Often patients with spinal cord injury are unable to perform motor tasks because they lack skill. That is, they do not know how to move optimally with their newly acquired paralysis. For example, rolling in bed is initially difficult for a patient with high-level paraplegia. An inability to roll is rarely due to lack of upper limb strength or poor joint range of motion; more often it is due to an inability to swing the arms rapidly across the body while lifting the head. The task is novel and must be learned. Some motor tasks are within themselves novel, such as performing a wheelstand. They also must be learned.

The learning of novel motor tasks by patients with spinal cord injury is analogous to an able-bodied person learning an unfamiliar sport such as tennis, golf, or swimming. The patient, like the sports person, is unable to roll in bed or perform a wheelstand because the task requires novel patterns of muscle activation. Physiotherapists can help patients master novel motor tasks in much the same way as sports coaches can help athletes learn new sporting skills.

Motor control and motor learning

The importance of training motor tasks for patients with neurological disabilities was first advocated by Carr and Shepherd as part of their 'Motor Relearning Approach', and later by Shumway-Cook and Woollacott in their ‘Task-Oriented Approach’ (also called the ‘Systems Approach’). These approaches are based on theories about motor control and motor learning and primarily developed for the physical rehabilitation of patients with stroke and brain impairments.

The mechanisms underlying motor control and the acquisition of motor tasks are complex and not fully understood. A range of paradigms, each with their own theories, have been used to explain motor control and motor learning. Two key theories which have influenced neurological physiotherapy are Bernstein’s 'motor schema theory' and Fitts and Posner’s three key stages of motor learning. These theories have primarily evolved from research with able-bodied individuals and athletes,
but arguably are equally applicable to patients with spinal cord injury. They are important because they help explain how patients with spinal cord injury learn motor tasks and how physiotherapists can best facilitate the learning process.

The ‘motor schema theory’ is based on the premise that control strategies are matched to the specific context of motor tasks. There are an infinite number of contexts for the performance of motor tasks, so it is not possible to learn separate motor strategies for all the possible contexts. Instead, it is proposed that motor tasks are largely controlled by motor schemas. Motor schemas provide a background programme or code which dictates the timing, order and force of muscle contractions. They are like basic building blocks which dictate the general rules for movement. Once motor schemas are set down, motor tasks can be performed with a certain degree of automaticity. This enables people to perform motor tasks while concentrating on other mental or physical activities. It also explains the skilled performer’s ability to perform a motor task very rapidly when there is little time to rely on feedback mechanisms. Motor schemas can be modulated to accommodate variations in speed or the precise way motor tasks are performed. Patients with spinal cord injury are initially unable to perform novel motor tasks because they do not have the necessary motor schemas. New motor schemas are required to code how, when and in what way non-paralysed muscles need to contract for purposeful movement.

Fitts and Posner proposed that motor tasks are learnt in three key stages. These are:

1. **Cognitive stage.** During this time people attain a general understanding and ‘cognitive’ map of the overall motor task. People use trial and error to gain an approximation of the motor sequencing. Attempts at movement are associated with excessive effort and unnecessary muscle contractions. Visual feedback and other sensory cues are particularly important during this stage.

2. **Associative stage.** Refinement of the motor task occurs at this point. The movement is performed in a more consistent way and unnecessary movements are progressively eliminated. People are increasingly attentive to proprioceptive cues which refine how movements are performed.

3. **Autonomous stage.** In this stage movement becomes more automated, requiring less effort and concentration. There is little error and little unnecessary associated movements. The skill can now be successfully performed in varied environments and does not require ongoing practice to maintain competency.

