European Journal of Neurology 2002, **9 (Suppl. 1):** 23–29

Gait training in hemiplegia

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Keywords:
spasticity, rehabilitation, gait training, treadmill, music motor feedback

Restoration of gait is a major goal in neurological rehabilitation. Before starting therapy, a comprehensive assessment is necessary to evaluate the deficits and remaining functions. A wide variety of therapeutic procedures are available and have to be adapted to the individual situation – different concepts of physiotherapy stress different features like: force exercise, reduction of spasticity, gait symmetry, utilization of equilibrium reflexes, stepping automation, endurance training, repetition of rhythmic movements, etc. The spectrum of available therapies was recently widened by treadmill training, with partial body-weight support, locomotor pharmacotherapy, selective reduction of spasticity by botulinum toxin injections, and by musical biofeedback, which have each proved to be successful in the restoration of gait pattern. Treadmill training based on partial body weight support, combined with enforced stepping movements has proved to be successful in the restoration of gait pattern. A common problem in hemiparetic gait, is the spastic inversion of the foot. If spasticity is not severe, an ankle-foot orthosis (AFO) is the appropriate technical aid. In other cases, botulinum toxin injection into spastic leg muscles has been successfully used to improve gait functions. In hemiparetic stroke patients, auditory (musical) rhythm, as a peripheral pacing signal, resulted in a significant increase in weight-bearing stance time on the paretic side. In addition, there was an improved stride symmetry with rhythmic cueing and a normalizations of gait pattern. These methods directed to gait improvement should be combined and adapted to the individual patient's needs, in order to obtain the best results.

Gait rehabilitation – general principles

The impairment of gait is frequently responsible for long-term disability and handicap. Where acute stroke patients are admitted to a general hospital, one third are not ambulatory after 3 months (Wade *et al*., 1987). In those patients in whom a partial recovery is observed (change of more than 60 points in the Barthel Index), problems often remain. The two most common problems are unsafe walking and difficulties in climbing stairs (Granger *et al*., 1988). The restoration of mobility is central to regaining independent living and gait training forms an essential part of the rehabilitation process. Intensive rehabilitation programmes are often of great benefit, since many patients with CNS lesions show a marked improvement in their mobility.

Opinion concerning the techniques used in gait training has been polarized by the different schools of thought concerning physical therapy. These are broadly divided into functionally orientated 'traditional' approaches and other techniques based on neurophysiological models. One concept which is frequently used is the neurodevelopmental technique (NDT) established by Bobath (Bobath, 1978). This primarily focuses on the reduction in spasticity and functional changes like force development; walking speed and endurance are considered to be of lesser importance (Davies, 1985; Davies, 1990).

The Brunnstrom method, the Proprioceptive Neuromuscular Facilitation (PNF) concept, or the Rood method are also widely used (Brunnstrom, 1970; Bobath, 1990; Voss *et al*., 1985). However, despite theoretical and practical differences between these approaches, no one procedure has been shown to have any greater benefit over another in terms of Activities of Daily Living (ADL), including mobility (Mauritz, 1990). It therefore seems appropriate that further developments of physiotherapy are required for the future, based on rational guidelines. In terms of gait function, alternative approaches are often very effective in restoring mobility in nonambulatory stroke patients (Hesse *et al*., 1994a; Hesse *et al*., 1994c; Malezic *et al*., 1994) and in patients with spinal cord injuries (Barbeau and Rossignol, 1994; Dietz *et al*., 1994).

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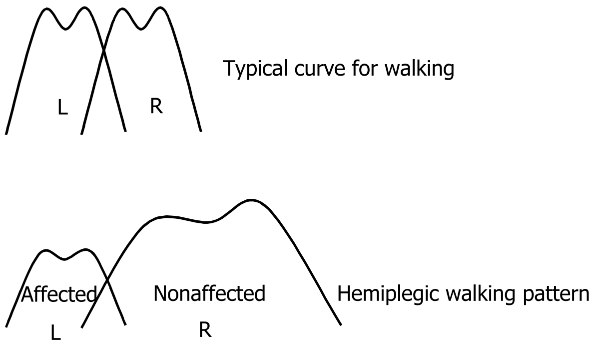

Figure 1 Ground reaction forces during gait cycle.

