CHAPTER 40: Optimizing motor performance and sensation after brain impairment

Annie McCLUSKEY [1,2] Natasha A LANNIN [3,4] Karl SCHURR [2] & Simone DORSCH [2 5]

[1] Discipline of Occupational Therapy, Faculty of Health Sciences, The University of Sydney, Cumberland Campus, Lidcombe, New South Wales, Australia (Email: annie.mccluskey@sydney.edu.au)

[2] The StrokeEd Collaboration, PO Box 3105, Regents Park, Sydney, New South Wales, Australia (Email: kschurr@bigpond.net.au)

[3] Alfred Health, 55 Commercial Road, Prahran, Victoria 3181, Australia
[4] La Trobe University, Bundoora, Victoria 3086, Australia (Email: n.lannin@latrobe.edu.au)

[5] School of Physiotherapy, Australian Catholic University, PO Box 868, North Sydney, New South Wales Australia (Email: simone.dorsch@acu.edu.au)

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ABSTRACT

This chapter provides a framework for optimizing motor performance and sensation in adults with brain impairment. Conditions such as stroke and traumatic brain injury are the main focus, however, the chapter content can apply to adults with other neurological conditions. The tasks of eating and drinking are used as examples throughout the chapter. Skills and knowledge required by graduates are identified, including knowledge of motor behaviour, the essential components of reaching to grasp and reaching in sitting, and how to identify compensatory strategies, develop and test movement hypotheses. Factors that enhance skill acquisition are discussed, including task specificity, practice intensity and timely feedback, with implications for therapists' teaching skills. Finally, a summary is provided of evidence-based interventions to improve motor performance and sensation, including high intensity, task-specific training, mirror therapy, mental practice, electrical stimulation and constraint therapy.

Key Points:

1. Essential knowledge in neurological rehabilitation includes an understanding of normal motor behaviour, muscle biology and skill acquisition.
2. Abnormal motor performance can be observed during a task such as reaching for a cup, and compared with expected performance. Hypotheses about the cause(s) of observed movement differences can then be made and tested.
3. Paralysis, weakness and loss of co-ordination affect upper limb motor performance. To improve performance after brain impairment, therapists should primarily focus on improving strength and co-ordination.
4. Many people with brain impairment have difficulty understanding instructions, goals and feedback, and consequently may not practice well. To teach people to practice well and learn skills, therapists need to be good coaches.
5. Motor performance and sensation can be improved using low-cost evidence-based strategies such as high intensity, repetitive, task-specific training, mirror therapy, mental practice, electrical stimulation and constraint-induced movement therapy.

1. Introduction

Upper motor neuron lesions typically cause impairments such as paralysis, muscle weakness and loss of sensation. These impairments can limit participation in everyday tasks such as eating a meal. *Motor control* is a term commonly used in rehabilitation (Shumway-Cook, 2012; van Vliet et al 2013) and refers to control of movements such as reaching to grasp a cup and standing up. Occupational therapists and physiotherapists retrain motor and sensory impairments that interfere with tasks such as grasping a cup and sitting safely on the toilet.

The aim of this chapter is to provide a framework that helps therapists to systematically observe, analyse and measure motor and sensory impairments. Targeted evidence-based interventions will be described that can drive neuroplasticity. Therapists need to proactively seek muscle activity and sensation. It is not enough to teach a person how to compensate using one-handed techniques, or to wait for recovery to possibly occur.

2. Essential Skills, Knowledge and Attitudes for Improving Motor Performance

Therapists should think of themselves as "movement scientists" (Carr et al 1987, Refshauge et al 2005). A movement scientist uses specialist knowledge from basic science (for example, neuroplasticity, muscle biology), applied science (for example, biomechanics of normal movement and motor control), education and adult learning (for example, coaching strategies, feedback and practice) to inform analysis and training. Valid reliable instruments are used to measure change in performance and evaluate the effectiveness of intervention. Systematic reviews and randomised controlled trials are critically appraised and their clinical implications used to guide treatment. The first step in this process involves movement analysis, where therapists identify missing or decreased essential components. Next, therapists can hypothesize about which impairments may be the cause of the movement problems and compensatory strategies, and make these impairments the focus of intervention. It is essential for therapists to understand the impairments that contribute to movement problems following stroke or brain injury.

3. Analysing Movement

Movement analysis involves observing a person as they attempt a task, then comparing the attempt with 'normal' movement. Therefore, therapists need to understand the biomechanics of normal movement, including kinematics and kinetics. The biomechanics of reaching to grasp a glass or cup will be described, to illustrate the process of movement analysis.

3.1. Normal Reaching to Grasp

The kinematics and kinetics of reaching to grasp have been described elsewhere (Alt Murphy & Häger, 2015). *Kinematics* refers to what can be seen (i.e. angular displacements, velocity and acceleration). For example, when a person reaches for a glass or cup, as shown in Figure 1, shoulder flexion and thumb abduction movements can be seen. The *kinetics* (or forces) that cause these displacements can be inferred but not directly observed. In the example shown, the anterior deltoid and thumb abductor muscles, respectively, cause the angular displacements that we observe.

It is helpful to have a framework when analysing reach to grasp. Normal reaching to grasp can be divided into three phases: transport, pre-shaping and grasp (see Table 1). Each phase involves essential components that are necessary for efficient performance (Carr & Shepherd, 2010). These essential components will be described in turn.

Figure 1. Transport and pre-shaping of the hand when reaching to grasp a glass.

These illustrations present the kinematics of reaching (i.e. what can be seen). 1a and 1b show the trajectory of the arm (the transport phase), and pre-shaping of the fingers and thumb.

Figure 1a

As the hand is transported forwards, the shoulder moves into forward flexion, external rotation [enabling the hand and thumb to reach the glass], elbow flexion and then elbow extension.

Figure 1b

Figure 1c

Figure 1c shows wrist extension, and the forearm held midway between pronation and supination. As pre-shaping occurs, the fingers are slightly flexed and rotated (at the metacarpal joints), producing pad-to-pad opposition in preparation for contact with the glass. The thumb is abducted to make a space for the glass, but also rotated at the base of the thumb, allowing pad-to-pad opposition.

Table 1 Phases and essential components of reaching to grasp a glass: A framework for analysis

Phase	Essential Components	Primary Muscles
Transport:	External rotation	• Infraspinatus, supraspinatus, teres minor, posterior deltoid
	Shoulder flexion	• Anterior deltoid, pectoralis major and minor, coracobrachialis, biceps brachii
	Protraction	• Serratus anterior, pectorialis major
	Elbow flexion and extension	• Biceps brachii, brachialis, triceps brachii, brachioradialis
Pre-Shaping:	Ulnar or radial deviaton	• Flexor and extensor ulnaris, flexor and extensor carpi radialis
	Supination	• Supinator, biceps brachii
	Wrist extension	• Extensor carpi radialis longus, extensor ulnaris
	Thumb abduction	• Abductor pollicus longus and brevis
	Thumb conjunct rotation (opposition)	• Opponens pollicus (thumb abduction and flexion at carpometacarpal thumb joint enabling pulp-to-pulp opposition of the thumb to the fingers)
	Metacarpophalangeal extension	• Extensor digitorum communis, extensor indicus (index finger) ,extensor digiti minimi (little finger)
	Interphalangeal flexion	• Interossei, lumbricals, flexor digiti superficialis, flexor digiti profundus
	Finger abduction	• Palmar interossei
Grasp:	Metacarpophalangeal flexion	• Interossei, lumbricals
	Interphalangeal flexion	• Interossei, lumbricals, flexor digiti superficialis, flexor digiti profundus
	Adduction and flexion of the thumb	• Adductor pollicus, 1st dorsal interossei, flexor pollicus longus and brevis, opponens pollicus

Transport refers to movement (trajectory) of the arm and hand forwards to the cup. Essential components include shoulder flexion, protraction and external rotation to move the arm forward, with varying degrees of elbow flexion and extension, depending on reach height and distance. When adults reach for a cup that is close (e.g. within 60% of arm's length), there is minimal hip flexion or trunk movement (Dean et al 1999a). When reaching for a cup that is equal to, or greater than an arm's length away (e.g. 100% or 140% of arm's length), the hips also flex to transport the trunk and arm towards the cup. Trunk displacement via hip flexion is observed earlier in the movement sequence when people reach for objects further away. The elbow may not fully extend at the end of reach (see Figs 1B and 1C), unless that is the only way the object can be reached (see Figs 2A to 2C).

Pre-shaping of the hand, fingers and thumb begins almost simultaneously with transport of the arm. Pre-shaping involves anticipating and making the shape and size of the cup. The forearm in Figure 1 is midway between supination and pronation, the wrist is extended and the thumb abducted, with sufficient metacarpo-phalangeal (MCP) extension for the fingers to fit around the object. The interphalangeal joints of the fingers remain curved, replicating the shape of the wineglass shown. The fingers may also be slightly abducted to conform to the shape of the object.

Grasp begins when the fingers and thumb touch the object. MCP and finger flexion, thumb adduction, and conjunct rotation of the thumb and fingers enable grasp, and apply an equal force from either side of the cup, keeping the cup upright in preparation for drinking. If any of these essential components are missing, a person will need to use compensatory strategies to reach, pre-shape and grasp. Compensatory strategies are discussed later in this chapter.

When reaching for an object, the brain automatically selects the most appropriate hand trajectory, decides when to begin forming the appropriate shape and anticipates how much grip force to use based on experience and visual input. There is initial acceleration of the hand followed by deceleration prior to grasp. The proportion of time allocated to acceleration and deceleration will vary depending on the nature of the object (eg a delicate wine glass vs a coffee mug) and intent of the person (eg picking up a knife to cut food or place the knife in the sink). In addition, adaptations to these anticipated forces may need to be made at the point of grasp.

This process of normal reach occurs with little or no conscious thought. Grasp is based on the *intrinsic* properties of the object, such as the shape, size and perceived fragility (eg a plastic cup vs a wine glass) and *extrinsic* factors, such as distance from the object, and whether the person is sitting or standing.

The timing and synchronization of reaching requires careful, systematic observation if differences are to be recognised, and compared to the expected essential components.. For example, in healthy adults, transport of the arm and hand begin almost simultaneously (van Vliet 1998), although the arm begins to move slightly before the thumb and fingers open.

Reaching to grasp in children has been investigated (eg Zoia et al 2006) and compared to adults reaching. If object size and distance reached are varied, 5-year old children and adults show very similar reaching strategies. The major differences are longer movement duration and deceleration times and a larger hand aperture, in 5-year old children. People with sensory impairments who are uncertain about their grasp may also reach with a larger than necessary aperture.

Figure 2. Reaching in sitting (cup within arms length then at 100% of arms length)

In Figs 2a and 2b, there is minimal hip flexion and trunk displacement when this lady reaches for a cup which is close and within arm's length. Her elbow remains flexed even when grasping the cup. In Fig 2c, the cup has been placed at arm's length, and on her affected side. Hip and shoulder flexion, and elbow extension all help this lady to successfully transport her hand forwards.

In summary, when reaching forwards for a cup, the arm begins to move slightly before the hand opens. When reaching for close objects the elbow typically remains flexed, with shoulder flexion and external rotation helping to transport the hand forwards. When reaching for distant objects, trunk and hip flexion help transport the hand forwards together with shoulder flexion, external rotation and elbow extension. These features are often referred to as "essential" components (Carr & Shepherd 2010).

3.2. Postural Adjustments in Sitting

In the next section, a summary is provided of adjustments needed to maintain sitting when reaching for a cup, and what features to observe when analysing sitting. The focus is on analysing and training sitting and leg extensor activation, not upper limb reaching. The focus is on the leg muscles because they are essential for sitting, and are more likely to be affected by an upper motor lesion than the trunk muscles. It is primarily the leg, not the trunk muscles, that prevent falling when a person reaches forward or to the side. Other features including *base of support*, *reaching distance* and *direction* will be discussed. These factors can be manipulated during analysis and training, to make seated reaching easier or more challenging.

When reaching for a cup in sitting, it is intuitively known and anticipated what will happen with reaching forwards, sideways or towards the floor in response to the effect of gravity. The motor control system anticipates which muscles are necessary to maintain balance and avoid falling. These postural adjustments are required, eg during dressing and toiletting. The base of support, direction and speed of reaching all influence the muscle activity required when reaching in sitting (Dean et al 1999a, 1999b).

The *base of support* is the feet and thighs when sitting with both feet on the floor (see *Figures 2a to 2c*). When reaching forwards beyond this base of support, the leg muscles are critical for maintaining upright sitting (Dean et al 1999a, 1999b). For example, when reaching for a cup at 140% of arm's length, tibialis anterior contracts prior to anterior deltoid in the arm. Soleus, quadriceps and biceps femoris muscles contract soon after, to control the forward movement of our body mass (Dean et al 1999a, Crosbie et al 1995). *See Fig 3a to 3F*.

