D. Reorganization of the human spinal cord and supraspinal centres

63. Summary of three new developments in neurosciences which provide the scientific basis for neurorehabilitation

Due to three new developments in neurosciences, namely (I) the concept of self-organization and coordination dynamics of neuronal networks, (II) the concept of rhythmic firing of subneuronal networks and single neurons and of the rhythm coupling between them, and (III) the concept of regeneration including neurogenesis in adult patients with CNS lesions, neuronal networks can be reorganized and repaired so that the somatic, autonomic and higher mental functions of the CNS can be improved to enable patients to perform again the necessary functions of everyday life.

I. The self-organization of neuronal networks of the CNS according to the afferent input and the potential for changes in self-organization has direct clinical consequences. From the potential for changes in self-organization it is inferred that, following CNS lesion, a much higher neuroplasticity can be expected as has been assumed so far.

II. Motoneurons in the human nervous system were observed to fire rhythmically for high activation in coordination with afferent fibres. Phase and frequency coordination has been observed in the spinal cord. At the stage of high activation, motoneurons are probably a part of the rhythmically firing premotor subnetworks. Moreover, evidence has been provided that, following CNS lesion, these self-organized spinal premotor oscillators partly loose their specific rhythmic properties and specific phase relations of rhythm coupling. A rhythm therapy and coordination dynamic therapy can be expected to improve the specific rhythmic properties of the premotor spinal oscillators and their phase relations of relative rhythm coupling among them respectively, and to restore more efficiently physiologic functions of the CNS. It can be expected that the partly lost phase and frequency coordination following CNS lesion can be re-learned. By a supervised re-learning of the timing of firing of neurons in the lesioned CNS, the lesioned CNS can be repaired.

III. It has been shown that, in the lesioned CNS of man and animals, different kinds of regenerative processes take place, including neurogenesis in adult man. It can be assumed that phylogenetically older CNS parts such as the spinal cord, the brainstem and the limbic system undergo most strongly innate repair mechanisms. Neurogenesis in adult man has been found so far in the gyrus dentatus (hippocampus). Scientific evidence has not been provided to rule out the possibility of neurogensis in other parts of the adult CNS, if an intensive coordination dynamic therapy is applied. The fact that patients with a damaged central pattern generating network in the spinal cord for walking and running (damage in the lumbosacral spinal cord) can re-learn to walk and run makes it likely that there is neurogenesis to a certain extent also in the spinal cord and brainstem.

Apart from functional repair data and innate repair mechanisms that contribute to the restoration of motor functions, it should be remembered that neurons can migrate and axons can grow over long distances. Functions of the neurons can therefore not be safely concluded upon based on the site of neurogenesis. Human adult neurogenesis can essentially enhance neuroplasticity because nerve cell replacement may be very important in critical areas of nerve cell damage or specific type of nerve cell damage. If for example, nearly all neurons in the spinal cord were destroyed by a certain disease, locomotion could only be re-established if there is neurogenesis of motoneurons.

64. Theory-derived therapeutical methods which make essential progress in neurorehabilitation possible

The therapy methods include (I) rhythm therapy (e.g., jumping on a springboard), (II) coordination dynamic therapy (e.g., exercising on the special coordination dynamic therapy device), (III) the use of integrative automatisms of the CNS (e.g., running), (IV) motivation of the patient, instructive learning and interpersonal coordination, and (V) the use of old learned movements (e.g., climbing staircases).

I. The *rhythm therapy* is aimed at repairing losses of specific rhythmic firing of self-organized premotor spinal oscillators and other neurons and the phase relations among the firings.

II. During *coordination dynamic therapy* single neurons, cell assemblies and extended neuronal network parts are made firing in relative coordination again. The re-learning of relative coordination of rhythmically and not rhythmically firing neurons is achieved by the space-time (up to a few milliseconds) correlated proprio- and exteroceptive re-afferent input, which is induced by the exercise of the patient on the training devices. The coordinated integrative functions of the CNS, lost due to the lesion, have to be re-learned by coordinating the coordination dynamic tendencies of neuronal networks of the CNS with the afferent and re-afferent input and the volitional impulse patterns. A patient with hemiparesis, e.g. is not using the paretic arm during walking or running. Instead, the arm and the hand assume a spastic position. If the arm can be made to move in coordination with the other limbs, spasticity reduces. A special case of the coordination dynamics, namely induction of co-movements (e.g., right-left coordination) by simultaneous afferent input has been demonstrated during swimming and exercising on the special coordination dynamic therapy device (Figs. 53,101C).