Gait training – methodologies

Traditionally, one of the specific goals in gait training is the restoration of gait symmetry, in order to regain a physiological gait pattern. In normal subjects, gait symmetry may be shown using kinematic, kinetic and, to a lesser extent, EMG recording. However, in hemiparetic patients, kinematic and kinetic data clearly demonstrate gait asymmetry (Figure 1).

In a normal person a typical curve has two peaks. The first peak reflects the heel strike, followed by a dip as the foot is rolled forwards. The second peak reflects push off at the end of the stance phase. The curve is very symmetrical between the left and right legs, with equal peaks and equal times, with the double stance phase in the centre. From the slope and the duration of this pattern, a symmetry ratio can be calculated. Ground reaction forces were recorded using force plates.

In a patient with a left hemiparesis, the pattern is very different. The involvement of the weak, affected leg is shorter, but that of the nonaffected leg is longer. This pattern is characteristic of hemiplegia.

The use of the NDT requires that reflex inhibitory movement patterns are established in order to normalize muscle tone. In the course of the training programme, symmetric weight acceptance and push-off are strictly controlled and nonuse of the paretic limb is avoided.

With advances in understanding of motor learning, skill acquisition and other aspects of modern neuroscience, these concepts have been challenged. In 1993–94, Hesse *et al.* found that there was no significant improvement in gait symmetry parameters after an intensive 4 week inpatient training programme (Hesse *et al.*, 1993; Hesse *et al.*, 1994b). One explanation of this lack of improvement may lie in the nature of the therapy itself. In a typical physiotherapy session, designed to normalize muscle tone, manoeuvres which inhibit tone and advanced postural reactions are applied during sitting or standing. Gait practice is only a small part of the programme and patients are encouraged to walk in a slow, controlled manner.

In children with cerebral palsy, Forssberg has reported that although they can be taught a normal gait during a therapy session, they revert to the previous pathological pattern once they lose concentration (Forssberg and Hirschfeld, 1990). This is also true of stroke patients undergoing gait training. Thus spending much time and effort on normalizing gait may be inefficient and it may be more effective to concentrate therapy on functional levels of locomotion.

Treadmill training

Gait is a repetitive cycle, so our aim was to increase the number of repetitive cycles of strides.

Studies in spinal cats have shown that interactive locomotor training, using a treadmill and body-weight support, improves locomotor performance. A motor-driven treadmill in conjunction with a suspension system (Barbeau *et al.*, 1987) has also been shown to be effective in the treatment of patients with spinal cord injuries and different levels of spastic paresis (Wernig and Müller, 1992). Two cases have been reported in which ambulatory hemiparetic patients used partial weight bearing with promising results (Waagfjörd *et al.*, 1990; Gregor *et al.*, 1992). In one study, a chronic hemiparetic patient received treadmill training without body-weight support and showed an improvement in step length symmetry, compared with traditional physiotherapy.

In recent years, this approach of body-weight support combined with enforced stepping movement was introduced in the rehabilitation of nonambulatory hemiparetic patients after stroke (Figure 2). It has been successful in the restoration of gait pattern by providing stabilization of the trunk, eliminating the need for equilibrium reflexes, and mandating complex stepping movements. Since it is task-specific, it allows many repetitions of complete gait cycles, instead of repetition of single elements or preparatory manoeuvres at an early stage of gait rehabilitation.

During training, the gait cycle becomes more symmetrical (Figure 3). Further support for the specificity of this training concept comes from the finding that balance training while standing could improve balance symmetry without improving gait symmetry in hemiparetic patients.

At the start of this training, two therapists provide physical help to correct gait deviations. On the paretic side, one therapist facilitates the swing of that limb. They also ensure that initial foot contact is with the heel, prevent knee hyperextension during mid-stance and encourage symmetry of step length and stance duration. The second therapist stands on the treadmill

Figure 2 The treadmill trainer with partial body weight support. The treadmill is driven by a motor with variable speed control (0.01–2.25 m/s). The patient stands on the treadmill and is supported in a modified parachute harness, suspended by pulleys.

