Neuromuscular Rehabilitation in Manual and Physical Therapies
Neuromuscular Rehabilitation in Manual and Physical Therapies
Principles to Practice

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Dedicated to Tsafi, Guy, Mattan and Pinooki
This book is for individuals who would like to help other individuals to recover their control of movement.

Neuromuscular rehabilitation is straightforward and uncomplicated: we all do it naturally all of the time. Throughout our lives we learn new movement patterns or recover our control after an injury. The means by which we achieve these changes are no different to neuromuscular rehabilitation. They all rely on the same neurophysiological, psychological and behavioural processes.

Neuromuscular rehabilitation integrates several branches of knowledge. They include medical, neurophysiological, psychological-behavioural and motor-control sciences as well as manual and physical therapy fields. The enormity of available information from these diverse sources can be overwhelming, in particular when trying to translate this information into a practical clinical approach. The main aim in writing this book was to collate and integrate all this information and present it in a practical, user-friendly format.

Over the years of working in clinics I have observed that neuromuscular rehabilitation of a person after joint surgery or musculoskeletal injury bears close resemblance to the clinical management of a stroke patient. It was clear to me that there is a unifying model for neuromuscular rehabilitation. However, it took a good decade and a half to put it together into a coherent and cohesive model, and one which is still being tinkered with. This unified model for neuromuscular rehabilitation is described throughout the book.

The information in the book is derived from several sources. It is a combination of my own research in the neurophysiology of manual therapy, the vast research in all the fields discussed above, my clinical experience of 23 years and my experience of teaching neuromuscular rehabilitation for the last 15 years. These experiences have made me aware of the academic and practical needs of the practitioners in this area. This is reflected in the contents of this book: it aims to bridge the gap between science and the practice of neuromuscular rehabilitation.

The contents and organization of the book

The book starts by identifying the main unifying model/principles for motor rehabilitation (Ch. 1), including the importance of a functional approach, skill- and ability-level rehabilitation and the code for neuromuscular adaptation. The following chapters discuss several areas that are relevant to neuromuscular rehabilitation. They include how movement is organized (motor control, Ch. 2) and how it is constructed from underlying control components called motor abilities (Ch. 3). These abilities are affected in various neuromuscular and musculoskeletal conditions and may, therefore, become the target of rehabilitation. Also, proprioception plays an important role in movement control and is often affected by musculoskeletal and central nervous system damage (Ch. 4).

The next important issue in rehabilitation is how to sustain the motor recovery in the long term. Chapter 5 discusses motor learning and adaptation principles and how to integrate them into the clinical management. The consequences of learning, neurophysiological/neuromuscular plasticity and adaptation are discussed in Chapter 6.

In musculoskeletal injuries the motor system reorganizes movement to prevent further damage (Ch. 7). The motor manifestation of this reorganization will be discussed as well as the indications for introducing neuromuscular rehabilitation after injury identified.

Once an individual acquires an injury, their beliefs, attitudes and behaviour may have important implications for recovery. Furthermore, the way a person uses their body or schedules their activities during the day may put them at risk for injury. These cognitive and behavioural factors are discussed in Chapter 8. This theme is continued in Chapter 9, examining non-traumatic pain conditions such as trapezius and jaw myalgia, and chronic neck pain. In this group of conditions the individual develops localized and debilitating pain without a history of tissue trauma.
Chapter 10 explores the principles of functional movement, motor control and learning/adaptation, and their use in rehabilitating patients with central nervous system damage.

Chapter 11 describes how to develop a rehabilitation programme using the key principles identified in the book. Chapter 12 describes some of the assessments and challenges of motor abilities and similarly for proprioception in Chapter 13. A summary of the book can be found in Chapter 14.

The book is supplemented by a DVD demonstrating some of the assessments and challenges of the motor abilities and their use in clinic. The movement challenges described in the book and DVD are derived from several sources. Some are research-based, others I have developed and used in clinic. Over many years of teaching I have observed professionals from different disciplines and their approach in rehabilitating movement control. Their wealth of experience and knowledge is part of this library of movement rehabilitation. It is a source book that aims to provide ideas and not recipes or treatment protocols for rehabilitation.

I hope you will find it useful.

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Prof Eyal Lederman
Introduction

This book explores how manual and physical therapists can help individuals to recover and optimize their control of movement. Musculoskeletal injury, pain experiences and central nervous system damage are all associated with diverse neuromuscular and movement control changes. The aim of this book is to provide the theoretical and practical basis for neuromuscular rehabilitation for these conditions.

This book is intended for manual and physical therapists of all disciplines (physiotherapists, osteopaths, chiropractors, sports massage therapists, etc.) who work with patients whose conditions involve the neuromuscular system. The book will also be useful for personal trainers, Alexander method teachers, Pilates instructors, postural integration teachers, Rolfing practitioners, sports trainers and individuals who experience losses in movement control.

A functional approach in rehabilitation

A functional approach in rehabilitation is the key concept underpinning the management described in this book.

Functional movement is defined here as the unique movement repertoire of an individual. A portion of this repertoire involves the movement behaviour associated with daily needs and demands, such as feeding, grooming, going places, etc. (general skills). Some movement behaviour may be partly shared with others whilst some may be unique to particular individuals; examples include physical hobbies, sports and occupational activities (special skills). For one person their functional repertoire may include playing tennis, for another standing on their head (yoga) or playing the piano and so on. Once a person learns a movement or a new skill it becomes a part of their movement repertoire and, therefore, their behaviour. Movement which is outside the normal repertoire of an individual will be termed here as extra-functional (Fig. 1.1).

Functional rehabilitation is defined here as the process of helping a person to recover their movement capacity by using their own movement repertoire (whenever possible). Hence, for a person who has motor losses at the knee and is unable to walk or run, the rehabilitation will be in walking, then running, jumping and stair-climbing, etc. If this person plays tennis, this activity will also be used in the rehabilitation programme.

However, rehabilitation is likely to be less effective if the remedial movement patterns or tasks are outside the individual’s experience (extra-functional). For example, it would be less helpful for a tennis player with a leg injury to be given rehabilitative exercise such as football, or leg presses in the gym or leg exercise lying on the floor (Ch. 2). For this particular patient, rehabilitation that incorporates tennis tasks is more likely to be useful. For a person who is suffering from lower back pain and enjoys yoga, a functional rehabilitation would consist of the shared functional activities (general skills), but may also include some of the upright postures from yoga (special skills). A less suitable rehabilitation approach would be to prescribe tennis to this individual. This may seem obvious; however, movement rehabilitation often prescribes extra-functional tasks such as core stability training.
on the floor, bracing the trunk or strength training with equipment. The question is how effective are these activities in recovering functional movement?

The introduction of extra-functional activities during rehabilitation raises some problems. Extra-functional activity or exercise requires learning a new task at a time when the patient is experiencing pain and/or loss of movement ability. This might not be the best time to enter a new exercise regime. Learning requires set-aside time, intense mental focus and physical effort. Often it means the patient has to be dependent on others for instructions and guidance during the training. A functional approach which aims to use the patient’s own movement resources does not require additional learning; the cognitive demands are less taxing and do not require protracted training. Also the set-aside time for practice is more manageable for the patient. This form of rehabilitation seldom relies on any specialized exercise equipment and the remedial movement challenges are integrated into the person’s daily activities. They can be practised anywhere and at any time. A functional approach is easy to apply and it empowers the patient to self-care.

There are exceptions to the functional approach in rehabilitation. There are circumstances where the patients will require specific exercises for particular motor losses; challenges which may not be provided by their functional repertoire. There are also situations where the individual is physically unable to perform functional activities. When and why the rehabilitation should stray from this model will be discussed throughout this book.

Rehabilitation levels: skill and ability level rehabilitation

Movement rehabilitation and motor normalization following injury occurs naturally for most individuals. Following injury most individuals will take physical actions that will support their spontaneous and unaided recovery. This would happen without any special knowledge or understanding of the underlying physiological principles underpinning their recovery. In this form of rehabilitation the individual is attempting to, partially or fully, execute the movement that has been lost. Attempting to walk becomes the rehabilitation for the person who lost the ability to walk. Similarly, if an individual with an arm injury is unable to reach; their repeated attempts in that pattern would often be their rehabilitation. The focus in this form of movement recovery is on the overall skill of performing the particular movement. This will be loosely referred to as skill rehabilitation (Ch. 9).

However, this approach does not always lead to the intended results. Individuals who are in pain or have motor losses may develop movement patterns that circumvent their losses. A patient may present with walking difficulties due to losses in the control of balance and coordination. One would imagine that by encouraging the patient to increase their walking, “walking would train balance and coordination during walking”. However, what may happen is that the patient will get better at using their compensatory pattern; walking slowly, using wider gait,
shorter steps, rather than truly improving their control of balance and coordination during walking.

Balance and coordination are part of several control building blocks that make up skilled movement. These building blocks are called sensory motor abilities. A therapeutic approach that targets the various motor abilities will be termed in this text as re-abilitation. At this level of rehabilitation the aim is to recover control losses associated with particular abilities. Hence, in the walking scenario described above, the rehabilitation would aim to challenge balance and coordination in dynamic and upright postures (Ch. 2).

Skill rehabilitation and re-abilitation are both clinically important and are often used in combination. However, there may be a shift of focus towards one of these particular approaches depending on the individual’s condition and their phase of recovery (Ch. 2).

The recovery of motor control can be facilitated by introducing the adaptive code element into the rehabilitation programme. It will promote a functional recovery that is more likely to benefit the patient in their daily activities. The results are more likely to be maintained in the long-term and could help to reduce the overall duration of the treatment programme.

**Developing a neuromuscular rehabilitation programme**

Much of the rehabilitation promoted in this book is the marrying of the three concepts discussed so far:

1. The focus on functional movement
2. The principle of skill/ability level rehabilitation
3. The code for motor adaptation (Ch. 9).

Through a simple three-step process the therapist decides which level of rehabilitation will be used and applies the motor adaptation elements to the treatment programme. Many of the remedial challenges are selected from the patient’s own movement repertoire. It really is that simple.

The beauty of it all is that these principles can be applied to any condition in which the neuromuscular system is implicated:

### Conditions with an intact motor system

- Neuromuscular changes associated with musculoskeletal injuries, sports injuries, post surgery, back pain and other musculoskeletal pain conditions (Ch. 7)
- Conditions where certain behaviours impede recovery or may lead to injury or pain (Ch. 8)
- Non-traumatic pain conditions, such as trapezius myalgia, chronic neck pain and painful jaw (Ch. 9).

### Conditions where there is damage to the central nervous system

- Stroke, head trauma and post central nervous system (CNS) surgery and all the degenerative conditions (Ch. 10).
The main difference in managing these conditions is in the magnitude of losses, the duration of recovery and the extent of potential recovery.

Summary points

• Neuromuscular rehabilitation aims to help the individual recover their movement control.
• Functional movement is the movement repertoire of an individual.
• Functional movement is individual-specific.
• Functional rehabilitation uses the patient’s own movement repertoire to help him/her to recover their movement losses.
• The rehabilitation promoted in this book has three basic recurring concepts:
  1. It aims to be functional.
  2. It uses the skill/ability level rehabilitation concept.
  3. It uses the learning/adaptation code to optimize motor control changes.
Motor control

The motor system organizes and controls skeletal muscle activation during movement, posture and the musculoskeletal aspect of behaviour and expression. The motor system spans the whole of the central nervous system (CNS). It is not a discrete functional or anatomical entity.

This chapter will examine how movement is organized and the implications it has for neuromuscular rehabilitation.

The organization for movement

Imagine an action such as reaching for a cup. For that action we need to collect information from all our sensors about our body and the environment. We can then select the most suitable response to get hold of the cup. Once a decision has been made a motor command ensues, muscles are activated and a reaching movement is the outcome. Some elements of the motor process will be at conscious level, “that we are reaching for the cup”, while a larger proportion will remain at a subconscious level, such as the fine postural adjustments that precede the action. Hence, any movement has conscious and reflexive elements and identifiable stages (Fig. 2.1):

- Integration stage
- Motor stage
- Sensory stage.

These stages should be viewed as a process with multiple sub-events rather than separate entities.

The integration stage

Once an individual has decided to take an action the role of the integration stage is to prepare the neuromuscular system for the execution of the associated movement. Within the integration stage there are two processes that have important implications for neuromuscular rehabilitation. The first is how movement is encoded by the motor centres for future use and the second is how movement errors are identified.

Motor programmes and movement parameters

Our movement repertoire is stored within the central nervous system as motor programmes. They are not centre-specific and seem to be stored throughout the central nervous system, including the spinal cord. The motor programmes are believed to be generalized schemes containing information about the movement sequences and their goals rather than specific muscle sequences. Writing is an example of such a generalized scheme. A word can be written in many different ways; it can be written fast or slow, from different angles, in larger or small amplitudes, whilst sitting or standing, or even in completely new, unrehearsed situations. It can be written with the non-dominant hand, with each foot and even with the pen held between the teeth. A mild stroke patient once demonstrated to me how she could write beautiful calligraphy with the affected arm/side. She would hold the pen in the
hand; stiffen her arm and write by moving her whole body. In these writing examples, the schema for writing is executable by any part of the body because it is not specific to any particular muscle group.11–15

Once a task has been learned the movement sequences become more robust to change, e.g. a person’s handwriting is unique and will remain largely unchanged through life. However, certain factors such as the force, speed, range/size of the writing can be changed at any time.2 By modifying these movement parameters any task can be performed with infinite variations.11–15

The movement parameters have an important role in neuromuscular rehabilitation. It has been demonstrated that in musculoskeletal injury or in pain conditions the motor system “narrows” these movement parameters. This reorganization of movement control is a protection strategy which serves to alleviate some of the stresses imposed on the damaged tissues (Ch. 7). For example, a person suffering from lower back pain may demonstrate trunk muscle force losses,21–23 reduced movement speed,23–26 reduced endurance,16–20 changes in the normal timing and duration of synergists in the trunk muscles,27–37 changes in coordinated movement of the pelvis and thorax,24,25 reduced postural stability31,34,38–40 and loss of the ability to respond to sudden postural changes.28–36,41 Hence, a person with back pain will often display a posture and gait which is different from their usual patterns. The normal schemes for walking are still preserved, but the movement parameters have changed. This motor reorganization will also influence certain building-blocks of movement called motor abilities (see Ch. 3).

The comparator system
Imagine that while lifting the cup it slipped from your hand resulting in immediate reflexive grasp. The error detection is carried out by the comparator system.

Once a movement pattern has been selected the efferent commands are transmitted to the spinal motor centres to initiate muscle activity. At the same time a copy of this information (efferent or efference copy) is transmitted internally to be processed by the comparator system (Fig. 2.2). Here, the information from the efference copy and the information from the sensory inputs are matched against the expected outcome of the action.2,42–45 Any mismatch will result in motor reorganization and correction of the movement.
The comparator system reduces the processing demands placed on the CNS by selectively drawing attention to movement, but only when there is a change from the norm. As long as the information is similar it will remain at a low priority within the overall motor processes. Hence, many of our familiar daily activities (e.g. walking) remain below consciousness until we make a mistake (e.g. tripping).

When learning a new task it will be acquired through a process of making errors and their correction. This error detection is carried out by the comparator system. This detection process is only functional during “active” rather than passive movement. It implies that motor learning will be more effective in rehabilitation approaches where the person is active and concurrently correcting their movement, in comparison to passive approaches.

The comparator system also plays a role in proprioception. When we move our limbs there is a sense of their weight and the effort that is required to move them. This sense of effort is believed to be derived internally by central processes (comparator) and not from the proprioceptors. It has been hypothesized that during motor development we learn to associate the effort with movement sensations (proprioception). Eventually, the sense of effort becomes a proprioceptive signal in its own right.

The sense of effort, as a source of feedback, is only present during active rather than passive movement. Hence, during active movement proprioceptive acuity increases, compared to the same movement being performed passively. It implies that more effective proprioceptive rehabilitation can be achieved by active rather than passive movement approaches. The full clinical implication of this phenomenon is further discussed in Chapters 4 and 13.

The motor stage

The motor stage is the culmination of the selection of movement schemes and the transmission of these efferent commands to the spinal motor centres.

One way to visualize the motor output is to imagine a person wearing an electromyographic (EMG) body-suit. This suit would have numerous EMG electrodes that could record the motor activity from every single muscle or, even better, from every motor unit in the body. Furthermore, imagine that the suit is covered by minute lights that would represent the intensity of the underlying motor events. Areas with high motor activity will be represented by brighter light and vice-versa. If this was possible, we would probably see a psychedelic light show throughout the body, with different areas lighting at different intensities – the motor output is a whole body event. These patterns would change on a moment-to-moment basis as the person moves or even while they are still.

The EMG suit would probably demonstrate that movement is achieved by shifting tension gradients throughout the body (Fig. 2.3). In order to move...
the arm to the mouth, tension develops in the anterior aspect of the upper limb, while on the opposite side the tension in the limb diminishes. The way to imagine it is as broad and dynamic **tensional fields**, rather than separate and individual muscles. These fields are widespread and are continuously varying in their intensities. Interestingly, most of the proprioceptors in our body are tension receptors (except for the skin, which has pressure receptors). It seems that during movement the nervous system “sees” areas of varying tensions rather than individual tendons, joint capsules or muscles.

**The complexity of recruitment**

The recruitment of muscle is composed of highly complex patterns. Imagine a simple movement such as turning the head. Some muscles will be recruited to produce the tensional field necessary to rotate the head; meanwhile all the antagonistic muscles will reduce their tensional field. Concurrently, muscles bilaterally will increase in co-tension to prevent the head from falling sideways (Fig. 2.4a). These muscles have to dynamically stabilize the movement while sharing some element in the execution of the turning motion. As the head moves beyond the centre of its gravity the action of these muscles will reverse. The antagonists develop low-level eccentric tension to counter the weight of the head; the original movers will drop in tension and so on. If we were to describe every muscle activity in this simple movement it would probably fill the whole of this book and beyond. This complexity is depicted in Figure 2.4b.

It has been demonstrated that every task or movement we perform will never exactly repeat itself. Throughout life “every breath you take, every step you make” and every heart beat is different. Yet, in all this complexity we somehow produce movement that is definable, precise and is unique to ourselves. It is now suggested that such variability is an essential healthy aspect of biological systems and that during injury and disease processes this variability tends to be diminished.

**Goal-orientated movement**

Movement is organized with an overall goal or purpose: we reach for a cup, hit a ball or walk to a location; but we don’t set out to move our limbs, move a joint or contract a muscle. For an outsider watching a person performing a task it can be broken down into the action or movement and its outcome, the goal. Once we learn how to achieve a certain goal, the action and the outcome are integrated to become a unified automatic response. They are represented internally as images of the goal. When we perform an action or task, thinking of the outcome/goal triggers the execution of the associated movement. Interestingly, 7-month-old infants favour learning by imitating movements that have obvious goals but not those that have ambiguous goals.

The whole body is organized to take part in the goal of the movement including all the anticipatory postural adjustments that precede it. Different parts of the body tend to “lead the way” during goal movement. The arms for reaching or throwing, the
legs for kicking or stepping over an obstacle and the head leads in the initiation of walking and turning. Head movement is also led by our senses, turning the head to a sudden noise, looking up or bending forward to smell or taste. The odd one out is the trunk: it rarely leads in movement. In rehabilitation of back conditions should the trunk/spine be a focus of movement training or should it be engaged within the overall movement goal?

**Clinical note**

Movement control should be associated with its goals during rehabilitation, i.e. rehabilitation should use goal-orientated and task-specific movements. Movement where the body itself is the goal may be less effective in recovering motor control (see also Internal and external focus and learning, Ch. 5).

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**Task-dependent muscle recruitment**

The muscle recruitment will vary considerably from one task to another. For example, the trunk muscles will display completely different activation patterns during standing, walking, reaching to the sides or forward, bending or lifting or any other imaginable movement. Furthermore, even within the same task, changes in the underlying movement parameters and other factors will influence the complex recruitment of muscles. They include:

- **The force** – movement which is similar but at a varying force will change the muscle recruitment.

- **The amplitude of movement** – how far a person reaches changes the pattern of trunk muscle activation.

- **The rate/speed of movement** – changing the speed of movement will also change recruitment patterns. For example, there is different trunk muscles recruitment during slow or fast arm movement.

- **The position or direction** – slight variations in underlying posture/position during movement will change overall patterns of muscle recruitment. For example, different positions during exercise will recruit different patterns in the trunk muscles. Likewise, movement of the body in a different direction will change the pattern of activation of the abdominal muscles.

- **Contact/contact-free movement (open-closed kinetic chains)** – muscle recruitment is different if movement is contact-free (e.g. waving your arm) from movement where the body makes contact with another base, such as the floor, wall or an object. Hence, muscle recruitment in the arms is different during push-ups (contact) than the same arms movement performed standing in space without contact. Interestingly, most of our body is involved in a mixture of these two contact patterns, except for the head, which is invariably contact-free. Does this mean that functional rehabilitation of the neck should focus on contact-free head movements?

- **Pain** – the experience, anticipation or fear of pain will influence the muscle recruitment patterns.
The current evidence suggests that alterations of task or small changes in movement parameters can have a profound and complex influence on muscle recruitment. No single pattern of muscle recruitment dominates movement (otherwise it would be impossible to move). This has important implications for rehabilitation and further enforces the concept of a functional approach. It suggests that patients should be trained in a variety of patterns that are similar to the goal movement.82

The movement should be practised in different positions, forces and speeds, and using both contact and non-contact patterns. This would aim to account for the infinite variability that exists in normal daily movement. Rehabilitation should not be restricted to set movement patterns with minimal variability or focused on particular muscles (e.g. weight-training or performing biceps curls). Such an approach will result in the patient’s learning to control muscles in relation to these specific tasks, in patterns which are unlikely to carry over to other tasks (see Similarity principle and transfer, Ch. 5).

The sensory stage

During movement the motor system collects information about internal physical events as well as information from the environment.3,44,83 This is provided by two feedback systems:

* Proprioceptors – which provide information about internal mechanical events
* Exteroceptors (vision and vestibular/hearing) – which provide information about the environment.

When we reach for an object our movement is organized in response to the information provided by these two feedback systems. Information from vision is used to estimate the distance and the size of the object to be handled.2 The proprioceptive and visual information is integrated with vestibular information to maintain the body balanced and upright during the reaching task.84–86 The skin receptors signal the contact of the fingers with the object and provide information about its mass, size and texture. Further information arrives from receptors in the muscles and joints, indicating the position of the arm in space and the relationship of different body masses to each other; the speed and direction of movement and the force of contraction (sense of effort).47,48,87–94

The processing of sensory information occurs both at a conscious and subconscious levels.94–98 However, much of this extensive information is processed at a subconscious/reflexive level, unless we draw our attention to any element of it.

Role of proprioception

Proprioception has several important roles in motor processes. It provides:

* feedback for immediate adjustments and refinement of movement
Motor control relies on proprioception for the final adjustment, refinement and synchronization of complex movement. It also provides information if the movement strays away from what is intended, e.g. walking and tripping. Proprioception losses may lead to unrefined and inaccurate movement, and are believed to predispose the individual to recurrent injury (see Discussion, Ch. 4).

During very rapid movements the processing of sensory feedback is too slow to allow correction of the ongoing movement. This is seen in activities such as walking, jumping, running, fast ballistic movements, typing or playing a musical instrument. In these movements the pre-programmed motor patterns precede the sensory feedback. The motor system, therefore, has to rely on the information gathered before the onset of, rather than from the instantaneous feedback during, the movement. Consequently, the correction of the movement occurs close to or at the termination of movement. For example, during running and jumping, the activation of leg extensors precedes the foot contact with the ground by about 150–180 m. This fact has implications for preventing injuries in sports. Since the afferent transmission time within the CNS is fairly fixed, improving proprioception is unlikely to reduce injuries that occur during high-velocity movements. However, injuries may be prevented by changing the way the person performs the movement (see Discussions on task-behaviour and correctness of movement, Chs 7 & 8).

Our mind is “shaped” by our experiences and our experiences are formed by our senses. Proprioception, therefore, is essential for learning or recovering control of movement. Therefore, partial or complete losses of proprioception may slow down rehabilitation. Indeed, re-abilitation of stroke patients with sensory loss may be more difficult than of those with an intact sensory system.

The importance of proprioception for motor learning can be also seen in medical conditions in which a subject loses all their proprioception (often due to damage to the dorsal column of the spinal cord). Under these circumstances, the individual is still capable of performing tasks learned before the onset of their condition. However, they may find it difficult to modify the task or learn a new one. In one such documented case, the subject could still drive the car he used before his illness, but could not drive a new car as he was unable to learn the fine adjustments needed for the new mechanical situation.

The refinement of the pre-stored programmes is also dependent on proprioception, without which the motor programmes deteriorate over time. This is experienced in everyday circumstances when attempting to carry out a physical activity that has not been rehearsed for a long time (e.g. cycling). A few “goes” are usually needed to refine the stored programme.

Proprioception also plays an important role in body-image and the sense of self. These topics are relevant to behaviour and movement control, but are outside the scope of this book (for full discussion see: Lederman 2005 The Science and Practice of Manual Therapy, Section 3).

Proprioceptors

Proprioceptors (mechanoreceptors) are found in the skin, muscles, tendons, ligaments and joints (see Table 2.1 for groups of mechanoreceptors and their actions).

Afferent fibres from mechanoreceptors converge segmentally on the dorsal horn of the spinal cord. This anatomical segmental relationship is lost within the spinal cord. The afferent fibres tend to diverge in an ascending and descending manner, over several segments, synapsing with different neuronal pools and spinal interneurons. This sharing of afferents by motor centres has also been demonstrated in the cortex. Hence, many synergistic muscle groups share common afferent inputs. This means that spindle afferents from one group of muscles supply the motoneurons of the muscle in which they are embedded, as well as other synergistic muscles.

The functional implications of the diverging synaptic connections can be demonstrated by tapping the biceps tendon. When tapped, the reflex response spreads to muscles as far away as the pectoralis major, triceps, deltoid and hypothenar muscles. Similarly, tapping the tendon of lateral oblique brings about a reflex muscle response in all the abdominal muscles. Even passive movement of the shoulder influences the gain of the motoneurons supplying muscles of the hand. This physical organization has functional logic. Performance of a task involves total body movement occurring over many joints and muscle groups. The information about activity
Table 2.1  Mechanoreceptor groups, their anatomical location and function.

<table>
<thead>
<tr>
<th>Receptor</th>
<th>Location</th>
<th>Function</th>
<th>Interesting stuff</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spindle afferents</strong></td>
<td><strong>Muscle tendon unit</strong></td>
<td>Feedback about length, velocity, acceleration, deceleration and minimally about the force of contraction</td>
<td>The more refined the function of the muscle, the greater the number of spindles per unit weight of the muscle. The detection of force is delegated to the Golgi tendon organ</td>
</tr>
<tr>
<td><strong>Muscle II afferents</strong></td>
<td><strong>Golgi tendon organ</strong></td>
<td>Feedback about dynamic changes in the force of contraction. They are not stretch receptors, as is sometimes believed. Contraction of a single muscle fibre to which they are attached will bring about an increase in their discharge</td>
<td>In some muscles, the capsule of the spindle is fused or continues to form the capsule of the Golgi tendon organ. They are connected to 10–20 muscle fibres and are generally not affected by mechanical events in other muscle fibres</td>
</tr>
<tr>
<td><strong>Groups III &amp; IV</strong></td>
<td><strong>Muscle</strong></td>
<td>Chemosensitive. Information about metabolic changes and muscle damage/inflammation</td>
<td>Have an indirect influence on proprioception, via spinal and higher centres. Can influence the sensitivity of the spindle afferents</td>
</tr>
<tr>
<td><strong>Groups I &amp; II</strong></td>
<td><strong>Joint capsules and ligaments</strong></td>
<td>Range, speed and position of the joint. Group I (dynamic and static, low threshold, slow adapting), Group II (dynamic, fast adapting)</td>
<td>Most joint afferents are only responsive to a movement arc of about 15–20°</td>
</tr>
<tr>
<td><strong>Group III</strong></td>
<td><strong>Joint capsules and ligaments</strong></td>
<td>Information about dynamic events in joints. High threshold receptors that become sensitized by extreme joint position or joint injury/inflammation</td>
<td>A lowering of threshold (sensitization) takes place at the receptor peripherally, but also centrally within the spinal cord</td>
</tr>
<tr>
<td><strong>Group IV</strong></td>
<td><strong>Joint capsules and ligaments</strong></td>
<td>Nociceptors. Convey information about excessive stresses at the joint. Become sensitized in joint inflammation</td>
<td>Although they are not true mechanoreceptors, movements activates some group VI, albeit providing a poor sense of joint position. Receptor sensitization by peripheral and central processes</td>
</tr>
</tbody>
</table>
in one group of muscles has to be conveyed centrally to be integrated with all the other spinal motoneurons and higher centres taking part in the movement.

Clinical note

The divergence of afferents has important implications for proprioceptive rehabilitation. It suggests that localized, joint/muscle-specific rehabilitation may not be as effective in recovering control losses as rehabilitation of whole movement patterns.

Nociception as feedback

When we are in pain we move differently. Nociception is an important feedback system from the body to inform us about tissue damage or the potential for it. In response to the experience of pain the motor system will reorganize movement that is less physically stressful.

Psychological and behavioural factors related to the pain experience will have profound effects on movement control. In many musculoskeletal conditions the intensity of the pain experience and/or the resultant fear of it will often reflect in more extensive motor reorganization (Ch. 8).²³,³¹,³⁸.

Table 2.1 Mechanoreceptor groups, their anatomical location and function—Cont’d

<table>
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<td>Skin mechano receptors</td>
<td>Skin</td>
<td>Convey information about the contact and surface texture of objects. Contribute to fast reflexive gripping when an object is slipping through the hand. Skin tension contributes to joint movement sense. More sensitive to dynamic rather than static mechanical stimulation</td>
<td>When skin mechanoreceptors near the nail bed are stimulated it elicits a sensation of flexion at the distal interphalangeal joint. Interestingly, the perioral area of the human face lacks any proprioceptors except for skin mechanoreceptors which play a role in the position of the lips</td>
</tr>
</tbody>
</table>

Clinical note

Injured individuals and those in pain will select movement patterns that are beneficial for them. It raises the question, when does this positive protection strategy become a dysfunction, and at what point should there be a therapeutic intervention to change it? These issues will be discussed more fully in Chapter 7.