# Principles of effective motor task training

The training of motor tasks in patients with spinal cord injury relies on physiotherapists’ problem-solving skills and their understanding of how patients with different patterns of paralysis move (see Chapters 3–6). Initially, physiotherapists need to identify the motor tasks which patients can hope to master (such as rolling, sitting unsupported, moving from lying to sitting, transferring or walking; see Chapter 2). This is formally done through the goal planning process. Patients are asked to perform these tasks and their attempts at each motor task are then analysed. The aim of the analysis is to identify which sub-tasks patients can and cannot perform, and determine the reason why patients cannot perform specific sub-tasks. The reason for failure to perform a sub-task needs to be expressed in terms of one or more impairments (usually lack of skill, strength, joint mobility or fitness). When lack of skill is the primary impairment, physiotherapists need to teach patients appropriate movement strategies. This chapter focuses on how physiotherapists can train important motor tasks which need to be learned by patients with spinal cord injury.
The importance of practice

A key feature of learning motor tasks is intense, well structured and active practice which is task- and context-specific. Task- and context-specific practice implies practise of precisely the task which needs to be learned. For example, patients with the potential to stand need to actively and intensely practise standing and patients with the potential to transfer need to practise transferring.

The practice of motor tasks, such as walking or transferring, can be difficult for patients who are at the early stages of rehabilitation and are unable to successfully perform any aspect of the task. There are two solutions. One is to provide sufficient manual assistance, supports or aids to make completion of the task possible. For example, a patient with insufficient strength in the knee extensor muscles can practise walking with overhead suspension, robotics, electrical stimulation or orthoses. Alternatively, a physiotherapist can manually support the knee in extension during stance. The second solution is to devise training drills which are ‘similar but simpler’.

The ‘similar but simpler’ approach

The ‘similar but simpler’ approach requires breaking complex motor tasks into sub-tasks and practising each individually, if necessary in a simplified way. Sub-tasks are progressively made more difficult as patients master them. Sub-tasks are then practised in an appropriate sequence until the whole task is mastered.

For example, a patient with C6 tetraplegia may be unable to move from lying to sitting because of an inability to bear and shift weight through the elbows in an awkward side-lying position: an essential sub-task of moving from lying to sitting (see Figure 7.1a). The patient may benefit from practising bearing and shifting weight in the same awkward position but with the elbows supported on a higher adjacent bed (see Figure 7.1b). Alternatively the patient may benefit from practising bearing and shifting weight in a prone position (see Figure 7.1c). In both instances the patient practises a motor task which is similar but simpler to the original sub-task. If patients are in the very early days of rehabilitation and unable to do either of these exercises, they might practise an even simpler variation, such as sitting in a wheelchair leaning through elbows placed on high adjacent beds (see Figure 7.2b). The
height of the bed can be adjusted to increase difficulty. These exercises are directed at improving patients’ ability to bear weight through the elbows because this is an essential sub-task of moving from lying to sitting.

If the same patient was unable to transfer due to an inability to lift and shift weight forwards and laterally (see Figure 7.2a), therapy would consist of simplified drills and exercises to address this specific sub-task of transferring. For instance, the patient could practise lifting through fully extended elbows while sitting on a plinth. Small blocks could be placed under the hands if this made the task easier for the
Figure 7.2  A patient with C6 tetraplegia unable to transfer between a wheelchair and bed (a) may benefit from practising a ‘similar but simpler’ task, as seen in (b) and (c).
Figure 7.2  Continued

A similar process is followed for patients with more advanced skills. For instance, a patient with thoracic paraplegia unable to perform difficult transfers in community settings might benefit from practising a similar but easier transfer between two physiotherapy plinths (see Figure 7.3). The transfer training concentrates on the particular sub-task which the patient is having difficulty with.

The principles are the same for training other motor tasks such as gait, moving from sitting to standing, or upper limb function for patients with different types of spinal cord injuries. For instance, a patient learning to walk with a reciprocating gait orthosis who is unable to swing the leg may benefit from practising the swing motion while standing one-legged on a block with the swing leg free to move. A patient learning to get from sitting to standing may benefit from initially learning to stand from a higher chair. Training of tenodesis grip might start with lifting and holding large light objects, and then progress to lifting and manipulating small heavy objects.

Regardless of what task is being trained, physiotherapists need to work backwards from the functional goal. Physiotherapists must identify the sub-tasks which patients are unable to perform and then devise similar but simpler ways of practising these sub-tasks.

Experienced physiotherapists have a large repertoire of appropriate drills and exercises for all the sub-tasks comprising the various motor tasks patients need to
learn. They draw on this repertoire to provide patients with varied, interesting and effective training programmes appropriate for patients’ stages of learning and rehabilitation. Examples of ways to simplify sub-tasks for training can be found throughout the tables in Chapter 3. Readers are also directed to a website developed by the author and her colleagues: www.physiotherapyexercises.com. This website describes hundreds of ways to simplify motor tasks. Alternatively, with a little imagination, physiotherapists can devise their own unique training drills.