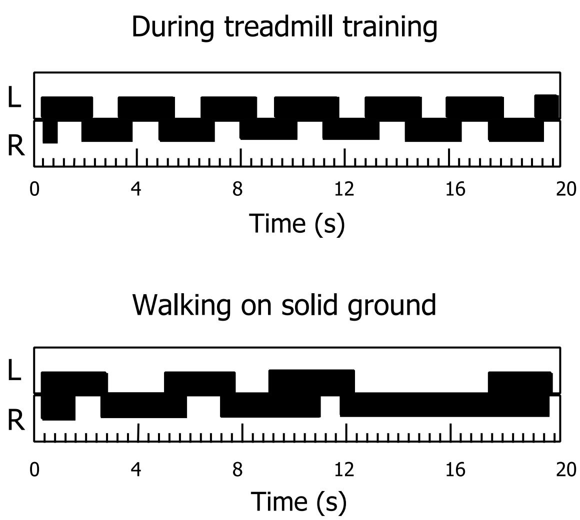

Figure 3 Representation of the gait cycle during treadmill training with 5% body weight support and during walking on solid ground in a patient with a left-sided hemiparesis. On the treadmill, a symmetrical gait is observed.

behind the patient and facilitates weight shift to the stance limb, hip extension, pelvic rotation and ensures that the trunk remains erect. Hip extension can be increased passively by the treadmill, or actively by the therapist manually prolonging the stance phase. Treadmill speed is adjusted to achieve a comfortable cadence and stride length for the patient and the initial body-weight support is between 25 and 40%. The level of support is reduced incrementally, as soon as possible, to enable full load bearing on the lower limbs.

All patients receiving locomotor training with the treadmill and body-weight support showed an improvement in gait capability, assessed by the Functional Ambulatory Category (FAC) test. (Figure 4). All but one patient could walk by themselves with verbal support after treatment. One patient required intermittent support. The gait velocity increased approximately threefold and cadence and stride length doubled.

Orthoses

In spastic hemiparesis spastic inversion of the foot is a common problem. This leads to initial contact with the forefoot, rather than the normal heel strike. If the spasticity is not too severe, an ankle-foot orthosis (AFO) is an appropriate technical aid to restore the physiological strike pattern. There are at least 20 or 30 different orthoses on the market and gait analysis can

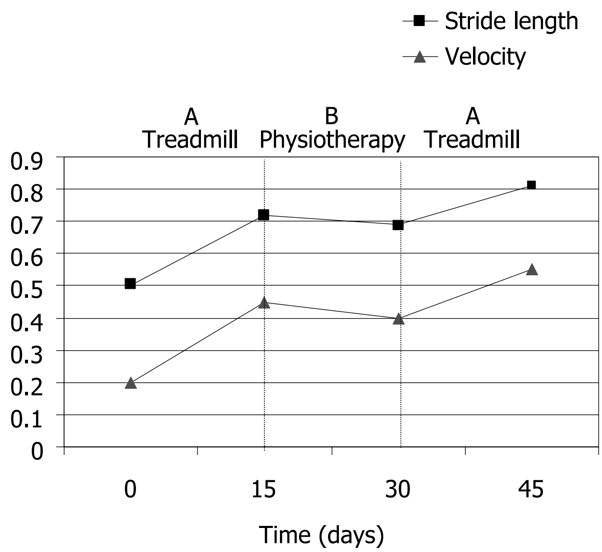

Figure 4 Changes in gait parameters in hemiparetic patients involved in an A–B–A programme of treatment. Treadmill training was performed on days 1–15, conventional physiotherapy on days 16–30 and treadmill training was repeated on days 31–45. Stride length and velocity showed marked improvement during treadmill training, in contrast to conventional physiotherapy. Points show the mean data from seven patients.

be used to assess the most effective model for an individual hemiparetic patient. By comparing the trajectories of different successive steps, barefoot and with an ankle-foot orthosis, one can compare the different models and select the most appropriate orthosis for the patient. In Figure 5 the benefit of an adjustable metal AFO is shown, in a hemiparetic patient.

