COVER STORY

It's all about nerves! Neuroplasticity and motor learning

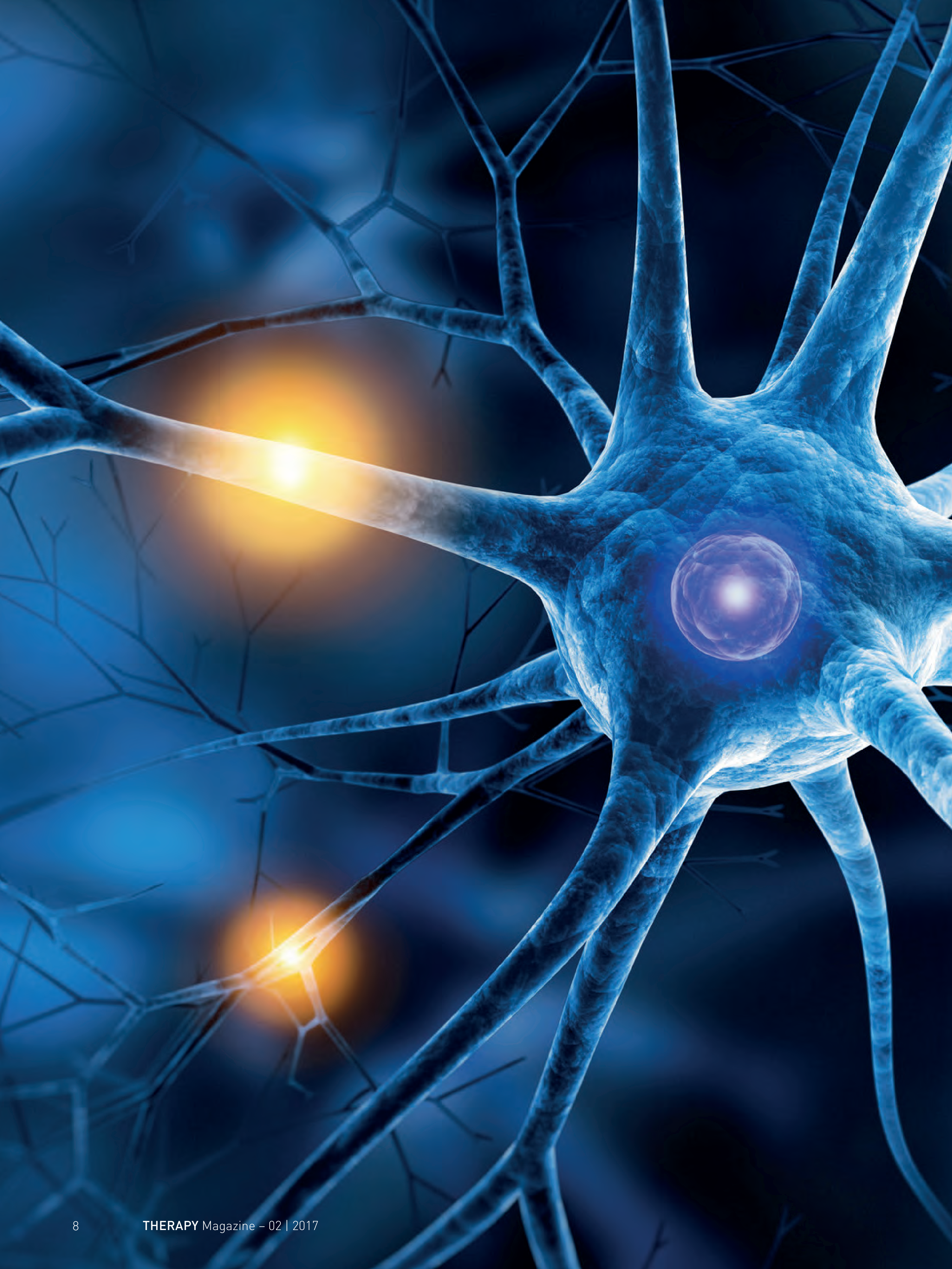
By Jakob Tiebel

The neural plasticity of the brain is the biological basis for successful motor rehabilitation following damage to the nerve system. "Neural plasticity" is any structural and functional adaptation of the brain that can result from changes to the environment and following damage to the brain [1, 5].