Summary points

- The motor system organizes and controls skeletal muscle activation during movement, posture and the musculoskeletal aspect of behaviour and expression.
- Motor processes have identifiable phases: integration, motor and feedback stages.
- Movement is stored as a scheme rather than as a fixed representation of the movement or specific muscle sequences.
- All movement is goal or task orientated and this should be reflected during rehabilitation.
- Rehabilitate whole movement – focusing on single muscles or muscle chains is not effective or essential for recovering motor control.
• Muscle recruitment changes according to the ongoing task or changes in the movement parameters.
• The motor system integrates proprioception and exteroception for the organization of movement.
• Proprioception provides information about internal mechanical events in the body.
• Proprioception is used by the motor system for the refinement of movement, motor learning and replenishing existing programmes.
• Pain is also feedback that has a profound influence on movement control.
• The aim of this chapter was to demonstrate the complexity of the motor output.
• This complexity promotes a functional approach in rehabilitation where the focus is on whole, goal-orientated movement.
• “Integrate in order to coordinate”.

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Motor abilities

When we observed an individual performing a specific task in which they are talented we often refer to them as being “skilful”. Levels of skilfulness can be observed even in normal daily activities such as the unskilled waddle of a toddler in contrast to the skilful walking of an adult. Similarly, we can instantly recognize the dysfunctional “unskilful” gait of a person with an injury.

A skill is how well a person can perform a given task. The proficiency in performing any skill is dependent partly on practice but also on the individual’s cognitive, sensory and motor abilities.

Motor abilities are motor control building blocks that underlie all movement. To be able to walk it is necessary to have control of balance, multi-limb and whole-body coordination as well as to have control of several other abilities. If any of these abilities is affected the skill of walking will be affected, as well as several other skills that depend on balance and coordination. Some of these specific control losses can be assessed, identified and become the focus of the therapeutic intervention.

In this chapter the different motor abilities are described. Their assessment and specific therapeutic intervention will be discussed in Chapter 12 (see also DVD).

Motor complexity model

The area of motor abilities is extensive and it is estimated that there are numerous such underlying abilities, perhaps running into the hundreds. As they are presented in the literature they are impractical as a model for rehabilitation. I have, therefore, taken the liberty of re-organizing them into a practical clinical approach. As a consequence, some of the abilities’ names have been changed to make them user-friendly and new abilities have been added (with apologies to Fleishman).

One clinically useful approach is to classify abilities according to their level of motor complexity. In this classification abilities are categorized into four levels, with skill being the top level (Fig. 3.1):

- Parametric abilities
- Synergistic abilities
- Composite abilities
- Skill.

Parametric abilities are the least complex control factors in this model. These abilities can be best described by looking at a simple movement such as reaching. Several variables of this movement can be modified without altering the overall pattern (these are the movement parameters described in Ch. 2). The movement can be executed with varying degrees of force and at different velocities (fast/slow). It can be carried out using different arm lengths (range); with the elbow fully extended or partially flexed. We can repeat this pattern of movement for long or short duration depending on our endurance. From this we can identify four such parametric abilities:

- Force
- Velocity/speed /rate
- Length
- Endurance.

The next level up in complexity is synergistic ability. During the reaching action, elbow flexors
and extensors have to be simultaneously controlled. As the movement variables are modified in one group they have to be reflected in the "opposite" group. Hence, synergistic ability is about the relationships between muscle groups or between movement pairs (flexion–extension, adduction–abduction, internal–external rotation or any combination of these patterns). There are two identifiable synergistic control patterns:

- Reciprocal activation
- Co-contraction.

Reciprocal activation serves to produce movement while co-contraction increases the stiffness and stability (steadiness) of joints during static posture and movement.4–7

Further up the complexity model are the composite abilities. These abilities rely on other composite abilities, but also on the less complex parametric and synergistic abilities. Using the arm-reaching movement as an example, it was identified that synergistic ability is needed for elbow movement. However, what happens during simultaneous shoulder and elbow movement? Now, the motor complexity has moved a notch up. The elbow synergistic control has to integrate with that of the shoulder. The harmonious coupling of the two areas can be considered as coordination ability. If at the same time the hand was to manipulate an object, the fine harmonious working of the fingers could be considered as fine coordination. The movement of the whole arm is single-limb coordination and multi-limb coordination if we were synchronously moving the other arm. Since the arms are attached to the rest of the body we have to also consider the harmonious integration of movement between the limbs and the trunk as body coordination.

However, there are other factors that come into play while we stand. Upright posture and locomotion depends on body coordination ability, but also on balance or postural stability. Furthermore, in daily activity we tend to perform in succession various tasks. The reaching movement, if it were while cooking, would be followed by actions such as holding, whisking or tossing food in a pan, etc. The ability to smoothly and rapidly change between actions is termed here as transition time. It is the time it takes to reorganize movement control between two dissimilar events. Finally, if the cooking was for a large number of guests and under a time pressure, we might find that our shoulders are tense and may feel achy and stiff. This psychomotor response to stress would be termed here as motor relaxation ability.
From the description above four major composite abilities have been identified:

- Coordination (fine, single- multi-limb and body coordination) ability
- Balance/postural stability
- Transition time
- Relaxation ability.

The individual’s skills are placed at the top of the motor complexity model as they contain various combinations of the abilities described above.

Abilities can affect each other, but they can also exist as independent motor losses. For example, in the hand of a stroke patient coordination ability can be affected independently of force and velocity abilities.8,9

The classification of abilities by complexity is a useful clinical tool. It provides a rational and methodical approach for assessing and treating specific motor control changes.

**Parametric abilities**

**Force control**

Force control is the ability to provide adequate force for optimal execution of movement. It is the ability to regulate force as well as recovering force losses. Included in force control is the ability to fully relax muscles. The way to think about force control is to imagine a light dimmer switch – it can be switched on/off or gradually dimmed.

**Force control** is the ability to regulate the force rather than make someone stronger. For example, a stroke patient can deliver a bone-crushing handshake, but may not be able to fine grade the squeezing force between low, medium and high forces.10,11 Conversely, in children with hemiplegia there are force losses but force regulation is saved in the affected hand.12,13

Force control is also the ability to fully relax muscles, i.e. no force. During movement some muscle groups will be motorically inactive. This motor relaxation is as important as motor activation for the execution of normal functional movement. The inability to relax force often results in severe movement dysfunction, such as seen in writer’s cramp (dystonias) or in stroke patients.14-17

**Force loss** on the other hand is the inability to generate sufficient force for the optimal execution of movement. Force loss can be due to direct physiological and pathological changes to the muscle tissue or its motor innervations. However, the most common manifestation is in failure of voluntary activation seen in musculoskeletal injuries. Like a light dimmer switch, the muscle forces are turned down by the central nervous system (CNS) to unload the damaged or sensitive tissues (Ch. 7).18-24 Centrally mediated force losses can also be seen in stroke patients as unilateral weakness (hemiparesis) or complete force loss (hemiplegia).16

Frequently, force loss is the most obvious movement deficit and can become the unjustified focus of treatment25,26, sometimes at the expense of overlooking other motor control changes.

**Length control**

Length control is the ability to effectively regulate the range of movement. This include both the elongation and shortening control of the muscles.

Length control changes are often observed in injury as a narrowing of the ranges of movement. This is a protection strategy to prevent further tissue damage. The hypersensitivity to stretching and reflexive guarding seen after injury is an example of length control. This can be seen during straight-leg raising, where there is a sudden resistance to hip flexion by muscle guarding. Another example is the loss of flexion relaxation of the back muscle in patients with chronic low back pain (CLBP).27 This is a length protection strategy to prevent the individual from bending fully forward. Regulation of length can be an important issue for patient with damaged CNS. For example, in stroke patient the hypertonic, hyper-flexed wrist and hand partly represent a dysfunctional control of length.

Often in rehabilitation the focus is on achieving maximum length. However, the inability to achieve maximum length could equally be due to an inability to effectively shorten the muscle. This is seen, for example, in neck conditions where there is an inability to rotate the neck to the symptomatic side (even when pain subsides). This could be due to changes in shortening-force control of the neck’s rotators. Similarly patients with stiff, non-painful, frozen shoulder may find full flexion difficult even after regaining the passive range of flexion. This may be due to the inability to produce effective length-force shortening of shoulder flexors to elevate the arm (Fig. 3.2). Hence, the therapeutic focus should be on the length-shortening synergy of the movement pairs (see below).

The control of length also relates to the maximum range, i.e. how far an active movement can be executed. Range losses are often seen in musculoskeletal conditions where the patient, due to immobilization or pain, was unable to use the full range of movement. This length change is partly shortening
adaptation in the muscles and connective tissues, but also a dysfunctional “learned shortening” within the neuromuscular continuum.

Length adaptation raises the issue of active and passive flexibility. Active flexibility is the maximum joint range achieved by active shortening and elongation of the local muscles. Passive flexibility is the extreme physiological range of a joint, achieved when all the local muscles are relaxed. If you extend your fingers actively, and without assistance, you will reach a specific range. Keep the fingers in the same position, then using the other hand push the fingers further into extension while relaxing the stretched hand. The passive range should be greater than the active range. Therefore, passive stretching is useful for improving passive range whereas length control is necessary for active flexibility. This has important clinical implications. For example, patients with the stiff phase of frozen shoulder can be stretched passively into shoulder flexion. However, when they are instructed to stand and raise their arm, they often can only achieve a relative small degree of flexion – a dysfunctional active range. Passive stretching does not necessarily improve the active range. For improvements in active range the patients should actively move their shoulder at the end ranges (see Ch. 12, Challenging length control and functional stretching).

**Velocity/speed control**

Speed ability is the capacity to regulate the rate of movement (acceleration/ deceleration) and the ability to produce maximum speed of movement.

The ability to regulate the speed is seen, for example, when moving the computer mouse at various speeds to control the screen pointer.

Maximum speed is how fast a movement or a task can be made between two targets. For example, walking a certain distance, reaching for an object or producing an explosive force (mixture of velocity and force). It is also the rate of producing static peak force, such as seen in sudden isometric contraction to block or resist a sudden perturbation.

Changes in speed ability are often seen in musculoskeletal injuries. Individuals tend to slow down their movement as an evasive strategy to pain but also to reduce the forces at the area of damage (reduce the speed = reduce the force). For example, patients with lower back pain tend to adapt a slow walk, which may not fully recover even when they are no longer in pain.

**Neuromuscular endurance**

In the context of motor rehabilitation, endurance is defined as the ability to maintain a physical activity until it can no longer be continued (neuromuscular fatigue). Fatigue often manifests as pain, reduced force and velocity of the affected muscles. The symptoms of fatigue are relieved by a period of rest.

A common clinical observation is that individuals with musculoskeletal injuries often demonstrate reduced neuromuscular endurance in the area of damage, even in the absence of pain. A similar observation is seen in patients who have suffered CNS damage, such as stroke and multiple sclerosis. Individuals who suffer from non-traumatic conditions such as trapezius myalgia and chronic neck pain also experience reduced endurance in the painful muscles during repetitive tasks (Ch. 9).

Reduced neuromuscular endurance is associated with central control mechanisms, which are partly reflexive (spinal) and cognitive/psychomotor (higher centres). It is also partly due to peripheral factors such as muscle atrophy following disuse or immobilization.

Endurance can be improved by physical training and degraded by disuse or injury. It suggests that the central mechanisms that control endurance are mutable and could be influenced by neuromuscular rehabilitation.
Synergistic abilities

Reciprocal activation and co-contraction control

Synergistic control represents the fact that “muscles don’t work alone”, but in a complex relationship to other muscles. This has important implications for rehabilitation. Damage to one group will inevitably alter the control of all its synergists. Even fatigue or delayed muscle soreness in one muscle group will have an influence on control of the non-exercised synergists. For example, fatigued hamstrings will influence the control of non-exercised quadriceps and similarly fatigued biceps will influence triceps control. The effect is likely to spread even to more distant synergists. For example, fatigue in quadriceps will influence the control of the non-exercised gastrocnemius muscle. Hence, it may be more effective to engage the synergistic pairs and whole movement cycles rather than single-muscle or single-direction rehabilitation (e.g. biceps curls).

There are two synergistic control patterns during movement (Box 3.1):

- Reciprocal activation
- Co-contraction.

Reciprocal activation is the simultaneous, active shorting and elongation of muscle pairs needed to produce movement at a joint.

Co-contraction is the simultaneous activation of several muscle groups to stabilize joints during static postures (static stabilization or steadiness) or during movement (dynamic stabilization). Co-contraction also has a role in refining movement.

The two synergistic patterns can be observed, for example, during head rotation. Some muscles will produce the rotation movement (reciprocal activation) while others will dynamically stabilize the head (co-contraction), keeping it upright and preventing it from flopping to the side. Once the head has reached its position, all the neck muscles co-contract statically to maintain the head in the upright position (otherwise the head will fall to the side).

During various motor activities, these patterns of contraction take place jointly but with one pattern being dominant, depending on the task and the angle of the limb (see Box 3.1). It should be noted that there are no specific muscles for reciprocal activation or co-contraction. Muscles can switch their roles between being stabilizers or “movers”, or both, depending on the position of the limb and the patterns of movement.

It has been demonstrated that both patterns of activation have separate cortical control centres, reflecting their distinct functional roles. During motor learning, motor control transforms from predominantly co-contractions into more reciprocal patterns (which are more energy-efficient).

Relative factors with synergisms

The two synergistic patterns represent the relationship between several factors that control the movement pairs (Fig. 3.3):

- The relative activation of the parametric abilities
- The relative timing and duration
- Dominance or failure of one of the synergistic patterns.

The relative relationship of parametric abilities can be observed in reciprocal activation. During

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Box 3.1

Home lab

Co-contraction and reciprocal activation exercise. With an outstretched arm draw large imaginary numbers from 1 to 10. Focus on your shoulder and feel how the muscles are reciprocally activated. Now draw small-amplitude numbers as fast as possible. You should now feel the shoulder muscles co-contract (as well as the rest of your body).
rhythmic movement force will increase on one side while reducing on the other; there is muscle elongation on one and shortening on the other. Velocity will be equal on both sides; however, one will be lengthening while the other shortening. In injury and pain conditions this normal relationship is modified. For example, quadriceps inhibition and hamstrings hyperexcitability have been demonstrated in knee injuries.63–65

Timing and duration in synergies
Imagine a simple repetitive movement such as elbow flexion–extension. During the phase change (i.e. flexion to extension), the muscles in the movement pairs will have to reverse their action from contraction to relaxation. These changes require complex synchronization in relative timing between the muscle pairs (Fig. 3.4). Furthermore, the relative duration of contraction or relaxation between the synergists also has to be finely synchronized.32,66–73 Such changes in timing and duration have been demonstrated in patients with lower back pain.68–71,74–78 There is some evidence that timing and duration issues may predispose an individual to injury.79,80

One aspect of timing that has received much attention in recent years is the onset time. This represents the period between the initiation of an action and the relative onset time of different muscles.32,66–73 This method has been used in research to examine how the onset timing changes in various musculoskeletal injuries and pain conditions.

Dysfunctional synergistic control
Failure in synergistic control can be due to several underlying mechanisms. It can be due to a dysfunctional control of parametric abilities within the synergism, i.e. the relative force, length and velocity. It can be about the relative timing and duration between the movement pairs. Another possibility is that one of the synergistic patterns becomes more dominant or the patient is unable to fully recruit that pattern to produce normal movement.

A change in favour of or dominance of one pattern of synergistic control has been demonstrated in
individuals with intact and damaged motor system. Patients with CLBP tend to increase their co-contraction strategy during movement. The dominance of co-contraction can also be seen in conditions such as writer’s cramp and hypertonicity in stroke patients. In stroke patients this was attributed to malfunction of the centres that control movement synergisms. It is also possible that one of the synergistic patterns becomes less effectively controlled. For example, functional instability of the ankle is associated with co-contraction failure. The loss of normal swinging of the affected arm in stroke could be seen as the inability to control reciprocal activation.

Composite abilities

The composite abilities described below have been narrowed down and modified to the ones that I feel are clinically important. Composite abilities are influenced not only by other abilities in the group but also by the contraction and synergistic abilities (Fig. 3.5).

Coordination

Coordination is the harmonious and synchronous control of two or more joints or body masses. Coordination may be affected locally, in the hand following immobilization (fine coordination); more widely, in the movement of a whole limb (single-limb coordination); bilaterally, in the coordinated activities of limbs (multi-limb coordination) or extensively, affecting the whole body (whole-body coordination).

Balance

Balance is the ability to efficiently maintain upright movement or stance with minimal physical stress and expenditure of energy. This ability depends on several factors: the sensory inputs from the vestibular apparatus, vision, proprioception, hearing, central integration/processing of sensory information, and control of whole-body coordination and balance. Failure in any of these systems or processes will manifest as unsteadiness and unrefined movement and stance or, at worst, the inability to maintain an upright posture.

There are differences between static balance (standing still, sitting) and dynamic balance (walking, running and climbing stairs). Dynamic balance is more complex as it makes greater demands on motor control and cognitive-motor processes. Patients who
demonstrate balance losses should be challenged both in dynamic and static balance (Ch. 12).

**Postural stability and instability**

Postural stability relates to local proprioception or motor control losses from the lower limbs or the trunk/neck that affect balance. It is often measured as the magnitude of sway or steadiness to perturbation during standing.

In musculoskeletal injuries reduced proprioception or loss of normal control of synergism at the area of damage may produce what seems like a balance loss. For example, patients with lower back pain may display postural instability associated with delayed response times in the trunk muscle.68–71,75,76 Similarly, patients with an ankle injury may find balancing difficult on the injured side due to proprioceptive and synergistic control changes in the lower limb.96

This is somewhat different to central losses where balance is more widely affected. In these conditions the patient may find balance to be equally difficult on each or both legs, or even whilst sitting.

The distinction between balance and postural stability has some clinical implications. In musculoskeletal conditions the losses relate more to postural stability rather than true balance control. Postural instability is more localized (e.g. affecting balance on one limb); patients take less time to recover and may use compensatory sensory-motor strategies that overcome these losses (weight-bearing on the non-affected side). However, central or vestibular causes for balance losses are generally more extensive conditions, require longer recovery periods and may only partially recover depending on the extent of central damage.

**Transition time**

Transition time is the period it takes to reorganize movement between two dissimilar events and to carry out the subsequent task skilfully (Fig. 3.6). For example, if you hop on a single leg from side to side and than suddenly stop, the body will sway until it settles into the static balance. This represents the organization time between dynamic and static balance. If this is repeated several times you will find that the organization of the static balance becomes progressively and more rapidly controlled.

Transition rate represents the duration it takes for sensory inputs to reach central motor areas, to process this information, to make decision
about the action to take and the time it takes the motor commands to reach the muscles (reaction time). It also includes the period required to complete all the postural adjustments and the observable execution of the movement in the subsequent task (movement time). The different elements within this chain of events can occur within a fraction of a second, too rapidly to be assessed separately in the absence of lab tools. Therefore, the term “transition time” has been introduced as a clinical reality. What is humanly possible (in my experience) is to observe the grand total of how rapidly and smoothly a person can change between two activities – inaccurate, but good enough clinically.

Longer organization times can be often observed in various musculoskeletal injuries and in patients with central damage. A stroke patient may have difficulties in organization within or between tasks, such as sitting, getting up and walking, or walking and turning around. Such activities are marked with a long pause for reorganization between the two actions.

Interestingly in sports, some triathletes report discoordination when running after cycling. This was associated with the inability of the motor system to effectively reorganize itself between the two intense physical activities.

Motor relaxation

Motor relaxation is the ability to reduce neuromuscular activity to the optimal level necessary for maintaining a motor task or to become inactive. Motor relaxation represents the flip side of motor activation. It is paradoxically a neurologically active motor process.

Motor relaxation and force relaxation control (see force ability) are seen in different conditions. There are several conditions where the individual develops pain conditions by tension holding, such as trapezius myalgia or chronic neck pain (Ch. 9). It is the inability to relax in a psycho-motor dimension. Force relaxation ability, on the other hand, is associated with more reflexive mechanisms where specific areas become hypertonic such as seen in central nervous system damage.

Although motor relaxation and force ability are the outcome of different processes, the clinical management has the same aims (relax the overactive muscles) using the same approach (motor relaxation).

Mutability of abilities

According to motor control research, some of the motor abilities described above are a mixture of genetic traits and learning that develop during childhood and adolescence. Coordination, for example, is one such ability that is genetically determined. Once the motor system has matured in adult life some of these abilities become resistant to change. However, they may retain a limited capacity to be modified by practice. In other words each individual has a “personal best” in any of these control variables (except in the parametric and synergistic abilities that rely partly on central and peripheral adaptation to training).

The aim in neuromuscular re-abilitation is to help the person recover their losses to the “best of their ability”, rather than improving their personal best. It has been demonstrated consistently that all abilities in the motor complexity model can be affected by musculoskeletal injury, psychomotor conditions or CNS damage, see summary in Table 3.1.

It should be noted that in musculoskeletal conditions there are no single ability changes. They are part of an overall protective strategy, with multiple options and containing a variety of component changes (the abilities). One common misconception about abilities is to view them as a unique, single outcome (or cause) of a particular condition. This is exemplified by the core stability training approach, where the focus is on normalizing the timing delay in the abdominal muscles. However, this change is only a small element in the overall motor strategy of a person suffering from back pain, as depicted in Table 3.1.

Can motor abilities be normalized?

There is some evidence that motor abilities can be normalized by training and rehabilitation.

Most obvious changes can be observed in the parametric abilities. For example, physical training has been shown to reduce arthrogenic inhibition in the knee (force control). In patients with early osteoarthritis of the knees and post meniscectomy, exercise rehabilitation has been shown to improve force and endurance abilities. In chronic lower back patients lumbar extension exercises were shown to improve trunk muscle strength, cross-sectional
Table 3.1  Examples of motor abilities affected in various conditions

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Parametric motor abilities</th>
<th>Synergistic</th>
<th>Composite</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Force</td>
<td>Length</td>
<td>Velocity</td>
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<tr>
<td>Lower back pain</td>
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<td>Force losses in trunk muscles in acute and chronic lower back pain (CLBP) patients.</td>
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<td>Loss of flexion relaxation in the spinal muscles during flexion in patients with CLBP.</td>
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<td>Extensors activation prevents full forward bending.</td>
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<td>Individuals with high pain-related fear had smaller excursions of the lumbar spine for reaches to all targets at 3 and 6 weeks, but not at 12 weeks following pain onset.</td>
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<td>Conditions</td>
<td>Parametric motor abilities</td>
<td>Synergistic</td>
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<tr>
<td></td>
<td>Force</td>
<td>Length</td>
<td>Velocity</td>
</tr>
<tr>
<td>Non-traumatic chronic neck pain</td>
<td>Demonstrated muscle weakness in cervical muscle in chronic whiplash patients.¹⁰⁴,¹⁰⁵</td>
<td>Reduced cervical range of motion in whiplash patients and chronic neck pain.¹¹²,¹¹³</td>
<td>Only small non-significant velocity changes in head movement.¹¹⁹</td>
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<tr>
<td>Trapezius myalgia – reduced force in affected side.¹⁰⁶</td>
<td>Reduced force in affected side.¹⁰⁶</td>
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<tr>
<td>Traumatic: chronic whiplash.</td>
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<tr>
<td>Force</td>
<td>Length</td>
<td>Velocity</td>
<td>Endurance</td>
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<tr>
<td>Knee</td>
<td>Abnormal relationship in force between quadriceps and hamstrings in anterior cruciate ligament (ACL) deficient knee.</td>
<td>Reduced knee range of motion – external-flexion moment during various gait activities in ACL deficient knees.</td>
<td>Normal endurance in quadriceps pre and post-operative ACL, but forces losses were present.</td>
</tr>
<tr>
<td>Force losses in quadriceps femoris after ACL repair.</td>
<td>Reduced walking velocity in painful osteoarthritis (OA) knees.</td>
<td>Reduced stabilization in individuals who have knee instability following ACL rupture with return to pre-injury activities.</td>
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<td></td>
<td>ACL injury - “non-copers” utilize a stabilization strategy which not only is unsuccessful but may lead to excessive joint contact forces and which have the potential to damage articular structures (Rudolph et al 1998). Increase co-contraction during walking in medial OA.</td>
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*References:*

64,114–116: Normal knee range of motion – external-flexion moment during various gait activities in ACL deficient knees.
107: Force losses in quadriceps femoris after ACL repair.
121–123: Reduced knee range of motion – external-flexion moment during various gait activities in ACL deficient knees.
129,130: Reduced knee range of motion – external-flexion moment during various gait activities in ACL deficient knees.
131: Reduced walking velocity in painful osteoarthritis (OA) knees.
136: Two different adaptive strategies following ACL tear. Change in reciprocal and co-contraction strategies.
137–139: Reduced stabilization in individuals who have knee instability following ACL rupture with return to pre-injury activities.
140: ACL injury - “non-copers” utilize a stabilization strategy which not only is unsuccessful but may lead to excessive joint contact forces and which have the potential to damage articular structures (Rudolph et al 1998).
142: Increase co-contraction during walking in medial OA.
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<tr>
<td>Force</td>
<td>Length</td>
<td>Velocity</td>
<td>Endurance</td>
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<tr>
<td>Shoulder conditions</td>
<td>Impingement – force deficits and muscular imbalance in the scapular muscles.\textsuperscript{108,109}</td>
<td>Impingement – bilateral (painful and non-painful sides) decrease in the time to peak tension during medial rotation of shoulder.\textsuperscript{97}</td>
<td>Impingement – reduced endurance in deltoid.\textsuperscript{132}</td>
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<td></td>
<td>Force control affected (ability to maintain a steady force) during submaximal contraction ~35% MVC.\textsuperscript{34}</td>
<td>Impingement – frozen shoulder-endurance in deltoid.\textsuperscript{34}</td>
<td>Impingement – reduced endurance of trapezius, deltoid, infraspinatus, and supraspinatus during submaximal contraction, not related to pain.\textsuperscript{34}</td>
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<td>Although range is reduced, may be associated with pathological changes in tissues.</td>
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<tr>
<td>Impingement – bilateral (painful and non-painful sides) decrease in the time to peak tension during medial rotation of shoulder.\textsuperscript{97}</td>
<td>Frozen shoulder-endurance in deltoid.\textsuperscript{132}</td>
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area and endurance. In patients with chronic neck pain, endurance and muscle strength improved after 2 weeks’ training specific to these abilities. A functional rehabilitation program was shown to improve the velocity of movement ability in lower back and knee damage patients.

The synergistic muscle activity in patients with different joint conditions has also been shown to be altered by physical therapy. In functional instability of the ankle, treatment by challenging postural stability virtually eliminated the symptoms of instability as well as significantly changing muscle onset times. Similarly, training was shown to change various factors in synergistic control of normal and anterior cruciate ligament (ACL) deficient knees. Postural stability and control of coordination was also shown to be improved by TaiChi, which is a movement approach that challenges these motor abilities.

Summary points

- Skill is the measurement of how proficient a person is in performing a particular task.
- Skills depend on a mixture of sensory-motor and cognitive abilities of the individual.

References


Pthomegroup

Motor abilities


Sensory abilities

Sensory losses, and in particular proprioceptive deficits, may lead to unrefined movement and the loss of ability to respond effectively to sudden demands and may impede motor adaptation/learning. This chapter will examine how proprioceptive losses may come about and the underlying peripheral and central mechanisms seen in different conditions.

Sensory abilities include proprioception and exteroception (vision, vestibular apparatus and audition). Generally, clinical care of exteroception is out of the scope of neuromuscular rehabilitation. However, these sensory contributions should not be underestimated and their losses should be considered in the overall management of the patient.¹

Sensory complexity model

Similar to motor abilities, sensory information can be categorized into groups of varying levels of complexity (Fig. 4.1).

Let us start with a simple movement such as elbow flexion–extension, preferably with the eyes shut. We can selectively focus our attention on the elbow before moving it. The awareness that the elbow is held at a particular angle is called position sense. As the elbow is moving, we now become aware of the direction, changes in velocity and acceleration–deceleration of the limb – a movement sense. There is also a sense of effort in moving and the limb’s own weight (Ch. 2).²⁺³⁺⁴ These elements of proprioception will be termed here as primary proprioceptive ability.

Now, let’s make this a little more complex. With the eyes still shut, try to touch the tip of your nose with the index finger. Your ability (or inability) to accurately reach that target depends on the integration of sensory information from the whole arm, head and position of the nose; plus all the information from the rest of the body. This is spatial orientation ability: the capacity to identify the position and direction of movement of any part of the body.

Finally, imagine standing, balancing on one leg and then maintaining the same touch-the-nose movement. Your success depends on the capacity of the motor system to integrate several sources of exteroceptive (visual, vestibular and auditory) and proprioceptive information. This level of sensory ability will be termed here as composite sensory ability.

Hence, proprioception can be categorized according to complexity, from low to high level, as following:

- Primary proprioceptive ability (position, movement and effort sense)
- Spatial orientation
- Composite sensory ability.

It should be noted that this classification is artificial and that all these abilities co-exist in normal functional movement. However, this sensory ability model has some clinical value – it can be used as a predictive tool to understand potential sensory losses in relation to various conditions. It can also provide a useful clinical procedure for testing more obvious losses and integrating sensory with motor rehabilitation. The assessment and challenges of proprioception are described in Chapter 13.
Proprioceptive acuity refers to a change in the ability of the individual to detect various aspects of movement. It can be the threshold to rate and amplitude of movement; for example, if the movement is very slow the individual may find it hard to identify whether the limb is moving at all and in which direction. Acuity is also the ability to detect a joint’s angle when maintained in a certain position or dynamically during movement.

Proprioceptive acuity depends on the intactness of the sensing apparatus (mechanoreceptors and their peripheral to central pathways) and the intactness of central integration/possessing of sensory information. Generally, in musculoskeletal injury the damage is to the proprioceptive apparatus in the periphery. Later it may be accompanied by adaptive central reorganization. Conversely, in central nervous system (CNS) damage, the peripheral proprioceptive apparatus is fully intact but the centres that process the information are damaged.