If thigh support is reduced when reaching forwards, the contribution of the leg muscles increases (Dean et al 1999b). If both feet are off the floor, the base of support is now only the thighs (see *Figure 3f)*. Consequently, postural adjustments cannot be made using the large muscles which cross the knees and ankles, and the feet cannot be stabilised on the floor. Instead, with this smaller base of support, only the muscles around the hip maintain sitting and prevent falling. Therefore reaching distance is significantly reduced when both feet are off the ground.

Reaching direction also influences leg muscle activity. Reaching for a cup on the right side results in increased right leg extensor activation (Dean et al 1999b). A leg amputation will reduce the distance a person can reach to the amputated side when not wearing a prosthesis (Chari & Kirby, 1986).

Figure 3. Postural adjustments required to stay upright in sitting, when reaching for a cup at distances greater than arms length

Figure 3a

Figure 3b

Figure 3a: This lady has been asked to reach for, and pick up a cup on her unaffected side, beyond arm's length. Her thighs and feet form her base of support. She looks at the object in **Figure 3b**, begins to pre-shape her hand, anticipates the effect that gravity will have on her base of support as she lifts her arm, then transports her arm forwards. To avoid falling forwards when lifting her arm, she pushes with her feet.

Figures 3c

Figure 3d

Figure 3c: this lady is reaching for a cup placed beyond arm's length, and on her affected side. This task is difficult for her, requiring greater leg extensor activity from her left leg. If she does not push through her left leg and foot, she will fall forwards and to her left.

Figure 3d illustrates her weight shift forwards and to her left side.

Figure 3e

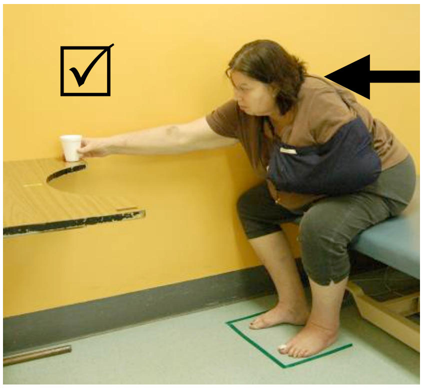


Figure 3e shows a training session involving practice of seated reaching. This lady is practicing reaching for a cup placed beyond arms length and to her unaffected side. When her skill and motor control improves, she will practice placing the cup across to the left side of the table. Her feet are on the floor and her thighs well supported. Electrical tape marks correct foot position.

Figure 3f

Figure 3f: the seat height has been raised, and this lady's feet are now off the floor. She cannot push with her feet. Consequently, she is unable to reach as far forward. To optimise successful reaching, the base of support available to a person needs to be considered and planned.

Research on normal reaching in sitting can be applied during analysis and when training people who have difficulty staying upright while reaching. For example if a person is unable to generate sufficient leg extensor force to prevent falling while reaching forward, the person will need to learn to activate the leg extensor muscles. Reaching forward will be easiest when there is maximal thigh support and the feet are on the floor. The person will be more successful if they are first asked to reach to a target within arm's reach. This practice will allow the person to learn to control hip flexion and forward movement of the trunk as they reach, before being expected to reach beyond arm's length.

Less muscle activity is required from the affected leg extensors if a person reaches to the unaffected side. Therefore, during analysis and training, it will be easier for a person to first reach for a cup on their unaffected side. Task difficulty can be progressed by reaching further, first to the unaffected side, then to the front, then to the affected side. As the person becomes more successful, the amount of thigh support can be reduced to increase the force required from the legs.

Feedback also helps to increase learning. If a person is unable to generate sufficient extensor force on their affected leg, they may need specific feedback about whether their leg muscles are working. Bathroom scales can give feedback about the force being generated through the affected leg (eg weight in kilograms). Bathroom scales can also indicate whether the leg muscles are pushing at the appropriate time (ie anticipating the transfer of weight forward) to prevent the person falling. Systematic, persistent practice of reaching in this way can improve reaching ability in sitting in stroke survivors in acute hospital (Dean et al 2007) and community settings (Dean & Shepherd 1997).

Before concluding this section, it is important to emphasise the problems that results from 'facilitating' or manually guiding movement. Training postural adjustments and sitting balance by moving a person will result in very different muscle activation patterns compared to self-generated movement. The person cannot anticipate when disturbances of movement will occur now, the direction or force. Manual guidance is unlikely to help the person activate muscles necessary for self-generated movement (for example, when cleaning themselves on the toilet). Such 'training' strategies are unhelpful and may cause the person to become fearful of moving during therapy.

Strategies used during analysis and training should aim to mimic the normal sequence of muscle activity specific to the task (*see Table 2 for examples*). If a person is unable to sit, the therapist will need to accurately analyse the reasons why they cannot sit, then develop training strategies specific to those difficulties.

In summary, seated reach can be progressed by gradually increasing the distance, and changing the direction of reach (ie to the unaffected side, then forwards, then to the affected side), and decreasing the amount of thigh support.

3.3 Focus on positive versus negative impairments

Impairments after a stroke or brain injury can be classified as either *positive* or *negative* (Ada & Canning, 2005). *Positive* impairments are 'added' features and include abnormal postures and exaggerated reflexes producing spasticity. *Negative* impairments are the loss of body functions and include paralysis (inability to activate muscles), weakness (loss of muscle strength), loss of coordination and loss of sensation. These negative impairments, particularly weakness, limit people with neurological conditions more than the positive impairments. Negative impairments after a stroke or brain injury have shown a clear association with activity limitations,

Table 2: Summary of seated reaching without back support

Reaching forward in sitting without back support, feet on the floor	**Anticipatory Muscle Activity** **Leg/Trunk**	**Implications for intervention**	**Possible training strategies**
Within arm's length	Back extensors Hip extensors	▪ Begin to train reaching within arm's length if the person is unable to activate their hip extensors ▪ Sit with back support to minimize initial task difficulty ▪ Provide trunk support if unable to sit without assistance	**Practice Set-Up** ▪ Sitting with back support: practice moving forward (hip flexors) and back (hip extensors) towards the back support ▪ Provide a vertical cue for sitting alignment (ie if the person is falling towards the **left,** position the person with a wall on the **right** side to provide a close vertical cue and feedback when they begin to fall ▪ Provide a visual cue (eg a line on the wall for appropriate shoulder position)
Greater than arm's length	Hip extensors Knee extensors Plantarflexors	▪ Practice sitting on a stable surface ▪ Specific training of hip and knee extensor strength and endurance on the affected side ▪ Sitting on a lower seat height and maximise thigh support to decrease extensor force ▪ Feet well supported on the floor	**Feedback** i. How long can the person maintain vertical alignment, keeping their shoulder next to the wall or next to a line on the wall)? ii. How much weight has the person put through their affected leg? Place bathroom scales under the affected foot for feedback about weight bearing
Reaching to the side	Ipsilateral hip, knee and ankle extensors	▪ Train reaching to non-affected side and to the front if the person is unable to reach to the affected side ▪ Gradually increase the distance the person is attempting to reach ▪ Gradually introduce reaching across the midline towards the affected side ▪ Ensure appropriate alignment of weight bearing leg (ie knee over foot, leg not abducted) ▪ Ensure the person begins to use their leg extensors in anticipation of weight transference to the affected side	**Progression:** Progress difficulty by: ▪ Increasing time in sitting ▪ Increasing distance from the wall ▪ Decreasing thigh support ▪ Increasing height of the seat ▪ Increasing distance reached ▪ Increasing distance reached to the affected side

whereas positive impairments have shown no consistent association (Ada et al 2006b, Harris & Eng 2007, Zackowski et al 2004).

Therapy textbooks (eg Brashear & Elovic, 2011), and many experienced practitioners), focus on the diagnosis and management of spasticity (a positive impairment), but provide less guidance on strength or co-ordination training. Yet addressing the positive impairments after stroke or brain injury is unlikely to improve activity. While acknowledging the possible presence of spasticity and contracture, we question the emphasis placed on these impairments. In this chapter, examples are provided of treatment strategies which focus on loss of strength and co-ordination (the negative impairments), along with evidence for these strategies. A focus on negative impairments is more likely to improve outcomes.

A final note about analysing and labelling motor impairments. Therapists sometimes use the term ‘spasticity’ or ‘high tone’ to refer to stiff or tight muscles, or stiff joints. Often what therapists describe as spasticity or high tone is a shortening of muscles (a contracture). Therapists need be learn how to distinguish between contracture and spasticity, in order to plan appropriate intervention. Commonly used assessments such as the Modified Ashworth Scale do not distinguish between contracture and spasticity whereas the Tardieu scale does (Patrick & Ada 2006). The Tardieu scale assesses the response of a muscle to a fast or slow stretch. A reduction in range of movement in response to a slow stretch is due to contracture, whereas a reduction in movement in response to a fast stretch is due to spasticity.

3.4. Recognizing Contractures

Changes in the mechanical-elastic properties of muscles and connective tissue limit joint range of movement after stroke (Vattanaslip et al 2000) and other neurological conditions. When analysing movement, a contracture can be recognised by loss of joint range and increased resistance to passive movement at a joint (Ada & Canning 2005). Resistance to movement is typically due to peripheral changes in muscle fibres and connective tissue (O’Dwyer et al 1996, Pandyan et al 2003), not to central nervous system changes or spasticity. Animal studies show that muscles shorten and lengthen in response to immobilisation. Animal muscles decrease in length when immobilised in a shortened position, for example, in a plaster cast (Tabary et al 1972, Williams & Goldspink 1978).

Contractures are undesirable for many reasons, including the effect they can have on a person’s performance. The incidence of contractures after a stroke is surprisingly high. A recent study of 200 consecutive stroke survivors found that 52% had developed a contracture at one or more joints by their six month follow-up (Kwah et al 2012). A person with contractures of pectoralis major, biceps brachii, wrist or finger flexor muscles may be unable to reach forward and pre-shape their hand to achieve normal grasp. Efforts are required to actively prevent muscle contractures using motor retraining, because there are no effective treatments for contractures once they develop (Katalinic et al 2010). Short duration stretch methods such as passive ranging of joints and external devices such as handsplints do not reverse contractures (Lannin et al 2007). Therefore, strategies to elicit muscle contractions and initiate movement are required. These strategies are discussed later in this chapter.

In summary, muscles adapt quickly to altered positions and immobilization. Sarcomeres and connective tissue can undergo structural changes resulting in loss of joint range of motion and resistance to movement, which can be felt during analysis. As yet, there are no demonstrated interventions that prevent or reverse contractures.

3.4. Recognizing Compensatory Strategies

When analysing performance, therapists need to recognize compensatory strategies that a person may use, resulting from loss of normal muscle activity (Carr & Shepherd 2010). Compensations may be caused by a muscle contracture, muscle weakness or both. For example, a person who cannot successfully reach forward to grasp a cup may use hip flexion and/or shoulder abduction to compensate for poor shoulder flexion. In previous years, these patterns of muscle contraction were called 'abnormal synergies', and believed to be part of the normal stages of recovery. However, there is no neurophysiological explanation for these synergies. Rather, this compensatory muscle activity is used as the best biomechanical option available to the person who cannot activate the required muscles appropriately (Carr & Shepherd 2010).

The more a person practices using compensations, the more they learn these neural pathways, which then become difficult to change. Therefore, therapists need to help people to contract their muscles more appropriately. When observing a person reach to grasp a cup, the kinematics of this movement should be compared to normal movement. For example, when a person is pre-shaping his/her hand to reach for a cup within arm's reach, is the person opening the hand and abducting the thumb at the beginning of reach? Thumb abduction and metacarpo-phalangeal extension of the fingers are essential and result in a grasp aperture large enough to accommodate the cup. Typically, people who have difficulty abducting their thumb, and/or extending their fingers and wrist will compensate by extending their thumb, pronating their forearm and/or abducting their shoulder (Carr & Shepherd 2010). *See Figure 4*. These strategies may lead to successful contact with a cup, but like most compensations, are inefficient and inflexible in the long term.

When a person transports his/her arm towards a cup that is nearby (ie within arm's reach), observe whether or not the person is using their shoulder flexors and external rotators, without using excessive shoulder elevation, internal rotation or abduction. The latter three compensatory movements may suggest weakness or paralysis of the person's shoulder flexors and/or external rotators. Alternatively, these shoulder movements may be a strategy to compensate for poor control of forearm, wrist, thumb or finger muscles. For example, if thumb abduction is missing but the person can extend their thumb, they may pronate their forearm, abduct and internally rotate their shoulder to enable the altered aperture between the thumb and index finger to approach the cup, as shown in *Figure 4B.* For a full discussion and analysis, see Carr and Shepherd (2010).