**Progression**

Training needs to be appropriately progressed. This is achieved by articulating goals for each therapy session (see Chapter 2). The goals may be for very modest increments in performance, but nonetheless must be clearly defined. As soon as a goal is consistently attained, a new goal is set. The new goal may be to perform the same task in a slightly different situation, at a slightly faster pace, or while performing concurrent tasks. Concurrent tasks might be physical or cognitive. For instance, gait training could progress to walking while carrying shopping bags or reciting numbers. Initially, the patient might practise in the fairly constrained and close environment of the physiotherapy gymnasium then progress to practising in a more complex and changing community environment with its inherent distractions. Goals should be written and their achievement recorded.

**Practice outside formal therapy sessions**

Complex motor tasks cannot be learnt without repetitious practice. Surprisingly, however, only two randomized controlled trials have looked at the effectiveness of
Both studies looked at the effectiveness of a wheelchair skills training programme, and demonstrated the effectiveness of structured and repetitious practice for the acquisition of wheelchair skills.\(^{25,26}\)

Practice needs to be performed during therapy sessions but also, wherever possible, practice should be performed in patients’ own time. Practice out of therapy time should be structured with the same care as practice in therapy time. Importantly, practice outside formal therapy needs to be monitored. For example, an ambulating patient who is asked to practise stepping outside therapy should be required to record either the number of steps or the time spent on this activity. Commercially available step counters can be used for this purpose. Physiotherapists need to review written records of practice, and provide feedback on the quantity and quality of practice to reinforce the belief that practice is important. Personalized exercise booklets provide an excellent way of structuring and monitoring practice, both within and outside formal therapy sessions (see Figure 7.4). The website at www.physiotherapyexercises.com can be used to generate professional looking customized exercise booklets.

One of the biggest challenges in designing effective training programmes is ensuring they maintain interest and motivation. This can be achieved by providing a variety of exercises, setting clear and attainable goals, and progressing task difficulty as performance improves. A particularly useful strategy for maximizing interest and motivation is to provide group sessions in which patients of similar ability practise together.\(^{11}\) This also serves to reduce demands on physiotherapists’ time. Other members of the rehabilitation team can encourage and promote practice outside formal therapy sessions. For instance, patients capable of transferring into bed can practise this transfer with nursing staff when getting in and out of bed each day. Patients capable of walking can walk to the bathroom and dining room as part...
of their daily routines. Such reinforcement of practice outside formal therapy sessions relies on good team communication, an effective goal planning process and an appreciation by all team members of the importance of a coordinated and consistent approach to rehabilitation. It also depends on good staffing levels and staff who are well trained in appropriate manual handling skills to ensure their own as well as their patients’ safety.

Effective training methods

Motor learning can be enhanced by effective use of instructions, demonstrations and feedback.

Instructions

Instructions need to be tailored to the stage of learning and the patients’ cognitive abilities. During the early stages of learning, instructions need to be general and targeted at the overall goal. For example, instructions appropriate for a patient’s initial attempts at transferring might outline the overall purpose of the task and one or two key strategies to prevent skin damage and injury (see Chapter 3). As some overall ability to transfer is developed, instructions can become more specific. Instructions might include suggestions for positioning of the hands or for timing of the lift. Instructions need to be articulated according to patients’ education and understanding of the task. Some will benefit from understanding the intricacies of movement and being cued to increase their awareness of internal feedback systems. For example, they might find it helpful to think about the position of the head in relation to the hips, or the amount of shoulder depression and trunk forward lean associated with a successful transfer. Others will be better served by the provision of external cues based on vision. For example, they might look down between their legs to ensure they have moved far enough forward in the wheelchair prior to transferring. (If the patient has moved far enough forward they should not be able to see the seat between their thighs.)

