Morphological changes post stroke develop within the first 4 weeks (Gracies, 2005; Pandyan et al., 2003). Contracture formation is one of the first changes to occur together with loss of strength (Pandyan et al., 2003). Furthermore loss of motor recruitment disturbing the normal motor program for activities has been discussed (Lee at al 1999; Kwakkel et al., 2016; Lieber et al., 2004).

Specifically the wrist extension is relevant for hand function (Ryu et al., 1991; Gates et al., 2016) and is the biggest limitation in stroke patients (Lee et al., 1999; Oxford Grice et al., 2003; Kwakkel et al., 2016). For most daily tasks a wrist extension of 40–60° is required (Ryu et al., 1991; Gates et al., 2016). Changes in the musculoskeletal tissue are however regular reported (Gracies, 2005; Lieber, 2004). These changes might impair the wrist mobility severely. Increased wrist mobility in a neurological case after applying manual mobilization has been documented (Smedes et al., 2014; Gallego et al., 2007).

The PNF-based exercises used in this case have been facilitated with manual guided mobilization and resistance to enhance cortical reorganization, since interventional studies suggest that subjects who actively exerts an effort have greater gains in motor learning (Liepert et al., 2000; Lotze et al., 2003; Perez et al., 2004; Moreira et al., 2017). The results from T2 might indicate a component of motor learning since retention of the results was achieved in this period (Wulf et al., 2010), however the follow-up time was only four weeks.

4.2. Hypothesis

Treatment of the issues mentioned with manual assisted, guided and resisted mobilization will result in a “forced use” of the affected hand. It was assumed that this might result in a re-education for functional use, addressing cortical reorganization

Table 2
an overview of patient monitoring.

Outcome measure	T0	T1	T1 − T0 (difference)	T2	T2 − T0 (difference)
AWE (degrees)	20	37	17	40	20
PWE (degrees)	25	45	20	50	25
Grip strength (Kg)	13.5	16.7	3.2	17	3.5
MAS	2	1	−2	1	−2
FAT	3	5	2	5	2
NHPT	31	23	8 sec.	21	10 sec.

T0 = start of the intervention; T1 = after 6 weeks of intervention; T2 = 4 weeks after end of intervention; AWE = active wrist extension; PWE = passive wrist extension; Kg = kilogram; MAS = Modified Ashworth Scale; FAT = Frenchay arm test; NHPT = nine hole peg test; sec. = seconds.

besides improving the structural impairments of the wrist itself. Furthermore positive experience of the patient will enhance mental processes and motivation to involve his affected hand and arm in ADL tasks, triggering motor learning effects (Lotze et al., 2003; Perez et al., 2004; Wulf et al., 2010). This approach has similarities with the underlying idea of CIMT, in which also a "forced use" effect is obtained by constraining the unaffected arm (Thrane et al., 2014; Wolf et al., 2006).

4.3. Clinical perspective

Patients face after a stroke primarily problems of neural origin (WHO, 1987). This might result in "learned non-use" leading frequently to "disuse" of the affected hand (Lee et al., 1999; Wolf et al., 2006; Kwakkel et al., 2008, 2016). Cortical reorganization processes might deal with the loss of cortical representation in a rehabilitation approach (Lotze et al., 2003; Perez et al., 2004; Moreira et al., 2017). A small, but lasting effect on the dexterity of the affected arm might come from "forced use" strategies (Lee et al., 1999; Wolf et al., 2006; Kwakkel et al., 2008, 2016). The results in this case report indicate effects on activities and on impairments as defined in the ICF (WHO, 2013). The NHPT improved close to normative values of 20.8 seconds (Oxford Grice et al., 2003), the use of the NHPT is advocated when the FAT is at its maximum, as was the case in this patient (Lin et al., 2010). Furthermore the results on grip strength are above the Minimal Detectable Difference (MDD) of 2.2 Kg (Bertrand et al., 2015). and the ROM of wrist extension is in the area of minimal required ROM for upper extremity ADL (Gates, 2016).

Although the follow-up (T2) was only four weeks, it still indicates possible motor learning effects since the effects of the outcome measures have retained (Wulf et al., 2010).

In this case-study the PNF pattern exercises with manual guidance and facilitations were integrated in functional task oriented therapy. In this comprehensive approach the patient was "forced to use" the affected arm. The typical "forced use" strategy based upon constraining the unaffected arm was not tolerated by the patient. Nevertheless, the design of the treatment used in this case mimics a kind of "forced use" towards the level "body function/body structure" within the international classification of functioning (ICF) and was integrated in the ICF level of activities (WHO, 2013).