Lifelong plastic changes to the brain are possible through behavioural changes, training and learning [6, 7]. Above all, they are based on changes to the strength of connection between nerve cells [8]. In addition, research results in recent years show that depending on the scale and location of the damage, different neural plasticity mechanisms aid the nervous system to compensate for functional breakdowns in an impressive way [9].

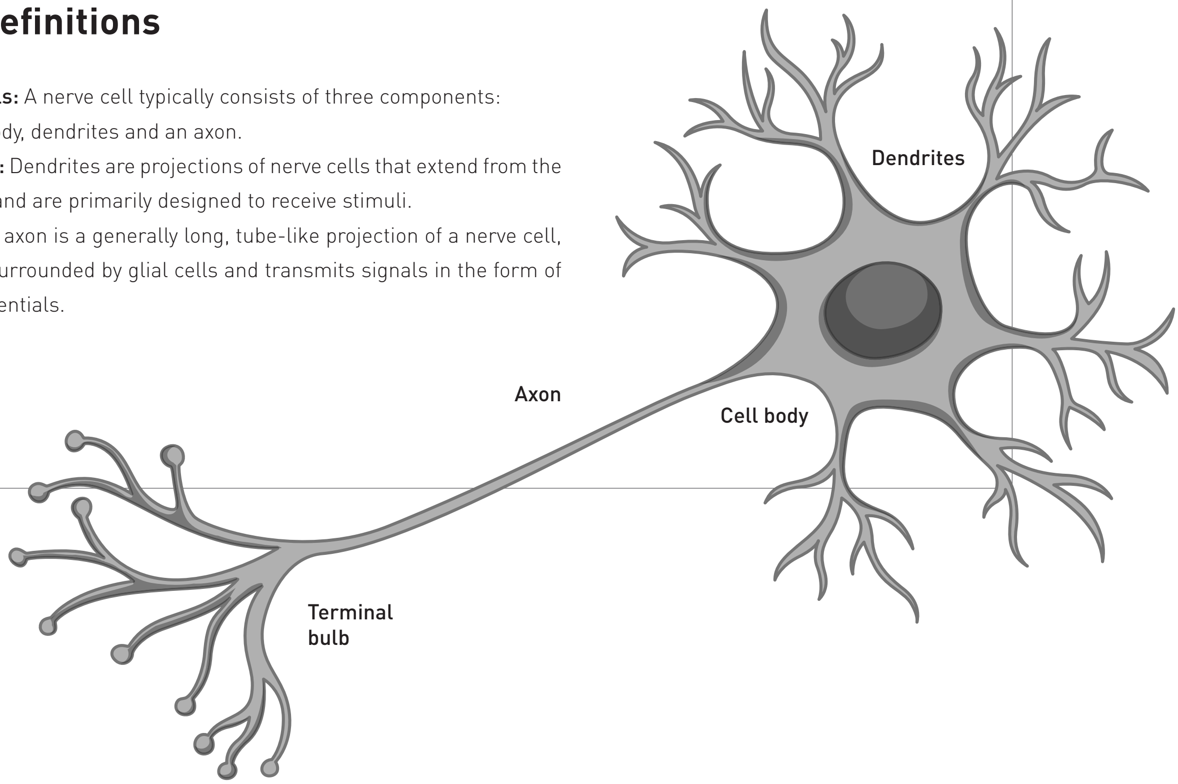
Spontaneous recovery

Damage in the region of the brain leads to the destruction of nerve cells, which is accompanied by a corresponding loss of neural functions. Intact regions that lies outside the damaged area of the brain but are connected to it often display reduced



Key definitions

Nerve cells: A nerve cell typically consists of three components: the cell body, dendrites and an axon.
Dendrites: Dendrites are projections of nerve cells that extend from the cell body and are primarily designed to receive stimuli.
Axon: The axon is a generally long, tube-like projection of a nerve cell, which is surrounded by glial cells and transmits signals in the form of action potentials.



function following the damage. Spontaneous reorganisation processes occur in the initial days and weeks, enabling the neighbouring regions to recover again. Ideally, this can significantly reduce the extent of the initial impairment.

In silent standby

In the process of unmasking suppressed intercortical connections, it is possible to bring about the activation of "silent" synapses [10]. Cao et al. have managed to provide evidence of the activation of areas neighbouring a damaged region after a stroke. As part of the recovering function, cortical representation fields are modified so that existing but unused, redundant nerve connections are activated [11, 12].