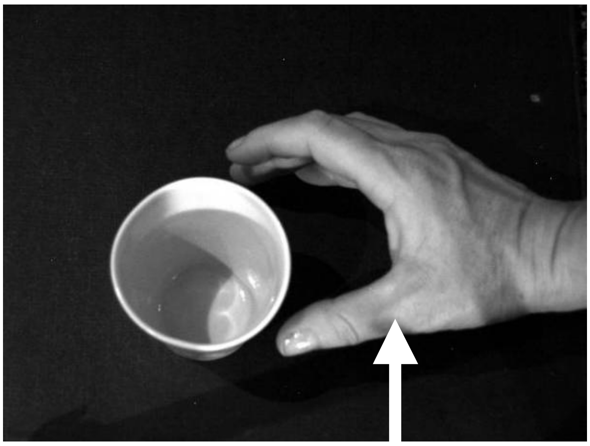
When reaching in sitting, it is normal to flex at the hips to reach distances at arm's length or greater (Dean et al 1999a). However, it is not normal to use hip flexion when reaching for an object such as a cup which is very close to the body. In that case, hip flexion and trunk movement may be compensations for weak shoulder flexors.

In summary, compensatory strategies are common, but should be minimized because they can prevent the learning of normal movement. Therapists need to analyse performance, identify missing essential components, hypothesize about the causes of observed compensations, then test these hypotheses.

Figure 4 Normal Pre-Shaping While Reaching for a Cup, and Commonly Observed Compensations

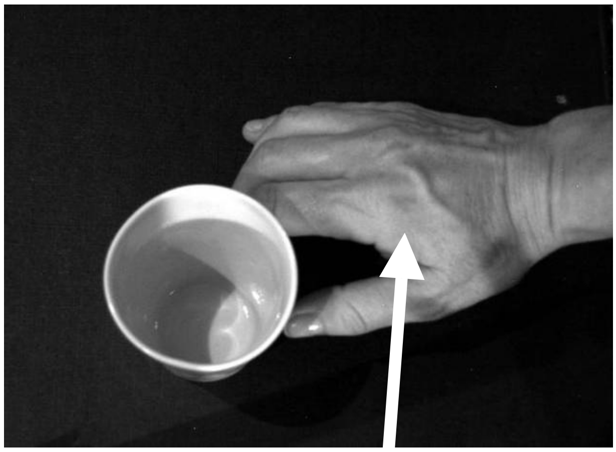
Figure 4a: Normal pre-shaping during reaching, with the thumb abducted and opposed and the person's wrist extended ready to grasp the cup.
Figure 4b: In the second photograph, the person is compensating during reaching for poor control of thumb abduction (a missing essential component). Instead, they are extending their thumb and pronating their forearm (both are compensations) to try and grasp the cup.

Figure 4a



Thumb Abduction

Figure 4b



Forearm Pronation

3.6. Hypothesizing about Compensatory Strategies

The final step in the process of analysing movement is to develop and test hypotheses about the causes of missing essential components, in order to plan treatment. One hypothesis might be that a person's shoulder muscles are paralysed or too weak to lift the limb up against gravity, to reach for a cup. That hypothesis can be tested by assessing muscle strength (i.e. conducting a manual muscle test or palpating the muscle belly during a movement attempt). If a person cannot easily reach forwards, two key muscles to check are anterior deltoid (a shoulder flexor) and infraspinatus (an external rotator). If these muscles are weak, strengthening will be required.

A second hypothesis might be that muscles such as the internal rotators, elbow, wrist and finger flexors are short or stiff due to contractures. The opposing muscles may be incapable of generating the necessary force to lift the arm, extend the wrist or open the hand. This hypothesis can be tested by manually checking the passive range of external rotation, forward flexion, elbow, wrist and finger extension and thumb abduction. Loss of range at any of these joints will change the person's ability to reach for an object such as a cup.

A third possible hypothesis might be that the person is using excessive muscle force to achieve the task (ie to pick up the cup). The may be using too many muscles, too much force, or both. A group of muscles such as the finger and wrist flexors may contract with excessive force when movement is attempted. Overactivity may occur, where most muscles in the arm switch on with effort, to help compensate for weakness in particular muscle groups, such as the shoulder flexors. This hypothesis can be tested by setting up the practice task so that effort is minimised. For example, the person could practice reaching with the arm supported on a table and a sheet of paper or cloth under the hand, to reduce friction during reaching.

A fourth hypothesis might be that the task or environmental set-up are too challenging given the person's functional abilities. The cup may be positioned too far in front or to the side for the person to grasp without compensating, or the table may be too high. These hypotheses can be tested by placing the cup closer or lowering the table. Taping a light polystyrene cup into the hand will also decrease task demands and eliminate the need for pre-shaping. The person can then concentrate on transporting the cup, not pre-shaping. Each movement hypothesis can be tested in turn.

Assuming the person's movement problems have been correctly analysed, the missing essential components and compensations identified and hypotheses tested, the next step is to design a programme to improve performance. This programme will need to address motor learning.

4. Teaching Motor Skills

People with brain impairment often have difficulty understanding instructions, using feedback, remembering their practice and learning motor skills. Therefore, therapists need to develop critical teaching skills and become effective coaches. Therapists need to understand motor learning, provide training that is task-specific, and give useful, timely feedback. Each of these factors will influence motor learning.

4.1 The Stages of Motor Learning

There is considerable literature on motor learning. The three stages originally described by Fitts and Posner (1967) are often used to inform rehabilitation practice: These stages are; (1) the verbal-cognitive stage; (2) the motor stage; and (3) the autonomous stage. In the first stage, learners rely on verbal feedback and external environmental information to achieve goals and understand the demands of a task. In the second stage, the focus is on the quality of movement, mass practice (Mastos et al 2007) and decreasing mistakes. Finally, in the third stage the learner is able to perform the task with less cognitive effort, cope more effectively with distractions and draw on their problem-solving skills when performing the task in novel situations. At each stage, learners need timely feedback about performance and goal achievement (Magill 2011; Schmidt & Lee 2005).

Using the previous training example of reaching for a cup while sitting, a goal might be for the person to sit upright for 30 seconds without falling to the affected side. In the first stage of learning, the person may require continual feedback about pushing through the affected leg, to avoid falling to the affected side. In the second stage, the person may recognize when he/she is beginning to fall, make an attempt to prevent this but require occasional assistance or prompting. In the third stage, the person can sit without assistance, conduct a conversation and reach forward to pick up an object without falling to the affected side. If practice tasks are too demanding in the early stages of learning, the person may be unable to achieve the goal. For example, asking the person to reach to their affected side before they can sit upright for five seconds would be unrealistic.

4.2 Making Training Task-Specific

The terms *task-specific training, task-related practice* and *specificity of training* are used in the literature (e.g. Hubbard et al 2009, Michaelsen et al 2006). These terms refer to therapy involving intentional practice of a specific movement, action or task, versus repetition of non-specific tasks (Bayona et al 2005) such as lifting the arm up high for no reason, touching the head or nose or stacking cones instead of practicing reaching for a cup. Examples of task-specific training include practice of pen or cutlery manipulation to improve writing and eating respectively, or picking up a cup to improve drinking. In the early stages of motor recovery, when a person cannot hold objects, implements can be taped into the affected hand or placed in front to encourage task-specific reaching.

Studies also demonstrate the importance of using real-life tasks for motor training. People with a brain injury produced more movement and improved co-ordination when reaching to control a computer game (Sietsema et al 1993) and while engaging in kitchen activities (Neistadt 1994) compared to simulating the tasks.

The bottom line is that people learn what they practice. If a person wants to learn to drink from a cup, they should practice reaching for and transporting a cup, not a plastic shape that vaguely resembles a cup. Early training might involve sliding or placing a lightweight plastic cup forwards on a low table, with the cup taped into the person's hand if the person does not have active hand movement. Advanced co-ordination training might involve moving and manipulating objects of interest, such as garments, eyeglasses, cutlery and writing implements, not beans or plastic counters. Training should replicate the skill or task that a person wants to learn. Valuable time should not be wasted on non-specific practice.

4.3 Maximizing Practice and Repetitions

More time spent practicing leads to improved performance across many skill areas (such as chess and golf), work tasks (such as typing) and playing musical instruments (Ericsson 2014). In a study involving 20-year-old violinists (Ericsson 2004), the best performers, as judged by conservatory teachers averaged 10,000 hours of practice during their lives. The second-best performers averaged 7,500 hours, the next-best, 5,000 hours and so forth.

A similar committment to practice is required by learners with acquired brain impairment and therapists, if motor performance is to improve. In a randomised controlled trial that demonstrated significant improvements in sitting ability (Dean & Shepherd 1997), people with a stroke each performed 2,970 reaches beyond arm's length during a 2-week training period. Carey and colleagues (2002) found that 1,200 repetitions of a finger tracking task improved neuroplasticity as observed on functional MRI scans. These brain changes correlated with improved motor performance on the Box and Block Test.

Massed practice and multiple repetitions are also features of constraint-induced movement therapy (CIMT, Taub et al 2013). CIMT involves intensive practice of tasks using the affected arm while the unimpaired arm is restrained. CIMT studies require participants to practice for three to six hours a day, aiming for at least 250 repetitions per hour. The number of repetitions required to improve performance after brain impairment remains unknown but thousands of repetitions are likely to be required.

Setting a repetition target can dramatically increase practice. In one study (Waddell et al 2014), 15 participants who had had a stroke completed an average of 2,956 repetitions of upper limb tasks during their hospital admission, averaging 289 repetitions per hour (95% CI, 280 to 299). Active practice during a therapy session averaged 47 minutes (95% CI 46.1 to 48.0). Action Research Arm Test scores improved by a mean of 10 points, from 25/57 at baseline up to 35/57 at discharge, and 40/57 one month later. In another study (Birkenmeier et al 2010), 15 outpatients who had had a stroke completed an average of 5,476 repetitions over six weeks, averaging 322 repetitions of upper limb tasks per hour (95% CI 285 to 358). Time spent actively practicing during each therapy session averaged 47 minutes, and Action Research Arm Test scores improved by a mean of 8 points (95% CI 4 to 12) from 21/57 at baseline, up to 29/57 six weeks later and 29/57 one month later.

Finally, practice that involves lots of repetitions but no transfer of learning will limit skill development. For example, using a fork with a built-up handle to repeatedly pick up pieces of soft bread will not enable a person to eat a meal successfully in a restaurant with a normal fork. People improve their performance by practicing in a variety of situations and experiencing errors during learning. People need to practice in different settings, with different movement parameters (for example, forks with different handles, and different foods). Increasing demands in this way helps learners to problem solve and fathom the rules underlying task performance (Magill 2011).

4.4 Giving Feedback

Accurate feedback is critical to the teaching and learning of motor skills. Feedback can be provided by the task itself (intrinsic feedback), or an outside source such as the therapist, biofeedback device or timer (extrinsic feedback). Extrinsic feedback has been further classified into two types: knowledge of performance and knowledge of results (Kilduski & Rice, 2003)

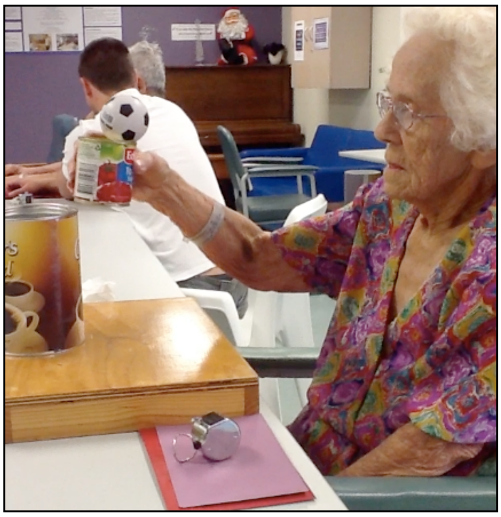
Knowledge of performance refers to information about the movement process or attempt, for example, 'You kept your elbow close to your body'. Extrinsic feedback can be very helpful to learners, particularly corrections that need to be made, and features to focus on during subsequent attempts (Kernodle & Carlton 1992). *Knowledge of results* refers to information about the movement outcome, for example "You picked up the cup 10 times in 20 seconds". Knowledge of results within a training session (ie how long it took to complete a task or the number of successful attempts to complete a task) can be used to set short term goals that are meaningful to the learner and related to the task being practiced. See Figure 5 for an example of a practice task involving feedback.

The amount and timing of feedback are important. Too much feedback can negatively influence learning (van Vliet & Wulf, 2006). Intermittent feedback is more effective than constant feedback (Winstein & Schmidt 1990). Concurrent knowledge of results – that is, feedback provided during performance – may also negatively influence learning. Providing summary or average feedback after task completion is more likely to benefit learning (van Vliet & Wulf 2006)

In summary, therapists should aim to provide auditory and visual feedback and encourage self-monitoring during sessions. Although it is unknown exactly what feedback schedule produces the best outcomes in rehabilitation, therapists can help people to monitor their own performance and generate their own feedback. Only then will learners be able to effectively practise unsupervised and maximise their rehabilitation outcomes.