The approach in this case has similarities with robotic designed rehabilitation as described by Tagahashi et al. (2008). In that study specifically hand function was treated with robotic assisted task training, hence also "forcing the use" of the affected hand. The availability of such advanced devices is limited to specific centres. An approach with manual assisted and guided training is imitating this robotic approach. Tagahashi et al. (2008) demonstrated statistically significant and clinical important improvements in dexterity. In the case described here there were similar results achieved. Possible explanation for the improvements can be an effect on motor evoked potentials (MEP) and a reduction in electromyography reaction time (EMG-RT), Shimura and Kasai (2002) demonstrated these effects in PNF-based positions. Kofotolis et al. (2005) documented a change in muscle force after applying PNF-based intervention. Furthermore possibly the therapy changed sensorimotor cortex function in a task specific manner. Specifically the use of PNF- diagonal movement patterns has beneficial effects in cortical adaptations and cortical organization in complex tasks (Moreira et al., 2017). The importance of sensorimotor integration to motor learning has been pointed out (Mahoney et al., 2011).

The decreased spasticity and the increased strength highlights the view that proprioceptive feedback and sensorimotor integration are important to the effectiveness of motor-based therapies (Ridding et al., 2000). The therapy provided here utilized several motor learning theories: active repetitive movement practice resulting in a variability of practice, maximum sensory input via tactile (grasping sensory-rich objects) and proprioceptive stimuli, a mixture of internal and external focus of attention via self-controlled learning and shaping etc. (Cauraugh and Kim, 2003; Krakauer, 2006; Bund and Wiemeyer, 2004; Taub and Crago, 1994).

Case studies seem to fit the best to explain the use of a comprehensive approach (Smedes et al., 2016). In case studies, the different components of the used strategy (here the PNF-concept) are described. When studying a single component from a specified approach for its specific effect, researchers have to narrow down the variability physical therapy can provide. One has to consider that in such a case, research is not conducted in the way therapy is provided, hence the choice of this case study. Given the type of study design, the results of this case report should not be generalized to large groups of patients with chronic stroke but rather could be used as a basis for further research in larger groups to determine the effectivity of applying the PNF-concept for hand function problems in stroke patients.

5. Conclusion and take-home message

The provided therapy in this specific case was successful in regards of changing patient's abilities in ADL. The results are comparable with those of advocated approaches from general guidelines. Therefore in cases where the CIMT approach is difficult to follow through, a specified PNF-based therapy has shown to be a feasible alternative.

The clinical reasoning in activity limitations and underlying impairments (ICF) is essential to determine a therapy approach that is supported with external evidence. Further research to determine the efficacy of a PNF-based rehabilitation approach is warranted.

Declaration of interest

The authors report no declarations of interest.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Adlers, S., Buck, M., Beckers, D., 2014. PNF in Practice, fourth ed. Springer publishers, Berlin, Heidelberg.

Bertrand, A.M., Fournier, K., Wick Brasey, M.-G., Kaiser, M.-L., Frischknecht, R., Diserens, K., 2015. Reliability of maximal grip strength measurements and grip strength recovery following a stroke. J. Hand Ther. 28 (4), 356–363.

Béjot, Y., Daubail, B., Giroud, M., 2016. Epidemiology of stroke and transient ischemic attacks: current knowledge and perspectives. Rev. Neurol. 172 (1), 59–68.

Bund, A., Wiemeyer, J., 2004. Self-controlled learning of a complex motors kill: effects of the learners' preferences on performance and self-efficacy. JHMS (J. Hum. Mov. Stud.) 47, 215–236.

Cauraugh, J., Kim, S., 2003. Stroke motor recovery: active neuromuscular stimulation and repetitive practice schedules. Journal of Neurology, Neurosurgery & Psychiatry.74 1562–1567.

Gallego, P.H., Moreno, J.M.T., López, O.L., Polo, S.C., Garcia, C.H., De Miguel, E.E., 2007. Indirect influence of specific Kaltenborn glide mobilizations of the carpal joint on a subject with neurological impairments. J. Bodyw. Mov. Ther. 11 (4), 275–284.

Gates, D.H., Walters, L.S., Cowley, J., Wilken, J.M., Resnik, L., 2016. Range of motion requirements for upper-limb activities of daily living. Am. J. Occup. Ther. 70 (1), 10.

Gracies, J.M., 2005. Pathophysiology of spastic paresis. I: paresis and soft tissue changes. Muscle Nerve 31, 535–551.

Heller, A., Wade, D.T., Wood, V.A., Sunderland, A., Langton Hewer, R., Ward, A., 1987. Arm function after stroke: measurement and recovery over the first three months. J. Neurol. Neurosurg. Psychiatry 50, 714–719.