Proprioceptive changes in musculoskeletal injury

Proprioceptive changes in musculoskeletal injuries often manifest as diminished acuity in position and movement sense. These changes together with nociception often result in unrefined motor control. Proprioceptive deficits have been demonstrated in the ankle, knee, shoulder, temporomandibular joint, lower back, and neck (whiplash injuries). Chronic neck pain was even shown to reduce acuity in upper limb (elbow, shoulder and spatial orientation of whole arm), suggesting a central processing change in sensory integration.

Various degrees of musculoskeletal injuries, surgical intervention and degenerative joint disease have been shown to have local effects on proprioception.
The clinical significance of proprioceptive losses is not clear. For example in severe neck pain conditions the losses are often less than 2.5°/C14 of error when compared to asymptomatic subjects.20,35,36 With more mild conditions, often the differences between symptomatic and asymptomatic subjects are less that 1° in proprioceptive error.22,37–41 It should be noted that even asymptomatic individuals can demonstrate up to 5° in proprioceptive error.38,41

**Short-term, reversible proprioceptive changes**

There is a common experience that following intense exercise we tend to feel unsteady (wobbly legs) and clumsy in the execution of skilled movements. This unrefined movement may be partly associated with the exercise-induced muscle damage and the effects it has on proprioception. Such proprioceptive changes are self-limiting and are expected to recover within minutes in the case of fatigue, or longer in the case of delayed muscle soreness after exercise.10,42–48

The changes in proprioception are generally modest. For example, immediately after eccentric quadriceps exercise there is a force drop of 28%, accompanied by 4.8 degrees of error. Following concentric exercise, there is a force drop of 15% and matching errors of 3.7 degrees.43 On the other hand, proprioceptive acuity may increase during normal warm-up where there is no fatigue or muscle damage.49

Several factors may contribute to this transient change in proprioception. Muscle swelling and sarcomere damage may influence the ability of the muscle receptors to effectively detect movement (Fig. 4.3). Furthermore, ischaemia or inflammation is known to change the chemical environment of the muscle receptors and their sensitivity (group III and IV chemosensitive afferents and the spindle afferents via spinal mechanisms).50–54

There may be also central reasons for transient changes in acuity. During eccentric exercise the efferent motor command may increase to compensate for the effects of fatigue. The proprioceptive errors are due to inaccurate comparison between predicted and actual feedback from the muscle (see comparator system, Ch. 2).43

Generally, these acute transient changes in proprioceptive acuity have little clinical implications and are unlikely to be affected by any special rehabilitative approach. In long-term injury or ongoing painful conditions they may become more permanent and, therefore, more relevant to rehabilitation (see below).

Where transient proprioception may be important is in sports management, particularly in the area of injury prevention during training and competition. During fatigue skillful movement may deteriorate, due to a combination of several factors, including reduced proprioceptive acuity (also reduced motor control and psychological-cognitive factors).55–57 These multidimensional factors may place the athlete in movement patterns that could predispose them to injury.58–61 The management of the athlete in this situation would involve the organization-behaviour of the individual, which is further discussed in Chapter 8.

**Long-term proprioceptive changes**

Long-term reversible and irreversible proprioceptive changes can be observed in musculoskeletal injuries. Several factors can combine to generate these changes:

- Damage to the receptors and/or their axons
- Structural-physical changes of the tissue in which the receptor is embedded
- Central sensory reorganization
- Pain-proprioception competition.

Many receptors and their axons have a lower tensile strength compared to the tissues in which they are embedded. Physical trauma to tissues and nerve trunks can damage the mechanoreceptors and their axons resulting in localized proprioceptive losses (Fig. 4.4A).14,15,31,61–64 These proprioceptive deficits can be very small and their clinical significance is unknown. For example, in cruciate ligament tears it can be less that 1.0 degree of movement.65
Another potential mechanism that may lead to long-term sensory losses is structural/physical change in the tissues in which the receptor is embedded. The proprioceptive apparatus may be fully intact, but its ability to detect movement may be hindered by changes in the surrounding tissues, in the form of adhesions or shortening (Fig. 4.4B). Furthermore, proprioceptors embedded in tissues that are torn or detached will lack the mechanical stimulation needed for the detection of movement (Fig. 4.4C).

Central sensory reorganization in response to injury may also influence long-term changes in proprioception. Reduced physical activity may result in sensory “disuse”, affecting the whole sensory continuum from the receptors to their central representation in the brain. For example, in the periphery, immobilization can lead to muscle spindle atrophy and changes in its sensitivity and firing rate. More centrally, it has been shown that tactile impoverishment and sensorimotor restriction of an animal’s paw causes deterioration in the cortical sensory map representing that area.

The reversal of disuse may be observed after reconstructive capsular and ligamentous surgery. Once repaired, proprioception tends to recover over a period of several months. This partly could be due to the patient’s returning to a more normal and pain-free use of the arm that promotes normal central reorganization of proprioception.

Central sensory reorganization can produce surprising findings. In individuals who had anterior cruciate ligament (ACL) reconstruction or shoulder injury, decreased proprioceptive ability was present in some measurements in the affected, as well as in the uninjured side.

**Competition in sensory information: nociception vs. proprioception?**

Changes in proprioceptive acuity after injury could be due to a competition between nociception and proprioception for central “attention,” occurring at reflexive and cognitive levels.

This competition in sensory information can be likened to a bottleneck effect. A vast array of information from the periphery floods the CNS. The system is incapable of attending to all these inputs and, therefore, only information which is relevant or important makes it through to attention. Pain, which may be interpreted as being the most important, will have dominance over proprioception in passing through this bottleneck of information.

There are several studies which support this sensory competition model. Experimental pain induced in muscle and subcutaneous tissues was shown to significantly impair passive movement detection in the pertaining joint. Proprioceptive acuity has been shown to reduce when experimental pain was induced in the muscles of the lower leg and, likewise, superficial experimental pain applied locally to the neck diminished neck proprioceptive acuity. Such sensory competition was also demonstrated in postural stability. When a painful heat stimulus was applied to the skin of the calf it resulted in greater postural unsteadiness.

Pain-proprioception competition is also evident in musculoskeletal injury. Patients with painful ACL damage seem to have larger proprioceptive deficits than those who have pain-free ACL damage. It was also demonstrated that proprioception improves after 6 months following shoulder decompression surgery where only the inflamed and painful subaccromial...
bursa was removed, i.e. proprioception won when the competition (pain) was taken out.\textsuperscript{71}

Another possibility for pain-proprioception competition may occur, more centrally, as an adaptive process. This phenomenon may be related to the principle that the more we focus on an experience such as a physical sensation or movement, the more it drives central adaptation.\textsuperscript{84–88} In this scenario the individual’s focus on their pain may facilitate pain imprinting while displacing normal sensory-motor central representation. For example, in chronic lower back pain there is a displacement of the cortical sensory-motor areas representing the lower back\textsuperscript{89} and, indeed, this condition is often accompanied by diminished proprioceptive acuity.\textsuperscript{16–19}

**Proprioceptive changes in central nervous system damage**

CNS damage could also lead to sensory losses. Depending on the extent and location of damage, all levels of sensory abilities may be affected. This is in contrast to musculoskeletal injuries where the primary proprioceptive abilities are largely affected. Another important difference is that in CNS damage the peripheral sensory apparatus is left intact, which provides a potential for peripheral-to-central recovery (Fig. 4.5). This however depends on the extent of the damage, neural repair and central reorganization (Ch. 10).\textsuperscript{90–94}

**Proprioceptive recovery**

Proprioceptive losses will partially or fully recover during a period of several months following musculoskeletal injury. The recovery of proprioception ultimately relies on peripheral and central processes: in the periphery, through the degree of repair of the receptors and the tissue in which they are embedded, and centrally, through the adaptation and reorganization of the sensory pathways and cortical maps.

There is some evidence that mechanoreceptors can partially regenerate following tissue damage. Such regeneration has been shown in muscle spindles, their axons and efferent motor supply and in skin mechanoreceptors (Fig. 4.6).\textsuperscript{63,64,95–97} In animal models there has been even some evidence for sprouting of new muscle and skin receptors, which took place within 6 weeks of injury.\textsuperscript{64,97,98} In muscle, the success of regeneration depends on the extent of internal damage and scarring and the duration of repair.

Being active is important for sensory regeneration. Muscle hypertrophy in response to exercising is associated with morphological and physiological changes of the muscle spindle. Such changes will increase the spindle’s sensitivity to detect movement.\textsuperscript{99–101} Centrally, exercise encourages the sensory neurons to produce growth factors that stimulate axonal regeneration and synaptic connections (Fig. 4.7).\textsuperscript{102}

The recovery of the tissue in which the receptors are embedded is also important for proprioception.\textsuperscript{103} Naturally occurring healing or surgical repair could lead to normalization of the tissue’s properties and consequently to better detection of movement by the receptors embedded in them. Some evidence of such recovery was demonstrated following spinal, ankle and shoulder surgery.\textsuperscript{68–72,104} It is possible that in some of these surgical repairs the tensions in the capsule had been restored, consequently re-establishing the receptors’ detection ability in the previously torn fibres (this does not occur in every surgical intervention, e.g. cruciate ligament).\textsuperscript{74} This suggests that passive or active movement may be advantageous for such sensory regeneration. It will optimize tissue repair, reduce oedema and scarring as well as optimize the mechanical environment necessary for receptor regeneration/adaptation.\textsuperscript{105}

The feedback from the spared receptors in the area of damage as well as from receptors from undamaged areas could also account for the recovery of proprioception (rather than through an
improvement of proprioception from the area of damage itself.\textsuperscript{106,107} In this scenario, the spared proprioceptors become more dominant and capture the lost central representation of the damaged receptors (Fig. 4.8). Such loss and recapture of somatosensory cortical territory has been observed during denervation and re-innervation of peripheral nerve and in the proximal limbs of amputees (Ch. 6).\textsuperscript{108} The other possibility is that the receptors that were damaged gradually regain their lost

**Fig. 4.6** Muscle spindle regeneration after damage to the nerve trunk. A, Normal spindle afferents (36 terminals). B, Regeneration after 8 weeks (36 terminals). (From Barker D, Scott JJ 1990 Regeneration and recovery of cat muscle spindles after devascularization. J Physiol 424:27–39, with permission).

**Fig. 4.7** Exercise encourages the release of growth factors by sensory neurons that stimulate axonal regeneration and formation of new synaptic connections. A and B, Sedentary animal. C and D, Three days exercised. E correlation between distance run and normalized axon length. (From Molteni R, Zheng JQ, Ying Z et al 2004 Voluntary exercise increases axonal regeneration from sensory neurons. Proc Natl Acad Sci USA 101(22):8473–8478 (Fig. 1), with permission.)
central territory as they regenerate and become more functional. Here too we can assume that active movement is the drive to sensory-motor plasticity. This was demonstrated in stroke patients. Functional rehabilitation brought about improvement in motor control that correlates with reorganization in the somatosensory cortex.\(^\text{109}\)

In can be concluded that after musculoskeletal injuries or CNS damage there is a potential for proprioceptive recovery. The studies suggest that recovery is a mix of repair and adaptation processes that occur throughout the sensory system.\(^\text{110}\) As such, proprioceptive recovery is expected to take several months rather than a few weeks. Often such intrinsic body processes can be optimized but not speeded up. Movement may help this optimization by facilitating tissue repair and providing the drive for central sensory-motor adaptation.\(^\text{110}\) However, the degree and timescale of recovery may be difficult to predetermine.\(^\text{111}\)

**Clinical note**

- Movement can help optimize repair and adaptation of the proprioceptive system.
- Movement will also help the repair and adaptation of the tissues in which the receptors are embedded. This may help to re-establish the receptors’ ability to detect movement.

**Does proprioceptive loss lead to further damage?**

Proprioceptive loss in the long-term is believed to contribute to muscular atrophy, recurrent joint injuries and eventually to progressive degenerative joint disease.\(^\text{46}\) In this model, diminished feedback will result in dysfunctional movement and joint instability, which will eventually lead to progressive joint damage. So far this model has been demonstrated only in one animal study.\(^\text{112}\)

Functional instability of the ankle is a condition which can be used to examine this theory. It is well established that a combination of sensory-motor losses at the ankle may predispose the individual to recurrent injury.\(^\text{11}\) Will this recurrent injury predispose the individual to progressive ankle joint damage? In a 20-year follow-up study of patients with chronic ankle instability, degenerative changes were observed only in six of 46 ankles. There was no correlation between persistent instability and joint degeneration.\(^\text{113}\)

Another area that could help us to explore the proprioceptive further damage model is delayed-onset muscle soreness (DOMS) after exercise. This transient muscle condition is accompanied by diminished proprioceptive acuity.\(^\text{10,42–48}\) Most individuals who experience DOMS will continue to exercise without acquiring any further damage/injury. If proprioceptive loss were to lead to injury, continuing to exercise would initiate a vicious cycle that would result in progressive damage.
Finally, in a recent prospective cohort study with 2–3 year follow-up the lumbar spine position sense was evaluated in 292 athletes. No significant differences in the repositioning errors or motion perception threshold between athletes with and without a history of lower back injury or between those who did and did not get injured during the follow-up.\textsuperscript{135}

**Clinical note**

There is no evidence yet that proprioceptive losses predispose the individual to gradual tissue damage. Perhaps large magnitude proprioceptive losses are required for this chain of events to occur.

**Are there proprioceptive-specific exercises?**

Patients who exhibit proprioceptive losses are often prescribed specific proprioceptive exercise. Is there a distinct kind of exercise and would it be better than any other functional activity?

Let’s take a look at the body – our ankle mechanoreceptors will be stimulated equally well whether we exercise on a wobble board or jump around the court while playing tennis. Indeed, the improvements in function or reported reduced incidents of injury after proprioceptive training are often attributed to enhancing motor control (e.g. synergistic control or coordination) rather than selective improvements in proprioception.\textsuperscript{74,76,106,107,114–117}

Yet, some studies do show that in musculoskeletal injuries there are some direct and local improvements in position sense following “proprioception training.”\textsuperscript{118–120} However, it seems that proprioception improves regardless of the type of exercise used. For example, proprioceptive acuity in the shoulder seems to improve with isokinetic exercises, lifting weights, exercises which mimic the movement of lifting weights, push-ups, arm movement using a resistance band or throwing a weighted ball.\textsuperscript{121–124}

If you feel baffled by all these findings, you should. How can specific exercises improve proprioception while the normal daily or sports activities of the individual do not? It could be that we become more attentive to proprioception rather than improving it. Imagine a simple task like writing. Once learned it becomes completely autonomous and out of our awareness. The focus of writing is external towards the goals of writing. If we were to increase the duration of writing the awareness and proprioception acuity of the hand will remain unchanged. So doing more of the same is unlikely to change proprioception. Now imagine that we were given a novel task that forced us to concentrate on our hand, say knitting. We have to become more aware of the fine hand movements of this new complex task. If we were to test proprioception of the hand at that point we may find that acuity has increased. This has come about because we are more attentive and focused on our hands, rather than by an improvement in proprioception. An analogy can be experienced by focusing to listening with your right ear. You will become more aware of the sound on that side; however, your hearing has not improved. Interestingly, it is claimed that elderly Tai chi practitioners have better proprioceptive acuity than their age-matched runners or swimmers and those who are non and exercising.\textsuperscript{125,126} Is it because Tai chi uses more focus and attention on the body (see Internal and external focus and learning, Ch. 5)?

Another possible mechanism for increased acuity may be related to the comparator system. When a new activity is introduced the comparator system becomes more engaged in error detection. The sense of effort, which is a part of this system, may consequently become more co-active. It could be that the increases in the sense of effort will temporarily enhance proprioceptive acuity.

The short of it is that as long as the individual is doing a novel exercise, awareness of proprioception may increase and give the false impression that the proprioception is improving. It would be interesting to see what would happen to proprioceptive acuity after several months when that exercise is no longer novel, and is autonomous and boring.

**Clinical note**

- There is no specific proprioceptive exercise. All activities are likely to be equally effective.

**Proprioception and prevention of injury**

There is a commonly held belief that proprioceptive exercise or training can improve proprioceptive acuity and, therefore, prevent sports-related injuries.\textsuperscript{127} The exercises that are prescribed often aim to challenge postural stability; they are performed at higher speeds and involve sudden unexpected perturbations, such as exercising on a wobble board (ankle disc exercise).\textsuperscript{117}
In sports, most injuries occur during very rapid movements. Under such conditions the foot–ground impact force takes less than 50 ms to reach its peak magnitude and ankle inversion can reach 17° in as little as 40 ms. The swiftness of these events does not leave sufficient time for even the shortest spinal reflexes to execute an adequate motor response to prevent injury.\(^{128}\) This lag in proprioceptive transmission time is immutable; it cannot be shortened by exercising. From a proprioceptive perspective, exercise cannot offer protection against injuries that occur during movement at medium to high velocities.

Furthermore, proprioceptive exercises on a wobble board are relatively slow, in the range of several hundreds of milliseconds. They are, therefore, unlikely to provide an optimal sensory training to protect the ankle against injury; even at medium movement velocities.\(^{128}\) (A Cochrane systematic review suggests only limited evidence for the efficacy of wobble board use for prevention of ankle injury.)\(^{129}\)

### Proprioceptive acuity and passive and active movement

Are passive manual techniques useful for rehabilitation of proprioceptive or motor control? Proprioceptive acuity tends to increase when the movement is more dynamic and active rather than passive (Fig. 4.9).\(^{130,131}\) When a subject’s joint is moved passively, the ability to distinguish the finger’s position is reduced compared to when the subject slightly stiffens their finger during the movement.\(^{2,132,133}\) This is reflected in more extensive cortical activity during active, in comparison to passive, movement.\(^{134}\) It has also been proposed that the superiority of position sense in active motion is related to the efferent flow and the sense of effort (Ch. 2).\(^{130}\) In active movement feedback is derived from both proprioception and this internal feedback, whereas passive motion tends to only stimulate the feedback portion of the motor system (Fig. 4.10).

This difference between active and passive motion was demonstrated in a recent study. Continuous active motion was compared with continuous passive motion for recovery of proprioception immediately after ACL reconstruction (unfortunately no control).\(^{135}\) Significantly better results were obtained in the active motion group (4.2 ± 1.6 vs. 1.9 ± 1.2 degrees).

### Summary points

- The sensory-motor system is a functional unit. There is no need to specifically target proprioception.
- Proprioceptive ability can be classified according to complexity from primary proprioceptive ability, spatial orientation ability to composite sensory ability.
- Proprioceptive acuity can be affected by peripheral and/or central causes.
- Musculoskeletal injury can affect the peripheral proprioceptive apparatus while CNS damage will affect central processing of proprioception.
- Recovery of proprioception involves both reparative and adaptive processes. As such, it may have its own inherent recovery period that may take several weeks or months to complete.
- Promoting normal functional movement will help proprioception by facilitating positive sensory-motor reorganization/adaptation.

References


Message to the patient – “keep on moving”. Active movement is better than passive movement in stimulating proprioception. All exercises are proprioceptive exercises. Recovery of proprioception is important for optimising movement control. It is still unclear if it provides protective function against future damage. There is no evidence that proprioceptive losses will result in long-term degenerative changes. Many of the proprioceptive changes seen after musculoskeletal injuries are very small and may have little or no impact on a person’s functionality. It seems that the body can tolerate such minor changes.


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Every day we take actions that result in movement and behaviour changes. This can be the consequence of being exposed to new experiences, learning a new task or recovering motor losses after an injury. However, we clearly don’t retain all that we have experienced. We seem to remember or learn only certain events. Some physical actions become our movement repertoire, while others seem to disappear in time. Similarly, how can we be certain that rehabilitation will result in effective and lasting motor changes?

To answer this question we need to examine how we naturally attain lifelong motor changes. It seems that there are certain factors within our behaviour that are important for facilitating adaptation in the neuromuscular system. These factors can be viewed as a form of code for neuromuscular adaptation. Rehabilitation programmes that contain these code elements are more likely to be effective in recovering motor losses and promoting long-term motor and behavioural changes.

The code for neuromuscular adaptation

The neuromuscular adaptation code elements can be identified by observing a person’s behaviour during a motor learning situation. For example, in order to learn to play the piano the individual has to be aware of the score, the relationship of the keys to the scales, placement of the hand on the keys and so on. It involves physical, active practice at the keyboard. The person will continuously monitor their mistakes and correct them; often playing the same scales in numerous repetitions. Furthermore, we are intuitively aware that lifting weights at the gym will not improve playing the piano. In order to play the piano one has to practise playing the piano. From this example five basic adaptation code elements can be identified (Fig. 5.1):

1. Cognition
2. Being active
3. Feedback
4. Repetition
5. Similarity principle.

It should be noted that motor learning and adaptation share the same neurophysiological mechanisms. However, rehabilitation following musculoskeletal injuries or pain conditions is not about learning a novel motor pattern. Most patients are fully aware of what movement they have to perform but are unable to physically carry it out. Their inability is often due to a mix of physical losses and an underlying motor reorganization or dysfunction (Chs 9–12).

Adaptive code 1: cognition

In the context of neuromuscular rehabilitation cognition is the mental process in which the patient is aware of and attentive to the movement experience, understands its aims and goals, and is able to make decisions and organize a response. It is also the process of thinking, rationalizing and memorizing.

The role of cognition in neuromuscular rehabilitation can be demonstrated by an example. A fell
runner who trained on rough terrain found that she was tripping with increasing regularity. Consequently she began to train on flat paved surfaces. She was aware that something had changed in her control, but could not understand her progressive inability. During challenged balance she demonstrated gross postural control losses that were later linked to recurrent severe bilateral ankle sprains. Patients often experience such progressive deterioration of performance without being able to understand their underlying causes and, consequently, how to rectify them. The role of cognition in this case was to inform the patient about her condition, bring attention to the specific losses and work out, with the patient, a management that would challenge these losses.

Neuromuscular rehabilitation is about changes in motor patterns or movement behaviour. Cognition is a potent modifier of behaviour and, therefore, of motor control. A change in movement behaviour can be as simple as bringing attention to the way a person performs a movement and correcting it verbally or by demonstration. For example, a teenage tennis player developed medial knee pain over a period of several weeks. It was brought to his attention that this injury could be related to a movement pattern which exerted a medial stress on the knee. He immediately recognized a newly acquired side-stepping pattern in which he would adduct and drag the non-weight-bearing leg on the ground. He also knew the solution (not to do it) and was aware how to implement the change. He required no further treatment and rapidly recovered from the injury (see Task-behaviour sphere, Ch. 8). The whole management took place within the cognitive dimension.

Cognition and phases of learning

We all have the experience that when we practise a new movement after a while we don’t have to think how to carry it out: it seems to occur just by “wanting” to do it. This phenomenon represents a phase in motor learning where there is a transition from a cognitive phase to a subconscious autonomous phase (Fig. 5.2). The early, cognitive stages of learning are characterized by the high levels of intellectual activity needed to understand the meaning of the information, the nature of the task and how to refine it. The individual may be aware of doing something wrong, but they are incapable of fully understanding and improving it.

As the individual becomes more proficient in performing a skill, it becomes more “automatic” and less under conscious control. In this phase, the skill is stored as a motor programme and becomes more robust to interference from other ongoing activities and environmental disturbances. Hence, in the cognitive phase it may be more difficult to multitask, whereas this becomes easier in the autonomous phase. Autonomous activity is not totally subconscious and some elements of the movement will remain in the individual’s awareness (Fig. 5.3). The transition between the two learning phases can often be observed in rehabilitation. Initially, the patient will perform a movement that is inaccurate and requires intense concentration. After several sessions the movement patterns become more skilled and subconscious. The hallmark of the transition into the autonomous phase is when the patient is no longer attentive to the movement and is able to multitask, e.g. simultaneously conversing with the therapist. This should be encouraged as it may help to facilitate the transition into the autonomous state.

Often a dysfunctional movement may become the habitual autonomous pattern. For example, some patients may be unaware of the compensatory/coping
strategies they use to compensate for control losses.\(^4\) In these situations the motor dysfunction is transferred into the autonomous phase and becomes resistant to change. To reverse this, the patient needs to be brought back to the cognitive phase and retrained in the correct movement pattern (see Task behaviour sphere, Ch. 8). Once they are able to execute the movement correctly, the rehabilitation would aim to assist its transition back to the autonomous state.

**Clinical note**

Generally, the aim of neuromuscular rehabilitation is to bring motor control to an autonomous state where it becomes part of the habitual movement repertoire.

**“Active cognition” and “passive cognition”**

There is a common experience that when we are driven as a passenger to a new address we may find it difficult to remember the route. However, having to actively learn the route tends to improve the memory of it.

There seems to be a difference in learning between being “actively” or “passively” aware. Subjects tend to learn a motor task more effectively when they are given more choice over how to practise and how much feedback to receive (“active cognition”).\(^5\) If they are given a pre-organized blocked training programme and predetermined feedback they tend not to learn the movement as well (“passive-cognitive”). This phenomenon has been demonstrated in maze training. One group received training that restricted their movements to the correct path, so that no choice was made (passively-cognitive). Another group was given choices while moving through the maze (actively-cognitive).\(^6\) The maze learning of the “choice” group was greatly superior to that of the “no-choice” group, although both forms of guidance were cognitive.

**Clinical note**

Motor learning could be optimized by enabling the patients to make decisions and enabling them to have control over the scheduling and sequencing during rehabilitation.\(^7\)

**Selective attention and memories of doing**

During rehabilitation patients are often guided to focus on the particulars of their movement or goals of their actions. This focus (selective attention) helps the sensory-motor system to adapt and modify our behaviour.\(^8\) Events which are out of attention will often be forgotten over time. In some remarkable way attention drives sensory-motor adaptation. The analogy is in listening to music and remembering only the melody line played by the lead instrument. Although we can hear all the other instruments, only the ones we focus on can be remembered. This phenomenon can be observed in (blind) Braille readers. The selective focus on their reading index finger results in specific enlargement of the finger’s cortical representation.\(^9\)

Generally, there is a limited ability to focus on more than one stream of information or actions at a time (try reading the next paragraph and count backwards from ten to zero).\(^10–12\) In musculoskeletal conditions pain itself may become the focus of attention and, therefore, competes with other attention demands.\(^10\)

**Internal and external focus and learning**

When walking across a room full of strangers most individuals have had the experience of becoming very aware of their own body and movement. As this happens, momentarily, we don’t know what to
do with our arms and the whole process of walking seems to become more awkward and less skilled. This experience may be due to a phenomenon that occurs when there is a shift of attention from the goal of movement to the details of how to do it.

When the focus of attention is directed to the goals of the movement it is termed external focus. When the focus is on the internal workings of the body or the details of the action it is often referred to as internal focus. During the early phase of learning attention is drawn internally to the particulars of the action – the technique, the position of the hand; the pressure used, etc. This focus shifts externally as the individual becomes more skilled in performing the movement.

For a skilled person, learning improves if training uses external focus directed to the goals of the movements rather than to the details of the actions. For example, there is greater accuracy in tennis serves and football shots when the subjects use external-focus rather than internal-focus strategies. Conversely, skilled performance can degrade if an internal focus is used, such as focusing on the hand during tennis serves. Even conscious tensing of the trunk muscle (internal focus) has been shown to degrade postural control.

The use of internal and external focus during rehabilitation may depend on whether the patient is an “unskilled injured” or “skilled injured”. The unskilled injured is a novice who in the process of acquiring/learning their skills has been injured. In this scenario, rehabilitation should comprise internal- and external-focus principles, since the patient still has to learn the novel movement, which requires some internal focus. In contrast, the “skilled injured” are experienced in the task, but are physically unable to perform it. An external-focus approach may be more beneficial for this group since they don’t have to learn the movement from scratch.

This does not exclude the use of both focusing approaches for the “injured skilled”. Skilled movements degrade over time, especially if the individual has been unable to perform normal movements due to a long-term injury – a sort of “motor forgetting”. This can be seen in patients who walk with a limp long after they have recovered from their injury. In this condition, it may be helpful to revert temporarily to an internal-focus approach, drawing attention to the particulars of the walking cycle, such as the heel strike. Internal focus strategies may be also be beneficial for patients with central nervous system (CNS) damage. (Although in my clinic I found that I tend to gravitate away from using internal focus with CNS-damaged patients).

It has been shown that the focus of attention during learning is different in children and adults. Children tend to favour internal focus whereas adults tend to focus more externally on the task. The difference could be due to the fact that children are less motorically experienced, whereas adults are able to draw on their previous motor experiences.

**Extreme internal and external focus**

How far internally can a person afford to focus before it becomes detrimental to learning? Some movement rehabilitation approaches promote internal focusing on particular muscles or muscle chains: a form of “extreme internal focusing”. In these approaches the muscle itself becomes the focus or movement goal. For example, in core-stability training transversus abdominis is often the focus of rehabilitation. Also currently in fashion is a focus on the improvement in the efficiency of the scapular stabilizers for shoulder conditions and the enhancement in the control of the deep anterior cervical muscles for patients suffering from chronic neck pain.

In the last decade several studies have examined this issue. In one such study participants performed basketball shots using either internal focus (focus on wrist motion) or external focus (basket). Compared to internal focus, the external group had better accuracy and lower EMG activity of the biceps and triceps muscles. This suggests that an external focus of attention optimizes movement economy.

Even focusing on the effort of the movement (internal) will result in inferior learning when compared to focusing on the goal of the movement (external).

In a study using balance as an outcome measure, participants were instructed to focus their attention on markers which were placed at different distances from their body. It was found that the postural control improved the further away the focus from the body was. In another study, participants balanced on a stabilometer while holding a tube horizontally. In one group the tube was empty while in the other the tube contained a ball that had to be kept central. Participants were instructed to either focus on their hands (internal focus), or on the empty tube (external focus) or on a sort of “super-external” focus on the ball in the tube. In both experiments, the external focus groups demonstrated more effective learning and transfer than...
the internal focus groups, both in learning the tube-ball skill and the balancing task itself. However, the super-external had the best learning outcomes both in the tube and the balancing tasks. This phenomenon of super-external focus was demonstrated in stroke patients. Two groups of patients trained in walking, but one group had to play with a ball while walking. The group with the extra-external task had greater improvement in walking than the group practising the single task of walking.

More recently this phenomenon was demonstrated in re-training postural stability after lateral ankle sprain. The external focus (“keep your balance by stabilising the platform”) was found to be more effective than the internal focus (“keep your balance by stabilising your body”). Furthermore, the internal focus group did not improve their balance at all.