Figure 5 Practice with feedback

This lady's practice has been set up so that she receives feedback about her reaching. The mini football will roll off the tin if she uses insufficient external rotation, forearm supination and wrist extension. Knowledge of performance provided by the therapist might include stating that: '*You are moving your body forward. You need to keep your back against the chair and lift your arm higher'*. Knowledge of results might include the number of successful attempts out of 10 repetitions, or time taken to complete 10 repetitions.



5. Evaluating Changes in Motor Performance

Therapists need to re-evaluate motor (and occupational) performance by using objective measures before and during training. Ideally a review of performance and goals will occur at every session. Performance can be measured using simple equipment. For example, to determine if a person with sitting balance problems is weight-bearing equally through both legs, a therapist may use bathroom scales. Other simple measures of performance include the number of correctly performed movements versus those performed with compensations, or distance reached.

If performance is not changing, the problem may lie with the therapist rather than the learner. Common reasons for lack of improvement include unclear instructions, feedback and goals. If instructions are unclear, the learner may not understand the expected goal. Similarly, if verbal feedback is unclear (or absent), the person may not understand how to alter their next movement attempt to achieve success.

In addition to considering the words therapists use to explain and correct movement attempts, the task chosen to elicit a movement attempt is also important. If the task is too difficult (or too easy), progress may not be seen. When re-measurement of performance shows little or no progress, it is vital to reflect on the possible reasons. If the movement hypotheses are correct, therapists can then critically appraise their teaching skills. Alternatively, if a different movement hypothesis is made, new training strategies will be needed. Therapists should not underestimate the importance of re-measuring performance, reflecting on their own teaching skills, and, above all persisting and expecting to see improved motor performance in every session.

The practice story in Box 1 shows how one occupational therapist developed his teaching and analysis skills, and applied evidence-based practice in rehabilitation.

Box 1 Practice Story

Leo is an occupational therapist in a large district hospital in rural Australia. He has over 10 years experience in adult neurological rehabilitation. Leo is dedicated to developing his skills. He has attended upper limb motor training workshops, videotaped clients, and discussed his training programs with peers. He has organised fortnightly peer review sessions where staff observe each other conducting a therapy session, and provide feedback about analysis and teaching skills. Leo regularly attends rehabilitation conferences because: "They are a great pick-me-up". Leo increased his knowledge and skills by conducting a randomised controlled trial of task-specific training as part of a masters degree (Ross et al 2009).

Here, Leo gives an example of Mary whom he saw following her stroke. He describes her motor control problems and compensations, and the upper limb training program provided over several months. This lady could not use her affected arm much when engaging in daily activities. She could not hold or transport objects such as a cup or a knife during meals.

"I saw Mary recently, who had recovery of some muscles in her arm, but a lot of overactivity, many compensations and little control in her hand. For example, when attempting to reach forwards to grasp a cup, she elevated her shoulder and abducted her arm, clenched her fingers, flexed her elbow, and moved her whole body forwards instead of just her arm and hand. She compensated for poor shoulder flexion, loss of external rotation and thumb abduction by using every muscle possible in her arm. It was hard work".

"Training sessions targeted her shoulder flexors in a lying position, which reduced the effect of gravity. We focused on the anterior deltoid muscle. This lady was asked to rest her hand on her forehead with the elbow flexed, and control her anterior deltoid in that position. When she could hold her arm there, she started sliding her hand back from her forehead to the pillow and the crown of her head, to control anterior deltoid in lying, then reaching higher to the wall to touch a marker. It was too hard in sitting. She couldn't lift her arm up against gravity without compensating. Other practice tasks focused on her shoulder external rotation, elbow, wrist and finger extension and thumb abduction. We pieced each component together, then eventually began working on functional reaching in a seated position" (see Fig 6).

"Mary practiced for about 2 hours a day for 3 months (unsupervised for some of the time), then 1 hour daily for another 3 months, then about 3 hours a week for the last 3 months. It took 36 weeks or 6 months before she had a functional grasp and release. In the first 6 weeks she completed 12,810 repetitions, averaging 427 reps per session (85 per exercise). After 36 weeks, she achieved 16/57 on the Action Research Arm Test, compared to 2/57 at the beginning, a 14-point change. With a combination of task-specific training, persistence on both our parts, objective measurement, intensive practice and feedback, Mary achieved improved hand function. Without this persistence and practice, I don't think she would have achieved this outcome".

Ensuring enough practice by people who have had a stroke or brain injury is a challenge. To help ensure individuals spend plenty of time each day practising, Leo uses typed practice records with imported digital photographs. The rehabilitation team runs a cross-disciplinary upper limb group several times a week, where people with stroke or brain injury follow their own practice program with co-learners, and supervision from therapists. Therapy assistants and relatives also help supervise individual practice after this has been documented with instructions, goals and illustrations by the therapist. Family members are involved in helping with practice as early as possible, because of the limited time available for 1:1 therapy.

Figure 6 Practice of Essential Components Required for Reaching (Forward Flexion and External Rotation) and Drinking from a Cup

Since having a stroke, Mary has had limited opportunities to engage in occupations such as drinking from a cup with her dominant right hand. She has weak shoulder flexors and external rotators, and cannot open her thumb or fingers to pre-shape correctly. The therapist is helping her to practice shoulder flexion and external rotation - essential components of reaching - while also maintaining wrist extension and forearm supination.

In this photograph, she is sliding the cup forwards while staying inside the black lines (electrical tape stuck to the table). The practice environment encourages external rotation, wrist extension and supination, and discourages compensations such as internal rotation and abduction.

Two drinking straws have been applied to her arm, one to the inner elbow and another on to the back of her wrist. These straws act as visual cues, reminding her to maintain shoulder external rotation (the straw stays in contact with the wooden block) and wrist extension (her knuckles stay in contact with the flexible straw). She is also learning to monitor her own performance, so that she can practise alone outside of therapy sessions. Notice the timer near the therapist's right hand, to record practice time and repetitions.

6. Evidence-Based Intervention to Improve Upper Limb Motor Performance and Sensation

There are several reasons why a person may be unable to reach for, grasp and drink from a cup, or dress without overbalancing. Different causes will require different interventions. Many therapy interventions have been tested in randomized trials and the collective findings synthesized in systematic reviews. Interventions shown to be effective in randomized controlled trials and systematic reviews are referred to in this section (*see Table 3*). It will be noted if interventions and training strategies have not been rigorously tested and rely on lower level evidence or personal experience.

In adult rehabilitation, interventions shown to improve performance of upper limb motor control commonly involve greater intensity of practice and repetitions and task-specific training strategies to improve strength (Pollock et al 2014; Veerbeek et al 2014). By definition, more intense practice and repetitions requires active involvement of the learner. One of the biggest challenges in rehabilitation is increasing the amount of practice. People need to spend as much time as possible actually practicing. One hour of therapy doing 100 repetitions is better than 1 hour of therapy doing 10 or 20 repetitions. Setting a target, for example, 300 repetitions per session, recording and reviewing repetitions helps to increase practice intensity (Birkenmeier et al, 2010; Waddell et al, 2014).

With greater recognition that intensive practice can improve outcomes, many therapists prescribe homework. In hospital, homework can be tailored to the individual and may involve use of 'off-the-shelf' programs such as the Graded Repetitive Arm Supplementary Program (GRASP, Harris et al 2009) available at http://neurorehab.med.ubc.ca/grasp/. Use of GRASP exercises in hospital significantly improved arm recovery compared to usual therapy in the trial by Harris and colleagues (2009). GRASP represents a low cost, efficient mode of delivery, which can be family-assisted. Programmes such as GRASP may be helpful for students and novice therapists who are learning how to prescribe task-specific motor training.

6.1 Strength Training for paralysed and very weak muscles

Some individuals may be unable to elicit a muscle contraction due to paralysis or produce adequate muscle force due to weakness. They need coaching to first elicit a muscle contraction, then increase the duration and strength of that contraction. Muscle strength training that involves effortful, repetitive practice improves strength and function and importantly, does not increase spasticity as many therapists believe (Ada et al 2006a, Harris & Eng, 2010, Morris et al 2004).

A systematic review of interventions for severe upper limb paresis (Hayward et al 2010) evaluated the evidence for robotic therapy, electromyographic or position-triggered electrical stimulation, rocking chair therapy and the SMART arm device. There was strong evidence that robotic therapy improves strength and activity of the upper arm but not the hand. There was limited evidence for the effect of other interventions on strength and activity.

One of the few randomized controlled trials targeting very weak muscles was conducted by Feys and colleagues (1998). These researchers recruited 100 people early after having a stroke, seated them in a rocking chair with their affected arm in a full-arm airsplint and resting on a table. The airsplint held their arm in elbow extension and enabled repetitive practice of shoulder protraction and retraction for 30 minutes daily over 6 weeks. The experimental group improved significantly more than the control group, and gains were maintained after 5 years. Greater gains were seen in people who had severe deficits at baseline. In a trial of the SMART arm, a mechanical device that provides a near frictionless surface to enable reaching movements and continuous visual feedback, greater gains were also seen in people who had severe motor deficits at baseline (Barker et al 2008). The implications of these studies are that providing a practice environment that allows high intensity, active, repetitive practice can make difference to outcomes for people with severe motor deficits in the affected arm.

Examples of practice tasks aimed at increasing muscle strength are shown in Figures 7 to 12.

6.2 Electrical Stimulation

For people who are unable to elicit a muscle contraction (i.e. the very weak), electrical stimulation will produce muscle contractions. Nascimento and colleagues (2014) examined the effect of cyclical electrical stimulation on strength and activity after stroke in a systematic review of the literature. A total of 11 randomized trials were included in the pooled analysis of the effect of electrical stimulation on *strength;* there was a moderate effect size in favour of cyclical electrical stimulation. Six trials were included in the pooled analysis of the effect of cyclical electrical stimulation on *activity*. There was a small effect size in favour of cyclical electrical stimulation. Overall, Nascimento and colleagues (2014) concluded that electrical stimulation increased arm movement more than conventional therapy.

Howlett and colleagues (2015) later synthesized the findings from published trials that evaluated the efficacy of electrical stimulation applied *during* activity (i.e. functional electrical stimulation or FES). Subgroup analyses found that FES had a large effect on upper limb activity (standardised mean difference, 0.69, 95% CI, 0.33 to 1.05). In summary, electrical stimulation is being used increasingly in adult neurological rehabilitation. Further research is needed to determine the most effective protocols for electrical stimulation.

6.3 Mirror Therapy

Mirror therapy uses visual illusion to trick the brain and promote motor recovery. The person watches a mirror reflection of their intact hand while performing repetitive movements. The mirror gives an illusion that the affected arm can move. This therapy is used with people who have moderate to severe weakness, to improve motor and sensory function and reduce neglect (i.e. where a person does not attend to their limb or environment on the affected side, and may collide with doorways or ignore food on one side of their plate). Most trials provided 30 to 60 minutes of supervised mirror therapy, daily for 4 weeks.

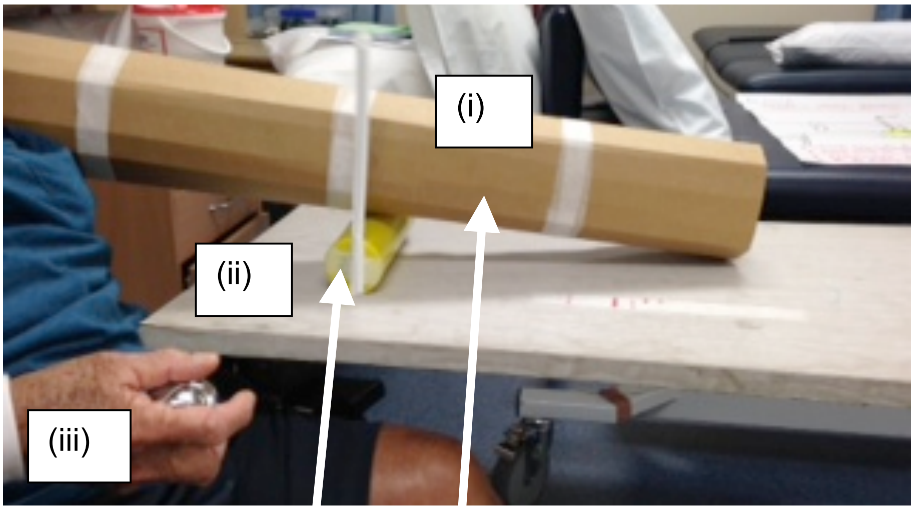
The most recent Cochrane review included 14 trials published up to June 2011 (Thieme et al 2012). They concluded that mirror therapy can improve motor function and activity performance, but has less effect on neglect. More recent randomized controlled trials have broadly confirmed these findings (Invernizzi et al 2013; Lee et al, 2012) with additional benefits reported for sensation (Wu et al, 2013) and neglect (Thieme et al 2013).

