Neurol Rehabil 2005; 11 (1): 1-6

Scientific Basis of Neurological Physiotherapy: Bridging the Gap between Science and Practice

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Abstract
Neurorehabilitation after a brain lesion aims at an optimal functional recovery. The contribution of physiotherapy to this process is the training of motor control. Experimental work indicates that physical activity in a stimulating environment facilitates neural re-organization and functional recovery. So modern physiotherapy is reflecting considerable change from older methods. The regaining of skill in critical tasks requires specific training, with intensive practice of actions in the appropriate contexts. In addition, the individual must have the necessary muscle strength and be fit enough to perform the tasks of daily life, including social and recreational activities.

Key words: motor learning, brain plasticity, rehabilitation environment, fitness training

Die wissenschaftliche Fundierung der Physiotherapie in der Neurologie soll Theorie und Praxis verbinden

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Zusammenfassung
Neurorehabilitation nach einer Gehirnschädigung soll zu einer optimalen Wiederherstellung der gestörten Funktionen führen. Der Beitrag der Physiotherapie zu diesem Prozess besteht in einem Training der Bewegungskontrolle. Experimentelle Studien legen nahe, dass körperliche Aktivität in einer stimulierenden Umgebung die neurale Reorganisation und die funktionale Erholung fördert. Um diesen Erkenntnissen Rechnung zu tragen, öffnet sich die moderne Physiotherapie neuen Methoden. Verlorengegangene Fähigkeiten auch bei schwierigen Aufgaben wiederzuerlangen, erfordert ein spezielles Training mit intensivem Üben der Bewegungen im entsprechenden Umfeld. Darüber hinaus muss der Betroffene über die notwendige Muskelkraft verfügen und körperlich in der Lage sein, die Aufgaben des täglichen Lebens einschließlich sozialer und Freizeitaktivitäten zu erfüllen.

Schlüsselwörter: motorisches Lernen, Plastizität, Rehabilitationsumgebung, Fitness-Training

Optimal functional recovery is the ultimate goal of neurorehabilitation after a brain lesion. The contribution of physiotherapy to this process is the training of motor control, and the major focus of modern physiotherapy is on the optimisation of motor performance in functional actions. Methods used are designed to provide a stimulus to the learning and acquisition of skill, and to increase strength, endurance, fitness and general well-being. Training is based on a contemporary understanding of the effects of impairments and secondary adaptations, biomechanics of functional actions, motor learning and cognitive science, exercise science, and recognition of factors that might influence brain re-organization after injury [11, 12].

Experimental work indicates that physical activity in a stimulating environment facilitates neural re-organization and functional recovery. This work is driving changes in methods of delivery of intervention to provide more effective and efficient training by constructing a rehabilitation environment that promotes physical and mental activity and skill acquisition. In such an environment the individual with disability can be an active learner with opportunity for intensive exercise and training rather than a passive recipient of therapy.

Modern physiotherapy is therefore reflecting considerable change from older methods, including those of *Bobath* [5, 6, 16]. Recent technological developments, together with changes in the conceptualising of how the human nervous system might function to produce skilled movement, are producing an increasing volume of movement-related research that has obvious relevance to clinical practice. Five decades ago, the "neurofacilitation" methods of *Bobath* and others were developed out of the stimulus-response para-

digms of neurophysiology and psychology with an emphasis on stimulating sensory receptors, in particular muscle and joint proprioceptors.
Experimental paradigms have shifted from a reductionist approach using animal models to an exploration of mechanisms of movement control in humans from the perspectives of biomechanical performance and skill as well as of physiological mechanisms. Technological developments in motion analysis and electromyography (EMG) have enabled biomechanical studies of balance and of actions such as walking, standing up, and reaching to pick up an object which are driving new training methods. Recently, new brain imaging methods are enabling an examination of organisational changes occurring within the brain itself in response to patterns of use. The trend toward a more scientific approach to clinical practice reflects to a large extent the increasing opportunity for physiotherapists to enrol in graduate and post-graduate courses, developing research skills and engaging in intensive study of specific fields.
An increased clinical research focus is enabling physiotherapists to test the efficacy of interventions. Systematic collection of objective data in clinical practice fosters changes to practice as more effective methods of training are developed and tested. It is apparent that Bobath therapy persists as the treatment of choice for many physiotherapists despite the lack of congruence with current scientific understanding of brain systems, human movement and the effects of impairments, together with a lack of evidentiary support of efficacy.