The adjustable metal AFO has many advantages. Although it is rigid, it allows articulation at the ankle and since it is adjustable it also enables changes to be made in line with the observed improvement in the patient. For patients with severe spastic inversion, its rigidity is considered to be a benefit. Alternative, thermoplastic orthoses are lighter and have a better cosmetic appearance, and are preferred by patients.

Botulinum toxin

Botulinum toxin has been used successfully to treat many neuromuscular conditions, including spasticity. In some of the initial studies, a significant reduction in muscle tone was reported in the leg adductors, the upper limb flexors and the calf muscles responsible for spastic foot drop (Das and Park, 1989; Snow *et al.*, 1990; Hesse *et al.*, 1992; Hesse *et al.*, 1994c).

Plantarflexor spasticity causes a number of problems during gait. These include: forefoot rather than heel contact, reduced loading and stance duration on the affected limb, stance equinus, reduced stride length impeding progress, lack of push-off, and dragging of the toes (Perry, 1992). In more recent years the findings of a number of studies on the effects of botulinum toxin on muscle spasticity have been reported.

In stroke patients suffering hemiparesis and severe muscle spasticity injection of botulinum toxin into the calf muscles resulted in decreased spasticity (Ashworth scale) (Burbaud *et al.*, 1996; Hesse *et al.*, 1996; Reiter *et al.*, 1998) and parallel changes in functional measures. In these patients, gait velocity was increased and foot inversion was reduced. Molteni (1995) also reported a study in which lower limb spasticity following stroke or traumatic brain injury was treated with botulinum toxin. Using video recording of gait, dynamic EMG, ground reaction forces analysis and 3-dimensional kinematic analysis, he observed a functional improvement in these patients.

Similarly, Hesse *et al.* (1994c) reported improvements in gait velocity and longer stride length, although cadence remained unchanged. In these patients Achilles tendon clonus was also reduced. Two weeks after the administration of botulinum toxin, the data for these patients showed a marked improvement in stance equinus and weight acceptance. Pressure trajectories of the feet of these patients also showed marked improvement (Figure 6).

The effect of treatment with botulinum toxin diminished with time and by 8 weeks after treatment muscle tone had increased in the patients involved in this study. However, despite this increase in muscle tone, the improvement in the trajectory of the affected foot was sustained. Gait cadence remained high, even in the presence of hypertonicity. Since these patients did not receive extensive physiotherapy during the 8-week period following toxin injection, it could be argued that the effects of the toxin injection may have been further enhanced using a comprehensive rehabilitation programme.

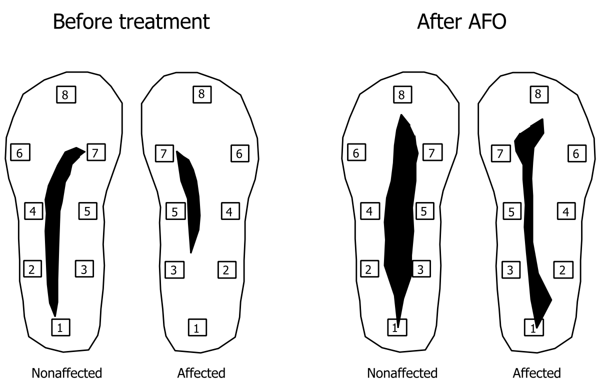

Figure 5 Trajectories of the centre of pressure under both feet during consecutive strides, without or with an ankle-foot orthosis (AFO), in a patient with a right-sided hemiparesis. With the AFO the patient regained the initial heel contact. The length and pattern of the trajectory on the nonaffected side also improved.