Interestingly, Eastern movement traditions, such as tai chi and yoga, often use internal focus strategies for learning and performance of movement. Yet, it was demonstrated that tai chi training improves balance, as well as coordination during gait initiation. It was as effective as functional balance and leg strength exercise (mostly external focus) in reducing the incidents of falling in pre-frail individuals.

Clinical note

Neuromuscular rehabilitation should move away from training approaches that focus attention on specific muscles, muscle chains or joints. Movement should be practised as a whole with an emphasis on external focus and movement goals. This approach is applicable to the majority of patients who receive rehabilitation: they know what to do but can’t do it (“skilled injured”). Patients with central motor losses may benefit from a mix of internal- and external-focus strategies. Probably, a pragmatic approach is best – see what the patient can cope with or what seems to be more beneficial (constructive tinkering in the face of uncertainty).

Adaptive code 2: being active

Being active and physically practising the movement is essential for neuromuscular adaptation. During active movement, the whole of the motor system is engaged. In contrast, during passive movement, there is no efferent activity or muscle recruitment (see The comparator system, Ch. 2). In order to learn we need to make mistakes and correct them. Without the efferent/motor component there are no errors to correct and hence little, if any, learning. This has been demonstrated in studies where vision was distorted by special lenses. The ability of the subject to learn to correct arm movement was greatly enhanced by active rather than passive arm movement. Interestingly, passive movement rarely occurs during normal daily activities. It can be inferred from this observation that the motor system is well accustomed to adapt to active rather than passive movement.

These issues of passive versus active approach are important in the context of neuromuscular rehabilitation and manual therapy. There are several disciplines that promote the belief that motor control can be somehow manipulated by passive approaches, for example spinal manipulation to normalize segmental muscle tone. Such approaches are likely to produce only brief, reflexive responses.

Facilitating motor learning with mental practice

Despite the apparent need for physical practice, motor learning can be enhanced by mental rehearsal or by a demonstration of a movement (Fig. 5.4). Mental practice has been shown to improve activities such as bowling, piano-playing and ball-throwing (can air-guitarists play real guitars?). Even movement variables such as force, endurance and movement-time have been shown to improve with mental practice. It was shown that in weight training the physical practice group improved their...
strength by 30% while the mental practice group increased it by 20%. This force increase by mental practice is probably due to central motor reorganization of force control rather than muscle hypertrophy.

Mental practice facilitates motor adaptation by activating the motor system in much the same way as physical practice. Imagining a movement activates cortical motor areas in similar patterns to those activated during actual physical practice. It may also engage minimally the muscles that are involved in the imagined task but without producing observable movement. When subjects are asked to visualize hitting a nail with a hammer twice, the electromyograph (EMG) trace demonstrates two separate bursts of activity that are correlated with the imagined movement. A similar process takes place when we mentally recite words. The vocal muscles are minutely activated, although no sound is produced (Fig. 5.5).

In the last few years mental practice has moved from the motor learning to the rehabilitation sphere and was shown to improve motor control in stroke patients. This learning strategy may also be useful for patients who have been immobilized or unable to move due to musculoskeletal injuries.

Adaptive code 3: feedback

Since we learn by making mistakes we need feedback to inform us how well we are achieving our movement goals. Feedback can be *intrinsic* from proprioception or *extrinsic* in the form of verbal instructions, visual demonstration or even physical, tactile correction of movement by a therapist/trainer.

Intrinsic, proprioceptive losses will impair the ability to correct, improve or learn new movement (Ch. 2 & 4). Under such circumstances the individual will often compensate for this loss by shifting their attention to another sensory source, e.g. to vision if proprioception is lost.

Extrinsic feedback plays an important role in rehabilitation and is often referred to as guidance or *kinaesthetic feedback*. It is often used to provide information about the details and “correctness” of the movement (“hold the racket this way”), the movement sequences (“swing it like this”) or the quality in performance (“good shot”).

Generally, guidance is more effective if it promotes an active gathering of information and problem-solving by the patient. The outcome is improved motor learning and a wider repertoire of movement responses and learning that transfers readily to other situations. For optimum learning, guidance should be kept to the minimum and should be rapidly reduced or fully withdrawn at the earliest opportunity.

Young children seem to depend on longer periods of feedback during motor learning. This may be due to their having a limited range of motor experiences on which they can draw when learning.

Adaptive code 4: repetition

We all have had the experience that to master a certain skill we need to put in the practice (Table 5.1). The frequency and the number of repetitions in practising specific tasks will have important implications for the recovery of motor losses. Like a well-trodden path on a grass lawn, actions that are repeated will pave stable and enduring neuronal paths within the CNS.

Repetition together with selective attention plays a crucial role in the transformation of motor experiences from short- to long-term memory. This transformation is a sequential process often described as occurring in three stages; from short-term sensory store to short-term memory and, finally, long-term memory. Once a pattern has been stored in the long-term memory it will not be lost in the absence of rehearsal. Indeed, this can be observed in activities such as swimming, cycling or playing a
musical instrument, activities that can be recalled after many years without practice.\(^\text{12}\)

The meaning and relevance to the individual, motivational factors and the emotional value in the experience also play a part in long-term memory. Generally, experiences with strong personal or emotional significance are more likely to transfer rapidly to long-term memory.\(^\text{12}\) The extreme example of this is often seen in individuals who have been in a single traumatic experience, such as a road traffic accident. They may develop long-term sensitization and motor/behavioural changes in the absence of any serious tissue damage.\(^\text{64}\)

Repetition and practice of tasks is important throughout the spectrum of neuromuscular conditions seen in clinic.\(^\text{65}\) In stroke patients it was demonstrated that repetition can result in positive gains in performance even after one day of training.\(^\text{66}\)

### Adaptive code 5: similarity principle and transfer

Following injury most individuals will take actions to overcome their losses without any medical intervention. These actions often resemble the movement patterns which they have lost. A person with a sprained ankle, who could not walk, will attempt to walk and, likewise, an injured tennis player will attempt to gradually return to playing tennis. This is nature’s “gold standard” for recovery of movement control – practise what you have lost (or what you would like to gain). This natural phenomenon is the basis of the similarity principle. It proposes that learning is more effective when the training resembles the task which is being recovered.\(^\text{40,67}\) The similarity principle is one of the most important issues in neuromuscular rehabilitation. It determines which activities or movement patterns will be the focus of treatment.

It seems that for learning or recovering particular movement patterns the practice should be both similar and within the context of the task. This suggests that if a patient cannot balance during walking, rehabilitation should focus on balance during walking.\(^\text{30,68,69}\) Equally, if force losses impede stair-climbing, then leg strength should be challenged during that or a very similar activity.\(^\text{70}\) If the patient, due to lack of coordination, cannot raise their arm to eat then rehabilitation should focus on coordination within similar movement patterns. Under these circumstances the individual parts of the whole movement are being practised simultaneously, i.e. the relationships between them are being rehearsed.\(^\text{12}\) Practising movement which is similar and within context is more likely to transfer to related daily activities. Transfer is the ability to take a motor experience from one situation and apply it to another.\(^\text{67,71–73}\)

Practising a dissimilar movement pattern or movement that is out of context may reduce the likelihood of transfer (Fig. 5.6). Imagine a patient who has standing difficulties due to a balance problem. The treatment will be dissimilar if strength exercises, such as standing knee squats, are used to challenge standing balance.\(^\text{74}\) The strength challenge is the dissimilar element as it fails to challenge balance. However, it is still performed within the context of standing. The rehabilitation will be out of context if the training for balance is practised sitting on a Swiss ball. In this situation the balance is similar but movement is performed whilst sitting and is, therefore, out of the context of standing. The rehabilitation can be both dissimilar and out of context, for example straight leg rising (dissimilar) practised on the floor (out of context).

The importance of similarity and context has been highlighted by several studies. Resistance

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**Table 5.1 Estimated numbers of repetitions required to achieve skilled performance**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Repetition for skilled performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cigar-making</td>
<td>3 million cigars</td>
</tr>
<tr>
<td>Hand knitting</td>
<td>1.5 million stitches</td>
</tr>
<tr>
<td>Rug-making</td>
<td>1.4 million knots</td>
</tr>
<tr>
<td>Violin playing</td>
<td>2.5 million notes</td>
</tr>
<tr>
<td>Walking, up to 6 years</td>
<td>3 million steps</td>
</tr>
<tr>
<td>Marching</td>
<td>0.8 million steps</td>
</tr>
<tr>
<td>Pearl-handling</td>
<td>1.5–3 million</td>
</tr>
<tr>
<td>Football passing</td>
<td>1.4 million passes</td>
</tr>
<tr>
<td>Basketball playing</td>
<td>1 million baskets</td>
</tr>
<tr>
<td>Gymnastics performing</td>
<td>8 years’ daily practice</td>
</tr>
</tbody>
</table>

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cycling or seated strength exercise will improve strength in these activities, but have little or no effect on walking for a stroke patient, because strength may not be the control issue here.\textsuperscript{75,76} Strength training in sitting may help the patient in getting up;\textsuperscript{76} a situation where force may be necessary. However, would not practising getting up be equally, or even more, effective? For stroke patients sitting and reaching training improves sitting and reaching, and the production of vertical force through the leg as they lean forward.\textsuperscript{77} The vertical force improvement in the leg seems to transfer to improvement in getting up from the sitting position, but no aspect of that training transfers to walking. However, training of stroke patients in walking improves walking speed and distance, but not balance.\textsuperscript{78,79} Balance seems to be improved by challenging balance.\textsuperscript{80} But challenging static balance in standing might not transfer well to dynamic balance during walking!\textsuperscript{81} Yes, the similarity principle can be that finicky.

How similar should training be?

Current research cannot provide the answer as to how far a treatment can stray from 100\% similarity (Fig. 5.7). The studies in motor control and learning are very adamant that it should be very close.\textsuperscript{12} However, most of these studies have been carried out on healthy individuals who are learning new and unfamiliar tasks. As discussed previously, neuromuscular rehabilitation involves individuals who are not true learners; they are being retrained in activities that they have experienced in the past. They are “readjusting” rather than learning something new.

We can imagine 100\% should give the best result. If walking is affected then just practise walking. However, in the case of a patient who is unable to execute 100\% similarity, how far can they afford to stray from that ideal and still improve? For example, I have been working with a stroke patient who was unable to walk, partly due to inability to flex
We proceeded to improve this movement in sitting. After a long and intense focusing on this particular movement the patient regained the ability to flex and extend the knee, as well as execute rhythmic pendular movements (similar but out of context to walking). It would be logical to assume that once it has been mastered, the patient should be able to transfer the control of knee bending to walking. This was a humiliating lesson in similarity and transfer. It had absolutely no effect on bending the knee during standing. It was as if he had never practised that movement at all.

It is difficult to identify how close the training should be to the goal of rehabilitation. The simple solution is to endeavour to keep the training close to the 100% similarity and in context; unless the patient is unable to perform similar movement patterns or execute them within context.

**Is recovery transferrable?**

Imagine a patient who has a balance/postural stability problem. We would expect that all upright, weight-bearing activities that depend on balance will be affected. Is the reverse also true? Would balance training during standing or walking transfer to running, skipping climbing stairs or playing basketball?

We can only assume that recovery in balance/postural stability in one or two weight-bearing activities (walking, stairs) will also improve all other related upright activities (running, hopping on a tennis court). If this assumption is correct it provides an interesting therapeutic shortcut. There is no need to rehabilitate every physical action in a person’s movement repertoire. All that may be needed is to “re-ableitate” the specific abilities which are shared by several skills. This assumption

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**Fig. 5.7** How similar is your rehabilitation? The effectiveness of practice can be assessed by examining how similar it is and whether it is in the context of the goals of training. Rehabilitation is likely to be more effective if it is similar and within the context of the movement goals of the treatment.

<table>
<thead>
<tr>
<th>Highly transferable</th>
<th>Least transferable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissimilar out of context</td>
<td>Similar within context</td>
</tr>
<tr>
<td>Similar out of context</td>
<td>Dissimilar within context</td>
</tr>
</tbody>
</table>

**Rehabilitating:**

**Walking**
- Lumbo-pelvic tilts practiced on the floor
- Core tensing or bracing
- Extension exercise on the floor
- Laying on the floor moving both legs in a walking-like pattern
- Core tensing or bracing in walking (this may seem surprising. As long as the person is walking they are practicing walking. The dissimilar movement is redundant as far as recovering control of walking)
- Walk

**Trunk control in upright movement**
- Abdominal muscle control on the floor or sitting
- Extension exercise on the floor
- Lumbro-pelvic tilts practiced on the floor
- As above
- Reaching, pulling and pushing during standing

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Dissimilar out of context
Core tensing or bracing
Extension exercise on the floor
Rehabilitating:
Laying on the floor moving both legs in a walking-like pattern
Core tensing or bracing in walking (this may seem surprising. As long as the person is walking they are practicing walking. The dissimilar movement is redundant as far as recovering control of walking)
Walk

Abdominal muscle control on the floor or sitting
Extension exercise on the floor.
Lumbro-pelvic tilts practiced on the floor
As above
Reaching, pulling and pushing during standing

---

The hypertonic extended knee. We proceeded to improve this movement in sitting. After a long and intense focusing on this particular movement the patient regained the ability to flex and extend the knee, as well as execute rhythmic pendular movements (similar but out of context to walking). It would be logical to assume that once it has been mastered, the patient should be able to transfer the control of knee bending to walking. This was a humiliating lesson in similarity and transfer. It had absolutely no effect on bending the knee during standing. It was as if he had never practised that movement at all.

It is difficult to identify how close the training should be to the goal of rehabilitation. The simple solution is to endeavour to keep the training close to the 100% similarity and in context; unless the patient is unable to perform similar movement patterns or execute them within context.
is somewhat supported by clinical experience. The time spent with the patient can never be sufficient to rehabilitate every skill. Yet, patients often improve in a wide range of physical activities as a consequence of a relatively short session time. This suggests that recovery in specific abilities practised in one activity may transfer to other activities that depend on these particular abilities.

The transfer of training can be in two directions: a "lateral" and a "vertical" transfer. A lateral transfer would be to similar tasks, such as from walking to stair-climbing. A vertical transfer is the same task but at increased difficulty (greater force, amplitude, speed, range, etc.). Walking with a rucksack which increases the load is a vertical transfer. It requires complex neuromuscular reorganization compared to free walking, but does not require any extra learning.

Lateral and vertical transfer was demonstrated in a study examining the effects of exercise on neuromuscular control after knee meniscectomy. The patients presented with neuromuscular deficits and functional limitations, which were evident several years after their operation. The exercise programme comprised postural stability training and functional strength and endurance exercises for leg and trunk muscles. The exercise group showed significant improvement in hamstrings strength and quadriceps endurance (vertical transfer), but, importantly, they also improved in one-leg hop, something they did not train for (lateral transfer). There is also evidence that training in tai chi transfers laterally to postural stability and coordination. Another example of vertical transfer was shown in subjects with lateral ankle sprain. It was demonstrated that training under moderately unstable conditions can transfer to improvements in postural control under more challenging stability conditions.

Movement strategies in painful conditions may also transfer to the opposite limb; probably through the same central mechanisms. In patients with chronic wrist pain, coordination losses were evident in the affected and, to a lesser extent, in the non-affected hand.

There may also be a sensory transfer between the two limbs. In individuals who had cruciate ligament reconstruction or shoulder injury, decreased proprioceptive ability was present in some measurements in the injured as well as the uninjured side.

The clinical implication of this inter-limb transfer is not clear. It is yet to be established whether treating the non-injured limb will result in significant clinical improvement of the injured limb (I am placing my bets on treating the injured limb).

**Variability in training**

The similarity principle suggests that training should be as close as possible to the goal movement. However, most movement patterns are highly variable. In the clinic often the variability is reflected in changing the movement parameters or varying the task itself. During the rehabilitation of walking, variability would reflect in practising different walking speeds or stride lengths. Furthermore, walking itself can be practised in different tasks: walk sideways, walk over an obstacle, stairs, heel-toe, walk and turn, and any other variation. From studies of healthy subjects and individuals suffering from central damage, such variability during training helps to improve retention and transfer and increases the movement repertoire.

Different tasks can be introduced in various sequences. **Blocked practice** is when each task is practised individually, for example walking only. Another possibility is to mix several related tasks in random practice, for example walking, stairs, running, skipping, etc. Generally, a more random sequence seems to be beneficial for individuals with an intact CNS. This form of practice introduces greater cognitive/motor processing demands on the individual. It tends to reduce performance during the training/treatment sessions but seems to benefit retention and transfer (which is the important bit).

Patients suffering from CNS conditions, such as Alzheimer’s and Parkinson’s disease, where cognitive demands can be an issue, seem to do better in retention and transfer when the tasks are practised individually and repetitively. Clinically, a
pragmatic approach is probably useful for scheduling of tasks. Use the patterns that the patient can cope with, rather than using a strict protocol.

**Neuromuscular exercises – do they exist?**

There is a trend to label some forms of training as neuromuscular exercise. Is there such a distinct training entity? All exercises performed actively by the patient are neuromuscular. Whether they are performed lying down, sitting or with the aid of machines; they are all challenging the neuromuscular system. Presumably, what is meant is that some exercises are more within the context of certain sports or related tasks. Hence, they are more functional to that particular athlete and their sports. This is in contrast to exercises such as the traditional force training in the gym, which are dissimilar, out of context and may even be extra-functional.

Is one approach better in some way? The very few studies that do exist generally demonstrate better outcome in various measures for the functional exercise (neuromuscular exercise) compared with more traditional strength training. However, it seems that functional training may bring about additional motor control benefits. For example, standing balance training can give the same strength gain in the leg as using specific machines for leg curls and leg presses. The balance training had the further advantage of improving balance and equalising the muscle forces between the dominant and non-dominant leg. Hence, exercises that are similar and within context are more likely to challenge a greater range of underlying abilities, including the composite abilities, such as balance/postural stability, single, multi-limb and whole body coordination.

**Summary points**

- For effective motor adaptation/learning, the practice needs to employ five principal elements: cognition, being active, feedback, repetition and similarity.
- Cognitive: the patient should be attentive to their movement and encouraged to process and make decisions about their actions.
- Active: being physically active is important for motor learning. Passive approaches are unlikely to be effective in promoting lasting and functional motor control changes. Mental practice, an active cognitive process, activates the whole motor system and, therefore, may be a valuable clinical tool.
- Feedback can be intrinsic from proprioception or extrinsic, such as guidance by the therapist.
- Repetition, repetition, repetition – very important for long-term memory.
- Similarity: rehabilitation should use movement patterns that are similar to and within the context of the movement being recovered.
- Rehabilitation which is dissimilar or out of context is unlikely to transfer from the session to daily activities.

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**Table 5.2 Differences in motor learning strategies between young children and adults**

<table>
<thead>
<tr>
<th>Young</th>
<th>Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observing, mimicking, some cognition?</td>
<td>Use cognition</td>
</tr>
<tr>
<td>Favour internal focus</td>
<td>Favour external focus</td>
</tr>
<tr>
<td>Cope better with less variability in practice</td>
<td>Favour variability</td>
</tr>
<tr>
<td>Need more feedback</td>
<td>Minimal feedback</td>
</tr>
<tr>
<td>Greater need for repetition</td>
<td>Need repetition but not as much</td>
</tr>
<tr>
<td>May require longer rehabilitation due to lack of motor experience (&quot;unskilled injured&quot;)</td>
<td>Know the movement but can’t perform it (&quot;skilled injured&quot;)</td>
</tr>
<tr>
<td></td>
<td>Motor re-adaptation and reorganization rather than true learning</td>
</tr>
</tbody>
</table>
• Experiences that possess a higher content of adaptive code elements have a greater potential for promoting long-term changes.
• Experiences with low code content will fail to promote any significant adaptation and will result in an ineffective, short-lived response to treatment.
• External focus is more effective for motor learning. Internal focus should be used only in learning novel movements or if the patient has “forgotten” how to move correctly. Internal focus should be withdrawn as soon as the patient is able to perform the movement.
• Internal focus approach may be more beneficial for patients with CNS conditions.
• Children and adults may use different motor learning strategies which may influence the treatment approach (Table 5.2).
• Air guitarists can’t play real guitars.

References


Plasticity in the motor system

Learning, retraining, motor reorganization in response to injury and return to functionality all imply that the motor system has the capacity to adapt to new experiences. Chapter 5 discussed the behavioural aspects of motor learning and how they can be used to promote sensory-motor adaptation. This chapter will examine the neurophysiological consequences of learning and their relevance to rehabilitation.

Sensory – motor adaptation

There are several neurophysiological processes associated with learning and sensory-motor adaptation (also termed neural plasticity).1–3 They include changes in the neuronal cell surface and its filaments, sprouting of cell dendrites and axons, growth of new synaptic connections and changes in neurotransmitter release at the synapses. More recent studies have demonstrated neurogenesis (new neurons) within specific parts of the brain, in particular the hippocampus, an area associated with learning and memory. Neurogenesis has also been observed after brain damage in the areas of neural tissue repair.4,5

Plasticity in the motor system is not centre-specific but tends to occur within the whole sensory-motor system.6 Tapping the index and middle finger of a monkey daily for several months was shown to change the cortical representation of the hand. The area representing the hand increased, distorting the cortical map in favour of the tapped fingers.3 In blind Braille readers there is an expansion of the sensorimotor cortical representation of the reading finger.7 Similarly in musicians, there is an increase in cortical representation of the playing fingers.8 These changes in the cortex were shown to occur fairly rapidly, within 3 weeks of practising a novel task.9 In the cerebellum, striatum and other motor-related cortical areas such changes are evident within a few days.10 Interestingly, cortical reorganization is so rapid that it can even be demonstrated shortly after proprioceptive deprivation by an anesthetic block.11

Adaptive changes related to motor learning have been shown to take place even in the reflexive part of the motor system and spinal cord. Monkeys can be trained by the offer of a reward to depress or elevate the amplitude of the stretch reflex.12–14 The reflex changes become evident within a few weeks to months and will persist for long periods of time, even after the removal of supraspinal influences, i.e. without the brain.13 This implies that the spinal cord has the capacity to retain learned experiences. Humans can also be taught to control their stretch reflex, but it only takes nine practice sessions.15 The reason for this difference may lie in the potent influence that cognition has in humans in accelerating the learning process (Ch. 5).

Further evidence for spinal cord “learning” was demonstrated in a study where animals that have only their spinal cord intact are trained to either stand or walk.16 The results were task-specific learning where each group could only perform the task in which it was trained (walk or stand). Training each group in the other task reversed these two conditions, i.e. the walking group could be trained to stand, and vice versa. Once the activity was changed, the animal was unable to perform the previous motor task; a sort of competition in adaptation.
Central sensorimotor plasticity can also be demonstrated following injury in the periphery. In normal circumstances, the palm of the hand is used more than the dorsum and, therefore, the median nerve has a wider cortical representation. When the median nerve is cut, the cortical map of the hand will change in size in favour of the intact radial nerve. If the median nerve is allowed to regenerate, it will recapture some of its lost cortical territory. Similarly, amputees or patients with spinal cord injuries show a lower threshold to excitation of muscles which are still innervated (proximal to the lesion). This is attributed to enlarged sensorimotor representation of the unaffected proximal muscles and shrinkage of the sensorimotor representation of the denervated muscles.

Even less dramatic events such as immobilization and subsequently remobilization will result in motor adaptation. It was demonstrated that during remobilization there was reorganization of the brain indicative of a “relearning” process. Such plastic changes in response to immobilization can also be observed in the spinal motor centre. Adaptive changes in the firing patterns of motor units can be demonstrated by straightforward joint immobilization. Most of the adaptive changes took place within the first 3 weeks, probably beginning within days of immobilization.

In patients with CNS damage the recovery of motor function is associated with motor reorganization in the brain. Imaging studies have demonstrated that functional recovery of movement in the affected hand is brought about by the shift of neuronal recruitment to other areas of the brain; areas which previously were not involved in controlling that particular movement.

### Peripheral plasticity – muscle, the acrobat of adaptation

By being a part of the neuromuscular continuum, muscle can exhibit dramatic adaptation in parallel to central plasticity. Changes in the muscle can be in the form of length adaptation, hypertrophy and changes in the fibre type of the muscle.

The adaptation in muscle tends to be fairly specific to the type of activity practised. Training in one form of activity, for example running, does not necessarily provide the neuromuscular adaptation required for, for example cycling (specificity principle in training), in the same way that the practice of yoga will not provide the adaptation required for lifting weights. When learning a new movement pattern the muscle (and for that matter, the whole motor system) will readapt to the newly practised activity. In the muscle this involves a degree of fibre destruction (hence the delayed onset of muscle soreness) and adaptive reconstruction according to the new demands placed on it. Such adaptive changes in the muscle happen quite rapidly within 2–3 weeks.

### The importance of physical challenges in adaptation

Physical challenges play an important role in promoting central reorganization and adaptation. In mice with partial spinal cord damage, treadmill training was shown to promote axonal sprouting and synapse formation proximal to the lesion and to improve motor recovery. Even neurogenesis is driven by general physical activity or by providing challenging environments for the individual.

However, not all exercises are equal. Motor learning that involves tasks such as coordination and balance encourages synaptogenesis, whereas treadmill exercise encourages the formation of new blood vessels in the brain (angiogenesis), with delayed synaptogenesis. In a further study, synaptogenesis was evaluated using similar exercise protocols in animals with an induced stroke. Synaptogenesis was evaluated after 14 and 28 days and was found to be intensively active within 14 days in the balance and coordination group, whereas in the treadmill group it was evident only at 24 days. Furthermore, in animals, early introduction of aerobic exercise after brain trauma tends to delay brain plasticity.

These studies have an important message for us:

**Neuromuscular rehabilitation is not just about exercising. It is about providing cognitive-sensory-motor challenges that will facilitate motor learning/adaptation.**

Hence, running on a treadmill could provide aerobic challenges and stimulate synaptogenesis (to a limit, otherwise marathon runners would have huge brains). However, running an obstacle course will be both aerobic and more cognitively demanding, since it involves more task variability and places greater challenges on various motor abilities. Similarly, playing a tennis game with a partner is more cognitively/motorically challenging than practising hitting
a ball against a wall. These cognitive-motor challenges may, therefore, result in more complex sensory-motor reorganization. The message here is that rehabilitation should follow a similar strategy. It should provide challenges that vary, are cognitively demanding and are fun and interesting (depending on the patient’s capacity). Avoid using “mindless” and tedious exercises.

Summary points

- Learning, retraining, motor organization to injury and return to functionality partly depend on the neurophysiological capacity of the motor system to adapt to new experiences.
- Motor adaptation is not centre-specific and can be observed throughout the neuromuscular continuum: brain, spinal cord and muscles.
- Central and peripheral adaptation occurs concurrently; separating them during treatment is artificial and ineffective. The muscle cannot be rehabilitated in isolation from its controller (the person).
- Rehabilitation is more about facilitating cognitive-sensory-motor processes and providing a stimulating and variations-rich environment. It is not just exercising.

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Motor reorganization in musculoskeletal injury

Musculoskeletal injury or pain will bring about profound cognitive, behavioural and motor control responses that serve to protect the body from further damage.\textsuperscript{1,2} This response to injury is termed here the injury response.

In this chapter we will explore how the motor system reorganizes movement in injury and what influence it will have on the motor abilities. It will also discuss in which situations should neuromuscular rehabilitation be used and at what point after injury it should be introduced. The chapter will also examine the relationship between long-term motor reorganization and recurrent injury and progressive joint/tissue damage.

The injury response

There seems to be a “standard” motor response to damage or pain no matter which area or tissue is affected in the body. This injury response often manifests as a slowing down of movement, a loss of force, reduced movement range and an increase in fatigability. It is as if the motor system has used a “dimmer switch” to turn down the four movement parameters (force, velocity, length/range, endurance, Fig. 7.1). Furthermore, to ensure that the individual will not be tempted to physically stress their injury, within the psychological dimension, another inhibiting process kicks into action: the curbing of the “will to move”. The individual will have an emotional experience of pain, fear of use, sense of weakness and loss of the will to carry out the movement.

This reorganization to injury can be put on hold during disastrous life-threatening events to allow the individual to reach safety. Hence, a person with a moderate leg or trunk injury may be able to escape from a burning house. Later, when there is perceived safety, the injury response will take over and in a matter of hours the person will become motorically unable to move. However, this injury response will be overrun by a survival response if this period of recuperation is suddenly interrupted by another life-threatening event. The person may find that they are, again, able to move using the injured limb.

There is an important point to this short story. The motor system can “switch” the injury response “off or on”, depending on priorities. In musculoskeletal injury the motor system is healthy and well functioning compared to the tissues which are undergoing repair. There is no motor dysfunction, motor pathology or movement dysfunction here. This reorganization is a positive and well-orchestrated response.

In musculoskeletal injury the tissue damage is a set quantity at any point in time, e.g. the number of torn muscle fibres. On the other hand, the motor response is a variable entity. The magnitude of the whole response, or elements within it, can alter on a moment-to-moment basis depending on numerous factors. Apart from the severity of tissue damage, they include physiological needs (having to walk to find food), socio-economic realities (having to go to work with back pain) and psychological factors such as the “will” of the individual, health beliefs, mood, motivation, fear or depression. This
highlights the fact that the organization to movement is a complex multidimensional process and not a crude, stereotypic “stimulus-response” reflex (although there is some of this in it). It also means that motor control in injury can be more effectively rehabilitated by treatment that embraces the psychological/cognitive and behavioural dimensions of the individual (Ch. 8). These have potent and often dominant modulating influences over the more reflexive control elements.3–7 For example, during movement subjects with high fear avoidance tend to reduce the force of their trunk muscles by half.8–10 It implies that their force losses can be recovered by cognitive changes without any trunk-strengthening exercise!

It should be emphasised that the injury response can be initiated during any pain experience even in the absence of tissue damage or inflammation. The system may “mistake” the pain for being an injury. This is often observed in the non-traumatic and chronic pain conditions (Ch. 9).