Although improvements in some trials were small, mirror therapy is inexpensive to deliver, can be completed in hospital or at home and is suitable for people with moderate to severe weakness.

Figure 7 Eliciting shoulder protraction

When a person is very weak and cannot move their affected arm, this protraction exercise can sometimes elicit movement. Figure 7a demonstrates the physical setup. The table is positioned close to the person's body, with the shoulder a little below 90 degrees. Their left elbow is held in extension by a cylinder made from a dismantled cardboard box, held together with tape. The cylinder is supported on a smaller cylinder or wooden dowel, providing a friction-free surface. There is a straw attached to the dowel with adhesive tape. The goal is for the person to protract their left shoulder, to move the straw from a vertical position to touch a mark on the table. Notice that this man has been given the responsibility of counting his practice and repetitions using the metal clicker in his right hand

Figure 7a



(i) Cardboard cylinder secured with tape, to hold the elbow in extension

(ii) Small plastic or wooden cylinder, which rolls easily on the table

(iii) Metal counter or clicker in the right hand, to record repetitions

Fig 7b Halfway to achieving the goal

Fig 7c Straw touches the table. Goal achieved.

Figure 8 Eliciting external rotation – a home practice setup.

This lady is practicing external rotation in preparation for forward reaching. **Figure 8a** shows the physical setup of the exercise. There is a large sheet of paper on the table, with pen marks showing the start position for her right hand (the dotted line, placed directly in front of her navel). Her hand and forearm are supported on the table to reduce the effect of gravity and make practice easier. The cloth under her right hand reduces friction when she moves. She places a small cylinder between her right elbow and her body, to reduce abduction and extension of her shoulder (which are compensations). The goal is to cover the pen mark by sliding her hand to the right, following the arc drawn on the paper, without abducting her arm.

In **Figure 8b** the lady has externally rotated her shoulder and covered the pen mark on the paper, without dropping the cylinder into her chair. As she becomes more proficient, she will slide her hand further across the arc to her right, towards the cup.

Figure 8a

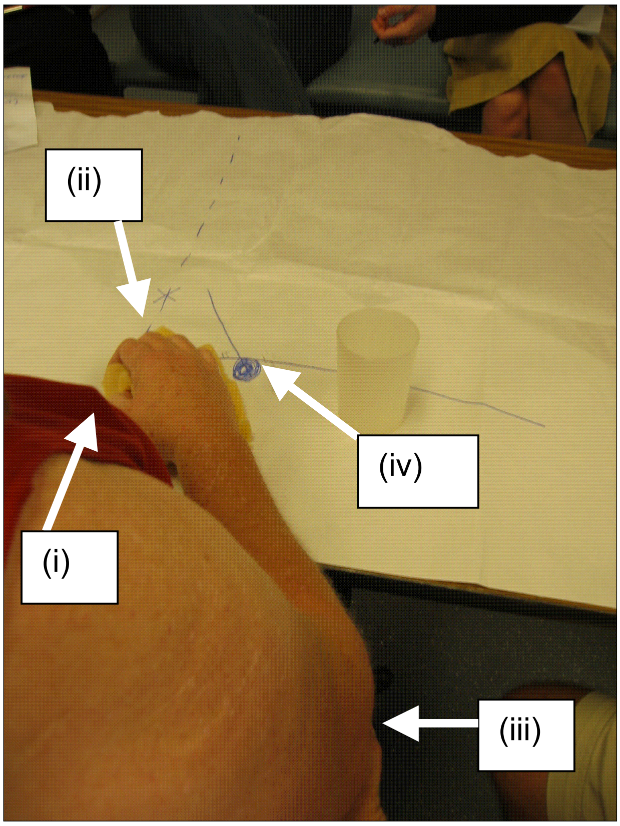
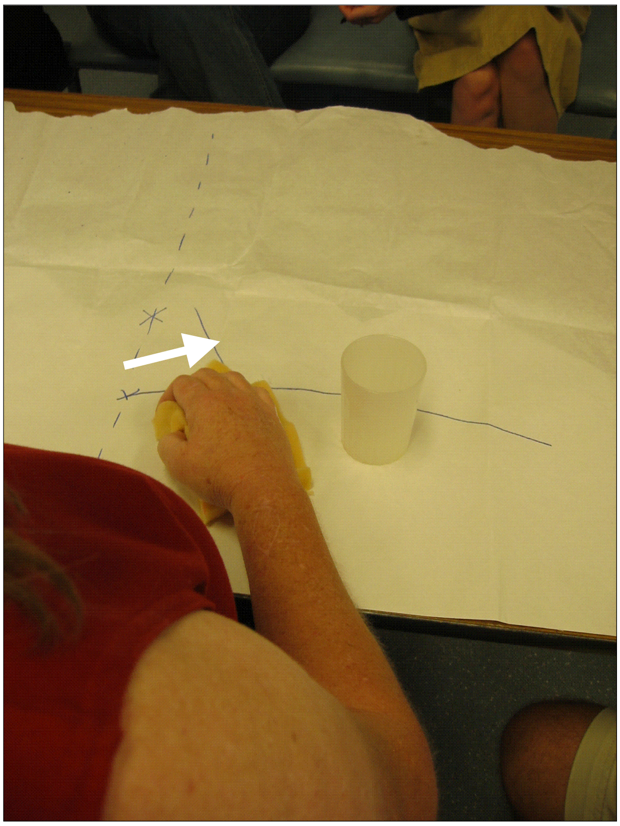


Figure 8b



(i)   Cloth placed under her hand to reduce friction

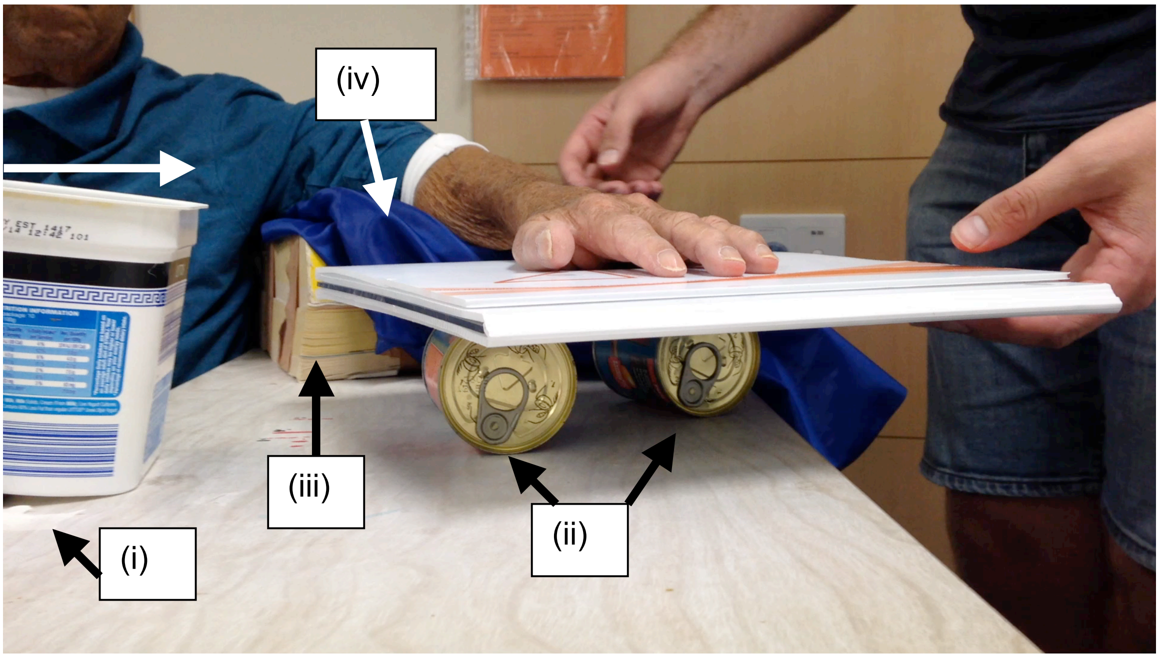
(ii)   Dotted line drawn on the paper, showing the starting position

(iii)   A small cylinder is held between her right elbow and her body (not visible),for example a light plastic cup

(iv)   The goal

Figure 9 Eliciting elbow flexion and extension

This man's elbow and upper arm are supported on a high table and firm surface such as telephone directories or a box, so that elbow flexion and extension are possible in the horizontal plane. A slidesheet has also been placed under his forearm to minimise friction. His hand rests on a flat board, which rolls on top of two cylindrical tins, which minimises friction. The plastic container in front of his body has a straw taped underneath, which is taped to the table. When the container is touched, it tips to his right, then returns to the start position. This set-up allows him to practice without a therapist present. The goal is for him to slide the board across to tip the lightweight plastic container 10 times by flexing his elbow, each time returning to the start position.



(i) Straw taped underneath the container, and to the table, to allow the container to rock when touched (in the direction of the arrows)

(ii) Cans or cylinders beneath the board, to minimise friction

(iii) Books to raise the shoulder to a horizontal position

(iv) Slide sheet to reduce friction

Figure 10 Practice for shoulder external rotation and forward flexion in standing

Both external rotation and shoulder forward flexion are essential for transporting the arm and hand forwards to reach for a cup or telephone. While this man is using extra muscle force to hold the pen (increased finger flexion), his response is typical of new skill acquisition, and is not a concern to the therapist.