Newly sprouted

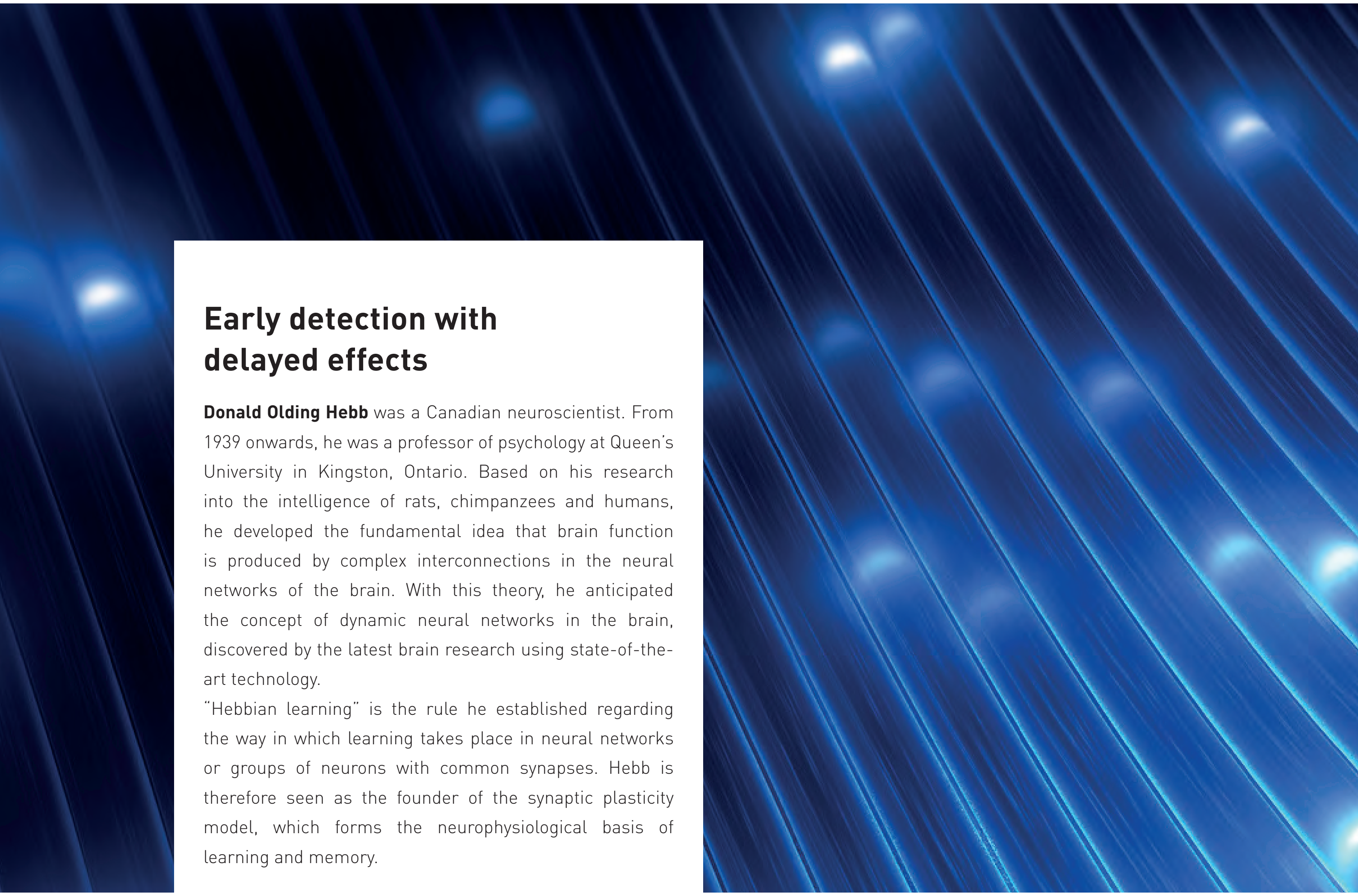
Plastic changes following brain damage can also be caused by dendritic branching in the sub-acute stage. Denervated neurons are capable of forming connections with other nerve cells by way of sprouting. This creates new contact points between nerve cells.

Along with dendritic growth, another potential mechanism of plasticity is axonal growth. As axonal growth takes significantly longer, the mechanisms will presumably only have a significant effect months or years after the damage is inflicted [3, 13, 14].