The motor system in injury

In response to damage, information about the damage arrives to the central nervous system (CNS) from nociceptors and proprioceptors (Fig. 7.2). This information together with the cognitive/emotional experience of the injury will be integrated to organize for the injury. The next stage in this process is the selection and activation of the motor programme that will modify posture and movement in relation to the injury. It would be interesting to know whether these programmes for injury are learned responses or are pre-existing templates. It seems that we all immediately “know” what postures to adopt when injured (anyone for a PhD?). Once the appropriate response has been selected the motor output will ensue, with the individual exhibiting the movement patterns associated with their injury.11,12 It seems that there can be several responses to any one injury. Each individual uses their own unique movement patterns. Such variation between individuals has been observed in impingement syndrome of the shoulder and chronic neck pain conditions.13,14 This has been also demonstrated in subjects with anterior cruciate deficient knees, where each person seems to have an individual compensating strategies during walking.15 Furthermore, an injured person may demonstrate several “movement solutions” to a given task.

These injury responses are task-dependent and would, therefore, change between different activities.16,17,18 It is also likely that the organization for injury changes over time.19,20
Clinical note

- It’s all too complex (but there is a solution)!
- Individuals have individuality in their injury response.

The signalling of damage

The signalling from the body is a mix of information about tissue damage from nociception and information from proprioception about the mechanical changes in the affected tissues. The perception of pain is evoked by the information from nociceptors and other receptors, such as mechanoreceptors from the skin, muscles and joints, which also contribute to the sensation of pain.

Proprioceptors can signal damage and promote motor reorganization in the absence of pain. When the knee is effused with non-painful saline it will initiate an inhibition of quadriceps motoneurons akin to the reflex patterns seen during knee injury. Similarly, non-noxious stimulation of the glenohumeral joint capsule will elicit strong inhibition of the shoulder muscles (see arthrogenic inhibition below).

Conscious awareness and the experience of injury will also have profound influence on the organization around injury. It may increase the levels of pain, increase movement incapacity and may even impede the rate of recovery. Generally, injuries that are psychologically traumatic, such as road traffic accidents, are more likely to have such negative influences.

The injury response and motor abilities

The turning down of the four movement parameters implies the involvement of the parametric and synergistic abilities in motor reorganization during injury (Fig. 7.3). It is expected that these abilities will be selective to the affected limb. However, local changes may be accompanied by complex whole-body pain/damage avoidance reorganization. In patients with lower back pain (LBP) motor reorganization can be demonstrated even in the unaffected upper limb. Furthermore, injuries affecting control on one side of the body may have a low-level cross-over to the opposite side.

Composite abilities such as local coordination may also be affected. They are expected to be associated with chronic musculoskeletal conditions, where movement dysfunction is progressing from an injury to a more chronic adaptive response. This is seen in situations where prolonged hand immobilization leads to local losses in coordination. Another possibility is that composite abilities, such as postural stability/balance and coordination, may appear to have been affected. However, they...
may represent the knock-on effects of changes in synergistic abilities and proprioception.

**Force control**

Patients with acute or chronic conditions will often complain of feeling that their joints or muscles are weak and that they fatigue easily.\(^{37,38}\) This experience may sometime persist long after the pain has been alleviated and repair seems to be fully resolved.

There is a biological logic in this mechanism. Forceful muscle activation will raise the intramuscular as well as the intracapsular pressure and may result in further damage to these tissues.\(^{61,62}\)

The force losses could be attributed to two processes. In the psychological dimension patients with musculoskeletal damage will be reluctant to fully activate their muscles because of fear of pain, and in the conscious sense there is a localized weakness and inability to successfully execute the movement.\(^{7,39-41}\) This may lead to disuse atrophy, in particular if the patient is withdrawing from physical activities. In the neurological dimension, another more reflexive mechanism reduces the gain of the spinal motoneurons in response to joint damage. This is often called *arthrogenic inhibition* or *failure of voluntary activation* (Fig. 7.4). The outcome of this is more localized force loss, reduced endurance and, consequently, muscle wasting.\(^{37,38}\)

Arthrogenic inhibition has been observed in acute knee effusion and inflammation,\(^{42-48}\) in a chronically damaged knee (anterolateral ligament [ACL] tears, osteoarthritis [OA] of the knee and ageing) and in the elbow joint.\(^{34-36,49-52}\) A similar process probably underlies the wasting of the multifidus and psoas muscles seen in patients with chronic lower back and neck pain.\(^{53-55}\) Such muscle wasting can occur fairly rapidly. In acute lower back patients wasting of multifidus has been observed within 24 hours of pain onset.\(^{55}\) Individuals who maintain physical activities after their injuries tend to reduce the negative effects of arthrogenic inhibition.\(^{52,60}\)

**Length control**

Another strategy to prevent more damage is to limit the range of movement by muscle bracing.\(^{63}\) The most dramatic demonstration of this is seen in acute conditions, such as acute torticollis or acute lower back pain, where the patient is immobilized rigidly by muscle contractions.\(^{64,65}\) Probably this bracing strategy is achieved by an increase in localized co-contraction combined with hyper-reactive control to the muscles that restrict the movement towards damage.\(^{64-67}\)

This controlled narrowing of range has also been observed in chronic conditions. In normal subjects during full forward bending the spinal extensor muscles tend to become inactive at the end range. However, in subjects with chronic back pain these muscles remain active even at the end range. Also in chronic back pain there is an increase in localized bracing by co-contraction, which will further limit the movement range.\(^{7,68}\) These control elements are all part of a strategy that aims to keep the person upright and prevent them from bending – movements which would otherwise overload the damaged/painful posterior spinal structures.\(^{7,69,70}\)

Such organization to limit the extent of movement can be seen also in painful muscle. When a muscle is injected with a painful irritant there is an inhibition of the painful muscle and excitation of muscles antagonistic to the movement.\(^{71-73}\) Similarly, when pain is induced in tibialis anterior there is reduced joint movement in the limb during
walking, which is controlled by a decrease in activity of the tibialis anterior and gastrocnemius muscles (synergistic control).71

**Velocity control**

Another hallmark of the injury response is slowness of movement.11,12,63,74–76 Individuals with back pain reduce their walking speed and when pain is severe they seem to move almost as if in slow motion. Often the crucial indication that they are improving is that their movement speed begins to recover.

The slowing-down response is mediated within the psychological/psychomotor dimension affecting overall movement, as well as within the neurological dimension as a localized reflex response directed to muscles at the area of damage.67,77

**Neuromuscular endurance**

One way of reducing stresses on a damaged area is to prevent the person from repeatedly loading it by reducing endurance.37,38 Localized, diminished neuromuscular endurance can be observed even in the absence of pain.19,37,38,69,78–80

**Synergistic abilities**

Co-contraction and reciprocal activation are profoundly affected following tissue damage and in pain conditions.81 Several control factors can change in injury:

1. The relative force, velocity, muscle length between the synergistic pairs
2. Augmentation or diminution of one of the synergistic patterns
3. The timing and duration of activation between the synergists.

At synergistic level, the reorganization of the parametric abilities is represented as changes in the relative forces, velocities, lengths and fatigability between muscle pairs. Such reorganization can be observed in knee effusion where there may be force losses in the quadriceps coupled with an increase in hamstrings reactivity (Fig. 7.5).47 Even fatigue or delayed muscle soreness in one muscle group will have an influence on control of the non-exercised synergists.82–85

A diminution of one of the synergistic patterns can be observed in different conditions. Functional instability is often the outcome of co-contraction inhibition.49,86–90 In the ankle joint it often manifests as a sudden “giving way” during foot contact. This control failure seems to be sustained long after the tissues have recovered and may predispose the individual to recurrent ankle injury.90

An increase in the dominance of co-contraction strategy can be observed in lower back patients.91 Co-contraction is considered to be an important control strategy to maintain spinal stability.92,93

Patients suffering from low back pain tend to use higher levels of co-contraction force to increase stability, but also limit the range of movement (Fig. 7.6). They also have different reciprocal activation patterns of trunk muscles, indicative of synergistic

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**Fig. 7.5** • Synergistic protective strategy to prevent further damage. Inhibition and weakness of muscle that pulls the joint into further strain and an increase in reactivity of the muscles that resist that movement.

**Fig. 7.6** • Joint bracing is a synergistic co-contraction pattern to increase stability and reduce the movement range.
reorganization. These control changes can be observed in every muscle group in the trunk, diaphragm and beyond. Remember, even muscles that are inactive have a role within the synergistic control strategy (Ch. 2).

Changes in timing and duration

The timing of activation of synergistic muscle group during co-contraction and reciprocal activation are also affected in injury and pain. Everything is possible here: from changes in onset timing to changes in the duration of activation. Delay in peroneal onset times can be observed in ankle and in tibialis anterior when this muscle is injected with an irritant. Patients with anterior cruciate repair were shown to have longer onset times of hamstring muscles activation. It is expected that all these timing differences would also affect the synergistic pair.

Synergistic timing can be very complex. This can be demonstrated in a study of trunk muscles activation during sudden trunk loading:

... for healthy control subjects a shut-off of agonistic muscles (with a reaction time of 53 msec) occurred before the switch-on of antagonistic muscles (with a reaction time of 70 msec). Patients exhibited a pattern of co-contraction, with agonists remaining active (3.4 out of 6 muscles switched off) while antagonists switched on (5.3 out of 6 muscles). Patients also had longer muscle reaction times for muscles shutting off (70 msec) and switching on (83 msec) and furthermore, their individual muscle reaction times showed greater variability.

This kind of complexity is not clinically friendly. It is not possible to test it or to even remember all of these minute details. Further complexity is introduced as this motor reorganization changes on a moment-to-moment basis during different postural and movement situations, i.e. these strategies are task-dependent. For example, during sudden postural challenges the onset timing of transversus abdominis can change depending on variables such as the phase of breathing, different velocities and direction of arm movement, and position of the trunk. In chronic lower back patients these timings tend to be reorganized, but still remain complex task-dependent patterns (Ch. 2).

Important clinical note

The fine motor changes described above are often single events within a more complex motor reorganization. They represent a moment in time within a particular task carried out in the lab. It is very easy to lose track of the whole person/response and to be hooked on single control aspects such as timing of transversus abdominis or the cross-sectional area of multifidus at L4-5 in CLBP. They represent different aspects of a larger reorganization (see Table 3.1, Chapter 3) and, therefore, these single factors should not be the ultimate therapeutic goal.

How to resolve this problem of complexity is not to worry about it too much. It is virtually impossible to analyse injury organization muscle by muscle or reflex by reflex. Rehabilitation should ultimately focus on overall control. Think movement not muscles!

To treat or not to treat

It was put forward above that the injury response is a healthy motor control reorganization to prevent further injury. The question that arises is whether we can improve on this system and is there a time that we should intervene.

The immediate short-term reorganization of the neuromuscular system after injury should not be the focus of rehabilitation. This protective function often resolves when repair is complete and pain is alleviated (Fig. 7.7). If it didn’t, we would all suffer from progressive motor disability from our multiple injuries throughout life. Perhaps in the first 2–3 weeks after injury the neuromuscular system should be left alone to do what it does best. All that is needed is for the patient to keep being active to facilitate this natural recovery, i.e. no specific rehabilitation is required. For example, we know that patients with acute lower back pain need no extra exercise to get better. The advice is to keep being active. Generally, individuals who keep up with their physical activities after injury have less pain and a better motor control status than those who withdraw from activity. However, overall management including gradual exposure, goal-setting, and cognitive-behavioural reassurance and empowerment can be helpful for some patients during the acute phase (Ch. 8).

So when does the injury response become dysfunctional? This occurs when the injury response is
maintained in the absence of a repair process, i.e. it serves no obvious functional/protective purpose and is impeding normal movement. There are four potential mechanisms that can account for maintaining a dysfunctional organization:

1. Severe injury or post-operative conditions where the repair is taking longer than usual to resolve (Fig. 7.8). For example, hand immobilization may lead to loss of coordination due to disuse (seen as plastic changes within the spinal cord and brain).

2. Physical constraints or immobilization that leads to a dysfunctional motor adaptation (Fig. 7.8). For example, hand immobilization may lead to disuse (seen as plastic changes within the spinal cord and brain).

3. Sensitization conditions where tissue damage has resolved but has remained painful (Fig. 7.9). Under these circumstances the CNS/individual may perceive pain as being an indication of damage and maintain a protective movement strategy, such as seen in individuals suffering from chronic lower back or neck pain.

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**Fig. 7.7** Acute injury. Motor re-organization serves a positive protective function.

**Fig. 7.8** Sensitization conditions where tissue damage has resolved but has remained painful. Under these circumstances the central nervous system/individual may perceive pain as being an indication of damage and maintain a protective movement strategy.
4. Psychological distress leading to “psychomotor” movement losses, such as seen in depression, anxiety conditions or high levels of fear-avoidance and catastrophizing (Fig. 7.10). 3–7 The therapeutic intention may change for the different groups, but the rehabilitation is often very similar. In the group that is recovering from injury or is sensitized and where there is no obvious psychological distress (e.g. fear-avoidance), the intention is to help to recover motor losses. In patients where there is high psychological distress but low evidence of tissue damage, rehabilitation is still the same, but the underlying therapeutic intention is to provide behavioural reassurance and empowerment, even in the absence of motor losses (Ch. 8).

Can the motor changes lead to further injury or progressive damage?

The short answer to this is we don’t know. The evidence is mixed and not well-researched. In this model, altered control results in abnormal mechanical stresses being imposed on the joints/tissues. This is believed to lead to further damage or recurrent injury. 49,87,89,114–116 This is supported by some evidence that motor instability, such as seen in ankle sprains, can lead to future recurrences. 86,90,117,118 Also there is some evidence that athletes with sluggish reaction times are more prone to back and knee injuries. 119,120

However, in a 20-year follow-up study of patients with chronic ankle instability, degenerative changes were observed only in six of 46 ankles, with no correlation to age or persistent instability.

There is also an interesting observation from working with stroke patients. It seems that the affected hand does not develop degenerative changes, although they suffer extensive motor control losses. 121 Similarly, ambulatory chronic stroke patients don’t seem to develop any progressive joint or soft-tissue damage in the affected lower limb.
(unless they have an injury due to loss of control). But what is very surprising is how little these stroke patients suffer from back complaints, even though they have severe motor control losses to the trunk/spine.

As noted earlier, if motor losses led to progressive damage we would never recover from our injuries. We would forever be in a negative loop of injury leading to motor loss, to further injury, further motor loss and so on. Imagine even an uncomplicated injury such as the low level of damage associated with delayed-onset muscle soreness after exercise. Although it is associated with motor reorganization/losses,122–124 most athletes will exercise during that period, seemingly without further progression of muscle damage.

Perhaps motor losses are more of an issue to individuals such as athletes who challenge their control of movement to the extremes of physical performance? But then we must suspect that all individuals have some motor losses related to past or current physical history and that these can be tolerated up to a certain point. Otherwise it would mean that athletes would be plagued with recurrent and progressive musculoskeletal pain and disability.

We need many more studies to establish how much control changes can be tolerated and how motor changes may interact with other factors to promote further damage.

### Summary points

- The motor reorganization following injury is a multidimensional strategy culminating in postural and movement reorganization aimed at reducing the mechanical stresses imposed on the damaged tissues – in this text it is referred to as the injury response.
- The injury response is a positive healthy response and not a motor dysfunction or pathology.
- This response is highly individualistic. It is a dynamic process changing on a moment-to-moment basis during different phases of repair, levels of pain, re-injuries, underlying pathologies, ageing, and psychological states, such as anxiety, stress and depression.
- Acute musculoskeletal injuries should be left alone – the body know best.
- Neuromuscular rehabilitation is useful when the injury response serves no obvious protective function. It includes:
  - conditions where the injury response has become an adaptive state, such as in chronic recovery from injury or surgery or conditions where there were movement constraints or immobilization
  - sensitization conditions where tissue damage has resolved but has remained painful
  - injury-related psychological distress that leads to “psychomotor” movement losses.
- Parametric and synergistic motor abilities are the ones most likely to be affected in musculoskeletal injuries.
- Composite abilities may change as a knock-on effect from parametric and synergistic abilities.
- Don’t get dazzled by scientific descriptions of the minute reflexive motor changes in injury – don’t lose sight of the forest for the trees.
- *Think movement not muscles.*

### Clinical note

The primary aim of neuromuscular rehabilitation is to help individuals to recover their control movement. It is unknown if rehabilitation would confer protective function against progressive tissue damage in the future.

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**Pthomegroup**

Neuromuscular Rehabilitation in Manual and Physical Therapies

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Cognitive and behavioural considerations in neuromuscular rehabilitation

Cognitions, behaviours and movement control are profoundly interlaced and inseparable and should be considered as an essential part of patient care in neuromuscular rehabilitation (Fig. 8.1).

A person’s beliefs, their attitudes and the action they take when they are injured or in pain can have important implications for their recovery. Furthermore, the individual’s movement repertoire may contain particular habitual patterns that could put them at risk of injury. These beliefs and behaviour can be challenged in ways that could help the patient to adopt different attitudes and modify certain elements in their behaviour, changes that could facilitate recovery and reduce the potential for future injury.

Injury cognitions and behaviours

A patient who used to be a keen runner withdrew from this activity due to mild lower back pain. He was advised by his surgeon to stop jogging because it would exacerbate the wear and tear in his back. Another patient had knee pain as a consequence of a fall in judo. He believed that “knees can be a problem” and considered stopping judo. A 65-year-old tennis player had surgery of his serving shoulder. He had all the possible shoulder conditions known to humankind affecting this joint. Will he ever be able to play tennis again?

All these patients are exhibiting certain beliefs about their condition that hold them back from resuming these activities. These beliefs often manifest as fear-avoidance (“I can’t walk because it causes my back pain and it will make it worse”) or catastrophizing (“I will never be able to walk again, I have to stop working.”).1–4 This group of patients is adapting their behaviour in response to pain, discomfort or movement losses, frequently withdrawing from activities that may help them to recover. Often these beliefs in combination with psychological and social factors predate the injury and could impact the potential for recovery. For example, the development of serious back pain disability can be predicted more accurately from psychosocial factors than from structural/ degenerative changes in the spine.5 The individual’s beliefs about their condition may also be influenced by previous negative injury/surgery experiences.

As the injury/pain lingers on, these factors feed the widening discrepancy between the “real” physical losses and the patient’s perceived inability (Fig. 8.2). For some individuals there is no such gap. They may suffer significant movement losses and may feel that their body has let them down.

![Diagram](Fig. 8.1 • Cognitions, behaviours and movement control are profoundly interlaced and inseparable.)
Patients suffering from physical losses and ongoing painful conditions will often experience feelings such as disappointment, anger, frustration, grief, helplessness, loss of control and depression. Frequently, the individual will become more focused on their loss and dominated by their disability. Their identity is that of an injured self, experiencing a negative change in their body and self-image.6–8 As time passes these psychological distresses may become more entrenched, further influencing the way the individual interacts with their environment.9

These psychological factors are as important as the physical aspect of the treatment and, therefore, should be addressed during rehabilitation.

Cognitions, beliefs and attitudes

Within the professional–ethical boundaries of manual and physical therapists there are several ways in which we can help our patients to transform their cognitions about their condition. This can manifest clinically as challenging their beliefs about the condition, focusing on positive attitudes and engaging their positive coping strategies. Our management will also aim to help the patient to contain their fears, anxieties and catastrophic thoughts by reassurance as well as by empowering them to self-care.10–13 The outcome from such transformations can be reduced pain, improved movement ability, a return to more normal occupational and recreational activities, and less health-seeking behaviour.10–17

Cognition and behaviour are inseparable. Hence, change in cognitions such as fear-avoidance will influence the person’s behaviour. Equally, challenging behaviour through the introduction of safe and non-aggravating movement experiences can influence how a person perceives their condition (Fig. 8.3).

There are several ways in which to assist the patient to transform their cognitions. Providing the patient with relevant information about their condition can be part of this process.15,18,19 People who have a better understanding of their condition can be empowered to self-care more effectively and are more likely to initiate behavioural actions that challenge their fears. If we take one of the above examples, the patient with the knee condition, it was explained to him that his knee had got better within normal expected times (2–3 weeks), that the fact that he had no history of knee injury, and that such an injury does not cause osteoarthritis. This was enough to reassure him to return to judo (see also: Working with cognitions: changing the narrative, Ch. 9).

Also focusing on the “abled-self” rather than “disabled-self” can help to reassure, pointing out to the patient what they can do, rather than what they can’t do. For example, I often see in clinic patients suffering from chronic back pain who are virtually symptom-free during demanding physical activities such as gardening, playing football or even windsurfing. The focus here would be on these “abled” activities – focusing on success. This approach also has a clinical manifestation. Movement rehabilitation often starts with what the patient is able to do and later experiments with their inability – start with the possible and then tease the impossible.
Further to the focus on the cognitive aspects, we must keep in mind the quality of the therapeutic relationship. Clinical attitudes that include being attentive to the patient’s emotional state, empathic, non-judgemental, caring and encouraging, will all have important implications for their process of recovery.

Reassurance by actions: the behavioural experiment

Generally, after an injury most individuals will return to pre-injury activities in a gradual manner. They take a series of chances in which positive movement experiences embolden them to take further steps to improve the condition. However, there are some injuries where the actions a person takes result in pain and may lead to a gradual withdrawal from these activities – sometimes beyond what is required to prevent further damage. In this scenario there is a growing discrepancy between the magnitude of tissue damage and the person’s perception of their injury and, therefore, their behaviour.

One therapeutic aim is to help the patient to narrow the discrepancy between the real and perceived losses. This can be achieved by implementing what most injured individuals do naturally: gradual exposure to the task. A graded challenge is a step-wise increase in a particular activity (Fig. 8.4). This grading can be achieved by increasing the duration, repetition or intensity of the remedial activity over time (think of expanding the four movement parameters – force, length, velocity and endurance).

A gradual challenge can have several clinical manifestations. It can start in the session during examination, where the patient is guided in movement patterns which they fear. For example, a patient with non-specific chronic lower back pain may be invited to perform different trunk movements or even jump gently on the spot. For those with long-term pain, and who are particularly apprehensive, the physical reassurance may start on the treatment table, as a challenge to the trunk in different movement patterns (see DVD section on trunk rehabilitation). All these physical challenges are carried out in a graded manner, within pain-free ranges and physically possible tasks and with the support and reassurance of the therapist.

Beyond the session the behavioural reassurance is to gradually expose the patient to the very movement and tasks which they fear. The patient makes a wish-list of the exercise or activities in order of importance. If the exercise, say, is to return to tennis after a back injury, this would be set as one of the therapeutic goals. The graded challenge can start with serving a tennis ball against a wall for 5 minutes a day, gradually increasing the duration, intensity and number of serves over several weeks and so on.

It is important to involve the patient in the decision-making about the form of challenges, the scheduling of the exposure and the setting of short- and long-term goals. Goal-setting is all about working out with the patient targets that are specific, measurable, attainable, relevant and have a realistic time scale (acronym SMART).

Behavioural reassurance can have a profound influence on recovery and should not be underestimated. It was demonstrated that in chronic back conditions, pain levels and functionality can improve equally well with cognitive-behavioural approaches as with physical exercise. It seems that both approaches share similar underlying process for improvement – empowering and reassuring by reducing the levels of anxiety/fear/catastrophizing. The exercise training is a form of behavioural approach that challenges and helps to transform the individual’s beliefs about their condition and attitudes to their body ("my back can do all this, so it must be OK"). The improvements observed in patient suffering from back pain have been attributed to these cognitive-behavioural factors rather than to the physical changes in trunk associated with exercising.

Fig. 8.4 • The behavioural experiment includes a gradual increase of challenges in specific activities. The challenge is increased in a stepwise manner, widening the four movement parameters. At particular times it may be necessary to consolidate the improvements if the next step up aggravates the condition.
Clinical note

Gradual exposure and graded exercise can also help the therapist deal with clinical uncertainties. We never know exactly the level of underlying losses and how complete the recovery will be. By gradual exposure the recovery limits are not preset but established during the behavioural experiment. This also ensures that our beliefs/attitudes don’t act to disenable/disempower the patient (e.g. “returning to work or tennis will further injure your back”).

Behaviour and musculoskeletal pain

Some musculoskeletal injuries are just bad luck. However, many are acquired and to a certain extent preventable. Such injuries can be due to the way a person uses their body or the frequency or duration in performing specific tasks or movement patterns. These conditions seem to stem from within different spheres of behaviour, each requiring a unique form of management.

For this purpose behaviour can be categorized into several spheres (Fig. 8.5). There are behaviours that are associated with the interface between the person and their physical environment: the way a person bends to lift, holds a tennis racket and serves, walking patterns and so on. This will be termed here as task-behaviour. There is also the behaviour associated with the organization, sequencing and scheduling of tasks and routines. For example, how often the person is bending to lift, how often they are having breaks and so on. This will be termed here as organizational-behaviour. Another sphere of behaviour is associated with the relationships of the individual to others, which will be termed here psychosocial-behaviour. Acquiring musculoskeletal pain conditions or injuries can be associated with actions within any one of, or a combination of, these behavioural spheres.

Task-behaviour sphere

A person may develop musculoskeletal pain conditions or injury by the way they use their body in relation to their physical environment (task-behaviour). For example, chronic neck pain can develop in individuals who spend many hours with their neck flexed in positions above 20 degrees. Similarly, individuals who spend more than half a day sitting in an awkward position may develop lower back pain. Individuals who are in an occupation that involves repetitive heavy lifting may have a slightly raised incidence of lower back pain. In sports, certain landing techniques can result in knee injury. In cyclists, an unsuitable seat height or bicycle position, or improperly adjusted pedal systems, may cause various lower-limb conditions.

Within the task-behaviour sphere the aim of guidance is to improve the human–physical environment interface by either modifying behaviour itself or the environment. In the case of neck pain it might be to provide postural advice on ideal neck position or to make sure the computer screen is placed at a correct height, etc. For the cyclist, it would be readjusting the bicycle to better suit the rider.

Organizational-behaviour sphere

Sometimes injuries are related to the organizational sphere of behaviour (sequencing, scheduling and organization of a task). In this scenario a condition may be prevented or helped by a change in the scheduling and by introducing variations in the tasks. For example work-related lower back pain is associated with repetitive heavy lifting and prolonged standing. Moderate positive improvements can be achieved in the organizational-behaviour sphere by encouraging the individual to return to work early and to ask to be given light duties and breaks, and by applying gradual exposure. However, educating workers in bending
and lifting techniques (task-behaviour) does not reduce the incidence of back pain/injury.\textsuperscript{43} It seems that this condition is acquired within the organizational rather than the task-behaviour sphere.

In sport, changes introduced within the organizational-behaviour sphere may help to reduce the potential for injury. Some sports injuries are due to overuse and burnout or may be due to fatigue during competition/games\textsuperscript{39,44,45} For example, runners and other endurance athletes can develop a wide range of overuse injuries in the lower limbs.\textsuperscript{39} The management of this group of individuals should be within the organizational-behaviour sphere, by introducing breaks/rest periods to reduce fatigue/exhaustion during training and games.\textsuperscript{39,45–49} On the other hand, guidance in the task-behaviour sphere, say, focusing on kicking or running technique, may be an ineffective intervention since the condition is acquired within a different sphere of behaviour.

Management in the organizational sphere is important for patients with chronic conditions who may find themselves in a negative loop – doing too much when they feel well, so being in more pain, then having to withdraw from physical activities, to be followed by a period of doing too much to catch up with time lost during withdrawal, and so on (termed \textit{activity cycling}, Fig. 8.6). This can happen also to the “overdoers”, often athletes, who exercise to the point of failure. This group of patients may benefit from a programme that combines gradual exposure and periods of rest (termed \textit{pacing}).

Sometimes the management has to involve both task- and organizational-behaviour. For example, patients with work-related neck pain may benefit from postural advice (task-behaviour) as well as advice on breaks and coping with high work demands (organizational-behaviour).\textsuperscript{40}

### Psychosocial behaviour

In the last two decades it has become more evident that the progression of many conditions from acute to chronic state can be predicted by psychosocial factors such as low job satisfaction, low support at work, socio-economic background and psychological distress.\textsuperscript{37,42,50,51}

The psychosocial-behavioural sphere is probably outside the scope of rehabilitation in manual and physical therapies. Where such factors are evident in the case history, the patient should be referred to professionals who specialize in this area of work.

### Management in behavioural spheres: an example

A recent population study has demonstrated that work-related neck and upper limb pain is associated with repeated lifting of heavy objects, prolonged bending of the neck, and working with arms at/above shoulder height, little job control and little supervisor support.\textsuperscript{52} Of this pain, 24% was attributed to exposure to work activities and 12% to exposure to psychosocial factors. Let’s examine each of these factors and explore what the intervention might be:

1. Repeated lifting of heavy objects – unlikely to be able to change this work posture. Therefore, intervention is in the organizational-behaviour sphere. Solution: provide more frequent breaks, provide light duties or mixed tasks.

2. Prolonged bending of neck – task- and organizational-behaviour spheres. Solution: at the task-behaviour sphere, correct working posture including modifying the work station. On the organization-behavioural sphere, provide more frequent breaks and mix with alternative tasks.
3. Working with arms at/above shoulder height – as in 1.
4. Little job control and little supervisor support – this is occurring within the psychosocial-behavioural sphere and is, therefore, likely to be outside the management speciality of physical therapists.

Prevention of injury: more exercise or task-behaviour?

In regards to prevention of sports injury, several studies have demonstrated that the frequency of leg injuries can be reduced by adding a neuromuscular approach to training (a sort of functional exercising). The aim of these approaches is to modify motor control of specific joints and to improve the position of, and minimize the stress on, specific joints. They are usually a mix of two rehabilitation approaches: one focused on underlying motor abilities by introducing functional tasks, and one focused on extra-functional challenges such as running, jumping, hopping and cutting tasks. The training also consists of movement education that emphasizes proper landing and cutting techniques (management in the task-behaviour sphere). This includes advice to land on the forefoot and roll back to the rear foot, to engage knee and hip in flexion and, where possible, to land on two feet. Players are trained to avoid excessive dynamic valgus of the knee and to focus on the “knee over toe position” when cutting.

It is possible that movement education (task-behaviour) is the more important element in these training approaches rather than modifying motor control. The leg injuries often occur in healthy non-injured athletes and are, therefore, unlikely to be due to underlying motor control losses. Furthermore, the subjects are highly trained athletes who are already at peak motor performance. Many of the additional neuromuscular exercises emulate what the athletes do anyway in their sport and are, therefore, unlikely to add to their movement control during the game.