Impairments

The need for practice to move on by responding to new knowledge is illustrated by examining research over the last few years that is changing the way in which impairments following a lesion of the upper motor neuron system are viewed. A re-evaluation of the relative contributions of muscle weakness, of adaptive changes in muscle such as increased stiffness, and of spasticity is requiring significant changes in clinical practice. The earlier view that spasticity is the major impairment underlying movement dysfunction led to the development of methods based on the premise that spasticity had to be decreased or inhibited in order to facilitate more normal movement [5, 6]. This view has been very influential over the past few decades. Muscle weakness was not therefore a primary focus in physiotherapy since spasticity was considered the cause of weakness and disability. Congruent with this view, therapists avoided exercise that required effort, as in strength training, since this effort was assumed to increase spasticity.
Of major significance to the planning of interventions are contemporary research findings that support the view that the major impairments interfering with functional performance after lesions of the motor system (upper motor neurone lesions) such as stroke are paralysis and weakness (absent or reduced muscle force generation), and loss of dexterity (disordered motor control) [25]. Weakness is characterised by impaired motor unit synchronisation, slowness in generating peak force and difficulty in sustaining force output. In addition, soft tissue adaptations occurring in response both to muscle weakness and to post-lesion inactivity and disuse impact negatively on the potential for regaining function. Adaptations to lack of muscle activity and joint movement can occur at all levels of the neuromuscular system from muscle fibre to motor cortex [27]. Adaptations include increased muscle stiffness*, and structural and functional reorganization of muscle and connective tissue [27, 41]. Adaptive motor patterns seen during attempts at functional actions reflect muscle weakness, stiffness and length discrepancy, and muscle imbalance due to weakness in some muscles and not in others. Other adaptations with negative consequences after a unilateral lesion such as stroke include "learned non-use" of affected extremities [43].
The significance of spasticity (velocity-dependent stretch reflex hyperactivity, [23]) for the regaining of motor function remains equivocal. There is little to support the view that reflex hyperactivity is a significant contributor to movement dysfunction following stroke. Some reports indicate that stretch reflex hyperactivity can develop some time after the lesion, suggesting that it may be an adaptive response to non-functional, contracted, stiff muscles [21]. In clinical practice, increased resistance to passive movement may also be referred to as spasticity, although mechanical and functional changes to muscle are likely to be major contributors. Clinical tests commonly used in research, such as the Ashworth Scale and the pendulum test, are not able to distinguish the relative contributions of increased stiffness of muscles and reflex hyperactivity.
The focus in therapy for many patients has therefore shifted from spasticity to weakness, and emphasis is currently on increasing muscle force generation and neural control, and on preventing soft tissue contracture by active stretch during exercise and, when necessary, by passive stretching.

Motor Learning and Task-specificity

Principal research areas driving current physiotherapy research and practice include motor control mechanisms, muscle biology, biomechanics, skill acquisition (motor learning), cognitive and exercise science [10, 11, 12]. Bridging the gap between scientific research in other fields and clinical practice has led to the formulation and testing of hypotheses related to clinical practice and the development of new training methods.
As a result of both the theoretical and the clinical evidence, intervention is increasingly focusing on task-oriented exercise and motor training, together with strength and fitness training, in order to improve the patient's capacity to learn motor skills and optimise functional motor performance. An increasing number of studies have shown positive effects in individuals with brain lesions of task-oriented prac-

*stiffness: a mechanical response to load on a non-contracting muscle and decreased soft tissue length tice and strength training on muscle strength and functional performance [e.g., 8, 9, 15, 17, 36, 40, 44, 45, 47]. Training that is sufficiently intensive can also produce a cardiovascular training effect [30]. Contrary to earlier therapeutic views, strength training does not result in increased resistance to passive movement (hypertonus) or in reflex hyperactivity (spasticity). New methods of stimulating activation in poorly innervated muscles are also being developed and include EMG-triggered electrical stimulation, and computer-aided training.