"Hebbian theory"

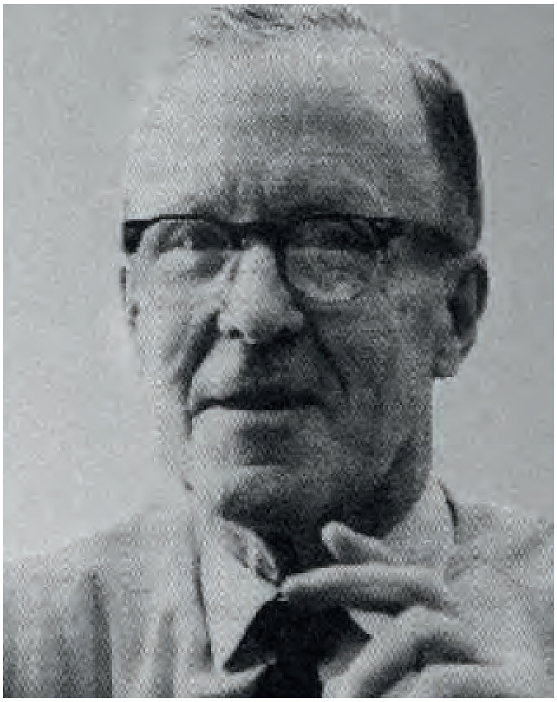
The most important mechanism for inducing plasticity is the modulation of pre-synaptic and post-synaptic efficiency in the sense of long-term potentiation (LTP) and long-term depression (LTD) [15].

The principle of LTP is also known as the "Hebbian theory" and is seen as the basis for all learning and memory processes. The "Hebbian theory" states that the strength of connection between two interconnected neurones increases when these are stimulated and fire simultaneously



Early detection with delayed effects

Donald Olding Hebb was a Canadian neuroscientist. From 1939 onwards, he was a professor of psychology at Queen's University in Kingston, Ontario. Based on his research into the intelligence of rats, chimpanzees and humans, he developed the fundamental idea that brain function is produced by complex interconnections in the neural networks of the brain. With this theory, he anticipated the concept of dynamic neural networks in the brain, discovered by the latest brain research using state-of-the-art technology.
"Hebbian learning" is the rule he established regarding the way in which learning takes place in neural networks or groups of neurons with common synapses. Hebb is therefore seen as the founder of the synaptic plasticity model, which forms the neurophysiological basis of learning and memory.