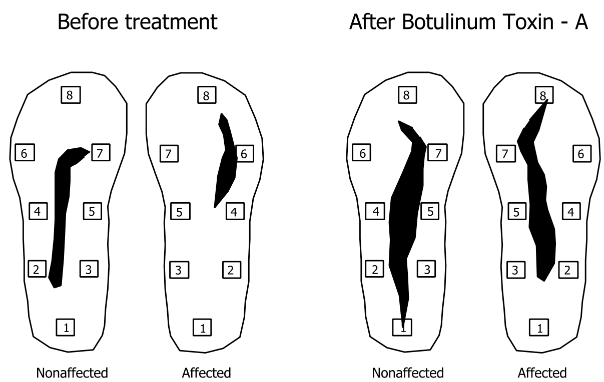

Figure 6 Trajectories of the centre of pressure under both feet during consecutive strides, before and after treatment with botulinum toxin, in a patient with a right-sided hemiparesis. After treatment, the foot contact in the affected limb improved. The length and pattern of the trajectory on the nonaffected side also improved.

Music Motor Feedback (MMF)

Another development which we have investigated is the use of music as a biofeedback cue. The presentation of rhythmic auditory cues, like music, has been shown to improve walking in Parkinson's disease (McIntosh *et al.*, 1997). In our clinic, these externally presented rhythmic cues have been combined with a musical motor feedback (MMF) system (Schauer *et al.*, 1996) (Figure 7).

In a controlled study, the effectiveness of this method in improving gait in stroke patients was evaluated (Schauer and Mauritz, in preparation). Gait velocity, symmetry, stride length, and heel-on–heel-off distance all improved significantly and the improvement was greater than that observed using traditional therapy alone. In using this device, the patients had fun in controlling the music. This increased their motivation which led to further improvements in their gait.

Gait trainer

One of the major disadvantages of treadmill training is the substantial physical effort required by at least two therapists to assist the patients in their gait (see above). Since the therapists tire, along with the patient, gait may become asymmetrical and the benefit of the sustained treatment is lost. For this reason, Dr Hesse and his group in our hospital, have developed a machine for more severely affected patients, which extends training beyond that of the treadmill (Hesse and Uhlenbrock, 2000) and releases some of the therapist's time. The patients are supported in a harness and stand with their feet on motor driven foot-plates (Figure 8).

The machine has a motor with planetary gearing which takes into account the fact that the swing phase is 40% of the gait cycle, while the stance phase is 60% (Figure 9). It also takes into account the angle of movement of the ankle and the fact that the centre of gravity moves by about 3 cm vertically and about 3 cm laterally during walking, as weight is shifted from one leg to the other. The height can be adjusted to suit the height of the patient and the speed can also be changed.

The physiological nature of this gait cycle was confirmed when EMG recordings were made in normal subjects using the gait trainer and the treadmill. The pattern of muscle activation was comparable using both machines.

The number of step cycles used during a session on the gait trainer is significantly higher than during normal physiotherapy. The gait trainer enabled patients to practice up to 1000 gait repetitions in one session.

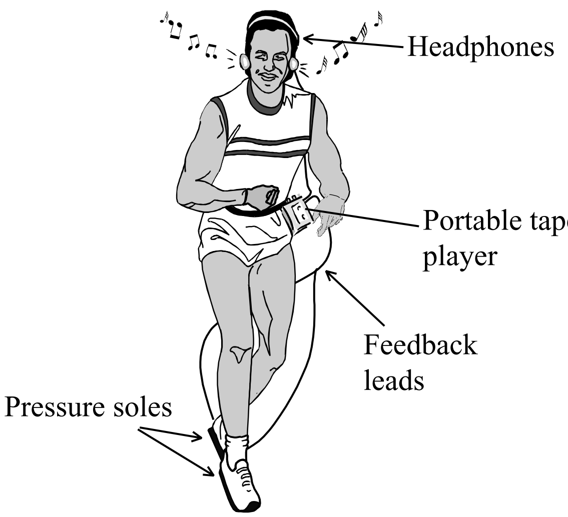

Figure 7 The MMF device consists of shoe insoles with sensors which detect ground contact by the heel. These sensors are connected by electrical leads to a portable tape player, compatible with the Musical Instrumental Digital Interface (MIDI) standard. Playing the music is initiated and controlled by the heel strikes or other pressure signals generated by the pressure sensors, enabling the patient to modify their gait in order to hear the music of their choice.