The idea that motor learning research can provide a rich source of scientific information to guide clinical practice has been available to the profession for several decades. The assumption is that training methods shown to be associated with improvement in motor skill in able-bodied populations are also likely to be effective in a person with disability who must regain skill in everyday actions and, in the case of a spinal cord injured person, learn new skills such as wheelchair locomotion. The process of acquiring skill is typically investigated with young healthy adults as they learn a novel task or train to improve a specific skill, and increasingly with people with motor disability. From such research the stages of learning have been described as first getting the idea of the movement, then developing the ability to adapt the movement pattern to environmental demands [19, 20]. In the initial stages the person learns to pay attention to the critical features of the action and is actively engaged in practice.

Considering the patient as a learner involves setting up conditions under which skill learning can take place. Awareness of the characteristics of each stage of learning enables the therapist to provide appropriate practice conditions to optimise performance [12]. In clinical practice, the learner's focus of attention shifts as muscle strength, motor control and skill increase. In walking, for example, it may shift from the feet to the surrounding environment; star billing for sit-to-stand may change from initial foot placement and increasing the speed of forward rotation of the upper body to the need to steady a glass of water while standing up. As part of the training process, the therapist may direct the patient's focus of attention away from an internal body-oriented focus (the feet, upper body movement) to an external focus that is directly related to the goal (avoiding obstacles on the floor). Some recent findings with healthy subjects have shown what a difference it can make to performance and skill development if the learner directs attention toward the effect of the movement (an external focus) instead of to the movement itself (an internal focus) [51].

Skilled performance is characterised by the ability to perform complex movements, with the flexibility to vary movement to meet ongoing environmental demands with economy of effort. This applies as much to everyday actions such as walking and standing up from a seat, as it does to recreational, sporting or work-related actions. Skill is task-specific. Although such actions as level walking and stair walking may share similar biomechanical characteristics, the demands placed on the individual by each action are different. The individual learns to reshape and adapt the basic movement pattern according to different contexts; crossing the street at pedestrian lights may require an increase in walking speed, negotiating obstacles in the house requires other changes in the walking pattern. Improvement in a particular action requires therefore practice of that action; that is, the learner has to practice in order for performance to become effective in achieving the specific goal. For some individuals, speeding up the action and improving power generation may be major performance goals. However, for those whose muscle strength and motor control are below a certain threshold, such practice may not be possible. Exercises to increase strength and control may be necessary, together with practice of the action under modified conditions, for example, standing up from a higher seat which requires less muscle force generation. Many repetitions of an action are required to increase strength and for the patient to develop an optimal way of performing the action [24]. Traditional physiotherapy has neglected the repetitive element of skill acquisition that forms an essential prerequisite in motor rehabilitation [9].

In training functional tasks, the therapist sets the goals in consultation with the individual and based on evaluation of the patient's capabilities. As "trainer", the therapist may point out how a movement is organised based on knowledge of critical biomechanical characteristics; provide verbal instructions, feedback, or demonstration; direct the person's visual attention; or highlight regulatory cues in the environment (e.g., height of an obstacle). However, it is the patient who must learn to organise movement that matches the environment in order to achieve these goals. Goal-setting involves organising the environment to be functionally relevant; that is, by providing meaningful objects of different sizes, weight, graspability, which allow for different tasks to be trained. Goals are concrete rather than abstract, for example, "Reach out and take the glass from the table" rather than "Raise your arm"; "Reach sideways to take the glass" rather than "Shift your weight over to the left". Recent research has illustrated the different outcomes when individuals after stroke work with concrete goals linked to real objects rather than with more abstract goals [46, 50]. *Wu* and colleagues examined a task in which subjects used one hand to scoop coins from a table into the other hand. Able-bodied and stroke subjects took part, sometimes with coins, sometimes mimicking the movement without coins. Both groups of subjects demonstrated faster movements, that were smoother and straighter, that is, characteristics of well-learned coordinated movement, when they scooped the coins compared to when they mimicked the action.