Demonstration

A demonstration of the task can provide patients with a clear idea of what they are trying to achieve. Sometimes the demonstration can be performed by the physiotherapist. Alternatively, video footage may be helpful, especially footage showing skilled performers’ early attempts at movement, and their improvements over time. As patients develop competency they may benefit from viewing video footage played in slow motion. They can be cued to look at specific aspects of the movement. Patients may also benefit from seeing footage of motor tasks performed in slightly different ways. This, with appropriate guidance from a physiotherapist, may prompt them to experiment with different movement strategies. Video footage of people with spinal cord injury performing a range of motor tasks can be found at www.physiotherapyexercises.com. Physiotherapists may find it useful to compile their own video libraries for demonstration purposes.

Feedback

If practice is to be effective, the learner must receive feedback. Feedback may comprise details about the success of task performance (knowledge of results) or details
about how well the movement is performed (knowledge of performance). Often knowledge of results is readily available: patients will know whether they have or have not succeeded in their overall attempts at task performance provided it is clear to them what constitutes success and failure. For example, the success of transferring may be evident from the ability to get from a chair to a bed. However, knowledge of performance may be less readily available: when the task is not performed successfully patients might not know why they failed. Knowledge of performance helps patients develop strategies to correct errors and improve subsequent attempts at task performance. Patients learn to move by making and then correcting errors.

The role of the physiotherapist is to provide both knowledge of results and knowledge of performance. The feedback needs to be well timed, accurate and in appropriate detail for the stage of learning. It can be provided in various ways, including with the use of video footage, mirrors, electromyography, scales and positional feedback displays, but most commonly it is provided in the form of verbal feedback from the physiotherapist.

Initially, verbal feedback needs to be directed at ensuring patients have knowledge of results. That is, awareness of when attempts at movement are and are not successful. With progress, feedback can become more specific. Feedback can be directed at knowledge of performance and, specifically, at the critical aspects of the movement which need to change. However, feedback which is too detailed merely serves to confuse patients. Novice learners of motor tasks have difficulties concentrating on more than one aspect of performance at a time. For this reason physiotherapists need to determine the key problem and restrict feedback to this issue. Invariably this means ignoring other less critical problems for a later stage. Feedback needs to be provided soon after attempts at movement and followed up with immediate practice. Patients should be encouraged to reflect on why attempts at movement either succeeded or failed.

It is important to distinguish between verbal feedback aimed at improving performance and verbal encouragement aimed at motivating patients to persist with practice. Clearly, verbal encouragement is important and patients should be supported in their efforts. However, encouragement should not be confused with feedback. If the performance was not good, then patients should not be misled by praise for effort. Patients quickly learn to ignore repeated, effusive praise which becomes meaningless and does little to improve performance. On the other hand, constant criticism based on unrealistic expectations will undermine motivation. An appropriate balance between the two extremes can be more easily achieved by setting realistic goals for each treatment session. Goals should be challenging yet achievable. During the early stages of learning, when successful task performance may be very difficult, goals can be set in terms of frequencies. For example, an appropriate goal for the early stage of learning might be to perform 10% of all attempts correctly. Alternatively, a goal may be to perform one small aspect of the whole task in a particular way.

Feedback can be provided with video footage. In this way, patients can view their own attempts at movement. Alternatively, more simple ways of providing feedback can be used. For example, a patient with C6 tetraplegia who is learning to shift and bear weight through one shoulder while prone can be given feedback by reaching for an object with one hand (see Figure 7.5). Instant feedback about ability to shift weight is provided by success in reaching for the object. For patients unable to lift their body weight in sitting, feedback can be provided with scales or an inflated blood pressure cuff under the hands (see Figure 7.6). Alternatively, a biofeedback device which generates noise or light with weight can be used. In all scenarios the patient receives instant feedback about the ability to shift body weight.

Electrical stimulation can also be used as a means of providing feedback and helping patients to learn appropriate muscle recruitment patterns. The stimulation of specific muscles at the appropriate phase of movement provides feedback and additional
cues for successful performance. For instance, stimulation of the dorsiflexor muscles during swing can help a patient learn to recruit these muscles actively during this phase of gait. Similarly, electromyographic biofeedback can be used to encourage appropriate activation of muscles. Alternatively, specific devices which provide

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**Figure 7.5** A patient with C6 tetraplegia learning to shift and bear weight through one shoulder while prone will receive instant feedback about success by attempting to reach for a target. Bathroom scales or a blood pressure cuff positioned under the weight-bearing arm can also be used to provide immediate feedback.