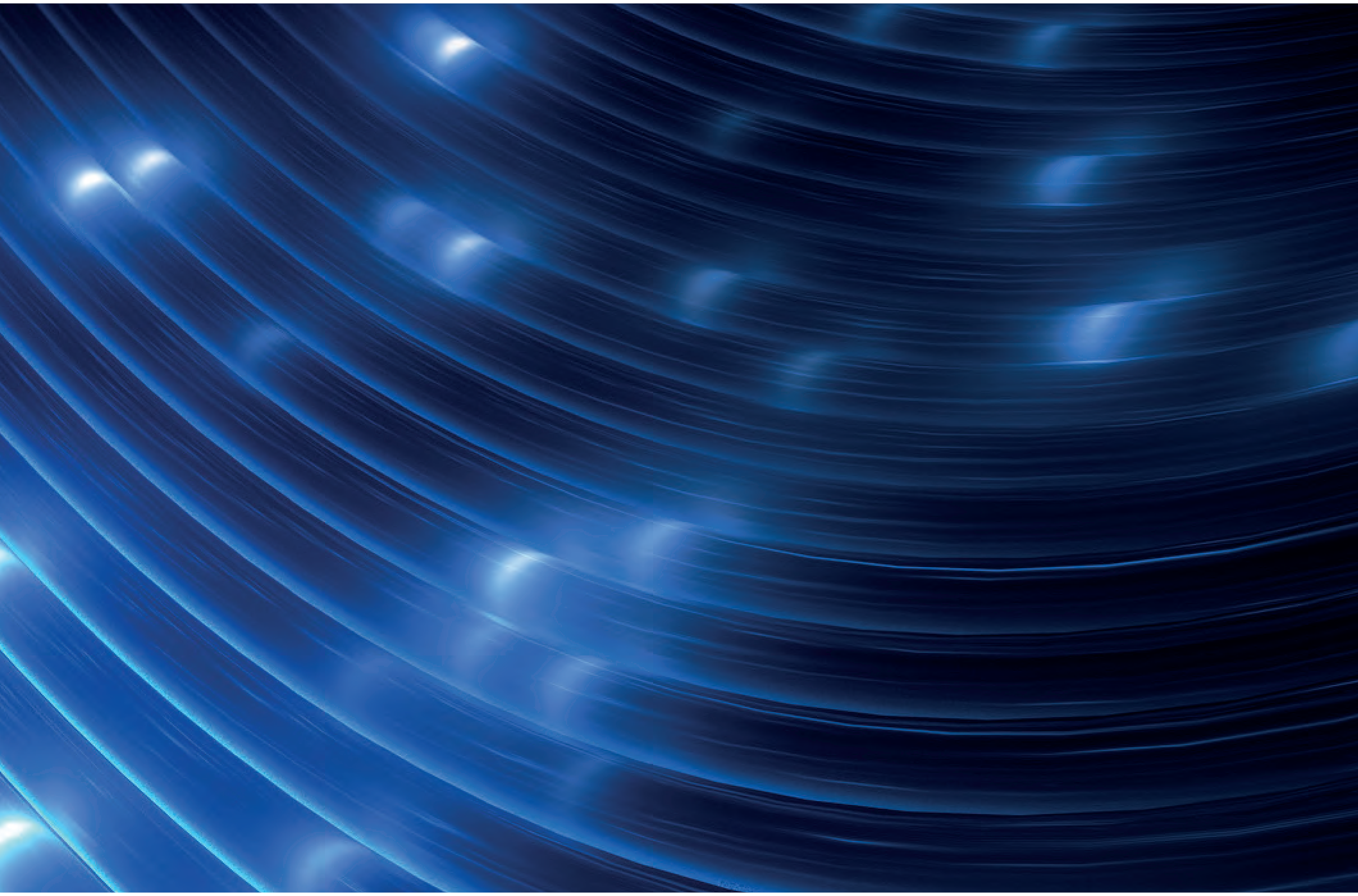


[1]. The theory applies to individual connections between nerve cells along with entire network structures [18]. Changes to the connection strength are based on growth processes and metabolic changes to one or more neurones [1].

With the long-term potentiation (LTP) and long-term depression (LTD) model, repeated synaptic activation patterns therefore alter the synaptic efficiency. In this way, contacts to other neurones and across the functions of cortical connections can be altered in the long term. This results in changes in the area of stimulation thresholds and receptive fields, which bring about a reorganisation of cortical representations [3, 9, 16].

Assumption of other pathways

The assumption of parallel and functionally similar pathways is known as vicariation. Other regions



of the brain take over the relevant functions in place of damaged regions of the brain. The areas of the cortex used for this generally have a similar microstructure. It can often be observed that the homologous structures of the contralateral hemisphere are involved in compensating for the loss of function [3, 9].

Sources for regeneration

The regeneration of neurones and the use of stem cells for restoring defective brain regions are the focus of ongoing research [9]. Experiments have already clearly shown that transplanted bone marrow cells can be differentiated for different nerve cell types [17].

The brain grows along with its tasks

Proof that the lifelong plasticity of our nervous system forms the basis of functional motor rehabilitation is one of the decisive catalysts for the paradigm shift in neurorehabilitation that has taken place in recent years. The insights into neural plasticity have paved the way for the targeted deployment of treatment technologies to positively influence the reorganisation of the nervous system following damage.

Basic principles

At this point, it is worth mentioning a few underlying principles regarding motor rehabilitation, which must be taken into account to ensure the best possible care for patients.

Important predictors for achieving a positive outcome, in terms of keeping the degree of disability to a minimum following neurological damage, include ensuring that therapy is initiated as early as possible [19] and is as intensive as possible [20, 21]. It is assumed that a combination of the two factors is a more effective approach [22, 23]. Daily training is recommended to last around three hours for individual and group therapy, depending on the patient's physical capacity [24].

Active, repetitive practice of skills and movements relevant to everyday life has proven to be a key element of modern therapy measures [21, 22, 25, 26]. Important principles for motor learning following damage to the central nervous system were put forward by Carr and Shepherd in 1987 and Shumway-Cook and Wollacott [27, 28]. Modern neurorehabilitation is currently largely based on the principles of motor learning [29]. In the context of motor learning, Freivogel differentiates between "isolated sensomotory training", according to which individual movements are practised in isolation, and "task-oriented training", according to which everyday activities are practised. Both principles are relevant to the treatment of neurological patients [26].