Hindle, K.B., Whitcomb, T.J., Briggs, W.O., Hong, J., 2012. Proprioceptive neuromuscular facilitation (PNF): its mechanisms and effects on range of motion and muscular function. J. Hum. Kinet. 31 (1), 105–113.

Hodics, T., Cohen, L.G., Cramer, S.C., 2006. Functional imaging of intervention effects

in stroke motor rehabilitation. Arch. Phys. Med. Rehabil. 87, 36–42.
Johnson, G.S., Johnson, V.S., 2002. The application of the principles and procedures of PNF for the care of lumbar spinal instabilities. J. Man. Manip. Ther. 10 (2), 83–105.
KNGF, 2014. Richtlijn; beroerte [royal Dutch physiotherapy association. KNGF guideline; stroke 2014]. Available from: https://www.fysionet-evidencebased.nl/index.php/kngf-guidelines-in-english. (Accessed 12 July 2017).
Khamwong, P., Nosaka, K., Pirunsan, U., Paungwali, A., 2010. Reliability of muscle function and sensory perception measurements of the wrist extensors. Physiother. Theory Pract. 26 (6), 408–415.
Kofotolis, N., Vrabas, I.S., Vamvakoudis, E., Papanikolaou, A., Mandroukas, K., 2005. Proprioceptive neuromuscular facilitation training induced alterations in muscle fiber type and cross sectional area. Br. J. Sports Med. 39 (3) e11.
Krakauer, J., 2006. Motor learning: its relevance to stroke recovery and neurorehabilitation. Curr. Opin. Neurol. 19, 84–90.
Kwakkel, G., Kollen, B.J., Wagenaar, R.C., 1999. Therapy impact on functional recovery in stroke rehabilitation: a critical review of the literature. Physiotherapy 13, 457–470.
Kwakkel, G., Meskers, C.G., van Wegen, E.E., Lankhorst, G.J., Geurts, A.C., van Kuijk, A.A., Lindeman, E., Visser-Meily, A., de Vlugt, E., Arendzen, J.H., 2008. Impact of early applied upper limb stimulation: the EXPLICIT-stroke programme design. BMC. Neurol. 8 (49), 14.
Kwakkel, G., Winters, C., Van Wegen, E.E.H., Nijland, R.H.M., Van Kuijk, A.A.A., Visser-Meily, A., Meskers, C.G.M., 2016. Effects of unilateral upper limb training in two distinct prognostic groups early after stroke: the EXPLICIT-stroke randomized clinical trial. Neurorehabilitation Neural Repair 30 (9), 804–816.
Lee van der, J.H., Wagenaar, R.C., Lankhorst, G.J., Vogelaar, T.W., Devillé, W.L., Bouter, L.M., 1999. Forced use of the upper extremity in chronic stroke patients. Results from a single blind randomized clinical trial. Stroke 30, 2369–2375.
Lieber, R.L., Steinman, S., Barash, I.A., Chambers, H., 2004. Structural and functional changes in spastic skeletal muscles. Muscle Nerve 29, 615–627.
Liepert, J., Bauder, H., Miltner, W.H.R., Taub, E., Weiller, C., 2000. Treatment-induced cortical reorganization after stroke in humans. Stroke 31, 1210–1216.
Lin, K., Chuang, L., Wu, C., Hsieh, Y., Chang, W., 2010. Responsiveness and validity of three dexterous function measures in stroke rehabilitation. JRRD (J. Rehabil. Res. Dev.) 47 (6), 563–572.
Lotze, M., Braun, C., Birbaumer, N., Anders, S., Cohen, L., 2003. Motor learning elicited by voluntary drive. Brain 126, 866–872.
Mahoney, J.R., Li, P.C.C., Oh-Park, M., Verghese, J., Holtzer, R., 2011. Multisensory integration across the senses in young and old adults. Brain Res. 1426, 43–53.
Malhotra, S., Pandyan, A.D., Rossewilliam, S., Roffe, C., Hermens, H., 2011. Spasticity and contractures at the wrist after stroke: time course of development and their association with functional recovery of the upper limb. Clin. Rehabil. 25, 184–191.
Mathiowetz, V., 2002. Comparison of Rolyan and JAMAR dynamometers for measuring grip strength. Occup. Ther. Int. 9 (3), 201–209.
McMullen, J., Uhl, T.L., 2000. A kinetic chain approach for shoulder rehabilitation. J. Athl. Train. 35 (3), 329–337.
Moreira, R., Lial, L., Teles Monteirob, M.G., Aragãob, A., Santos David, L., Coertjens, M., et al., 2017. Diagonal movement of the upper limb produces greater adaptive plasticity than sagittal plane flexion in the shoulder. Neurosci. Lett. 643, 8–15.