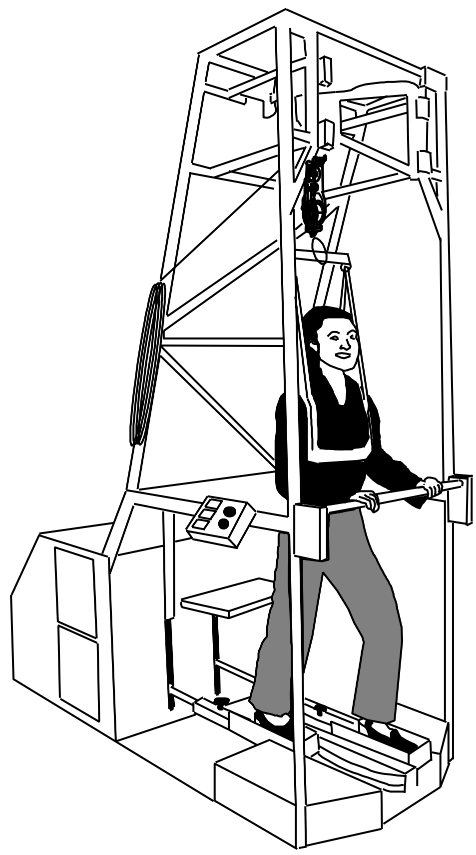

Figure 8 In the gait trainer, the patient is supported in a harness and their feet are placed on motor-driven foot plates. The machine takes the patient through a physiological gait cycle, enabling them to practice their gait many times over.

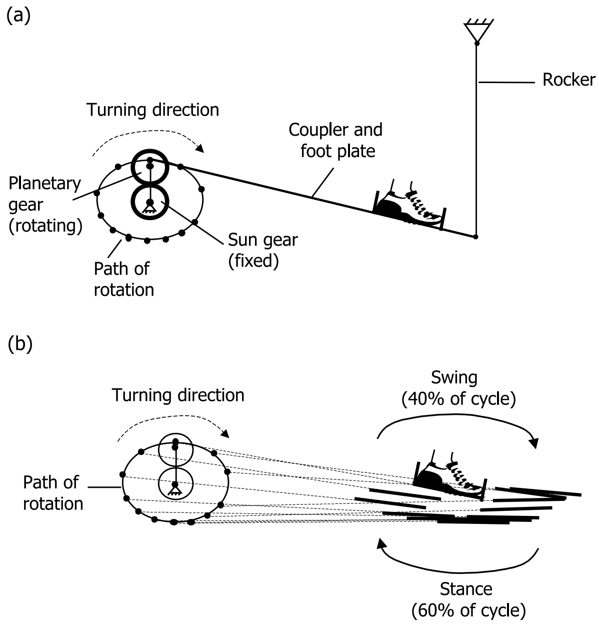

Figure 9 The planetary gearing and modified crank and rocker system, which simulate the gait cycle. The foot is placed on a foot plate (a) which is coupled to the motor. The rotation of the planetary gears moves the foot plate into a series of positions which simulate a physiological gait cycle (b) with 40% swing and 60% stance.

Hesse and Uhlenbrock (2000) reported the outcome of the use of the gait trainer in two nonambulatory hemiparetic patients. When this gait trainer was added to their therapy both patients regained their ability to walk. These patients and their therapists, reported highly symmetric, gait like movements. The therapists commented that the movement of the trunk was almost physiological, probably as a result of control of the centre of gravity.

Since these findings were in only two patients and the use of the gait trainer was in addition to standard therapy, it is clear that well designed studies are required to evaluate the benefit of this equipment.

In this review, I have presented an overview of the different approaches, which can be used in gait therapy. In order to achieve the best result for the individual patient it is probable that it will be necessary to combine two or more of them.

Acknowledgements

I would like to thank Hilary Francis of Ipsen Ltd, for assistance with the manuscript and figures.

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