Even though the improvement of rhythmicity and the training of coordination dynamics have the same basis, they are not identical. In neuronal network parts functionally separated due to CNS lesion, subnetworks may fire rhythmically with rather specific phase relations among them; still the integrated functions of the whole CNS are lost. Only restoration of the coordinated, integrative interactions of functionally separated parts of the CNS will essentially improve somatic, autonomic and higher mental functions.

III. *Integrated automatisms* like walking or running, mainly generated in the neuronal networks of the spinal cord, can be used to 'tell' supraspinal neuronal networks in an integrated way by interlaced networks what they have to re-learn and what they have to contribute to the 'cooperative task network organization with physiological output'. The stepping automatism is mainly induced by the afferent input from the feet and is self-organized in the neuronal networks of the spinal cord (see stepping in newborn and anencephalic babies above).

Bobath and others used automatisms and reflexes to reorganize the lesioned CNS. Running represents a unique automatism. On the one hand, it is generated by a highly integrated network organization which includes the movements of arms and legs and the activation of trunk stability and breathing. All muscle activations are coordinated and rhythmic. On the other hand, the stepping automatism is innate, walking is used in everyday life and running is an escape automatism throughout the life. The induction of rhythmic movements in adult man at certain sites is not necessarily of benefit for the reorganization of the lesioned CNS, since rhythmic movements must be directed towards learning of physiologic movements. The lesioned CNS has to be instructed how it has to reorganize itself. The CNS as an 'adaptive machine' can be changed in its functioning in a positive and negative sense.

In the reorganization of the CNS it is of utmost importance with what efficacy the CNS can be reorganized, because motor learning and reorganization need a lot of time like learning at school. In a first approximation, the change in self-organization is most likely proportional to the number of movements or activations per therapy time.

IV. *Motivation, instructive learning and interpersonal coordination.*

a. The patient has to be continuously supported and *motivated* to make him/her intensively and continuously train. The opportunity for motivation is often good, as feeling of safety and support is needed by the patient due to the CNS lesion. Still, a big problem remains how to motivate the patient continuously, especially when he/she lacks drive.

b. The patient needs the therapist for *instructive learning*. During the rhythmic movements, weak movements improve in performance and strength by rhythmic instructions which have to be coordinated with the movements and are to be given at an effective timing. For *self-instructive learning*, the patient gives himself, at appropriate timing, instructions in parallel with the will for performing the movement. Self-instructive learning is as effective as instructive learning, only the patient is often too exhausted or too much concerned with other movements or activations to do it.

c. The patient needs the therapist for *interpersonal coordination*. Interpersonal coordination takes place at a lower level of organization, and therefore needs no concentration on the part of the patient. The therapist only has to be in the field of vision and the patient must be able to hear and/or feel the therapist.

d. The patient needs the closeness of a close person to cope with the lesioned CNS. The dysfunction of the CNS induces anxiety in the patient.

How to handle a patient in motor learning for speech has beautifully been described by A.J. Lerner's (book) and F. Loewe's (music) musical 'My fair lady', first performanced in 1956. The musical grew out of the comedy 'Pygmalion' by Bernard Shaw, originating back to the Roman poet Ovid (43 B.C.-17 after C.); Pygmalion was a king who got in love with a statue of a virgin made by himself. The goddess Aphrodite enlived the statue and Pygmalion took the virgin for his wife. In 'My fair lady', the professor treats the young lady for 3 to 6 months with honey and whip to motivate her. He measures and documents the progress with an equipment and uses bio-feedback (speaking into the flame). The musical even tackles the issue of self-confidence of the patient (if a woman is treated as a lady, then she is a lady), the incorrect behavior of the professor (he handles the 'patient' as an object rather as a human being, he tries to project his opinion onto the patient), and the developmental deficiencies of the society (the human being is valued by how he/she speaks and what he/she wears).

V. *Old-learned movements,* which are stored integratively on a lower level of integration in the CNS, are probably only little affected by local traumatic lesion. The training of such old learned movements should be helpful to 'tell' the CNS what it has to re-learn. A tetraparetic patient with a cervical spinal cord lesion could hardly hold the tennis racket because of the lesion. But when he managed to hit the ball, the ball flew the desired direction. The patient could have hardly achieved a comparable quality in playing tennis if, after the lesion, he were a beginner.