Summary points

- Cognition, behaviour and movement control are inseparable.
- Behaviour is the observable action of the individual.
- Certain beliefs, attitudes and behaviour can lead to chronicity that will affect movement control.
- Helping individuals to modify their injury behaviour and challenging their beliefs and attitudes about their condition can facilitate recovery.
- Musculoskeletal pain and injury can arise in normal individuals from habitual physically stressful or inefficient movement patterns, i.e. behaviour leading to injury or pain.
- Some injuries and pain conditions can be acquired by the way the person uses their body in relation to the physical environment (task-behaviour).
- Some injuries and pain conditions can be acquired by the way the person organizes and schedules their physical activities (organizational-behaviour).
- Helping individuals to modify their task and organizational-behaviour could help to prevent musculoskeletal injury and pain.
- Neuromuscular rehabilitation is not just about exercising.
- Movement control and behaviour can change solely by cognitive means.

References

CHAPTER 8
Cognitive and behavioural considerations in neuromuscular rehabilitation


Neuromuscular Rehabilitation in Manual and Physical Therapies


Managing non-traumatic pain conditions

While writing this chapter, I was treating a 40-year-old patient for severe neck pain and stiffness which have developed over a period of 9 years. The patient had to stop driving because she was no longer able to turn her head. She had no history of neck trauma and the neck imaging was normal. Although active movements of her neck were severely restricted, the passive range was almost full, with pain only at the extreme ranges of rotation. Her condition started shortly after starting a new computer-based job, in which she experienced high levels of psychological stress. This case represents a large group of the patients who suffer from chronic (and acute) neck and shoulder pain conditions without any history of trauma.

There are several such acquired non-traumatic conditions that are now well documented. The upper body and arms seem to be common areas for these conditions, including chronic neck and shoulder pain, trapezius myalgia, muscular jaw pain and tension headaches. Probably some of the chronic, non-specific back pains fall into the same group of conditions.

Although in different areas, it seems that many of these conditions share similar underlying processes. They are all associated with psychological-behavioural factors, and are believed to be transmitted via the motor system to various muscles, which may, eventually, become painful (Fig. 9.1).

Traditionally these conditions have not been regarded as being within the sphere of neuromuscular rehabilitation; however, they should be. These conditions have an important motor component in their development (possibly) and persistence. Neuromuscular rehabilitation that encompasses cognitive and behavioural factors may have an important role to play in their management.

From emotion and behaviour to pain

The non-traumatic pain condition is a curious entity. It was demonstrated that when a group of normal and healthy individuals is introduced to a manually repetitive task, within 6 months about a third develop a painful trapezius myalgia. This condition is further worsened if the individuals are experiencing psychological distress. Repetitive low load work and psychological distress can each be a factor that leads to the development of this painful condition. However, when combined, their effect seems to be magnified. The question is: how can pain and movement losses develop without an injury?

One of the most persistent findings is the individual’s inability to relax their muscles during and after the performance of work-related tasks, during time off work or leisure activities. During any given task there are periods when the muscles “switch off” or have very low level motor activity. These have been termed rest gaps or relative rest periods (Fig. 9.2). Generally, symptomatic individuals have overall reduced rest periods and there is a relationship between loss of rest gaps and an increase in pain levels and loss of range.
Individuals who are not in pain and who display such patterns of muscle activation are believed to be at an increased risk of developing trapezius myalgia. Lundberg, who has done much research in this area, states, “it is possible that lack of relaxation is an even more important health problem than is the absolute level of contraction or the frequency of muscular activation”.2

It seems that individuals “learn” a dysfunctional motor pattern which they habitually use during times of psychological distress or increased repetitive physical demands. The individual may be unaware that they are tensing their muscles. When these dysfunctional motor patterns become habitual they can be more resistant to change and tend to recur in the same muscle groups: the tension holding becomes autonomous (Ch. 2). The person will have to be brought back to the cognitive phase of motor learning in order to modify these patterns. The management would focus on relaxation ability using the principles of motor learning (see below and Ch. 3).

There seems to be a general trend to tense muscles in the upper part of the body and less caudally or in the limbs. Upper trapezius and frontalis were found to be the most common areas for muscle tension. This may account for the high frequency of chronic pain conditions seen in the upper body such as trapezius myalgia, chronic pain around the scapula, upper thorax and neck pain.

The inability to relax may also be present in musculoskeletal conditions where there is a history of injury. In chronic whiplash disorders it has been found that some of the muscle pain is associated with an inability to relax. This tension may be related to the traumatic nature of the injury or in response to ongoing pain.

**Changes in the muscle**

The lack of rest periods may eventually lead to muscle-fibre damage, circulatory changes and pain. Much of these changes takes place in the “slow twitch” (type I) muscle fibres, supplied by a low threshold motor unit. During muscle contraction these units are the first to be activated and the last to switch off. It means that even during low-level physical activity, psychological stress or under high cognitive demands, these units would be continuously active.

A frequent finding in biopsies taken directly from the tender points demonstrates focal muscle fibre damage, as well as grossly hypertrophied type I muscle fibres. These are all indications that the muscle fibre is under excessive mechanical stress.
and undergoing cycles of injury and incomplete regeneration (Fig. 9.4). The damage to cell membranes is associated with a release of pain-promoting substances locally and within the central nervous system (CNS).

Another important finding is of reduced microcirculation to the damaged fibres as well as indications of energy crisis within the muscle cell. This reduced flow impairs oxygen delivery and removal of metabolites in the working muscles and, consequently, will result in muscle pain.

The areas of damage are associated with an increase in pressure-sensitive points in the muscle. Repetitive activity or exercise tends to increase the pressure sensitivity and raises the level of pain. The patient often assumes that this pain is due to the muscle’s being further damaged and inflamed. However, the non-traumatic pain conditions are not considered to be inflammatory disorders. There are no inflammatory cells in the damaged muscle fibres or tender points. It only feels like that to the patient.

**Message to the patient regarding non-traumatic pain conditions**

- They are associated with only minor (but painful) changes in the muscles.
- There is low-level damage that is reversible.
- You can exercise as much as you want. It might be uncomfortable but you will not increase the damage.
- The pain is not due to inflammation. Anti-inflammatory medications are unlikely to help.

**A secondary hypersensitivity pain condition?**

Part of the experience of pain in the non-traumatic condition may be associated with a secondary hypersensitivity process. Such hypersensitivity often develops as a consequence of an ongoing experience of pain.

In essence, the longer a certain nociceptive pathway is active, the more its threshold is reduced and the more it becomes sensitized (like a well-trodden path, Fig. 9.5). It is an adaptive process; a “pain learning or imprinting” phenomenon that occurs throughout...
the CNS (often termed central sensitization). Consequently, as time passes, even minor events in the person’s life may trigger disproportionately greater pain experiences (Fig. 9.6).

Once the sensitization has taken place it is does not seem to be dependent any longer on nociception from the damaged tissue; it is now an autonomous pain condition. The pain condition now “resides” within the CNS and is more open to influence by other central processes, such as the moods, emotions and cognitions of the individual.

Managing non-traumatic pain conditions

It was once believed that patients suffering from non-traumatic pain conditions were suffering from localized muscle pathology. The therapeutic focus was in the periphery, targeting the painful muscle. The treatment often consisted of muscle stretching, massage, muscle energy technique, trying to switch off trigger points, and various forms of exercise. In my clinical experience many of these treatments have some effect, but with diminishing returns. The effects would only last for a short time; the patients remained in a chronic state of pain.

It was demonstrated that even the injection of botulinum toxin into the painful muscles (a toxin that causes muscle paralysis) has only a temporary effect lasting about 3 months. This study carries an important clinical message. The therapeutic attention should move away from treating the periphery – the muscle or the symptoms of the conditions. But where should the focus be?

In the last decade the role of psychological–behavioural processes in these conditions has became more evident (Fig. 9.7). These studies indicate that we should be focusing on these processes (“the person”) and away from treating the periphery (the muscle). A more successful clinical outcome can be achieved by workplace changes, providing the patient with a better understanding of their condition, promoting self-care and engaging the patient’s coping strategies. Within this management, the patient can be trained to relax the tense and painful areas (see below).

Working with cognitions: changing the narrative

When individuals are in pain or have an injury, their beliefs about and attitudes towards their conditions are constructed into an internal narrative. They may
contain messages that the pain is due to a serious pathological process affecting the muscles and/or joints in the neck; that the condition is permanent and non-reversible and will result in some neck movement disability. Many patients will withdraw from physical activities believing that they are inflicting further damage on their painful tissues. These attitudes and beliefs hold them back from taking positive actions that could help them to improve.

Providing the patients with an alternative narrative can help to reassure and empower them. The alternative narrative can include information about possible underlying processes associated with these conditions. They can be informed that it is not a pathological condition in the muscle, that pain is not necessarily an indication of damage and that the damage is microscopically small. Since muscle repairs and regenerates very quickly, once the causes are removed the muscle is expected to recover fully. It will not leave permanent damage, and physical activity, although painful, does not increase the damage.

Sometimes raising the patient’s awareness and bringing their attention to the sensations in their body in relation to what they feel can be helpful. Some patients believe that somehow their muscles “tense on them”. They might not be aware that they tense their own muscles and that they may be able to control the level of tension. The management aims to bring the patient’s awareness to the situations where tension rises, as well as exploring with the patient some coping strategies that would help them to relax.

Fig. 9.6 • Central sensitization in chronic whiplash syndrome. Injection of an irritant into the muscle results in wide-spread sensitivity. (From Koenbek Johansen M 1999 Generalised muscular hyperalgesia in chronic whiplash syndrome. Pain 83(2):229–234, with permission).
Working with behaviours

Several work-related factors are associated with trapezius myalgia and chronic neck pain. These include work postures that involve long periods of neck and arm use in awkward postures, particularly when the arm is used above shoulder level. Further risk factors are repetitive bending and twisting of the upper spine/neck and sedentary work for more than 5 hours a day.39,98–100

We can see from the above that preventive intervention has to be in both the task and organizational spheres of behaviour (Ch. 8). Task-behaviour is the way people use their body in relation to objects. The working posture should be assessed and advice given where risk factors are identified (if necessary patients can get themselves photographed at work using their mobile phones and bring the photo(s) to the session). Organizational behaviour was identified as the way people organize their tasks into complex routines. Minor modifications, such as the introduction of rest periods, reducing the duration of sitting and/or alternating it with other non-sedentary tasks may be helpful. Even adding physical exercise during work has been shown to have a positive effect on neck and shoulder complaints.101

During periods of stress and/or increased workload individuals may be drawn away from coping strategies that could help them to unwind and self-care. For example, sedentary workers with low levels of leisure-time activity had a higher prevalence of neck disorders.102 It is useful to identify these coping strategies and encourage the patient to reintroduce them into their routines. Unwinding can be a form of leisure activity such as – reading, sports, exercise, playing a musical instrument, meditation or yoga; any activity that brings the person “back to themselves”. Avoid imposing your own coping strategies on the patient, find out what works for them.

Mind over motor: use of relaxation ability

In the last few years the trend has been to introduce exercise to individuals suffering from chronic neck pain and trapezius myalgia, despite the finding that there are associations with an inability to relax and overuse syndrome. Very little research has been carried out to assess the therapeutic value of relaxation.103,104,105

Relaxation is a motor learning process and, therefore, practice should incorporate the five code elements for neuromuscular adaptation: cognition, being active, feedback, repetition and the similarity principle (Ch. 5).

In my experience the approach that had a major positive therapeutic effect was the introduction of “focused motor relaxation” and integrating it with the adaptation code. In this approach the patient is trained to direct relaxation to the specific painful areas. This learning can be achieved by different means: focused relaxation, contract–relax or gentle elongation to encourage letting go.

Focused motor relaxation could commence on the treatment table with the therapist palpating the patient’s neck and shoulder, focusing on areas where the patients feels pain and stiffness. Using the hands the therapist provides the patient with manual or verbal feedback, guiding the patient through a process of focused motor relaxation (cognitive element). Where tender and stiff areas in the head/neck/shoulder are found, the patient is prompted to “soften” them (active element). An immediate and continuous feedback about the state of the muscle is verbally conveyed to the patient (feedback element). Once the patient is able to relax a particular area, the therapist can move on to other symptomatic areas, carrying out...
this search-and-relax procedure. The search-and-relax procedure is repeated several times during the same and subsequent treatments (repetition element).

The contract–relax method can be added to bring awareness to muscles that patients find difficult to relax. The patient is instructed to “tense” the affected area, followed by a slow relaxation. During the slow relaxation the patient is made aware of the sensation of relaxation in the muscle. Gentle passive elongation can also be used to give a sense of length in the shortened, tense muscle. During this manoeuvre the patient can experience the “letting go”: how the muscle is relaxing and elongating. (It is not a stretching technique for the muscle.)

Missing in this approach is the similarity principle. Relaxation training on the treatment table is dissimilar to relaxation during upright posture and various upper-body tasks. It is also out of context to the place and situation in which the patient experiences the tension (e.g. work). 30 Hence, the relaxation training should be practised in the postures that are associated with the pain and tension. For example, computer users are invited to sit in the typing position (I have a keyboard in the clinic for that purpose). While the patient is writing or typing, the therapist applies the search-and-relax procedure on the neck and shoulders. Verbal and manual feedback is used to guide the relaxation process. The shoulders and neck are guided into positions that suggest the individual is relaxing (e.g. dropping the shoulders).

The patients are encouraged to transfer the relaxation experience to their daily activities: a functional relaxation. The aim is to achieve movement patterns in which there is minimal tension and optimal energy efficiency. This functional relaxation combined with biofeedback was demonstrated to increase the trapezius relative rest time during computer work. 106 This approach is akin to the relaxation-in-movement used in the Alexander method. A recent study has shown that six lessons in Alexander technique combined with exercise (mostly walking) achieved long-term improvements for back pain sufferers. 107

**Managing the painful jaw**

A similar focused motor relaxation approach can be used to manage patients suffering from muscular jaw pain (bruxism). This condition is marked by an increased clenching of the jaw and grinding of the teeth, mainly during the night, resulting in muscle pain and even in tooth and temporomandibular joint damage 20,21 Painful jaw condition is also associated with psychological stress and anxiety states and shares many of the processes seen in trapezius myalgia, including the loss of relaxation ability. 12–17,24

The same neuromuscular approach described above is used for managing patients suffering from jaw pain: focused motor relaxation using the search–relax method while palpating the different face/jaw muscles. The patient is guided to “make their jaw heavy” and “let the teeth separate”. This is combined with gentle elongation, dropping of the lower jaw. For the similarity principle the patient is encouraged to transfer the sense of relaxation to daily situations and to three key points during the night: just as they fall asleep, during the night and immediately upon waking-up (there is some evidence of nocturnal spontaneous muscle activity in patients with lower back pain and patients with chronic trapezius myalgia). 54,108

There are several focused relaxation exercises that can be given to the patient. They should remind themselves during the day to make the “jaw heavy” and to try to keep their upper and lower teeth slightly separated to prevent clenching. Another is to pronounce the sound “baaa” (not to be practised in the presence of sheep). This may seem very silly, but it encourages relaxation of the “clenchers” of the jaw. Once the jaw is relaxed the patient should be able to hold it and move it freely from side to side. This can be used by the patient to assess their ability to relax the jaw.

**A note on relaxation ability**

Patients with chronic tension headaches and lower back pain are less able to discriminate between the different levels of muscle tension at the painful area. 109 They generally overestimate low and underestimate high levels of muscle tension. For this group relaxation training for tension headache was found to be less effective. 110

Perhaps in this group of patients we should be looking at improving the cognitive abilities of introspection and discrimination?
Focused motor relaxation is not a general relaxation technique for reducing general arousal. It is a behavioural approach that aims to promote motor relaxation ability during various activities, including stressful ones.

Non-traumatic pain: the injury response and exercise

In the non-traumatic conditions the nervous system may initiate an injury response related to the individual’s experience of pain. This response is often disproportionate to the underlying damage, which is often minimal. As such, the parametric abilities and synergistic control are likely to be affected. Indeed, losses in some of these abilities have been demonstrated in chronic neck conditions. However, it should be noted that these changes are more likely to be the outcome of the condition than the cause. There is no association between low muscle strength, low muscle endurance, and reduced spinal mobility for developing neck pain (also lower back pain).

Exercise for non-traumatic pain conditions

The injury response to the experience of pain has led several groups to develop neck and shoulder exercises to overcome these control changes. Several studies have demonstrated some benefit from various forms of exercise in the reduction of the symptoms of trapezius myalgia. These include strength and/or endurance training, non-specific general exercise and specific neck exercises. Interestingly, also useful were Qigong and coordination exercises, which promote relaxation and movement efficiency. However, exercise is only of limited benefit when compared to other interventions (massage, ergonomic advice) and their effects tend to diminish over time. In order to sustain some effect, the individual would have to maintain a punishing, ongoing exercise regime.

Treating the consequences, i.e. the symptoms, may provide temporary relief, but does not solve the underlying problem – exercise by itself is not motor rehabilitation. The person will “learn” the specific exercise control, but it will not transfer to control for daily functional patterns. This is important, as it became fashionable to apply the core stability type training to the neck. This includes using “the hammer” of force and endurance to beat the system into shape. It is often accompanied by exercise that aims to modify the onset timing of the deep and superficial neck muscle using the erroneous concept of focusing on particular muscles and extra-functional movement patterns. Such approaches do not transfer to control of normal functional neck movement.

It is curious why exercise should have a positive effect for individuals who are suffering from an overuse condition and an inability to relax. Furthermore, how it is that such different exercise approaches have a positive effect? Generally, when everything seems to work, something else is happening. Probably the main reason for improvement with exercise is to do with psychological factors that include empowerment of the patient, reducing fear of use and providing a proactive coping strategy to pain. This phenomenon is seen in patients with chronic back pain, where all forms of exercise seem to be equally effective in improving this condition.

It is also possible that exercise has a modifying effect on pain mechanisms associated with central sensitization rather than eliminating the causes. Another possibility is that, exercise may bring about adaptive changes that reverse some of the damage seen in the affected muscle fibres as well as helping to re-establish normal perfusion to the damaged fibres. However, all the physiological effects of exercise are likely to be temporary if the patient stops exercising and the underlying causes are not dealt with.

A neuromuscular rehabilitation approach to neck exercise

Any exercise can be used for reassurance, including the ones described above. However, these exercises are dissimilar to normal neck movement. Most functional head movements are non-contact, whereas resistance exercises are all in contact (Ch. 2). Also the head follows our senses or leads in certain activities such as walking and turning. Hence, it might be more beneficial to challenge neck control in contact-free and goal-orientated movement.
This control can be challenged, for example, by instructing the patient to draw imaginary numbers in space leading with the tip of their nose (Fig. 9.8a,b,c). Sets of numbers from 0 to 10 can be used in different head positions (Fig. 9.8a). During the exercise the patient is instructed to relax their neck and shoulder muscles and to attempt to perform the movement as smoothly as possible. This is to account for the finding that patients with chronic neck pain tend to have more “jerky” neck movements (due to reduced coordination and synergistic abilities).129

Another exercise is to repetitively nod the head in a “Yes-Yes” (Fig. 9.8b), “No-No” (Fig. 9.8c) patterns throughout the range of rotation (see Video, part 3).

Clinical notes on passive and active approaches

So what should we prescribe to our patients, exercise or relaxation or both? A pragmatic approach is needed here. Basically, try one approach and if it does not produce the expected results, move on to another.

Generally, start with a relaxation approach and the number-counting exercise. This approach requires the least commitment of time and effort from the patient, and it can be easily applied at work or in stressful situations. This approach could be useful if the patient is suffering from high levels of pain. The active approach/exercise may be left out if the patient improves and shows signs that the relaxation approach is sufficient for maintaining the improvement (I would usually expect improvement within 3–6 weeks).

If the patient is not showing signs of improvement then use an exercise approach. This can be introduced in a gradual manner, using some of the techniques described above.

If the patient has a history of exercising, they should be encouraged to return to their sporting activities. They are also more likely to take on any exercise given by the therapist. If the patient has no such history they are unlikely to adhere to exercise. In this case the therapist may return to the relaxation option. This, of course, does not exclude the concurrent use of relaxation and exercise approaches.

Fig. 9.8 • Challenging movement control of the neck. In all the procedures the patient is instructed to relax their shoulder and neck, and to perform the movement as smoothly as possible. A, drawing imaginary numbers from 0 to 10 at the end range of rotation. B, Small amplitude “Yes-Yes” movement and C, Patient is instructed to perform repetitive, small amplitude “No-No” movement patterns at the end range.
**Summary points**

- Individuals may acquire painful musculoskeletal conditions without injury.
- Often these conditions develop in low-load, repetitive physical activities (e.g. using a computer).
- They may also develop in response to psychological distress.
- These conditions often manifest as pain and tender points around the head (tension headache), suboccipital area, neck and neck-scapular muscles (trapezius myalgia) and jaw (bruxism).
- Probably some forms of non-specific lower back pain are also associated with this group of conditions.
- All these conditions share similar processes: inability of the individual to relax, transmission of tension via the neuromuscular system to specific muscles, hypertrophy and damage of specific muscle fibres and disturbance to microcirculation, and release of pain-related substances locally.
- A secondary, central pain sensitization may play an important role in the pain experience.
- Intervention should be all-inclusive – a combination of cognitive, psychosocial, behavioural and neuromuscular approaches.
- The aim in the cognitive dimension is to reassure and empower the patient to self-care.
- In the behavioural dimension the individual should be assessed and guided in their task and organizational behaviour.
- Focused motor relaxation should be used to train the individual in how to relax their painful muscles/areas.
- Focused motor relaxation is a motor learning experience. It is not about reducing arousal.
- Transferring the relaxation to functional daily activities is important. Promote relaxation-in-movement.
- The patient’s own coping strategies are very important for reducing stress and chronic states of arousal.
- Exercise can provide temporary relief from pain. However, it has only limited and short-lasting effect.
- Pain cannot be beaten into submission! Avoid punishing exercise regimes and avoid painful manual techniques.
- Neuromuscular rehabilitation is also about motor relaxation.

**References**


[22] Pthomegroup: Managing non-traumatic pain conditions

CHAPTER 9
Managing non-traumatic pain conditions

Electromyogr Verwandte Geb


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Larsson B, Bjork J, Elert J, Lindman R, Gerdle B. Fibre type proportion and fibre size in trapezius muscle biopsies from cleaners with and without myalgia and its correlation with ragged red fibres, cytochrome-c-oxidase-negative fibres, biomechanical output, perception of fatigue, and


Neuromuscular considerations in managing individuals with central nervous system damage

A young teenager with cerebellum tumour, with loss of coordination and balance, a young sports person with partial cervical cord damage with complex movement control losses, a stroke patient who has little use of one side of the body. These patients are presenting with extensive and diverse motor losses. How can neuromuscular rehabilitation help and how would the management differ between the conditions? Would it be different from neuromuscular rehabilitation of musculoskeletal injuries?

From a movement-control perspective the main difference between patients with intact and with damaged central nervous systems (CNS) lies in the magnitude of motor losses and the potential for recovery. Central damage is associated with more extensive motor control losses, longer rehabilitation duration and, frequently, only partial recovery. However, the underlying principles of rehabilitation remain unchanged: the use of a functional approach in rehabilitation, the use of skill and ability-level rehabilitation and applying the principles of motor adaptation (Table 10.1).

The motor process in central injury

From a functional perspective CNS damage can be viewed as a processing failure and miscommunication within the motor system (Fig. 10.1). It is the incomplete and fragmented progress of the motor process from one stage to another: the organizer of movement has become partly disorganized.

Damage to the higher centres may impede the individual’s ability to perceive incoming information, analyse it, integrate the information into movement strategies and carry out a skilful action. Furthermore, under normal circumstance the spinal motor centres are under the dominant and integrative influence of the higher motor centres. Following damage to the higher centres, activity in the spinal motor centres may become disorganized, resulting in dysfunctional muscle recruitment and reflexes (Fig. 10.1).

Abilities affected

Central damage can result in complex and widely varying movement control losses. A description of all the potential damage and related functional changes is outside the scope of this book. However, the observable control changes can be analysed using the motor complexity model (Ch. 3).

In CNS damage there will be direct control losses in composite abilities, as well as synergistic and parametric abilities (Fig. 10.2). In central damage the change in abilities represents real losses, whereas in the intact system, such as in musculoskeletal injuries, the change in abilities is mostly a strategic reorganization of movement. Hence, central damage is more difficult to recover than adaptive reorganization.

Within the parametric abilities, force control is commonly affected, with either loss (hypotonic) or abnormal increase in involuntary force seen as hypertonicity. Some patients may find it difficult to “turn the muscle off,” which also represents loss of force control (Ch. 3). Interestingly,
when a stroke patient is taught how to relax the forceful reflexive hypertonic muscle, a weak voluntary force ability is often found to be underlying it. Velocity is often affected, with the patient only able to produce slow movements in a limb or during more general patterns such as walking. A change in velocity control may also manifest as a sudden loss of control at certain angles within a movement range. For example, a stroke patient may be able to move the knee into

Table 10.1 Difference and similarity in neuromuscular rehabilitation for individuals with intact and damaged central nervous system

<table>
<thead>
<tr>
<th>Factors in neuromuscular rehabilitation</th>
<th>Central nervous system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intact</strong></td>
<td><strong>Damaged</strong></td>
</tr>
<tr>
<td>Functional approach</td>
<td>Easily applied for most conditions</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive</td>
<td>Cognitive elements easily applied</td>
</tr>
<tr>
<td></td>
<td>Use external focus</td>
</tr>
<tr>
<td>Being active</td>
<td>Engages the full motor process</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td>Acuity changes, often minor</td>
</tr>
<tr>
<td></td>
<td>Feedback using verbal visual and manual guidance</td>
</tr>
<tr>
<td>Repetition</td>
<td>Varied practice with random mix of tasks</td>
</tr>
<tr>
<td>Similarity</td>
<td>Keep it similar to functional movement</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery duration</td>
<td>Weeks</td>
</tr>
<tr>
<td>Recovery success</td>
<td>Mostly full</td>
</tr>
</tbody>
</table>

Fig. 10.1 • In central nervous system damage there is interruption to the normal organization of motor processes. Under these circumstances, the lower more reflexive elements of the motor system may become more dominant.
extension while maintaining a constant velocity; at a certain angle the movement will be taken over by a fast reflexive extension. Length control often manifests as chronic dysfunctional shortening of the hypertonic muscles.\textsuperscript{11}

Various factors within movement synergism are likely to be affected by central damage. It will include failure relative force, velocity and length, timing and duration of muscle activation,\textsuperscript{12} or the dominance of one of the synergistic patterns.\textsuperscript{13} For example, the hypertonicity and rigidity during movement can be seen as uncontrolled co-contraction.\textsuperscript{13,14} Dynamic co-contraction loss can be seen in patients who can control movement in one plane, as long as they are supported bilaterally. Joint flexion contractures can be viewed as the dominance of one group of muscles over its synergistic group.\textsuperscript{9} Loss of rhythmic movement such as arm swing can be viewed as loss of reciprocal activation.

The composite abilities can be affected either directly or due to the knock-on effect from parametric and synergetic ability losses. This would include losses to all coordination levels.\textsuperscript{11,15} Loss of fine control can often be seen as the inability to manipulate objects with the hand.\textsuperscript{16} Single-limb coordination loss is often evident as the inability to control the movement at a specific joint, or to integrate it with other joints into a synchronous limb movement.\textsuperscript{17,18} Multi-limb coordination losses are often seen in activities such as rhythmic arm swinging during walking,\textsuperscript{19} where each side can be swung separately but not together. Similarly whole-body dis-coordination is evident in loss of synchronization of the different body masses during movement.\textsuperscript{10,20}

Relaxation ability is also important in rehabilitating movement control in patients with central damage. It is the flip side of motor activation: it requires motor control and, hence, may facilitate re-communication within the motor system; helping to re-establish central inhibitory influences. Basmajian\textsuperscript{21} pointed out that patients with CNS damage can fully relax their hypertonic muscles to electromyogram (EMG) silence. A potent long-term control of hypertonicity could be to teach the patient focused motor relaxation of the affected muscles (Ch. 9). For example, in one particular stroke patient, the hand and wrist were locked solid into flexion contracture over a period of 5 years. Initially, the patient’s partner would have to use all her strength to prise the hand open. Using focused motor relaxation, the patient learned to overcome this motor pattern and maintain the hand relatively relaxed and unclenched. This improvement remained unchanged and is maintained throughout the day and night (autonomous phase of learning).

Patients with central damage may present with a longer transition time when performing a variation within the same or between dissimilar tasks, e.g. the transition time to turning around during walking or from sitting to standing.\textsuperscript{22}

Balance ability/postural stability is frequently affected in CNS damage.\textsuperscript{23,24} It can arise from central balance losses or represent loss in other composite abilities, such as whole-body coordination or synergistic control in lower limb or trunk.\textsuperscript{25}

The patient’s clinical progress may not translate immediately into improvement in daily activities.\textsuperscript{23} In order to perform a particular skill several underlying abilities need to recover to a certain critical level. A patient may have difficulties in raising their hand to the mouth, although the force and speed of arm movement may have improved. This could happen if there is a lag in improvement in other abilities, such as single-limb coordination or synergistic control at a specific joint.

**Sensory-proprioceptive abilities**

Proprioceptive losses are often varied and include a reduced perception of joint position and of movement, and an inability to feel muscle activity or to determine the force used. It will also affect the more complex sensory abilities such as limb/body orientation and composite sensory ability.
The proprioceptors are still “out there”, but the centre cannot perceive them. This preservation of peripheral mechanisms of proprioception provides the potential for re-communication by the “rewiring” of alternative routes (Ch. 6).

Under normal circumstances the motor system is centrally controlled with proprioception providing feedback (Ch. 2). Following central damage, there is a loss of the dominant integrative influences from supraspinal centres. The consequence may be an increase in the influence that proprioceptors have over the lower spinal motor centres. Consequently, the segmental influence of the mechanoreceptors will become exaggerated, resulting in dysfunctional muscle activity and reflexes. Such reflex responses seem to be more prominent during passive stimulation of the limb. When the limb is actively used, these reflex influences tend to diminish, probably due to the overriding influences of the higher centres. Hence, using active movement during rehabilitation may be more useful than trying to abolish the dysfunctional reflexes.