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**Figure 7.6** A pair of bathroom scales placed under the hands can provide feedback about success of lifting.
auditory feedback about the position of joints can be used. In all scenarios, the patient receives some type of feedback to improve the ability to appropriately recruit muscles for purposeful movement.

**Balance**

Effective movement requires the body’s centre of mass to remain over the base of support. This is achieved by activating specific muscles at the right time, both before and during task performance. The postural adjustments required during particular motor tasks are specific to that task. Appropriate postural adjustments prevent falling. When a task is performed without falling we say the patient is balanced.

Balance is a particular problem for patients with spinal cord injury because paralysis can render the usual postural adjustments impossible. Patients with spinal cord injury need to learn to make new postural adjustments to prevent falling while performing everyday motor tasks. Much of the training of motor tasks involves learning appropriate postural adjustments to perform motor tasks without falling.

The use of the term ‘balance’ is, however, problematic because it implies that balance is a discrete motor task. Yet it is not possible to separate balance from the successful performance of motor tasks. They are one and the same thing. This has important implications for training. It suggests that balance should not be taught out of context of functional motor tasks. For example, if a patient with thoracic paraplegia has difficulty staying upright when repositioning the hands during a transfer manoeuvre then the patient needs to practise staying upright while transferring (see Figure 7.7). There may be little value in practising ‘sitting balance’ outside of the

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**Figure 7.7** A patient with T4 paraplegia having difficulty maintaining an upright position while repositioning the hands during transfers may benefit from practising repositioning the hands in a ‘similar but simpler’ task while sitting on the edge of a plinth.
context of transfers, for example by catching and throwing a ball in sitting. Throwing and catching a ball may require quite different postural adjustments to those required while transferring.

**Treadmill training with body weight support. A way of providing intensive practice**

It is difficult to provide task- and context-specific practice of stepping and walking for patients with the potential to walk but with extensive lower limb weakness. Ideally, practice needs to involve stepping and walking in an upright and weight-bearing position. However, this may be difficult for patients with significant lower limb paralysis because often they require extensive physical assistance to remain upright and move their legs. Providing this assistance can be strenuous for physiotherapists and can cause injury to patients and therapists.

One relatively simple way to reduce the effort and risk of practice is to use orthoses or walking aids. For example, if a patient with an incomplete lesion is having difficulty walking because of knee collapse during stance, a knee extension orthosis can be used (see Chapter 6). However, walking with an orthosis does not require the use of the same muscles as walking without an orthosis. It would therefore be better if patients could practise without an orthosis in a way which does not depend on excessive manual assistance from physiotherapists.

Overhead suspension with partial body weight support can be used to avoid orthoses and provide a more normal walking pattern without the need for physiotherapists to physically hold patients upright. It provides a way of enabling very disabled patients to engage in intensive gait practice using a relatively normal walking pattern. Electrical stimulation and robotics can be used to drive the legs. Alternatively, there are gait training devices incorporating motor-driven footplates which move the legs backwards and forwards on the spot in standing. The relative effectiveness of these different interventions is unclear, although presumably interventions which closely mimic gait and encourage active recruitment of muscles are more likely to have lasting therapeutic effects than interventions which do not.

Walking with partial body weight support can be done overground or on a treadmill (see Figure 7.8). Overground walking is achieved with a mobile suspension system which moves as the patient walks. These systems generally provide less stability because the entire apparatus moves with the patient in any direction. Some patients will be unable to walk in a straight line with overground suspension unless a physiotherapist guides the apparatus. In contrast, the treadmill suspension system is fixed in place over the belt of the treadmill so there is usually no need to control the direction in which the patient walks. The speed and incline of the treadmill can be changed to accommodate a patient’s skill level.

There are advantages and disadvantages of treadmill and overground walking but one clear difference is the opportunity for practice. Treadmill walking reduces reliance of more independent walkers on physiotherapists, thus increasing the opportunity for practice. It also provides a means of encouraging patients to walk faster and with a more appropriate inter-limb coordination. Some argue that treadmill walking helps ensure that patients fully extend the hips at the end of stance, although others argue that the hip extension provided by the treadmill is passive and does not encourage active recruitment of the hip extensor muscles.