65. Practical aspects: Starting the therapy

Reorganization of a lesioned CNS should start as early as possible. Sufficient oxygen supply to the CNS must be secured. If coordinated movements are performed with little effort, the oxygen supply needed may be compensated for by the improvement of the blood circulation due to the movements. Fractures of the skeleton should be reconstructed invasively to allow as early as possible therapy for reorganizing the CNS with the outcome of physiologic movements and to avoid the development and establishment of pathologic CNS organizations (spasticity). Movements have to be exercised which the patient is able to perform with and without support. Especially, a device for performing coordinated arm, hand, finger, leg, foot, toe and trunk movements in recumbent position is suitable, because the patient is lying safely on the back, and arms and legs can be fixed so that movements can be performed even if the patient cannot move actively (coma patients) or is not cooperative. Support by therapist is necessary. In spinal cord lesions coordination dynamic therapy has to be started long before the spine is healed; and in brain lesions therapy should be started already at the intensive care unit when the patient still has not regained consciousness. Conventional arm and leg movements alone will keep the joints mobile, but will not force the CNS to reorganize in the way that physiologic movements are generated later on. With the increasing stability of the skeleton and increasing volitional power of arms and/or legs other equipement has to be used additionally, first with the support by the therapist and without it later on. Generally, devices are used which the patient can manage at that stage of the restoration of motor functions. The patient has to tolerate some pain, but the therapist has to judge whether the pain is dangerous (may damage a joint) for the patient or not, especially when the patient has only little pain sensitivity left. If possible, best is to choose equipment for therapy which cause no or only little pain. In conscious patients with brain lesions it may happen that the patients complain of having pain, even though they have no pain, to avoid exhausting exercising. Unconscious children may cry possibly to have it more comfortable or to demonstrate their own will. It is a mistake to believe to be on the safe side if administering only little therapy not to overstrain the lesioned CNS, because pathologic network organizations may develop (epileptic seizures) and critical essential periods for re-learning may be missed [40].

66. Reorganization of the CNS following spinal cord lesion: case reports 1-7

Case 1: *Compression lesion of the lower spinal cord including the conus medullaris [135].*
A 15-year old female patient suffered a compression lesion of the lower spinal cord due to an extended ependymoma (benign tumor). Pain present before the operation did not allow her to run over the last 5 years. Due to continuous pressure the leg functions were lost first, followed 3 days later by the loss of continence (control of urinary bladder and rectum). Five days after the decompensation laminectomy was performed and the tumor removed. Intramedullary cysts from Th4 to Th12 were left.

Three months after the surgery, coordination dynamic therapy was started (Figs. 66,67) under the guidance of the author (G.S.) to improve locomotion and continence. At the beginning of the therapy, the patient could walk a bit (no physiologic positioning of the feet), could not run and had continence broblems. The daily therapy of the cooperative patient included stretching, crawling, free walking (Fig. 67), jumping on a springboard (Fig. 66B,C), air-walking (Fig. 66D), supported running and finally free running. Because of a fast progress it was possible to abandon treadmill training. The variability with the air-walker and springboard training is shown in Fig. 66. The strider and the springboard could be brought into a nice surroundings, assembled (Fig. 66A) and used for therapy (Fig. 66D).

The therapy was provided by the older brother of the patient under the supervision by the author. Free walking (Fig. 67) improved quickly, and free running was achieved (Figs. 66G,67). The therapy with the brother was stopped after 10 days because of intensive pain developing in the lumbar region. The author succeeded in relieving the pain by letting the patient jump rotational movements a few hundred times on the springboard. The therapy could now be continued, and walking, running and jumping in anti-phase could be trained without pain. The