Neuromuscular rehabilitation in central nervous system damage

The aim in neuromuscular rehabilitation is to facilitate recovery by providing movement-related cognitive stimulation and physical challenges. In response to such physical challenges the nervous system has been shown to undergo remarkable neural plasticity with related improvements in movement. This plasticity is marked by formation of new pathways by neuronal sprouting, formation of new synapses and the shifting of movement integration to non-affected parts of the brain (Ch. 6).

The treatment programme consists of the three basic principles of neuromuscular rehabilitation: functional movement (using what the patient already knows), focus on skill/ability-level rehabilitation depending on the patient’s capacity and facilitating more effective long-term neuromuscular recovery by the use adaptation code elements. Patients who have suffered substantial motor losses and who cannot perform any functional movement could be started on ability-level rehabilitation. Equally, rehabilitation should not regress to a level below the patient’s movement capacity (Ch. 11).

Using the code for neuromuscular adaptation

Use of cognition

Cognitive abilities play an important part in the capacity to learn and recover functional movement in patients with CNS damage (Fig. 10.3). Working in the cognitive dimension includes the use of attention and focus, and providing the patient (and their carers) with the understanding of the treatment goals and the principles used to achieve them. Patients who suffer cognitive losses may find it difficult to utilize these cognitive strategies and consequently a slower rate of recovery. Some of these cognitive abilities are described in Box 10.1.

Within the cognitive dimension internal and external focus is used pragmatically. The ideal is external focus on the goal of movement or overall task. This fits well with skill-level rehabilitation. However, some patients who have major movement losses may revert to using internal focus.

The ultimate aim of the treatment is to move from the cognitive to the autonomous/subconscious execution of movement. This can be achieved by adding simultaneous activities (multi-tasking) that require a different focus of attention.

Being active, feedback and repetition

The patient should be encouraged to actively perform the movement whenever possible. This will
engage all the different motor stages (Ch. 2). Active movement is ideal, but if not possible, start with assisted passive movement. In hemiplegic stroke patients, passive movements elicited some of the brain patterns seen during active movements.44

Feedback can take several forms. It can be in the form of verbal or visual guidance, by demonstrating the movement. Manual guidance can be used to assist and correct movement pattern. Intrinsic feedback (proprioception) can be stimulated by passive movement, skin rubbing, firm holding and massaging. Several studies have demonstrated that such sensory stimulation can improve the sensory and motor ability of stroke patients.45–47 However, passive forms of sensory stimulation are only likely to have a limited effect on motor learning/adaptation (Chs 2, 4 & 13). Proprioception may be enhanced by performing the movement with eyes shut. Conversely, vision can be used if proprioceptive loss is extensive.

In stroke patients repetition has been demonstrated to improve walking distance and speed, sit-to-stand tasks and the activities of daily living.48 It was demonstrated that repetition can give positive gains in performance of a task even after one day of training.49 On the first appointment I tell the patient and their carers to remember the three “Rs” – Repetition, Repetition and Repetition!50

**Similarity principle**

The patient’s own movement repertoire is used during the rehabilitation. This is in line with the functional approach similarity and context principles discussed in Chapter 5. If walking is being rehabilitated, then walking should be practised. If sitting to standing is being rehabilitated then this should be practised, and so on. This is the message that has been repeated is recent systematic reviews.51,52

Underlying abilities should be challenged within functional movement. A reaching movement can be practised at different force levels, directions, speeds and repetitions (parametric abilities), using the full cycle of the paired movement, e.g. reaching and withdrawing the arm (synergistic ability). This movement should also be integrated into other composite abilities such as multi-limb coordination or organization rate. Coordination should be practised with movements that are similar to daily activities. This should include a mixture of single-limb, multi-limb and whole-body coordination practice.53 Even balance ability should be practised in context. If walking balance is affected, balance should be practised in walking (dynamic balance) and not in standing (static balance). Standing balance may not transfer well to walking balance.24

When working with patients with low movement capacity rehabilitation might need to stray from the similarity principle. It may have to regress to ability-level rehabilitation on the treatment table or other body-support systems. However, the ultimate goal should be functional rehabilitation at skill level.

**Summary points**

- Many of the principles of neuromuscular rehabilitation can be applied during the management of individuals who suffer CNS damage.
- Both skill- and ability-level rehabilitation should be used simultaneously.
- The rehabilitation plan should contain the motor adaptation elements – cognition, active, feedback, repetition and similarity.
- Keep the training as close as possible to daily functional movement.
- Avoid complex movements that are not within the normal movement repertoire of the individual – train them in something they already know (but can’t do).
- Neuromuscular rehabilitation in central system damage is a long-term process, psychologically and physically demanding for both the patient and the therapist. Make it fun, interesting and continuously challenging.
- There is nothing like one brain to stimulate another.
References


Developing a rehabilitation programme

This chapter aims to provide a framework for neuromuscular rehabilitation using the principles of motor control and adaption.

We can learn about sensory-motor rehabilitation by observing what individuals naturally do when they attempt to recover their movement losses. Most frequently they tend to use a mixed strategy of re-ability within skill-level rehabilitation. For example, a person with a shoulder injury, after a short period of rest, will attempt to use their shoulder in what looks like a challenge to the movement parameters (parametric abilities). They will try to reach further (challenging length control), progressively lift heavier objects (challenging force control) and attempt to move faster to reach (challenging velocity control). They will tend to increase the number of repetitions of specific tasks or to sustain particular arm postures as a challenge to endurance. Within that behaviour, a person will often be aware of what is wrong with their movement and try to correct it (cognition & feedback). They will be actively seeking to improve it (being active), they will repeat the action numerous times (repetition), and these challenges will be performed within their daily routines (similarity and functional movement). This is nature’s "gold standard" for self-recovery.

Neuromuscular rehabilitation follows the same strategy. It uses three key principles:

1. Use of functional approach in rehabilitation
2. Use of skill/ability-level rehabilitation
3. Use of the code for neuromuscular adaptation.

The rehabilitation programme follows these principles using a threestep process. The first step is to identify activities from the patient’s movement repertoire which will specifically challenge their control losses. The next step is prioritizing the level at which rehabilitation will be used (ability/skill levels). Within the ability level it includes identifying and challenging specific control losses/changes. Finally, the motor adaptation elements are incorporated into the overall management.

The recovery of motor control is an intrinsic person/body process. The role of neuromuscular rehabilitation is to create ideal conditions in which this process is optimized.

A functional approach

The aim of a functional approach in rehabilitation is to utilize movements that the patient already knows rather than teaching them something new (extra-functional, see Ch. 1). The challenges to the losses are selected from the patient’s repertoire of general and special movement skills. This process of selection can be exemplified by the case study of a patient who had suffered acute peripheral nerve damage brought about by a disc prolapse. After spinal surgery she was left with a moderate foot drop. The special skills within her functional repertoire included performing music and treadmill running in the gym. The challenges for the leg and foot were selected from these movement experiences (Fig. 11.1). From the general skill level, the challenges included climbing stairs, two stairs at a time, walking on the heels or toes, balancing on the affected side, gentle forward lunges onto the affected foot or lunges initiated from the affected side. From the special-skill sphere, movements included foot tapping to music with the forefoot or heel (which she
does all day), graded running on the treadmill in the gym and so on. The alternative would be to use extra-functional challenges (for her) such as introducing a wobble board, resistance bands or exercise machines at the gym, activities of which she has no experience. Is this approach more effective and one which she is more likely to adhere to (Ch. 1)?

**Skill-level rehabilitation and re-abilitation**

The next step in the rehabilitation process is to decide whether it should be at skill or ability level. Skill-level rehabilitation aims to engage the individual in executing their losses as closely as possible to the skills which have been affected. Ability-level rehabilitation (re-abilitation) aims to challenge specific losses in motor abilities (Fig. 11.2).

Skill-level rehabilitation assumes that by practising the affected movement/skill, the underlying motor “inabilities” will be challenged and, consequently, recover. Hence, for the patient described above much of the movement control of the leg and foot would be expected to recover by the time she returns to weight-bearing activities. These functional activities by themselves, and without further modification, will help to recover these particular movement losses.

However, some patients may present with persistent dysfunctional movement control, regardless of the fact that they are active (assuming that tissue repair processes have resolved). There could be several reasons for this:

1. Cognitive/psychological factors, injury beliefs and attitudes
2. Persistent pain or fears of it
3. Behavioural factors, such as task- or organizational-behaviour factors
4. Movement reorganization to injury ending up as an habitual movement pattern
5. Reorganization/change/losses in sensory-motor abilities.
Cognition about injury and pain, persistent pain and fear of it, behavioural factors and habitual patterns are all manageable within skill-level rehabilitation. In these conditions movement control is optimized by cognitive and behavioural means (Ch. 8) and there is no need to focus on specific motor losses.

There is also a possibility that imperfect practice leads to imperfect performance, i.e. when a patient is in pain they use, and inadvertently “learn”, injury-related movement strategies. These patterns may persist even when the patients are no longer in pain. In this scenario, the rehabilitation is still at skill level, where the patient can be made aware of their movement “shortcomings”. This is movement learning in a task-behaviour sphere and would be in the form of kinaesthetic feedback, providing information about the details and “correctness” of the movement (“hold the racket this way”), the movement sequences (“swing it like this”) or the quality in performance (“good shot”).

Another possibility is that certain underlying ability losses/changes maintain the movement dysfunction (motor inability). These inabilitys could be residual elements of a control system that is still functioning in an injury mode (assuming there is no permanent and extensive tissue damage and the patient is not in severe pain). For example, the inability of a patient to execute a reaching movement (skill) may be due to local force or coordination losses in the arm (ability). A person with central nervous damage may be unable to walk normally (skill) due to losses associated with control of balance (ability).

In contrast to skill rehabilitation, at ability level, the challenges (training/practice/exercises) are specific to the underlying ability losses. In the case of balance, the therapist may challenge the patient’s balance ability while standing or walking (Ch. 12). In the example of reaching, the underlying force or coordination abilities would be challenged during the reaching movement. In both of these examples the rehabilitation is challenging the particular inabilitys within the skill level. This ensures that the treatment obeys, as closely as possible, the similarity and context principles.

It is not entirely clear why underlying inabilitys do not spontaneously recover with normal functional movement. One likely possibility is that individuals may use movement strategies that circumvent and avoid an effective challenge of their motor losses. This may be observed in a person with balance inability. They may compensate for their losses by walking with a wider gait pattern, with shorter step intervals or shuffle along. They may simply avoid or minimize activities that are related to their loss. These patients would benefit from ability-level rehabilitation, as discussed above. In contrast, skill-level rehabilitation, which would encourage the patient to increase their walking distance, may not be effective in recovering balance ability. All that may happen is that patients will become very skilled at using the dysfunctional gait patterns.

In summary, the main difference between skill- and ability-level is that skill-level focuses on the correctness of movement or task. The patient is simply encouraged to carry out the movement that they are unable to perform. It may require some task-behaviour guidance but not special treatments or specific challenges that are beyond functional movement. Re-abilitation, on the other hand, requires more specialized, focused and specific challenges that target the underlying inabilitys.

**How to choose the level of rehabilitation**

Generally, the treatments integrate skill- and ability-level rehabilitation, with the emphasis shifting between the two modalities.

Re-abilitation is rarely used outside the context of skill level. This would happen only for patients who have severe CNS damage, musculoskeletal injuries or post-surgery and who are unable to carry out any functional movement. For example, force re-abilitation may have to commence on the treatment table for a patient who cannot stand due to complete force losses in the leg. However, once the patient is able to weight-bear, the force re-abilitation should be in upright postures, i.e. re-abilitation within the context of a skill.

**Merging the adaptive code with rehabilitation**

The five elements of motor adaptation – cognition, being active, feedback, repetition and the similarity principle – should be integrated into both skill- and ability-level rehabilitation. Once a movement pattern/task has been identified as the goal of rehabilitation the patient should be made aware of its aims and focus on it (cognition). They will benefit from
the therapist’s guidance/aid (feedback). The movement should be repeated during and after the clinical session and resemble real functional patterns (repetition and similarity).

**Similarity spheres**

Similarity and context were identified as two of the key principles of motor adaptation (Ch. 5). They imply that effective rehabilitation is achieved when the training is similar to the goal task/skill. Perhaps it is important to examine what rehabilitation should be similar to. This depends on the functional repertoire of the person, the abilities affected, and which area of the body is the focus of treatment (Fig. 11.3). Hence, rehabilitation is often a combination of applying the similarity principle in these spheres:

- **Skill**
- **Ability**
- **Functional characteristics of body area.**

Skills can be divided into two broad areas. One comprises the *general skills* of doing everyday collective activities necessary for basic human needs (walk, stand, run, sit, dress, eat, etc.). The other comprises all the special activities that people undertake outside their daily actions, such as specialized occupational skills, sports, and physical hobbies (*special skills*).

Generally, treatment progresses from recovering the general skills to recovering the special skills. This sequence is used because the special skills often require a higher degree of motor control, impose greater physiological and physical demands on the body and hence involve specific and more extended periods of rehabilitation. However, it does not exclude the possibility of starting at the special skill level if the general skills have recovered prior to rehabilitation.

These considerations will have an important bearing on the design of treatment. For example, leg rehabilitation of a tennis player and an office worker will share similarities in the general skill but different in the special skill spheres. An office worker may need leg rehabilitation that will promote normal functional daily use of the leg, i.e. walk, stand, etc. A tennis player would need a similar general skill rehabilitation as well as special skills rehabilitation. The challenges would include movements that resemble the actions of playing tennis such as jumping, lunging, sudden acceleration, sudden change of direction, explosive force, etc.

Another similarity consideration is which particular abilities have been affected. At ability level, treatment should seek to be specific to the underlying inabilities (see more below). As discussed elsewhere (Ch. 5), balance losses should be rehabilitated with balance challenge and force losses with force challenge. But balance cannot be rehabilitated by force, nor force by balance.

Also important within the similarity principle is which part of the body is rehabilitated. Clinically, the functional characteristics of the different body areas can be summarized into three broad groups: upper limb including hand, lower limb and trunk including head and neck. Obviously, arms don’t do the actions that legs do. Therefore, leg rehabilitation is more about weight-bearing activities, such as balancing, walking, stepping, etc. Arm rehabilitation is more about reaching, holding, lifting, fine manipulation of objects, etc. Hence, knee rehabilitation is within the context of what a knee does, within the context of what a leg does, within the context of what the person does. This would be very different from shoulder rehabilitation, which would be executed within the context of what the person does with the arms.

This may seem like an obvious principle. However, often patients receive movement rehabilitation which is totally unrelated to the function of the particular part of the body. This includes floor exercise (core stability) for trunk rehabilitation, balancing exercise for the arm (using a Swiss ball), and lying, straight-leg rises to strengthen the leg muscle. All these rehabilitation regimes are totally dissimilar to the function and control of that particular body part.
In Table 11.1 the similarity grid is introduced as a clinical tool to help to develop the rehabilitation that is specific for their functional experience, remains close to the similarity principle and is specific to the control losses. It helps to identify the three areas of similarity that are particular to the individuals and their condition. The similarity grid should be used together with the history notes and clinical findings. It is a management and not a diagnostic tool. Copies of the similarity grid can be downloaded at www.cpdo.net/neuromuscularrehabilitation.

The similarity grid by an example

Let’s look at the similarity grid using the patient with the foot drop as an example. The patient feels that the foot is weak and unsteady in all weight-bearing activities. Her sports activities are mainly running. How can we design the assessment and rehabilitation? Using the similarity grid we can start the process by testing the underlying parametric/synergistic abilities. It was identified that control of force, length, velocity and endurance has been affected (tick the appropriate boxes on the grid, Table 11.2A). This control loss is affecting the movement pairs in the foot (flexion–extension/inversion–eversion). This loss is present in static and dynamic of the foot, implying loss of control in the two synergistic patterns (tick “co-contraction” and “reciprocal activation” boxes). As a knock-on effect she has postural instability when attempting to stand on the affected leg (tick related box). Next on the grid is the body area in focus (tick “leg” box). Finally, the losses in the leg are influencing all the general and special skills such as running (tick related boxes). By observing the grid, the management and the type of challenges are mapped out clearly (see description at the beginning of this chapter).

Let us look at another example: the young tennis player who gradually developed knee pain due to dragging his leg on the ground when side-stepping (from Ch. 5). Examination of the limb revealed no motor losses. Tenderness was found on the medial aspect of the knee and it was diagnosed as a mild strain. The pain occurs only when he is playing tennis, so we can tick the “special skills” and the “leg” boxes (Table 11.2B). The fact that the onset of the condition was gradual implies that while playing he is habitually using a pattern that may stress the knee (rather than a traumatic injury). Hence, the management will be at skill-level focusing on the task-behaviour, correcting his side-step. Yes, it can be as simple as that. What is important here is that the grid is helping to prioritize the management but also suggesting what not to treat.

Another example is to look at the grid and the patient described in Chapter 10, who is suffering from chronic neck pain. Her conditions started gradually when she started a stressful computer-based job. She had no history of head/neck trauma. On examination, she had marked reduced neck rotation (Table, 11.2C, tick “length control”) and loss of movement smoothness at the end ranges (tick “coordination” and “reciprocal activation”). We suspect from the history a loss of relaxation ability (tick box), which affects her throughout the day and during work (tick boxes). The management of this patient is described in Chapter 10.

Finally, in Table 11.2D is a description of a chronic stroke patient with mixed presentation on one side of the body: here all the boxes are ticked. This is to demonstrate the difference between managing a person with an intact and one with a damaged CNS. The general rule is that the more this grid fills up, the more extensive and complex is the patient’s condition, often reflecting central damage.
Is motor rehabilitation of the spine different for a disc injury, degenerative changes of the facet joints or non-specific back pain? Is there a difference in neuromuscular rehabilitation of a patient with medial or lateral meniscus or cruciate ligament damage? Do we need intricate knowledge of all the motor changes associated with each condition in order to treat them effectively? The answer is, probably not; which is very fortunate for all of us. This is largely due to the similarity principle. Ultimately, the body area in focus has to be rehabilitated similarly and in context to what it does functionally, regardless of the tissues involved (see similarity principle Ch. 5). Hence, neuromuscular rehabilitation of the back will be carried out in patterns that are similar to functional trunk movement during bending, lifting, pushing and standing, etc., regardless of which tissue is damaged. Knee rehabilitation will be in movement patterns that resemble knee movement during weight-bearing activities, again, regardless of the anatomical location of the injury.

The similarity principle provides us with a useful clinical short-cut: a context principle (Fig. 11.4). At the basic level of context, a joint does what a joint does. A hip, knee, ankle and foot all have their distinct physiological patterns of paired movements, such as flexion-extension, rotation etc. (motion level). At the next level of context all the leg joints move in patterns that reflect what the whole leg does (context level), within the next context level of what the person does with their legs, within their environment, e.g. stand, run, squat, climb stairs, etc.
This means that at the lower level of context, which focuses on specific joints, the rehabilitation would be unique to each particular joint to account for their characteristic function. Hence, rehabilitation that commences on the treatment table will be markedly different from knee to the hip. However, once we move up one level, within the context of the whole leg, within the context of what a person does with it, the rehabilitation is no longer specific to a single joint. The leg will be rehabilitated as a whole in some functional pattern. It means that at this level hip, knee and ankle injuries are rehabilitated in much the same way, i.e. within weight-bearing activities (see part 2 video).

**Rehabilitation and movement capacity**

Ideally, a patient should be treated or trained at a level that matches or is somewhat above, their current movement capacity. If the patient can stand, rehabilitation of the leg should be in standing. Similarly, a patient who is suffering from lower back pain should be rehabilitated in upright tasks if they able to stand and move in upright posture. In these two clinical examples, there is no therapeutic/motor control value in challenging movement at a level below the patient’s capacity. Exercising on the floor or treatment table would be below this capacity (which, unfortunately, is a very common approach for trunk rehabilitation in several physical therapies).

Is there a place for this capacity downgrading approach? It is reasoned that it is easier to train movement in a recumbent position and then transfer this experience to more complex upright tasks. Furthermore, it may help to reassure the patient that movement is safe. From motor learning and transfer perspective this is unlikely to be an effective training method (see similarity and context above). There may be some merit in a capacity-regressive rehabilitation as a way to reassure the patient that movement is OK. However, it can also convey the opposite message that movement is unsafe, especially if the patient is already able to perform some of their daily activities in upright postures.

**Beyond the session: creating a challenging environment for repair and adaptation**

Motor recovery is an adaptive and reparative process. It is dependent on the exposure of the individuals to the physical and cognitive-motor challenges that will drive this process.
This can be achieved by co-creating with the patient an environment that challenges and competes with their current state. The re-created environment should extend to their daily activities. This can be achieved by using functional movement from the patient’s daily routine or providing specific exercises that will challenge motor losses throughout the day (Fig. 11.5). This approach was exemplified in the management of the patient with the foot drop described above.

Rehabilitation that is limited to the clinic will occupy a small fraction of time within the patient’s life and will, therefore, be less effective. The lack of challenges outside the session time will compete with the adaptation environment created during the session. The winner of this competition in adaptation will be the one the patient is most exposed to.

**Summary points**

- Recovery of motor control is an intrinsic person/nervous-system process.
- This recovery is dependent on psychological, behavioural, neurophysiological and tissue-related factors. Often many of these factors are interrelated.
- The role of neuromuscular rehabilitation is to optimize the recovery of movement control, working with all these factors.
- There are thee main principles to consider in neuromuscular rehabilitation: functional movement, skill- and ability-level rehabilitation, and the code for neuromuscular adaptation.
- A functional approach promotes the use of what the patient already knows. Challenges to specific motor losses can be found within the person’s movement repertoire.
- At skill-level rehabilitation the patient simply aims to do the movements they can’t do.
- Cognition about injury and pain, persistent pain and fear of it, and behavioural factors can all be managed within skill-level rehabilitation.
- Ability-level rehabilitation (re-ability) focuses on specific underlying motor losses that prevent the person from attaining their movement goals.
- The challenges to the motor abilities should be similar and within the context of functional activities.
- The challenges should be introduced at a level that matches, or is above, the patient’s movement capacity.
- In the neurological dimension there is no injury-specific rehabilitation. An area is rehabilitated according to its function rather than to its underlying pathology.
- Rehabilitation is functional and like real-life movement. There is no need for fancy complicated stuff.
Within the motor complexity model the different motor abilities can be assessed, losses identified and recovered through specific movement challenges. The clinical process that focuses on these underlying control factors has been termed “re-abilitation”.

Before describing the various assessments and challenges for the different abilities there are several clinical considerations related to re-abilitation:

* Assessment is a process of information gathering about the movement control of the individual. The aim of the assessment is to provide a better understanding of the patient’s movement control rather than a diagnosis.
* Specific abilities can vary greatly between individuals or opposite sides of the body, even in normal healthy individuals. False positives are frequent and will contribute to clinical uncertainty. Several abilities should be assessed rather than relying on the outcome of a single assessment.
* Each motor ability can be assessed in several ways – there is no one single assessment procedure.
* In complex neuromuscular conditions, such as stroke, it may be difficult to assess all losses in one go. In these cases information is often gathered during several treatment sessions.
* Subjective responses from the patient are also important. During testing the therapist may not be aware of fine control failure. Yet the patient may report a subjective feeling of fatigue, weakness, an inability to control the movement or an inability to fully perceive the position of the limb.
* The assessments often become the challenge itself. This allows a smooth transition from assessment to challenge without presenting the patient with an endless battery of tests.
* Often the challenge is characterized by introducing variations in the intensity, duration and repetition of particular movement patterns that enhance specific abilities.

The assessments and challenges of abilities described below are provided as examples (see summary, Table 12.1). Photographs of these challenges can be found on pages 142–161. The section containing the photographs is divided into challenges to control of the lower limb, upper limb and the trunk. A demonstration of these challenges (and much more) can be found in the accompanying DVD.

There is no strict protocol governing the assessment and challenge of abilities. Every patient and their condition is different. Furthermore, most conditions tend to vary and change over time. Be creative and invent assessments and challenges that suit the present clinical situation. There is no way to remember every single assessment – there are too many possibilities!

### Parametric abilities: assessment and challenge

The four parametric abilities were identified as force, length, velocity and endurance abilities.

#### Force control

There are several factors that have to be considered when assessing and challenging force ability:

* Ability to fully relax
* Ability to produce maximal force
<table>
<thead>
<tr>
<th>Motor ability</th>
<th>Parametric abilities</th>
<th>Re-abilitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td><strong>Force relaxation:</strong> Instruct patient to let go, assess the resistance to passive movement.</td>
<td></td>
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<tr>
<td>Force relaxation</td>
<td><strong>Maximal force:</strong> Static force – patient holds a static position and resists therapist-imposed movement. Work within movement pairs (e.g. flexion–extension). Dynamic force – patient performs a cyclical task against resistance. <strong>Force grading:</strong> Patient gradually increases/decreases force against resistance.</td>
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<tr>
<td>Force relaxation: Instruct patient to let go, assess the resistance to passive movement.</td>
<td><strong>Maximal force:</strong> As assessment. Add different joint angles/limb position. <strong>Force grading:</strong> As assessment. Randomize the forces.</td>
<td></td>
</tr>
<tr>
<td>Max force</td>
<td><strong>Max length and full length:</strong> Compare passive active ranges of movement or active ranges of non-affected/affected sides. <strong>Length grading:</strong> Patient is instructed to slowly move the limb between two ranges. Look out for how smooth the movement is</td>
<td>As assessment. Change variables such as limb position, force (either dynamic or static) and velocity.</td>
</tr>
<tr>
<td>Max shortening</td>
<td><strong>Max velocity:</strong> Patient moves limb/trunk as fast as possible from one spatial position to another. <strong>Velocity grading:</strong> Movement at progressively increasing rate or alternating between fast and slow movement (tracking assessment).</td>
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<tr>
<td>Reciprocal activation</td>
<td>The ability to control local movement at a joint.</td>
<td>Pendular movement of the limbs or trunk. Observe cyclical tasks.</td>
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<td>---------------------------------------------------------------</td>
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<tr>
<td>Composite abilities</td>
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<tr>
<td>Coordination</td>
<td>The harmonious and synchronous control of two or more joints or body masses.</td>
<td>Instruct the patient to perform different tasks, observe the ability to control the movement within the same limb and in relation to other limbs.</td>
</tr>
</tbody>
</table>
| Balance and postural stability | The ability to maintain upright movement or stance efficiently and with minimal physical stress. | **Dynamic balance**: Observe tasks such as walking, walk and turn, hopping on single leg, etc.  
**Static balance**: Standing on both legs, narrow the standing base and finally single leg. | More of the assessment. |
| Transition time       | The duration needed to re-organize movement between two dissimilar tasks and to carry out the subsequent task skillfully. | **Vertical transition**: Assess transition within the same ability by rapidly alternating between two extremes, e.g. fast-slow or forceful-gentle.  
**Lateral transition**: Take two abilities such as reciprocal activation and co-contraction and instruct the patient to change rapidly between them. | Same as assessment. Once specific contraction or composite abilities improve, introduce the transition rate by mixing the contraction abilities, e.g. moving at low force and fast, to suddenly shifting to a strong force and slow movement. |
| Motor relaxation      | The ability to reduce neuromuscular activity to an optimal level necessary for maintaining a motor task or to become inactive. | Difficult to estimate during active movement.  
Sometimes postural indications, such as tensing the shoulders.  
Assess resistance to passive movement.  
Also palpate muscles during rest or during tasks (may not be very reliable assessment, consider adding contract–relax during the palpation). | Guide patient on how to relax while on the treatment table or during specific task, e.g. slowly turn your head while trying to make the neck soft. |
• Ability to grade the movement force.

Assessing force control

Relaxation ability can be assessed by instructing the patient to let go and make the limb heavy. At this point the therapist moves the patient’s limb passively while assessing the level of background resistance.

Resistance to passive movement of the neck and trunk/spine can be assessed more effectively when the patient is lying down. It assesses the resistance to movement between body masses rather than being a test for segmental or individual joint range of motion. For example, neck relaxation can be assessed by moving the head mass in counter-rotation to the thoracic mass.

Assessing muscle tension by palpation alone, although possible, can be misleading. This is partly because of the inaccuracy of palpation itself as a diagnostic tool, but also due to the fact that passive resting muscle tone can be high, although the muscle is motorically silent. One way to overcome this difficulty is to use contract–relax during palpation. The therapist can then compare the tightness (tone) in the muscle between the active and relaxed states.

Maximal force production can be assessed either in movement or in statically held positions. The test for control generally aims to encompass the movement pairs. For example, static force can be tested by instructing the patient to hold the limb in a particular position, say elbow flexed at 90 degrees. While in this position the force is challenged both in flexion and extension. Dynamic force can be assessed by instructing the patient to produce a repetitive reaching movement while providing resistance through the whole cycle of movement (challenging force within the synergistic pairs).

To test force grading control, simply ask the patient to perform the same movements but at different force levels, e.g. “try moving with the least amount of effort, try maximal effort and now try a force level in-between”. Loss in control of force grading is more obvious in patients who had CNS trauma, but more difficult to assess in individuals with musculoskeletal injuries (who have an intact CNS).

A note on force ability

Recent studies have demonstrated that functional weight-bearing exercises are as effective in improving force ability in the leg as specific knee-strengthening exercise. However, the functional group benefited a bit more – there are added improvements in balance ability (146% improvement compared to only 34% in the strength group), and a tendency to equalize muscle strength imbalances between the dominant and non-dominant legs. Apart from these obvious advantages such functional challenges can be developed in clinic and as exercise without the need for any equipment (in my clinic I have only a treatment table and patients are given only functional exercise).

Another note on force, it has generally been assumed that fatigue and metabolite accumulation is a prerequisite for strength gains, i.e. pain = gain. However, a recent study has demonstrated subjects who weight-train with sufficient rest periods between sets have the same strength gains as...
subjects who train with fatigue. This suggests that patients do not have to be put through a gruelling painful treatment to achieve force improvement (in particular if they are recovering from a painful condition).

Length control

There are several factors that have to be considered when assessing and challenging force ability:

- Full active range control
- Full active shortening control
- Grading of length.

Assessing length control

The full active range can be assessed by comparing it to the opposite side or to the passive range. Both length and shortening control should be examined when comparing the active-passive ranges of movement. Failure to actively reproduce the passive ranges may imply changes in length-shortening control of synergistic muscles. (Note: there is often a normal discrepancy between active and passive ranges, passive being greater than active range. Hence, in this assessment look out for gross differences).