It should be noted that the benefits of task-oriented skill training and strength training are also being reported in studies of children with cerebral palsy [4, 13]. Although the primary deficit is injury to the brain, adaptive changes in the musculo-skeletal and cardiorespiratory systems also impose severe limitations on the gaining of functional motor performance [7, 38]. Many of these changes are preventable or reversible [14].

Performance of an action that is effective in consistently achieving a specific goal with some economy of effort is said to be skilled. We assume that the acquisition or learning of skill, involving practice and exercise, is a manifestation of the internal processes that make up what is called motor learning. Motor learning itself cannot be directly observed. It is a set of complex internal processes that can only be inferred from a relatively consistent improvement in performance of an action, that is, a relatively stable change in motor behaviour as a result of practice of that action [31, 39]. That is to say, it can only be inferred from the behaviour observed when certain characteristics of motor performance are measured over a period of time [31]. To know whether or not performance has improved, the therapist has, therefore, to measure the person's performance at the start of training, at various stages throughout rehabilitation and periodically after discharge home.

Brain Plasticity: Role of Exercise and Training

Important insights into mechanisms mediating motor recovery after injury to the sensorimotor cortex are now beginning to emerge. Neurophysiological and neuroanatomical studies in animals and neuro-imaging and other non-invasive mapping studies in humans are providing substantial evidence that the adult cerebral cortex is capable of significant functional reorganisation [e.g., 2, 34]. These studies have demonstrated plasticity in functional topography and anatomy of intact cortical tissue adjacent to the injury and of more remote cortical areas. Of critical importance for rehabilitation is that experience, learning and active use of the affected limbs appear to modulate the adaptive reorganisation that inevitably occurs after cortical injury. It seems likely from current research that, for rehabilitation to be effective in optimising neural reorganisation and functional recovery, increased emphasis needs to be placed on promoting motor learning using intensive and repetitive task-oriented exercise and training [e.g., 26, 32, 33].

The Rehabilitation Environment

If brain reorganisation and functional recovery from brain lesions is dependent on use and activity, then the environment in which rehabilitation is carried out is likely to play an important role in patient outcomes. The rehabilitation environment is made up of the physical or built environment (the physical setting); the methods used to deliver rehabilitation (type of intervention, intensity, dosage); the staff (their knowledge, skill, attitudes, and ability to teach). Evidence from animal experiments suggests that the nature of the environment, its physical structure together with the opportunities it offers for social interaction and physical activity, can influence outcome after a lesion. In animal research, the aspects of the enriched environment which appear to be critical as enhancers of behaviour are social stimulation, interaction with objects that enable physical activity [3], and an increased level of arousal [49]. Observational studies of rehabilitation settings provide some insights into how patients spend their days. The results suggest that the rehabilitation environment may not be sufficiently geared to facilitating physical and mental activity or social interaction, and that it may not function as a learning environment [1]. Other studies suggest that a large percentage of the patient's day is spent in passive pursuits rather than in physical activity. The issue of how much time is spent in physical activity including practice of motor tasks, and how this time is organized, is a critical one for rehabilitation. Focussing on task-oriented training requires considerable changes in physiotherapy practice not only in methods used but also in delivery. Therapy is changing from a dependence on therapist-controlled movement in a one-to-one therapist-patient relationship. Physiotherapists are exploring different ways to organize the delivery of physiotherapy to enable the patient to be an active learner; for example, examining the effects of a more interactive relationship between patient and therapist, of small group training sessions including circuit training, of sessions where patients work in partnership with each other [29] or independently at work stations using printed guidelines and diagrams. Technological innovations are aiding the development of computer-aided training methods which foster independent practice. What the patient is actually doing in physiotherapy must be effective if increasing the amount of time spent practising is to improve outcome. Evidence is emerging that cortical reshaping depends on the nature and intensity of practice, rather than simply on its presence [42]. Furthermore, what the patient does outside time allotted for supervised training is also likely to impact significantly on progress. For example, self-propulsion in a one-arm driven wheelchair using non-paretic limbs is at odds with goals to increase strength and control of paretic limbs [18]. If the patient spends more time in this activity than in exercising the impaired limbs, it is not hard to guess the probable outcome.