Figure 10a

Figure 10b

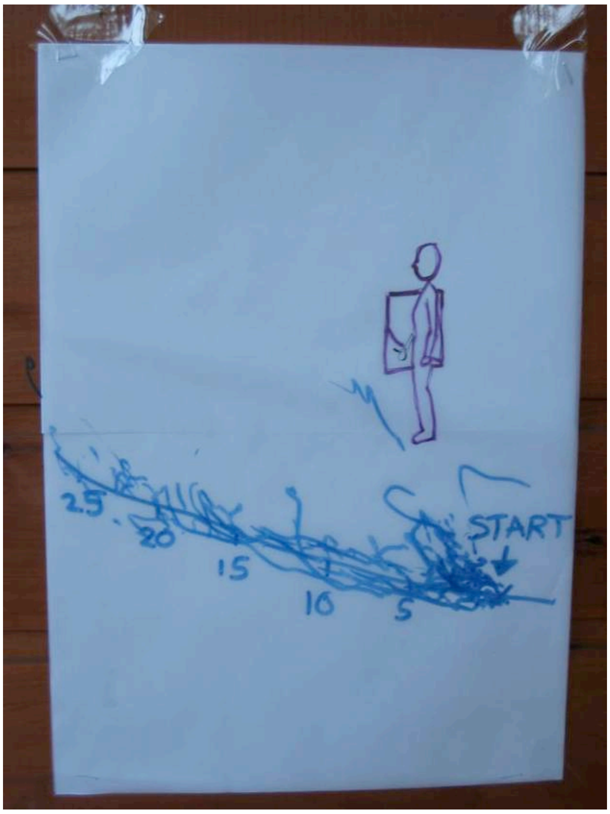


Figure 10c

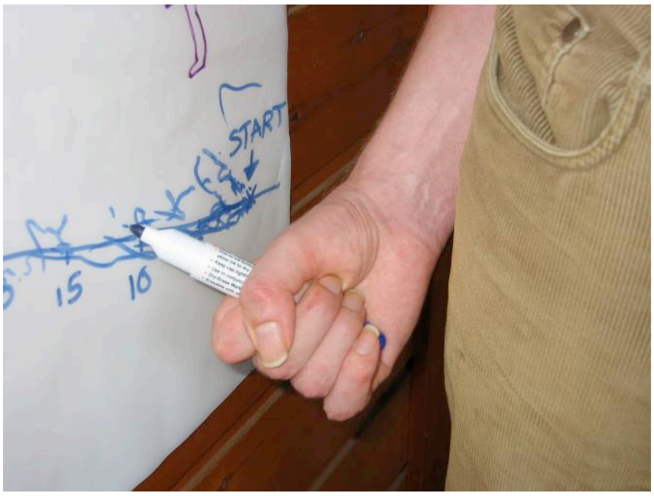
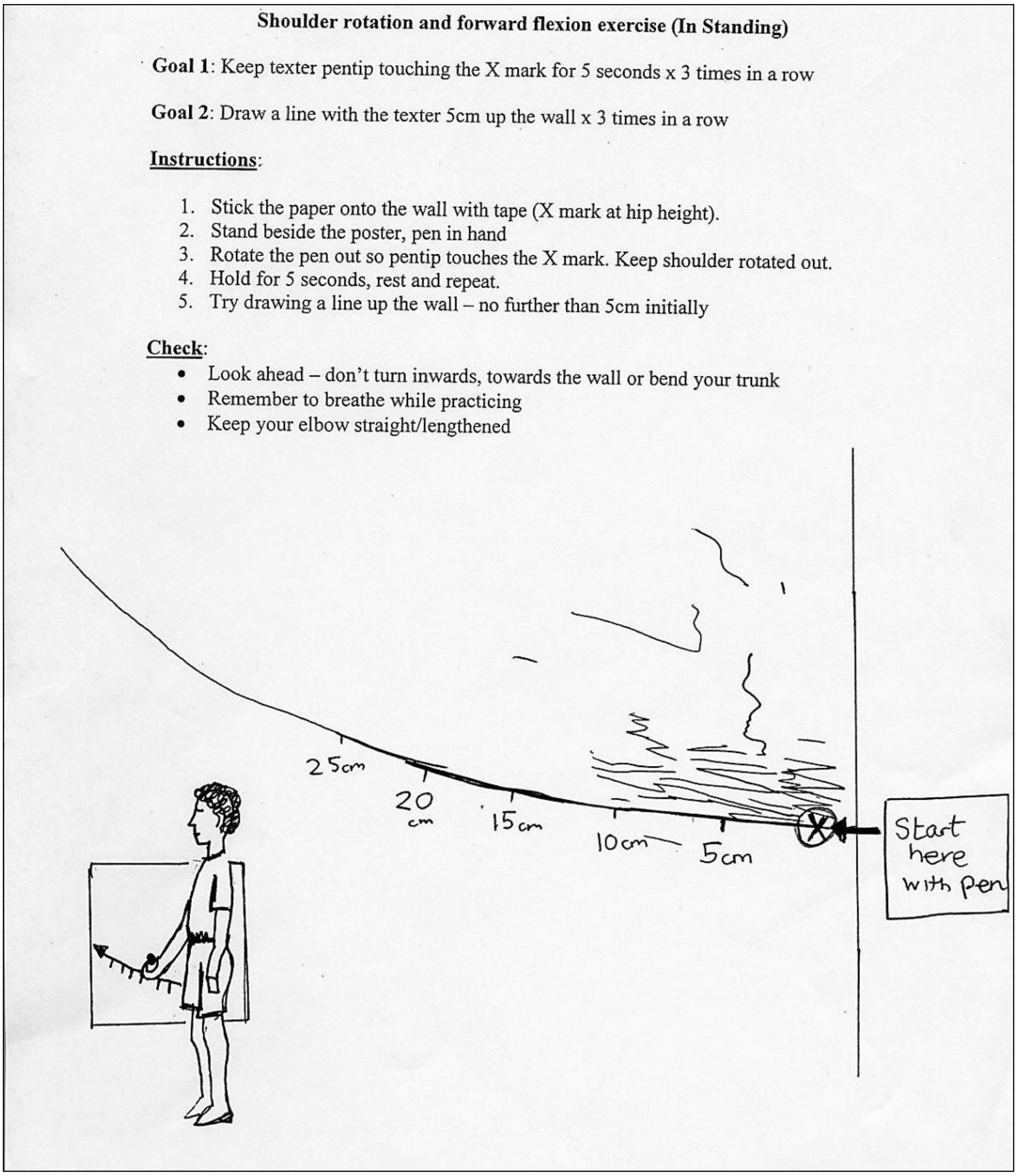


Figure 10 (continued) This man's practice sheet (**Figure 10d** below) illustrates the short and medium term goals, and instructions to help minimize compensations.

The first goal (Goal 1: Keep the texta pentip touching the X mark on the paper for five seconds) demands a sustained contraction of his external rotators combined with full supination. Without some external rotation, the goal cannot be achieved (except by trunk rotation). The second goal (Goal 2: Draw a line five cm up the wall) demands sustained external rotation and shoulder flexion.

Figure 10d



Shoulder rotation and forward flexion exercise (In Standing)

Goal 1: Keep texter pentip touching the X mark for 5 seconds x 3 times in a row

Goal 2: Draw a line with the texter 5cm up the wall x 3 times in a row

<u>Instructions</u>:

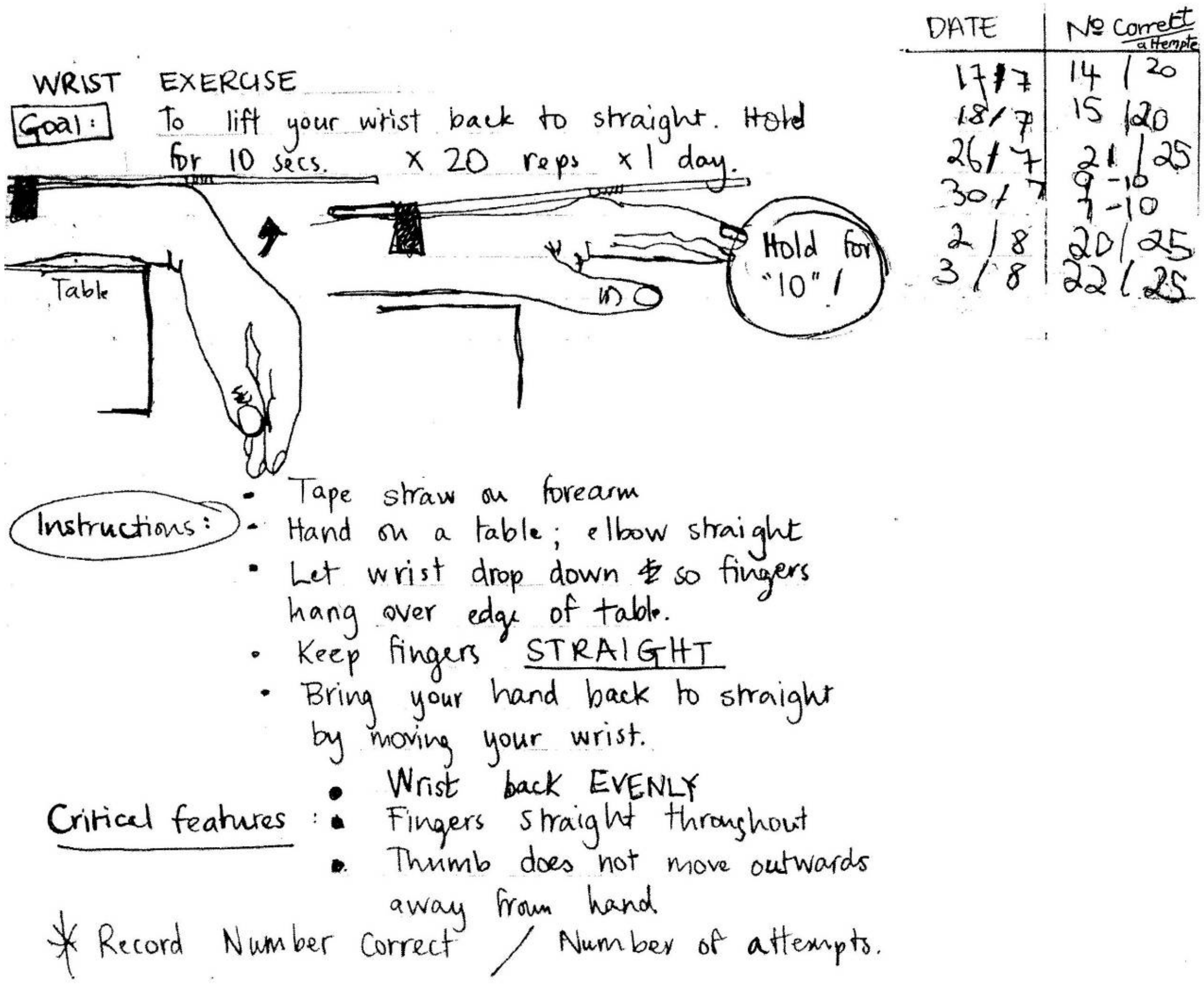
1. Stick the paper onto the wall with tape (X mark at hip height).
2. Stand beside the poster, pen in hand
3. Rotate the pen out so pentip touches the X mark. Keep shoulder rotated out.
4. Hold for 5 seconds, rest and repeat.
5. Try drawing a line up the wall – no further than 5cm initially

<u>Check</u>:

- Look ahead – don't turn inwards, towards the wall or bend your trunk
- Remember to breathe while practicing
- Keep your elbow straight/lengthened

Figure 11 Eliciting Wrist Extension

Wrist extension is essential for most occupations involving reaching, such as picking up a cup to drink. The page shown below from a practice book illustrates the wrist extension exercise, the goal (to lift the wrist back to the ‘straight’ position and hold for 10 seconds, x 20 repetitions), extra instructions and a place to record practice attempts (date, number of correct attempts).


WRIST EXERCISE

Goal: To lift your wrist back to straight. Hold for 10 secs. x 20 reps x 1 day.

Table

Hold for "10"!

DATE	№ Correct attempts
17/7	14 / 20
18/7	15 / 20
26/7	21 / 25
30/7	9 - 10 7 - 10
2/8	20 / 25
3/8	22 / 25

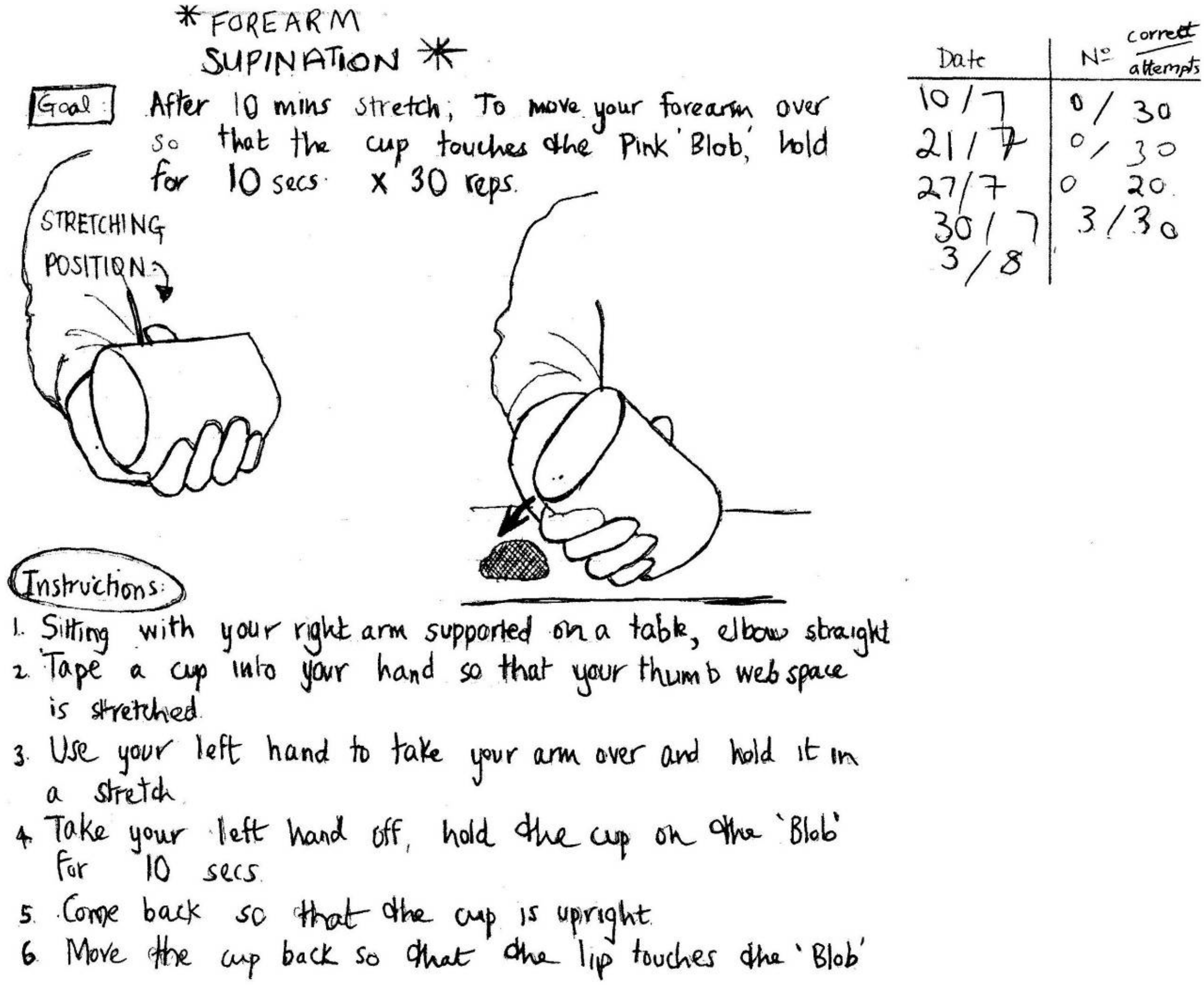
Instructions:
- Tape straw on forearm
- Hand on a table; elbow straight
- Let wrist drop down & so fingers hang over edge of table.
- Keep fingers STRAIGHT
- Bring your hand back to straight by moving your wrist.