Grading of length is usually a finer level of motor control. Hence, the loss of this control is more evident in individuals who have suffered CNS damage. For example, a stroke patient when instructed to gradually move the knee from flexion to extension may flick the knee into full extension, being unable to control the mid-ranges.

Challenging length control and functional stretching

An effective way to work on length control is to take the limb, trunk or neck passively to the end range. The patient is than encouraged to perform functional movements at the end range – functional stretching (see miscellaneous on DVD). For example, in the shoulder, fully flex the patient’s shoulder passively (see Fig. 12.47). Once the full range is achieved, instruct the patient to perform any functional movement, such as waving or pulling and pushing a sash window. The advantage in this approach is that both sides of the movement pairs are being retrained simultaneously – the shortening control of shoulder flexors and lengthening control of shoulder extensors (see also stretching versus length control, Ch. 3).

Velocity/speed control

The most common issues in velocity control are:

- Max velocity
- Ability to grade acceleration/deceleration.

Assessing velocity/speed control

An example of an assessment for this ability is to instruct the patient to move, as fast as possible, the affected limb between two positions marked by the therapist’s hands (see Fig. 12.46). Another speed assessment is to observe the time a patient may need to complete a simple task such as getting up from sitting, walking a certain distance or the number of repetitions that can be achieved within a given time.

Somewhat different from speed of movement is the ability to grade the speed of movement. One way to test this ability is to instruct the patient to hold their arm, touching the therapist’s hand. The therapist moves their hand in space at varying speeds while the patient attempts to track the therapist’s hand movements.

Challenging velocity/speed control

Re-abilitation of velocity control is the same as the assessment. The patient is instructed to move their limb between the two spatial positions marked by the therapist’s outstretched hands. Further challenge can be introduced by the therapist holding their apart in various positions - wider apart or in different planes of movement (see Fig. 12.46).

Endurance (neuromuscular)

Assessing endurance

Generally, endurance can be assessed by instructing the patients to perform repetitively specific tasks and looking for signs of fatigue (a gradual increase in pain and failure in voluntary activation).

The assessment of endurance can be by observing the patient perform repetitions of functional tasks such as walking, getting up from sitting, etc. It can also assess local fatigue in a limb. This type of assessment can be performed either in dynamic or static
states of the limb. For example, endurance during dynamic conditions can be assessed by instructing the patient to move their limb repetitively between two positions and note how rapidly they fatigue.

Static endurance can be assessed by instructing the patient to maintain a particular limb position, during which time the therapist applies force perturbations repetitively, in one or several directions.

**Challenging endurance**

Treatment is the same as the assessment. The challenge of endurance can be alternated between dynamic and static endurance.

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**Clinical note**

Often training involves repetition to the point of fatigue; this is believed to be a signal for muscle adaptation or even motor learning. Although repetition is an important element for neuromuscular adaptation, fatigue is not. If the patient fatigues too rapidly, they may be unable to carry out sufficient number of repetitions. This is important in situations where the re-abilitation is focused on abilities other than endurance or force, such as coordination, velocity and control of timing and duration of synergists.

Sometimes fatigue is the first or most obvious symptom of an underlying motor problem. For example, I am currently working with a patient who experiences disabling fatigue of the shoulder during swimming. He seems to have no other motor losses to the shoulder. Focusing on endurance ability has resulted in tripling his swimming distance.

### Integrating parametric and synergistic abilities

The assessments and challenges of motor abilities are for movement control rather than for the assessment of individual muscles. As was discussed previously, muscles don’t work alone but in complex synergisms (Ch. 3). It would be expected that muscle injury will result in control changes to the damaged muscle as well as all its synergists. For example, a biceps muscle injury is likely to influence the parametric control to biceps as well as all its synergists in the shoulder and elbow. Hence, the parametric abilities should be seen and challenged within the context of synergism and movement pairs (e.g. flexion/extension, Fig. 12.1).

### Synergistic control

In the section above, some ideas were put forward for assessing and challenging the parametric abilities within their movement pairs/synergies. Unique to this level of motor control are the timing and duration of activation between muscle groups (or movement pairs).

Another consideration is the ability to utilize the correct pattern of synergism for particular movement requirements.

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**Fig. 12.1** Parametric abilities should be integrated into the synergistic level, working in paired movement patterns. Avoid movements in a single direction and targeting single muscle groups.
Synergistic abilities

Co-contraction assessment

Within co-contraction there are two patterns that can be assessed:

- Static co-contraction
- Dynamic co-contraction.

To assess static co-contraction, the patient holds the limb in the position to which the challenge is to be introduced. The therapist applies perturbations attempting to move the limb/trunk away from that position. These are low force and amplitude perturbations, applied rapidly with sudden changes in the direction of movement, usually within the movement pairs, e.g. flexion–extension (see Fig. 12.46). The different movement pairs can be challenged individually, in sequence or randomly.

When co-contraction is affected the patient will be unable to “stiffen” the joint to provide adequate resistance to the imposed movements. There is a perceivable delay before the patient is able to “kick-in” with a muscle contraction to resist the perturbation; particularly during the sudden change in direction. Another common observation is that patients with synergistic control losses may attempt to increase the force of co-contraction to overcome losses in timing.

This assessment should commence at a low perturbations rate and force, gradually increasing it as the patient becomes familiar with the movement.

This test can be repeated in different joint angles and ideally in positions where failure may be suspected. For example, instability may be more evident in plantar- rather than dorsi-flexion, a position where the foot is more likely to “twist” during weight-bearing activities.

To assess dynamic co-contraction, the patient can be instructed to move their limb in one plane, say, a sawing movement with their arm. As the patient is performing the task, the therapist introduces sudden unexpected perturbations perpendicular to the direction of movement (see Fig. 12.46). If the patient has good control over this ability they should be able to successfully maintain the movement in one plane.

Challenging co-contraction

Static co-contraction challenge is an extension of the assessment described above. The assessment then becomes the challenge by introducing the repetition element and varying the movement parameters (force, velocity length/angle).

Dynamic co-contraction re-ability can have two forms. One form is as described in the test above, where the patient tries to maintain movement in one plane against sudden perturbations. Another form utilizes the phenomenon that dynamic co-contraction is more evident during fine or fast movements (Ch. 3). Hence dynamic co-contraction can be challenged by introducing fast limb or trunk movements within a narrow range. The range can be determined by the therapist’s hands. The patient is instructed to swing their limb or their trunk between these markers as fast as possible (same procedure as for reciprocal activation but faster, see Figs 12.46 & 12.61).

Clinical note

There are several conditions where dysfunctional co-contraction patterns are present (reflected in timing and duration changes). This is often seen in psychomotor problems such as muscle tensing associated with stress or in patients with CNS damage (Chs 9 & 10). In these conditions the aim is to normalize co-contraction and allow more effective reciprocal activation. This can be achieved by guiding the patient on how to relax antagonistic muscle groups during movement. (It has been demonstrated that in some patterns of movement, co-activation virtually disappears when subjects are instructed to relax at the initiation of movement). The re-ability goal is that movement which is dominated by co-activation will shift towards reciprocal activation with practice (see more in Ch. 3).

Reciprocal activation assessment

The timing of reciprocal activation is very difficult to assess in clinic. The assessment is more observational, examining the “smoothness” or quality of movement. One method of examination is to instruct the patient to perform rhythmic pendular movement of the limbs or trunk (see Figs 12.19, 12.46 & 12.61). Pendular movements are predominantly reciprocal activation recruitments that involve rapid, out-of-phase, contraction and relaxation of the movement pairs. They are, therefore, useful to assess as well as challenge reciprocal activation ability.
Challenging reciprocal activation

Any cyclical and rhythmic movement will promote reciprocal activation of the synergists. Often the inability of the patient to produce smooth reciprocal movement is due to an uncontrollable and overriding co-contraction. Sometimes this can be reduced by simply instructing the patient to relax during the movement of the limb. Control of reciprocal activation may also be influenced by the velocity of movement. The challenge can start with slow reciprocal movements, during which the patient is instructed to make it “as smooth as possible”, increasing the movement velocity as they improve.

Composite abilities

In Chapter 3 the composite abilities were identified as:
- Coordination
- Balance/postural stability
- Transition time
- Relaxation.

Coordination

There is no single way to assess coordination. Many of the tests are worked out on the spot depending on the area of the body affected. There are several coordination levels: fine control, single-, multi-limb and body coordination.

Coordination assessment

A simple way to assess coordination is to observe the quality of movement during particular tasks. Failure in coordination often manifests as the loss of smooth synchronized movement and an inability to accurately reach a target. Sometime losses in coordination are overcome by the patient reducing their movement velocity. The challenge to coordination can be made progressively more demanding by increasing the rate or the complexity of movement.

Upper limb (as an example)

Fine control in the hand can be assessed by instructing the patient to approximate the thumb and the fingers in different sequences, manipulate an object such as a pen between the fingers, or to simply write numbers or join dots on paper.

Single-limb coordination can be assessed by instructing the patient to alternately touch with their index finger two reference points, such as their other hand and the therapist’s hand. To increase the challenge, this assessment can be performed at a progressively faster rate or by continuously changing the reference points. This is done by the therapist’s moving their hand to different spatial positions. Another simple test is for the patient to touch and follow the therapist’s hand as it is moving in space (see Figs 12.20 leg and 12.54 trunk; for arm see DVD).

Multi-limb coordination tests essentially examine the patient’s ability to use the arms simultaneously and synchronously during specific tasks. It can start as a simple test to see if the patient can swing their arms as if walking, passing an object between the hands to more demanding tests such as tracking with both arms the movements of the therapist’s hands.

Whole body coordination can be assessed by observing the patient performing whole body daily tasks such as walking into the room, getting up from sitting, dressing, etc.

Challenging coordination

Re-abil-tation of coordination at all levels is the same as the assessments described above.

Balance and postural instability

Balance assessment

Balance should be tested both while standing (static) and during movement (dynamic).

Static balance can be assessed by progressively narrowing the standing base in order to increase the demand on balance control; starting with feet apart, side-by-side, one foot directly in front of the other and eventually standing on one leg. Further balance challenges can be achieved by balancing on the ball of the feet, closing the eyes or drawing an imaginary number with the non-weight-bearing leg (see Figs 12.36–12.39). In this assessment, look out for the time spent on one leg, and how demanding the balance for the weight-bearing foot is. Fine-balance deficit may only become apparent as the base becomes smaller and vision is reduced.17

Dynamic balance assessment can take several forms. The most immediate is to observe the patient perform activities such as walking across
the room, walking around the table, climbing stairs, etc. There are several indicators when dynamic balance is affected such as use of broader walking base, the time spent on the affected side (shorter duration), a shuffled walk (not raising the feet to clear the ground), taking small steps and unusual body sway (some of these findings may also represent other motor control losses).

The single leg balance described above also can be turned into a dynamic assessment by instructing the patient to hop on one leg. Forward-backward, side-to-side and diagonal skipping can be added to further challenge dynamic control.

Most of the tests described above for balance are initiated and performed by the patient. As such this challenge is expected and the patient has sufficient time to organize for it (in anticipated tasks there is motor organization before the movement commences, a “feed-forward” phenomenon). However, in real life situations there are unexpected events that challenge balance, such as tripping or being jostled by others. Often, patients with balance deficits may find it difficult to meet such challenges since there is no anticipatory postural adjustment. The patient has, therefore, to rely on their transition time (which is a mixture of reaction and movement time).

Unexpected challenges that resemble real life situations can be introduced during the balance tasks. The therapist can stand behind the patient and introduce small amplitude perturbations (pushes) in different directions. These challenges can be introduced during static balance or during walking; in particular during the stance phase of the gait cycle of the affected limb (see Fig. 12.38).

Patients who have central balance losses can also be assessed in unsupported sitting. When gently jostled there may be a small but observable delay before they are able to correct their sitting position. I have occasionally observed this in elderly patients suffering with mild CNS degeneration. This sometimes can help to differentiate problems of motor loss affecting the legs from those that are centrally mediated.

Challenging balance/postural instability
Challenging balance is an extension of the assessments.

Transition time
Transition time is the ability to rapidly and smoothly organize movement from one particular action to another. This can be within a single ability (vertical transition time), such as alternating between fast and slow movements or between any two abilities or tasks (lateral transition time). This can be assessed by introducing sudden, unexpected changes to the movement.

Transition time assessment
A vertical assessment of transition can be the observation of the patient’s capacity to perform two extremes of a single ability. For example in force control, to quickly alternate between full relaxation and maximal contraction, in speed control the capacity to alternatively produce slow and fast movements, such as in the arm tracking challenge.

Transition time can be also assessed by introducing sudden changes in the direction and range. For example, in the test where the patient has to move their arm between two spatial positions (see above speed ability), the therapist can introduce sudden changes in the distance between, or the position of, the two hands.

Transition time assessment in balance ability could be to alternate between dynamic and static balance, for example quickly walk then suddenly stopping and balancing on a single leg.

Transition time can be assessed by instructing the patient to perform two different tasks, such as observing the time it take sitting to standing, etc. (it also requires other abilities such as speed of movement). It can also be assessed by instructing the patient to alternate between two abilities, such as reciprocal activation and co-contraction. For example, the patient could start by tracking with their arm the therapist’s hand. At particular positions the therapist suddenly stops and the patient has to maintain that position while the therapist applies the co-contraction challenge described above. Failure often manifests as a delay in organizing the stiffness (co-contraction) needed to overcome the perturbations.

Occasionally it may be possible to estimate reaction time. For example the patient, while sitting on the treatment table, is instructed to maintain their knee flexed at 90 degrees. The therapist applies a force to flex the knee against the patient’s resistance. The therapist suddenly removes their hand but the patient has to maintain the knee position (at 90 degrees, without overshooting into extension). The extent to which the patient can maintain the original flexed position provides a rough estimate of the reaction time.
A variation of the reaction time element is to instruct the patient to simultaneously tap both their hands on the therapist’s hands. The therapist surprises the patient by continuously changing the position of the hands, which the patient is trying to follow. How well the patient is able to follow the sudden change of position can provide some assessment of their reaction time.

Challenging transition time

The challenges are an extension of the assessment described above.

Vertical and lateral transitions are often mixed during the re-abilitation. This can be exemplified in treating the hand of a CNS-damage patient. At first, work with each contraction ability separately (vertical transition); moving the thumb at different speeds, and forces. Once these specific abilities improve, introduce the lateral transition rate by mixing the contraction abilities, e.g. instructing the patient to move the thumb slowly and fast, to suddenly shifting to a strong force and slow movement, etc.

Motor relaxation

Psychomotor relaxation assessment and challenge

This ability can be difficult to fully assess. Often the diagnosis is made from the case history, particularly in pain conditions where there is no history of physical trauma. Otherwise the assessment and challenge of this ability is similar to those described for force relaxation ability described above. Motor relaxation training was discussed in Chapter 9. For discussion on differences between force relaxation and motor relaxation see Chapter 3.

Summary points

- Re-abilitation is the process of assessing and challenging specific motor abilities.
- The aim of the assessment is to provide a better understanding of the patient’s motor abilities. It is a process of information gathering.
- Specific abilities can vary greatly between individuals or opposite sides of the body, even in normal healthy individuals.
- Abilities can be assessed in many different ways.
- Many of the assessments often become the challenge itself.
- The challenge is often characterized by introducing variations in the intensity extent (length), duration and repetition of particular movement patterns.
- There is no strict protocol for re-abilitation. Be creative and invent assessments and challenges that suit the situation.

References


### Demonstration of challenges

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**Note** Some procedures are difficult to demonstrate in still photography, and are therefore only demonstrated on the DVD. Each procedure challenges several underlying abilities, for example, the hip procedures in standing can be used to challenge trunk balance and coordination. All the challenges should be graded, with an incremental increase in the four movement parameters (force, velocity, length/range and endurance).
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Reciprocal activation challenge for the leg and hip. Introducing continuous variations in planes of movement and length control. The practitioner starts with simple repetitive patterns and graded, by increasing the velocity of movement, position of, and the distance between the hands. This procedure also challenges single-limb coordination.

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Demonstration of challenges: upper limb

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**Fig. 12.45** • Reciprocal activation and force challenge to the shoulder and arm in the lateral plane (A & B) and (C) AP planes.
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Demonstration of challenges: the trunk

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**Fig. 12.50**  Co-contraction challenge of the trunk in the AP plane. The patient attempts to keep their trunk and legs in line against AP forces applied at the ankle. This challenge can be performed with the legs straight or with the knees slightly bent which tends to reduce the leverage and forces on the lower back.

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Fig. 12.55 • Co-contraction and force challenge to the trunk in rotation. The patient resists the turning force applied by the practitioner.

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Fig. 12.59 • Dynamic co-contraction control. Patient moves their arms and trunk in the AP plane (flexion–extension), during which the practitioner applies lateral perturbations.

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Fig. 12.61  •  Reciprocal activation, trunk in AP plane. The patient swings their arms between the two positions marked by the practitioner’s hand. It is important that the patient keeps their elbows locked in extension. This will ensure that the trunk is recruited to a greater extent in the movement. When working with patients who suffer from back pain the movement should be in ranges that are pain free. The range can be increased as the patient’s condition improves. Often changes in the range can be seen within a few cycles during the session.

Fig. 12.62  •  Reciprocal activation, trunk in lateral plane. Same procedure as in Fig. 12.61. A transition time challenge can be introduced in all this group of procedures by the introduction of sudden changes in the length or plane of movement.
Fig. 12.63 • Reciprocal activation and force control of trunk in the AP plane. The patient pulls and pushes against varying levels of resistance provided by the practitioner.

Fig. 12.64 • Reciprocal activation and force control of the trunk in the lateral and rotational planes. Same procedures as in Fig. 12.63. In this group of procedures a transition time element can be added by introducing a sudden change in the resistance force provided by the practitioner.
The recovery of proprioceptive ability is a combination of repair and adaptation of the mechanoreceptors and their central representation as well as the repair and adaptation of the tissues in which the receptors are embedded (Ch. 4). These are intrinsic processes that are greatly facilitated and optimized by active movement. All of the motor challenges described in Chapter 12 will also stimulate proprioception.

However, some patients may be unable to execute active movement and may, therefore, require passive forms of proprioceptive stimulation. This chapter will explore ways of assessing and facilitating proprioception recovery.

### Sensory ability: assessment and challenge

The sensory complexity model discussed in Chapter 4 can be used as a framework for assessing and stimulating proprioception. Three levels of sensory ability were identified:

- Primary proprioceptive ability (position, movement and effort sense)
- Spatial orientation
- Composite sensory ability.

The assessment of composite sensory ability is outside the scope of this book; therefore, the focus will be on proprioception (see Table 13.1 for summary of proprioceptive assessment).

### Assessing position and movement sense

All the tests described below should be done with eyes closed (the patient!).

#### Position sense

This can be assessed by matching the position of the unaffected side to the affected side. For example in the knee, the patient sits with knees flexed at 90 degrees. The practitioner passively moves the affected lower leg to a new angle (the subject has to completely relax the leg). The patient has to match this position with the unaffected leg (Fig 13.1). If only the affected leg is available for testing, the practitioner can move the joint to a specific position. The patient has to remember this position and then actively recall it after the practitioner moves the joint to a different position (see DVD, Part 4 sensory assessment).

This assessment bypasses the sense of effort. It might be worth trying the same test but with the patient actively moving the affected leg to a particular position and then matching it with the unaffected leg. This would resemble a more real-life situation where proprioception is engaged during active movement (to include the sense of effort).

#### Movement sense

The therapist moves the affected limb slowly while the patient attempts to mirror the movement with
the unaffected limb (same procedure as in Fig. 13.1 but the movement is more continuous, see DVD, Part 4 sensory assessment).

If only the affected limb is available for testing, the therapist can move the patient’s limb passively within the movement pairs, e.g. flexion or extension. The patient has to identify in which direction the joint is moving.

### Spatial orientation

The patient’s eyes are closed.

**Assessment**

This ability can be assessed by creating two target points: one static and the other moving.
For example, the dynamic target could be the patient’s nose, and the static target point the practitioner’s index finger (Fig. 13.2, see DVD, Part 4 sensory assessment). The patient is instructed to touch these two reference points repeatedly with their index finger. The assessment can be made more challenging by instructing the patient to slowly rotate their head during this procedure. Look out for accuracy in reaching the targets and the speed of movement. In this assessment the patient has to build up a spatial map of the position, distances and directions of the limb in relation to the trunk and other limbs.

Another test is to hold the patient’s unaffected arm and move it slowly in space in different directions. At the same time the patient has to actively follow and replicate these movements with the affected arm.

### Challenging the feedback

The challenging of proprioception is somewhat different to the assessment described above. The challenge can take several forms:

- Any exercise or active movement of the affected limb
- Increasing the afferent stimulation by passive manual approaches
- Reducing the visual feedback.

Any exercise or active movement will stimulate proprioception. This is by far the ideal way to challenge and help proprioceptive recovery. This issue has been discussed at length in Chapters 2 and 4. The next options, passive stimulation and reduced visual feedback, should be used if the patient is unable to execute active movement. Some patients
who have a limited ability to execute movement may benefit from the alternate use of passive and active movement.¹

Manual passive approaches

Generally, passive manual techniques will stimulate proprioception without engaging the efferent and motor elements of the system.

Various groups of proprioceptors will be recruited by different manual techniques.² For example, skin mechanoreceptors can be maximally stimulated by dynamic events such as massage and stroking. Maximal stimulation of joint receptors can be achieved by articulation techniques such as cyclical rhythmical joint movement or oscillation. Proprioceptive stimulation in muscles can be achieved by rhythmic cyclical stretching. Alternatively, the patient can be instructed to contract isometrically while the therapist introduces rhythmic perturbations to the limb. Generally, active–dynamic techniques produce the largest proprioceptive barrage; second to these come passive–dynamic techniques. The influence of the different techniques on proprioception is summarized in Figure 13.3.

Passive manual proprioceptive stimulation may have a role in sensory rehabilitation of severely disabled individuals who are unable to initiate voluntary movement. In healthy individuals, passive stimulation was shown to drive adaptation in the cortical areas involved in preparation and execution

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**Fig. 13.3** • Summary of the effects of different physical stimulation and the related manual-therapy techniques on proprioception. Shaded circles represent the extent of receptor recruitment.
of movement. A similar finding was demonstrated in patients who had motor hemiplegia with severe motor deficit. This study demonstrated that 4 weeks of proprioceptive training (daily passive motion to the affected wrist), together with standard rehabilitation, promoted further adaptation in sensorimotor centres. However, it is not clear how well this central topographical reorganization translates into improvement in proprioception or motor control.

Proprioception vs. vision

One way of directing attention to proprioception is to instruct the patient to shut their eyes while exercising. It was demonstrated that when subjects learn to balance on a beam, those blindfolded had developed better balance ability than subjects who trained with partial or full vision.

However, when this ability has to be transferred to another movement situation, the source of sensory information during the training is not as important as the similarity between the two tasks (see similarity principle Ch. 5).

Summary points

- Proprioceptive abilities can be assessed by using the sensory complexity model.
- Proprioceptive losses following musculoskeletal injuries can be very small and not detectable by clinical examination.
- Active movement is more effective for stimulation and recovery of proprioceptive losses.
- There are no specific proprioceptive exercises. All exercise will engage the full motor system including proprioception.
- Passive, proprioceptive manual approaches should only be used in the severely disabled individual with severe motor losses.
- Exclusion of vision during movement will drive attention to proprioception.
- The message to the patient with proprioceptive losses: “keep on moving”.

References

Neuromuscular rehabilitation: summary

- Neuromuscular rehabilitation aims to help the individual to recover their movement control and optimize their functional capacity.
- It is an inclusive approach that encompasses the cognitive, behavioural and neurophysiological dimensions of the individual.
- The rehabilitation promoted in this book has three basic recurring concepts:
  - It aims to be functional
  - It involves skill/ability-level rehabilitation
  - It uses the learning/adaptation code to optimize motor control changes.

Functional rehabilitation

- *Functional movement* is the movement repertoire of an individual.
- Movement which is out of the individual’s experience is termed *extra-functional*.
- Functional rehabilitation utilizes the patient’s own movement repertoire to help them to recover their movement losses. It uses actions the patient is already familiar with but can’t carry out.
- Extra-functional movement requires a period of learning/training and is, therefore, not ideal for individuals who are in pain or recovering from an injury.

Skill/ability-level rehabilitation

- Neuromuscular rehabilitation can be within a skill and/or ability level.

- Skill is how proficient a person is in performing a particular task.
- Skill depends on practice and a mixture of the sensory-motor and cognitive abilities of the individual.
- Motor abilities are the various control factors that underlie movement.
- At skill-level rehabilitation the patient simply aims to carry out the movements they are currently unable to complete.
- Ability-level rehabilitation (re-abilitation) focuses on specific underlying motor losses which prevent the person from attaining their movement goals.
- Cognition about injury and pain, persistent pain and fear of it, and behavioural factors, are all manageable within skill-level rehabilitation.

The code for neuromuscular adaptation

- Learning, retraining, motor organization to injury and return to functionality depend on the capacity of the motor system to adapt.
- These adaptive processes can be optimized by introducing five principal elements: cognition, activity, feedback, repetition and similarity.
- Cognition involves thinking, rationalizing, memorizing, focusing, being attentive, deciding on actions and understanding the aims and goals of the rehabilitation process.
• Being physically active is important for neuromuscular adaptation. Passive movement approaches are unlikely to be effective in promoting lasting and functional motor control changes.
• Feedback can be intrinsic from proprioception or extrinsic as guidance from the therapist.
• Repetition, repetition, repetition – practice is very important for long-term memory.
• Rehabilitation should use movement patterns that are similar to, and within the context of, the movement being recovered.
• Experiences that possess a higher content of adaptive code elements have a greater potential for promoting long-term changes.

**Motor abilities**

• Motor abilities can be classified according to their level of motor complexity: parametric, synergetic and composite abilities.
• Parametric abilities are: force, velocity/speed/rate, length, endurance.
• There are two identifiable synergistic control patterns: reciprocal activation and co-contraction.
• Composite abilities are: coordination (fine, single- and multi-limb, and body coordination), balance/postural stability, transition time and motor relaxation.
• Motor ability changes can be observed in musculoskeletal injuries and pain conditions and in patients suffering from central nervous system (CNS) damage.
• There is evidence that motor abilities can be normalized by activities that challenge them specifically.

**Sensory ability**

• The sensory-motor system is a functional unit.
• Proprioceptive acuity can be affected due to peripheral and/or central causes.
• Musculoskeletal injury can affect the peripheral proprioceptive apparatus while CNS damage will affect the central processing of proprioception.
• Recovery of proprioception comprises both reparative and adaptive processes. As such, it may have its own inherent recovery period that may take several weeks or months to complete.
• Promoting normal functional movement will help proprioception by facilitating positive sensory-motor reorganization/adaptation. There is no need to specifically target proprioception.
• All exercises are proprioceptive exercises.

**The motor system in musculoskeletal injury**

• The motor reorganization following injury is a multi-dimensional strategy culminating in postural and movement reorganization aimed at reducing the mechanical stresses imposed on the damaged tissues – in this text it is referred to as the *injury response*.
• The injury response is a positive healthy response and not a motor dysfunction or pathology.
• Acute musculoskeletal injuries should be left alone – the body knows best. The patient should be encouraged to keep active.
• Neuromuscular rehabilitation is useful when the injury response serves no obvious protective function. It includes:
  • Conditions where the injury response has become an adaptive state, such as in chronic recovery from injury or surgery, or conditions where there were movement constraints or immobilization
  • Sensitization conditions where tissue damage has resolved but the patient still experiences pain
  • Injury-related psychological distress that leads to “psychomotor” control losses.
• In the neurological dimension there is no injury specific rehabilitation. A body area is rehabilitated according to its function rather than to the underlying pathology.

**Cognition and behaviour**

• Cognition, behaviour and movement control are inseparable.
• Helping individuals to modify their injury behaviour and challenging beliefs and attitudes about their condition can facilitate motor recovery.
• Some injuries and pain conditions can be acquired by the way the person uses their body in relation to the physical environment (task behaviour), or by the way in which the person organizes and schedules their physical activities (organizational behaviour, often overuse injuries).
• Guiding individuals in how to modify their task and organizational behaviour could help to prevent musculoskeletal injury and pain.
• Movement control can change solely by cognitive means.

Non-traumatic pain conditions

• Individuals may acquire painful musculoskeletal conditions without traumatic injury.
• Often these conditions develop in low-load, repetitive physical activities (computer use) or in response to psychological distress.
• These conditions often manifest as pain and tender points around the head (tension headache), suboccipital area, neck and neck-scapular muscles (trapezius myalgia) and jaw (bruxism).
• All these conditions share similar processes – inability of the individual to relax, transmission of tension via the neuromuscular system to specific muscles.
• Intervention should be all-inclusive – a combination of cognitive, psychosocial, behavioural, organizational and neuromuscular approaches.
• Focused motor relaxation should be used to train the individual how to relax their painful muscles.
• Transferring the relaxation to functional daily activities is important. Promote relaxation-in-movement.
• The patient’s own coping strategies are very important for reducing stress and chronic states of arousal.
• Neuromuscular rehabilitation is also about motor relaxation.

Damaged central nervous system

• Many of the principles of neuromuscular rehabilitation can be applied to managing individuals who suffered CNS damage.

Further thoughts on motor recovery

• Recovery of motor control is an intrinsic person/nervous-system process.
• This recovery is dependent on psychological, behavioural, neurophysiological and tissue-related factors. Often many of these factors are interrelated.
• The role of neuromuscular rehabilitation is to optimize the recovery of movement control, working with all these factors.
• Rehabilitation is more about facilitating cognitive-sensory-motor processes by providing a stimulating and variations-rich environment. It is not just exercising.
• The movement challenges should be introduced at a level that matches or is above the patient’s movement capacity.

Finally

• The only clinical certainty is uncertainty – don’t fight it, learn to work with it. You will never know all the answers but you will be expected to provide expert care.
• Complexity rules! Don’t become lost in the labyrinth of the neuromuscular system; look at the whole, not at minute details.
• Neuromuscular rehabilitation is a creative process; it is not protocol-based. Every patient is different and presents with new challenges. You will forever have to problem-solve on your feet.
• Think movement not muscles.
• There is nothing like one brain to stimulate another.
• Make it fun, interesting and continuously challenging.
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