Motor learning – A matter of principle

The ability to move is fundamental to people's ability to interact with their environments, and one that is often taken for granted. People are normally consciously engaged with the ability to move only if the processes involved do not take place automatically if, for example, they are affected by an illness.

The recovery of motor skills following damage to the central nervous system can be seen as a motor learning process with which functions can be restored through targeted exercise. Motor rehabilitation is therefore a form of motor learning that aids the relearning of movement [30, 31]. This is why the type of training has a decisive influence on motor leaning [24]. The motor learning process can be divided into three stages. Basic principles for instruction, feedback, repetition and shaping must also be taken into account. These are outlined below [32].

Learning takes place in stages

In the cognitive phase, the support of therapists

is important and beneficial to learning. However, information and assistance must be reduced to the bare essentials. Modern treatment is essentially based on a "hands-off" principle. The focus is on the goal-oriented activity of the patients, not the influence of the therapist. In this stage of learning, it does not yet make sense to have variations, which also disrupt the learning process [26].

The second stage of the learning process is known as the associative stage. In this stage, exercises can be varied with caution to gradually increase the level of difficulty. Targeted feedback from the therapist remains important, but after defined exercise intervals rather than after each individual movement.

In the autonomous stage, variations can and should be made regularly. As the patient's performance improves, additional difficulty can be integrated in order to intensify the exercise, making it necessary to readjust the movement. This creates the additional goal of continually improving particular aspects of movement.

Inside out – Where to focus attention

During therapy, patients can direct their attention towards various aspects. This largely depends on the instructions of the therapist. If the patient is advised to concentrate on the movement process, this is known as an internal focus. Focusing attention externally on the objective of the movement, however, has been shown to be more effective. Studies by Wulf et al. show that movements with an external focus are learned faster. When formulating movement orders, it can be helpful to use metaphors [33, 34, 35].

The objective of a 2013 study by Johnson et al. was to evaluate the proportional use of internal and external focus by physiotherapists during the treatment of stroke patients. On average, the therapists gave the patients instructions 76 times and feedback 22 times per therapy session. This corresponds to an average value of one instruction every 14 seconds. The therapists gave numerous instructions to ensure that the patients would have to reflect on many of the details of the task before them. They also repeated the instructions very often over a short space of time, including while the movement was being performed. An average of almost 70% of instructions were focused internally and only around 30% were focused externally. Physiotherapists therefore mainly instruct their patients in such a way that they concentrate on the movement itself and the execution of the movement (internal focus). The authors of the study point out that it is precisely this approach that can hinder the automation of movements and motor learning, along with the ability for the learning to be successful [36].

Against this background, an external focus should strictly be the preferred option [33][34].

Feedback

The success of motor learning is largely based on the intrinsic feedback mechanisms of the patient. There is a distinction here between the knowledge of performance and the knowledge of result.

The therapist's external feedback mechanisms and, for example, the use of biofeedback can successfully support the patient's learning process. However, dosage here is also crucial. Intrinsic and extrinsic feedback often overlap. Less can often mean more for patients in this respect [37, 38].

Above all, therapists have the task of instructing and training patients to ensure that they are capable of creating the required intrinsic feedback themselves [31].

Repetition

There is no authoritative information on the number of repetitions required for relearning a movement. The number of repetitions depends on the complexity of the movement and the patient's ability to learn, among other things. However, it must be assumed that with complex movement processes a significantly higher number of repetitions is required for relearning than is used in therapy [26]. Mehrholz describes repetition as the single most significant factor for lasting and sustained progress in the execution of movements. It is the most important variable when learning many activities [39]. Frequent repetition and practice of simple and complex movements should be considered the main requirements for a successful learning process and bring about long-lasting automation and optimisation of movement processes [26, 40].

Reaching the limits of patients' capabilities

Successively increasing the degree of difficulty in the context of motor learning is known as "shaping". Patients should be given movement tasks that they are only just able to complete and can be made gradually more difficult based on their capabilities. Movement programmes can be further optimised if combined with frequent repetition and corresponding feedback on achievement of the movement target.

The target must be to systematically increase the requirements of the patient and to continually exercise at the limit of his or her abilities [41, 42].

LITERATURE

The references for this article are available at www.thera-trainer.de/therapy