Critical features:
- Wrist back EVENLY
- Fingers straight throughout
- Thumb does not move outwards away from hand

* Record Number Correct / Number of attempts.

Figure 12 Supination Practice

Practice book showing the exercise (Forearm Supination) and goal, in the learners own words: ‘After 10 minutes stretch, to move your forearm over so that the cup touches the pink ‘Blob’, hold for 10 seconds’. Additional instructions have also been added, and a section for recording practice attempts.



6.4 Reducing Muscle Force during Grasp

Some individuals contract too many muscles, or the wrong muscles when reaching for, and grasping objects. This behaviour is characteristic of early skill acquisition (and is not spasticity). Until learners have mastered a new skill, they recruit too many muscles. Therefore one aim of therapy is to reduce effort and help the person focus on the muscle actions required for task performance.

Changing the demands of a task and the environment can reduce effort. For example, asking a person to lift a light plastic cup off the table instead of a glass, or slide rather than lift a cup along the table will help to reduce effort. If a person is unable to grasp while reaching, taping a cup into their hand will reduce task demands and help them concentrate on reaching. If too much force is applied, using a disposable polystyrene cup that deforms easily when grasped will give the person feedback about their force production (See Figures 13 and 14). No trials of these interventions have been published to date.

Different instructions may also help a person to become more self-aware and learn to control some muscles more, and others with less force. For example:

> *'When you next reach forwards for the cup, **slide** rather than lift your hand. Watch your hand and keep it the same shape as the cup. Notice if your fingers and thumb close as you reach. If they start to close, see if you can keep your fingers and thumb 'soft' as you reach'.*

or: *'This time, when you close your fingers around the polystyrene cup, don't press so hard. Try not to squash or deform the cup. If you press too hard, the water will come up above the marked line. Use light pressure on the sides of the cup'*

Figure 13 Practice to decrease finger and wrist flexion force while transporting a cup to drink or while carrying liquid

The person has been asked to gently press the side of the polystyrene cup, and move the cup edge between the two lines on the wooden stick (see left photo, Figure 13a).

When the short-term goal has been achieved, the person can progress to transporting the cup of liquid up onto a box, stand while holding the cup, and finally walk and carry the cup

Figure 13a

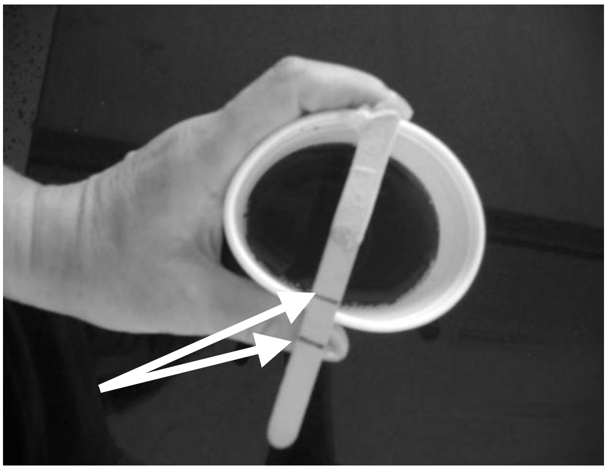
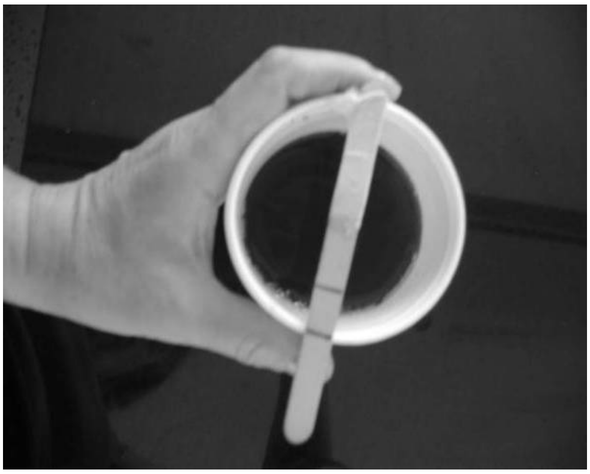


Figure 13b



Short-Term Goal: Press the cup inwards 1cm to the second pen mark, release and repeat x 3

Medium-Term Goal: In sitting, maintain the round shape of the cup (**Figure 13b**) and lift onto a 5cm box

Medium-Term Goal: Maintain the round shape of the cup (**Figure 13b**) while standing up and sitting down 5 times from a 45 cm chair

Long-Term Goal: Carry a full cup of water 3 times, from the kitchen to the dining room table, without spilling any liquid

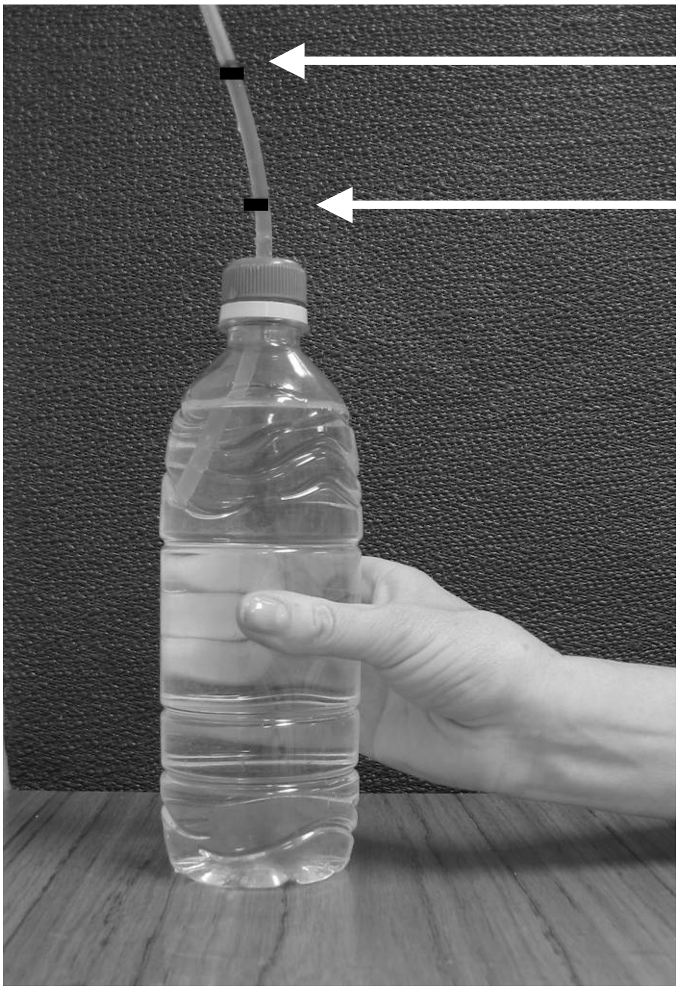
Figure 14 Practice to modulate finger and thumb flexion force while holding a plastic bottle which deforms easily

The person has been asked to gently press the sides of the plastic bottle, and control the water levels between the two black lines on the tube. Too much pressure causes a jet of water to shoot out the top, which gives immediate feedback to the learner about the amount of force being generated. The practice demands attention for successful performance.

To construct the training device, first drill a hole in the top of a plastic bottle cap. The hole should be just large enough to accommodate the suction tubing. Insert tubing down through the hole, fill the bottle with water and seal the unit tightly with the screw top. If necessary, seal the unit with tape to prevent air escaping.

Short-Term Goal: In sitting, push water up and down between the two black lines 5 times, without water escaping from the tube.

Medium-Term Goal: In sitting, keep the water level with the upper black line and lift the bottle up onto a 5cm box, 5 times, without water escaping from the tube.



6.5 Co-ordination Training

Some individuals can grasp and pick up but not manipulate objects such as a cup, knife or fork. Training of advanced hand function involves more than cutting up slices of bread or copying lines of writing. Careful analysis enables therapists to determine which essential components of skilled performance are missing or altered. This stage of analysis and training demands careful observation and problem solving. Tasks requiring advanced skill performance (and analysis) include handwriting, use of cutlery and chopsticks.

With small objects, training of grip force during lift-off and manipulation will be required, with repetitions and feedback. Healthy adults typically apply a force slightly higher than the minimum required, to prevent object slippage (Nowak & Hermsdorfer 2003). However, people with chronic stroke and intact sensation (n=10) often apply significantly greater mean grip forces (≥ 39%) at lift-off compared to healthy adults (Quaney et al 2005). Blennerhassett and colleagues (2006) reported different findings for 45 people with stroke and 45 healthy adults, who were able to pick up a pen lid concealed from view, using a pinch grip.

They reported prolonged time and excessive grip force prior to commencing the lift in half the people with stroke, as well as fluctuating forces and extreme slowness. However excessive safety margins were not present in all cases.

The message for therapists from these studies is that people who have had a stroke typically have difficulty preparing a suitable grip force and using the normal feed-forward mechanisms. Impaired sensation is likely to compound these problems. However, training strategies are likely to be similar for people with and without sensory impairment. Training needs to involve task-specific practice, with numerous repetitions and frequent feedback. If a person has difficulty using a knife, fork or pen, the person needs to engage in part-practice with these utensils. Picking up an object precisely without spinning or rotating the handle, cutting food and writing all require appropriate force production and accurate opposition of the forces of the thumb and fingers to be successful. See Figures 15 and 16 for two examples.

Figure 15 Practice to improve fork control. This lady cannot sustain flexion of her fourth and fifth digits around a fork handle when trying to pick up food. When she tries to use her fork, the handle rotates and she loses her grasp. Part-practice has been devised to help improve flexion of her ring and little fingers around a fork handle. The first two photographs below (Figures 15a and 15b) show her setting up the practice. She has been asked to hold a coin between plastic tweezers for 5 seconds. This task sustains her attention. She gets feedback instantly if her grasp weakens, because the coin drops onto the table.

Figure 15a

Figure 15b

The left photograph below (Fig 15c) shows her still holding the tweezers and coin (coin no longer visible), then turning her hand over, flexing the wrist and pressing the index finger down on the end of a spoon. She finds it much more challenging to keep her fourth and fifth digits flexed in this position while her index finger is extended, as it needs to be while using a fork. Again, she receives instant feedback if her grasp weakens because the coin drops out of the tweezers – feedback which would not be provided by a standard fork.

The final photograph (Fig 15d, below right) illustrates how the tweezers and fork handle can be taped together, to enable fork practice to progress. This lady can continue her practice with the coin held between plastic tweezers, and learn to transport small pieces of soft vegetable or bread squares from plate to plate, without dropping the coin.

Fig 15c

Fig 15d

Figure 16 Part -Practice of Pen Rotation

This practice aims to improve pen control and handwriting. The short-term goal is to rotate the pen/pencil 10 times in 30 seconds by the end of one week. The medium term goal is to rotate the pen/pencil 10 times in 20 seconds by the end of 2 weeks.

Instructions - remind the person to:
- Roll the pen/pencil a ½ turn in each direction
- Aim to cover then uncover a pen mark along the barrel of the pen (see arrows below)
- Allow the pen/pencil to rest against the webspace while practicing
- Use the middle finger to re-adjust pen position when necessary
- Avoid using the other hand to help
- Aim to practise for 5 minutes x 3 times daily (15 minutes daily)
- Try not to hold the pen tightly
- Practise with different pens/pencils to help generalize this skill

Figure 16a

Figure 16b

6.6. Mental Practice

Mental practice and imagery have been used to promote motor recovery. This type of practice is used routinely in sports training to improve skill acquisition. In rehabilitation, a person can for example mentally rehearse the task of picking up a cup and imagine the transport and pre-shaping actions, without physically attempting the actions. This therapy is not used with people who are paralysed or who have significant cognitive or communication difficulties. Participants need to be able to concentrate, plan and physically attempt a movement when unsupervised.

A recent systematic review of mental practice (Braun et al, 2013) summarised the effects of 16 studies, 14 of which involved people who had a stroke. Positive short-term effects were reported for arm/hand function, activities of daily living and cognition including attention, planning and route finding and arousal. Longer-term outcomes have not been reported to date. There was large variability in the type and dose of therapy provided in the trials. This therapy requires discipline and has some similarities with meditation. Mental practice is not expensive or harmful and has the potential to improve arm function in stroke participants who can engage with the therapy.

6.7 Constraint-Induced Movement Therapy

Constraint induced-movement therapy (CIMT) improves movement and use of the affected hand and promotes neuroplasticity of the brain. CIMT involves 4 active components delivered intensively over 2 weeks: (1) task-specific repetitive practice, for between 3 and 6 hours per day; (2) 1:1 shaping or coaching, with feedback and progression of task practice; (3) a restraint such as a mitt, or splint and sling, worn for 90% of the waking day; and (4) a transfer-of-training package involving home practice (Taub et al, 2013). The restraint is used to discourage physical use of the unaffected hand and greater use of the affected hand, but the restraint does not appear to be essential (Brogårdh et al 2009; 2010; Krawczyk et al 2012). It is probably the intensive task-specific practice and coaching that promote neuroplasticity and change arm function. For a detailed description of CIMT eligibility criteria and procedures, see Taub and colleagues (2013).