Fitness Training

An aspect of therapy for neural lesions that has received little attention until recently is the intensity of exercise and the extent of cardiovascular stress induced during physical activity. The detrimental effect of low exercise capacity and muscle endurance on functional mobility and resistance to fatigue can be compounded by the high metabolic demand of adaptive movements. Stroke patients are often unable to maintain their most efficient walking speed comfortably indicating that the high energy cost of walking and poor endurance further compromise functional performance [35, 48]. There are several reports of improved aerobic capacity in chronic stroke with appropriate training such as bicycle ergometry [37], with graded treadmill walking [30] and with a combination of aerobic and strengthening exercises [44]. As might be expected, the effects are exercise-specific. Generalisation occurs, however, in the improvements noted in general health and well-being. *Teixeira-Salmela* and colleagues [44] assessed subject's general level of physical activity on the Human Activity Profile, a survey of 94 activities which are rated according to their required metabolic equivalents. The results indicated that subjects were able to perform more household chores and recreational activities after strength and aerobic training.

It is interesting to consider that despite the fact that stroke and cardiac disease share common risk factors and pathophysiology, physical rehabilitation for these conditions varies considerably. It is well documented that stroke patients have low physical endurance when discharged from rehabilitation. Deconditioning has been shown to occur within the first six weeks after stroke in a study that measured exercise capacity in the early post-stroke period. Patients performed incremental maximal effort tests on a semi-recumbent cycle ergometer [22]. This deconditioning may be a consequence of the relatively static nature of typical rehabilitation programs and indicates that intensity of training needs to be addressed specifically and early after an acute brain lesion.

Recently *MacKay* and *Makrides* [28] investigated the aerobic component of physical and occupational therapy for stroke patients by monitoring heart rate (using heart rate monitors) and therapeutic activities bi-weekly over a 14-week period without influencing the content. The major finding was that the therapy sessions involved low intensity exercise and activity that did not provide adequate metabolic stress to induce a training effect. Although one might expect progressively higher exercise intensities over time as functional status improves, any increase in HR_{mean} and HR_{peak} did not reach statistical significance.

Concluding comments

The regaining of skill in critical tasks requires specific training, with intensive practice of actions in the appropriate contexts. In addition, the individual must have the necessary muscle strength and be fit enough to perform the tasks of daily life, including social and recreational activities.

Entry level physiotherapy curricula have to respond to evidence of the importance of exercise and training for individuals with chronic disability, with the inclusion, as core knowledge, of subjects such as biomechanics, exercise science and motor learning. The skills required for training individuals with disability, how to adapt training and exercise to the patient's level of performance should also form a significant part of the education of physiotherapy students as well as of skill upgrading in continuing professional education.

Anmerkung:
Prof. Carr und Prof. Shepherd führen vom 20.5.–22.5.2005 einen Workshop für Ärzte und Therapeuten in den Schmieder Kliniken Konstanz zum Thema "Task oriented motor training: from science to practice" durch. Informationen unter www.schmieder-kliniken.de, zenith@kliniken-schmieder.de oder 0 77 34/86 22 43.

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