Myers, J.B., Lephart, S.M., 2000. The role of the sensorimotor system in the athletic shoulder. J. Athl. Train. 35 (3), 351–363.
Oxford Grice, K., Vogel, K.A., Le, V., Mitchell, A., Muniz, S., Vollmer, M.A., 2003. Adult norms for a commercially available Nine Hole Peg Test for finger dexterity. Am. J. Occup. Ther. 57, 570–573.
Pandyan, A.D., Johnson, G.R., Price, C.I., Curless, R.H., Barnes, M.P., Rodgers, H., 1999. A review of the properties and limitations of the Ashworth and modified Ashworth Scales. Clin. Rehabil. 13 (5), 373–383.
Pandyan, A.D., Cameron, M., Powel, J., Stott, D.J., Granat, M.H., 2003. Contractures in the post-stroke wrist: a pilot study of its time course of development and its association with upper limb recovery. Clin. Rehabil. 17, 88–95.
Peolsson, A., Hedlund, R., Öberg, E., 2001. Intra-and inter-tester reliability and reference values for hand strength. J. Rehabil. Med. 33, 36–41.
Perez, M.A., Lungholt, B.K., Nyborg, K., Nielsen, J.B., 2004. Motor skill training induces changes in the excitability of the leg cortical area in healthy humans. Exp. Brain Res. 159, 197–205.
Ridding, M.C., Brouwer, B., Miles, T.S., Pitcher, J.B., Thompson, P.D., 2000. Changes in muscle responses to stimulation of the motor cortex induced by peripheral nerve stimulation in human subjects. Exp. Brain Res. 131, 135–143.
RIVM, 2017. Volksgezondheidszorg.info [internet] Bilthoven, The Netherlands [cited August 23, 2017]. Available from: https://www.volksgezondheidenzorg.info/onderwerp/beroerte/cijfers-context/huidige-situatie#!node-prevalentie-en-nieuwe-gevallen-van-beroerte.
Ryu, J.Y., Cooney 3rd, W.P., Askew, L.J., An, K.N., Chao, E.Y., 1991. Functional ranges of motion of the wrist joint. J. Hand Surg. 16 (3), 409–419.
Sharman, M.J., Cresswell, A.G., Riek, S., 2006. Proprioceptive neuromuscular facilitation stretching: mechanisms and clinical implications. Sports Med. 36 (11), 929–939.
Shimura, K., Kasai, T., 2002. Effects of proprioceptive neuromuscular facilitation on the initiation of voluntary movement and motor evoked potentials in upper limb muscles. Hum. Mov. Sci. 21 (1), 101–113.
Smedes, F., van der Salm, A., Koel, G., Oosterveld, F., 2014. Manual mobilization of the wrist: a pilot study in rehabilitation of patients with a chronic hemiplegic hand post-stroke. J. Hand Ther. 27 (3), 209–216.
Smedes, F., Heidmann, M., Schäfer, C., Fischer, N., Stepien, A., 2016. The proprioceptive neuromuscular facilitation-concept; the state of the evidence, a narrative review. Phys. Ther. Rev. 21 (1), 17–31. https://doi.org/10.1080/10833196.2016.1216764.
Tagahashi, C.D., Der-Yeghiaian, L., Le, V., Motiwala, R.R., Cramer, S.C., 2008. Robot-based hand motor therapy after stroke. Brain 131, 425–437.
Taub, E., Crago, J., 1994. An operant approach to rehabilitation medicine: overcoming learned nonuse by shaping. J. Exp. Anal. Behav. 61 (2), 281–293.
Thrane, G., Friborg, O., Anke, A., Indredavik, B., 2014. A meta-analysis of constraint-induced movement therapy after stroke. J. Rehabil. Med. 46 (9), 833–842.
Wolf, S.L., Winstein, C.J., Miller, J.P., Taub, E., Uswatte, G., Morris, D., Giuliani, C., Light, K.E., Nichols-Larsen, D., EXCITE Investigators, 2006. Effect of constraint-induced movement therapy on upper extremity function 3 to 9 months after stroke: the EXCITE randomized clinical trial. JAMA, J. Am. Med. Assoc. 296, 2095–2104.
World Health Organization, 1978. Cerebrovascular Disorders (Offset Publications). World Health Organization, Geneva. ISBN 9241700432. OCLC 4757533.
World Health Organization, 2013. How to Use the ICF: a Practical Manual for Using the International Classification of Functioning, Disability and Health (ICF). Exposure Draft for Comment [online]. WHO, Geneva. October 2013[cited 2014 Dec 24]. Available from: www.who.int/classifications/drafticfpracticalmanual.pdf.
Wulf, G., Shea, C., Lewthwaite, R., 2010. Motor skill learning and performance: a review of influential factors. Med. Educ. 44 (1), 75–84.