Treadmill walking may have an additional and important benefit over other types of gait training devices. Accumulating evidence indicates that some sensory aspect associated with stepping on a treadmill triggers a spinal cord-mediated stepping
Figure 7.8 A patient with incomplete tetraplegia walking on a treadmill with overhead suspension and manual assistance from a physiotherapist.

There is little doubt that, in animals, stepping is orchestrated within the spinal cord. The spinal cord networks which control stepping have been referred to as central pattern generators. As early as 1906, Sherrington was able to elicit coordinated rhythmic movements in the hind limbs of animals with complete transections of the spinal cord. Since this time, similar types of cyclical motor response, such as scratching and paw shaking, have been demonstrated in animals with transections of the spinal cord. Central pattern generators for walking have also been demonstrated in infants and people with spinal cord injury. Technically, these cannot be called reflexes as they are too complex and involve rhythmic and reciprocal activation of many muscles. However, in other respects, they are similar to reflexes because once triggered they can be generated without input from higher centres. Central pattern generators provide spinal cord integrated coding for certain complex but repetitive response and that this response is trainable. Some believe that treadmill walking can improve neurological recovery in people with spinal cord injury.

Figure 7.8 A patient with incomplete tetraplegia walking on a treadmill with overhead suspension and manual assistance from a physiotherapist.
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motor behaviours. This coding is normally modulated by input from higher centres and sensory feedback from muscle and cutaneous receptors.57

In animals, central pattern generators can be trained with treadmill walking. Studies of cats have shown that they can regain the ability to step independently with their hind limbs on a treadmill even if the spinal cord is completely transected.69 The ability to step is, however, only regained after intensive stepping on a treadmill, initially with body weight support and maximal assistance but ultimately without support or assistance. It is believed that some aspect of cyclic walking provides a sufficiently strong sensory stimulus to the spinal cord to stimulate neural rearrangement within the spared spinal networks. This enables the cat to ultimately step independently with the hind limbs on the treadmill, even though there is no input from higher centres. These findings in animals underpin the current intense interest in the potential therapeutic role of gait training with treadmills in people with spinal cord injury.69–71

Perhaps the same neural adaptations demonstrated in cats in response to cyclic walking on a treadmill can also be triggered in people with spinal cord injury. At this stage, attention has primarily been directed at using treadmill training for people with incomplete lesions and some potential to walk, not for people with complete spinal cord injury.

Single case studies and uncontrolled clinical trials in people with incomplete spinal cord injury provide some evidence of physiological benefits of intense treadmill walking with overhead suspension.48,54,72–82 However, the results of these studies need to be interpreted with caution, both because they lack the rigorous control of randomized trials and because it is not clear what mechanisms cause the observed outcomes.83 These studies do not necessarily indicate that central pattern generators have been trained39,58,61 because it is possible that treadmill training has a peripheral strengthening effect on already innervated muscle fibres.84 The benefits of treadmill walking on neural growth and regeneration of the damaged spinal cord are yet to be demonstrated.58

Studies of the physiological effects of treadmill training are interesting but they do not tell us whether the intervention is of clinical benefit. Proof of clinical benefit requires rigorously designed clinical trials to tell us if treadmill training improves the ability of people with spinal cord injury to walk more than simpler methods of gait training. One large randomized controlled trial involving 146 patients with recent but incomplete spinal cord injury compared treadmill training with conventional gait training methods. Conventional gait training consisted of standing and stepping practice with orthoses, aids, manual assistance and, if necessary, parallel bars.60 Importantly, all patients in both groups received the same overall time on gait-related activities. Treadmill training did not produce consistently better outcomes than conventional training. These results are in keeping with a Cochrane systematic review which summarized the results of randomized controlled trials in people following stroke.85 Similar conclusions have been drawn by others.86,87 These results imply there is nothing therapeutically unique about treadmill gait training.88 Treadmill training is probably no more or less effective than other ways of providing intensive task- and context-specific practice to patients with the potential to walk.39,83

References