The collective research in stroke rehabilitation (over 50 randomized trials and six systematic reviews) shows a moderate effect of CIMT on upper limb motor performance, measured using instruments such as the Action Research Arm Test (Nijlands et al, 2011; Stevenson et al, 2012). Eligible participants in trials typically have active wrist and finger extension at study commencement. Most studies have used a modified CIMT program (44/51 trials - see Kwakkel et al 2015). It is not yet known if CIMT can drive recovery in people with a very weak or paralysed arm, who have no hand function. A systematic review by Nijlands and colleagues (2011) suggested that lower intensity CIMT in hospital, for up to 3 hours per day is feasible and improves outcomes more than standard upper limb therapy. A Norwegian trial (Thrane et al 2014) provided CIMT early after stroke, for 3 hours daily over 10 days. The researchers found significant improvements at discharge, but differences between experimental and control groups were not maintained after one month.

6.8 Sensory Retraining

Therapists can use active and/or passive approaches to address sensory impairments. Active approaches involve the person exploring and discriminating between stimuli, such as the shape, weight and texture of a lightweight plastic cup versus a pottery coffee mug. Passive approaches include use of electrical stimulation, thermal stimulation (heat or cold), pressure or movement by a therapist to increase sensory awareness of the limb, for example, intermittent pneumatic compression, but typically with little or no active exploration by the person.

A Cochrane review highlighted preliminary evidence for the effect of one active approach, mirror therapy, and two passive approaches, thermal stimulation and intermittent pneumatic compression (Doyle et al, 2010). Since that time, other studies have confirmed small effects from mirror therapy on sensation (Internizzi et al, 2013). Fleming and colleagues (2015) found immediate benefits in arm and hand function after 12 sessions of electrical stimulation to the 3 upper limb nerves, administered immediately before a task-specific motor training session. Although benefits were recorded after 2 days, these gains were lost after 3 and 6 months. Conforto and colleagues (2010) also applied electrical stimulation to the median nerve of stroke survivors, immediately before motor training and found immediate changes in function but differences between control and experimental groups had reduced after two months. Therefore, electrical stimulation to a person's affected arm may help to improve return of movement and sensation.

Finally, sensory discrimination training of the affected upper limb has shown positive results in one trial when compared to non-specific exposure to sensory stimuli (Carey et al, 2011). In that study, 50 people who had a stroke and were living in the community were randomised into either an experimental or control group. The 25 experimental group participants received 10 training sessions of generalised sensory discrimination training, with one third of each session divided equally between training of texture discrimination (discriminating between different plastic grids and fabrics), limb position sense (wrist angle) and tactile object recognition (exploring and manipulating objects such as a cup, cutlery or coins). Training involved graded progression of discriminations from easy to difficult, provision of feedback and intensive training. After 4 weeks, changes in the Standardised Somatosensory Deficit (SSD) index were significantly greater for the experimental vs control group (19.1 vs 8.0 respectively) with a mean between-group change of 11.1 SSD points (95% CI, 3.0 to 19.2) in favour of the experimental group. Improved sensation was maintained at the 6 week and 6 month follow-up. While that study and intervention still need to be replicated, the sensory training program can be implemented by therapists with fidelity using the manual and DVD (Carey 2012, available at http://www.florey.edu.au/research/new-tools-for-a-new-era-in-sensory-training).

7. Preventing and Managing Secondary Impairments

7.1 Contractures

Loss of shoulder external rotation range of movement is common after stroke. In one study (n=52), the majority of people with stroke experienced a loss of external rotation range greater than 60-degrees (Lindgren et al, 2012), with some participants unable to attain neutral (0-degrees) or mid range between internal and external rotation. This loss of range correlated with shoulder pain (Lindgren et al, 2012) and will affect performance, particularly self-care tasks. Therefore, it is important for therapists to anticipate and prevent contractures.

Muscle stretching has become a popular intervention for managing muscle length changes and contracture, in addition to strengthening opposing muscles. Some years ago, animal studies suggested that stretches of 30 minutes prevented the development of contractures in otherwise immobilized mice soleus muscles (Goldspink & Williams 1990, Williams 1990). Unfortunately the changes observed in animal muscles were not reproduced in human stretching studies. For a complete review of stretching research, see Katalinic and colleagues (2010). Disappointingly, high quality randomized controlled trials have not found statistically or clinically worthwhile benefits from prolonged stretches in people who have had a stroke, traumatic brain injury or spinal cord injury. One study involving people who had had a stroke provided shoulder, arm and hand positioning for 30 minutes, 5 days a week for a month in conjunction with task-specific motor training; that study demonstrated a small benefit, which was maintained when stretches stopped (Horsley et al 2007).

Sustained stretches have also been applied using serial casts to immobilise muscles in their stretched positions. Serial casts produce transient changes in range of motion at the elbow in adults with traumatic brain injury, however, these improvements were not sustained after cast removal (Moseley et al 2008)

Studies investigating the effect of hand splinting to prevent contracture after stroke and brain injury have shown no difference in wrist extensibility compared to controls (no splint), even when splints were worn overnight for 4 weeks (Lannin et al 2007) and overnight for 3 months for thumb web-space contractures (Harvey et al 2006).

To conclude, there is uncertainty about whether stretch interventions are effective in the long term, and if they are, it is not known for how long stretches should be held or how often stretches should be administered. The current evidence strongly suggests that therapists should not be routinely applying stretches or splints while people are participating in active rehabilitation.

7.2 Shoulder pain

Shoulder pain can limit a person’s participation in activities. Therefore, therapists often aim to reduce pain. The causes of shoulder pain are still uncertain, but may include impingement of tissues around the shoulder joint, trauma from pulling on the arm, and loss of external rotation. A Cochrane systematic review (Ada et al 2005a) found that shoulder strapping with adhesive tape delayed the onset of shoulder pain but did not reduce pain once it had developed, nor did strapping improve function. Since that review, other randomized controlled trials have confirmed the benefits of strapping for preventing and delaying the onset of shoulder pain after a stroke (Appel et al, 2011; Griffin & Bernhardt, 2006; Pandian et al, 2013). For example, Griffin and Bernhardt (2006) reported a mean of 26 pain-free days for the intervention group compared to 19 pain-free days in a placebo controlled group and 16 pain-free days in the control group.

Electrical stimulation can also reduce shoulder pain when applied to the supraspinatus, posterior and middle deltoid and trapezius muscles (Koog et al, 2010; Viana et al, 2012).

7.3 Shoulder subluxation

Shoulder slings and supports have not been well researched despite their frequent use in practice (Ada et al 2005a; 2005b). Current expert opinion is that external supports such as wheelchair and chair attachments are needed to support the weight of the arm (Foongchomcheay et al 2005). Triangular slings can reduce a shoulder subluxation but slings that do not support the arm will probably not reduce a subluxation (Ada et al 2005a; 2005b).

Electrical stimulation shows more promise as an intervention by stimulating muscles around the shoulder joint. Electrical stimulation is typically used with people who have little or no muscle activity. Ada and Foongchomcheay (2002) conducted a meta-analysis involving four trials of electrical stimulation to prevent subluxation early following a stroke (average 17 days post-stroke). Electrical stimulation reduced subluxation by an average of 6.5mm, but had no worthwhile effect on reducing pain or improving functional recovery. No clinically important differences were found when stimulation was applied later (60 days or more post-stroke), based on meta-analysis of data from three randomised trials. Ultimately individuals need active training to help strengthen paralysed and weak muscles around the shoulder and upper arm.

7.4 *Improving Movement in People with Spasticity*

There is growing evidence that therapists overestimate the number of people with clinical spasticity (e.g. O'Dwyer et al 1996). Research has also demonstrated that when spasticity is reduced using botulinum toxin (type A), this intervention does not improve active use of the hand or arm (Shaw et al, 2010; Sheean et al. 2010). Taken together, these findings suggest that routine interventions to reduce spasticity in adults with a neurological condition are not indicated and therapists should focus on addressing negative impairments, loss of strength and motor control.

For people with spasticity that interferes with function, the most common medical intervention is chemodenervation using botulinum toxin type A (BoNT-A). Results from a meta-analysis show that BoNT-A can reduce spasticity compared to placebo treatment (Cardoso et al 2005). However, BoNT-A does not improve dexterity or functional outcomes. The BoTULS study (Shaw et al, 2010) was a large trial that evaluated the addition of BoNT-A to an upper limb therapy programme. No between-group differences were reported in upper limb function when measured by the Action Research Arm Test. So while BoNT-A can temporarily reduce spasticity, it has not been shown to lead to improved functional use of the hand.

In summary, people affected by a stroke or brain injury usually want improved use of their hand, not just less spasticity. The evidence-based interventions recommended in this chapter have been shown to improve function, and may be a better focus for therapists than BoNT-A.

8. Future Directions

The earlier rehabilitation begins, the better the recovery from conditions such as stroke and brain injury. Greater intensity of treatment translates into better outcomes. Gains in motor control and sensory recovery continue for many years. Many therapists are moving away from 'hands-on' therapies towards evidence-informed interventions that apply motor learning theory and promote neuroplasticity. One-on-one therapy is being supplemented with homework and group programs where people practice together. Family-assisted programs such as GRASP (Harris et al 2009) are also being implemented more in hospitals to increase practice opportunities.

Tele-rehabilitation is one mode of delivery that can increase practice and reduce travel time and costs, with some sessions provided with therapists and some by distance using telephone and the Internet (Chumbler et al 2012). However, evidence of improved upper limb outcomes after stroke using tele-rehabilitation was still limited at the time of the most recent Cochrane review (Laver et al 2013).

The need for increased intensity of practice has led to the testing of novel rehabilitation techniques such as virtual reality and robotic therapy. Virtual reality, including interactive low-cost videogames such as the Wii, enable people to practice independently or semi-supervised, helping to increase practice dosage. A systematic review was recently conducted of studies involving virtual reality and interactive videogames and adults with stroke (Laver et al, 2015). Virtual reality significantly improved upper limb function (standardized mean difference 0.28, 95% CI, 0.08 to 0.49) based on 12 studies with 397 participants. Robotic therapy allows some of the labor-intensive training to be performed by automated devices, increasing repetitions, upper limb function and activities of daily living post-stroke (Mehrholz et al 2012; Pollock et al 2014). Although improvements are similar to those achieved with dose-matched intensive task-specific training (Norouzi-Gheidari et al 2012), a robotic device allows individuals to practice semi-supervised. The cost of robotics will hopefully decrease in future, allowing more services to offer this intervention to people with neurological conditions.

As the evidence grows in support of more intensive therapy, interventions such as constraint therapy, virtual reality and robotics will be used more often, because they increase practice and improve arm recovery. With technologies improving continuously, it is not possible to predict what advances will become routine practice in the future. The important message is, therefore, to remain abreast of current scientific evidence.

9. Conclusions

This chapter has focused on the process of analysing and retraining motor performance and sensation in adults with brain impairment. The content is necessarily impairment-focused because much of upper limb rehabilitation, particularly in hospital settings, focuses on eliciting muscle activity and strength training prior to return of functional grasp. Therapists need to remind themselves and the people they are working with of the occupational goals of training, for example, eating a meal with family members using cutlery in both hands. Once a person can grasp and manipulate objects, tasks and goals are more obvious. While the overall goal may be to increase engagement in occupations, therapists should not ignore impairment-focused interventions

.

Table 3 Summary of motor control and sensory problems affecting the upper limb, and possible interventions for people with neurological conditions

Motor Control Problem	Possible Interventions and Evidence from Key Studies
Eliciting contractions in paralysed muscles	• Repetitive contractions and practice of shoulder protraction in sitting "Rocking chair therapy" (Feys et al 1998; 2004) • Cyclical electrical stimulation (Nascimento et al 2014) • Mental practice (Braun et al 2013) • Mirror therapy (Thieme et al 2012, Wu et al 2013)
Increasing strength in weak muscles	• Robotic therapy (Hayward et al 2010) • SMART arm device (Barker et al 2008, Hayward et al 2010) • Electrical stimulation (Howlett et al 2015, Nascimento et al 2014) • Triggered electrical stimulation (Hayward et al 2010, Thrasher et al 2008)
Decreasing force in overactive muscles	• Repetitive contractions and practice, wrist and forearm muscles (Butefisch et al 1995)
Increasing co-ordination, speed and control	• Constraint-induced movement therapy (Kwakkel et al 2015, Nijlands et al 2011, Stevenson et al 2012) • Task-related training in groups (Blennerhassett et al 2004)
Improving sensation	• Mirror therapy (Doyle et al 2010; Wu et al 2013) • Electrical stimulation (Conforto et al 2010, Fleming et al 2015) • Task-orientated sensory training (Carey et al 2011)

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