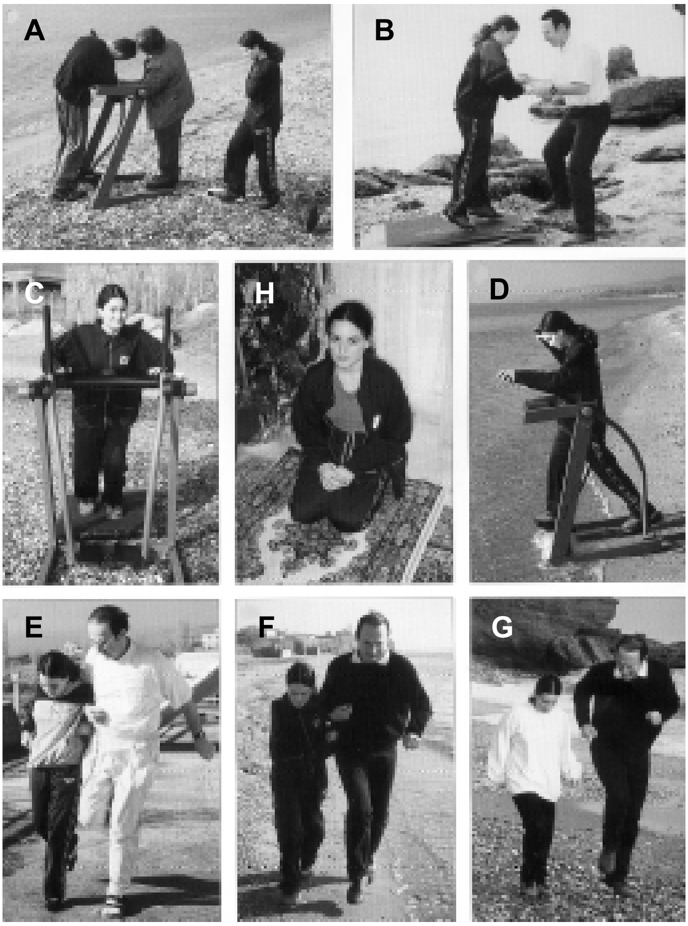


Figure 66 A-H
Outdoor coordination dynamic therapy to enhance motivation in a 16-year-old patient following conus medullaris compression by an extensive ependymoma and after extirpation of the tumor. A. The air-walker is being assembled by the father and brother. B, C. Jumping in antiphase on a springboard. Instead of wall bars support is given by the therapist (author G.S.) (B) or the air-walker (C) is used. D. Air-walking at the sea (Thrakikon Pelagos, Greece). E, F. Supported coordinated running 'on the roofs of Alexandroupolis' (Greece) (E) and at the sea (F). G. Patient during free running. H. Reddish face due to hypersensitivity to antibiotics.

Fig. 66 I-M
I. Running, 2 months later than in E-G; the vitality of the running increased. K, L, M. Jumping at the sea and climbing in the mountains to train non-rhythmic movements.

reason for the pain was not the surgery but a marked scoliosis. By jumping every day in the morning and in the afternoon at least 200 times in rotation, no pain occurred any more, even though the training load increased. Because the patient had not really been walking (and of course running) for the last 5 years, at the beginning she did not believe that she could run any more. The fear from running could be taken quickly from her. After a few days of supported running (Fig. 66E,F) free running was achieved (Fig. 66G). The running performance was al-

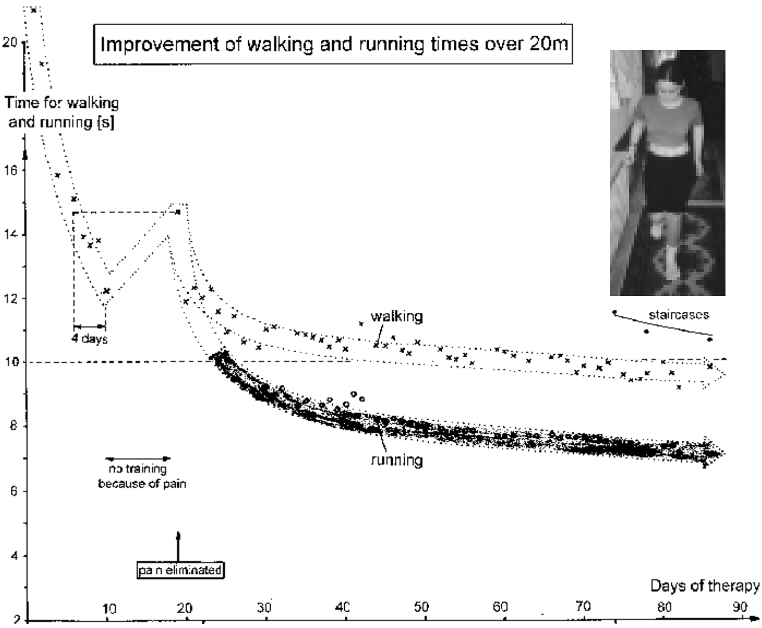


Figure 67 Improvement of walking and running times over 20 m in a 10 m long floor with one turning point. Start of therapy 3 months after the extirpation of the ependymoma. The walking times (crosses) improve quickly. A therapy break of 8 days because of a strong pain in the lumbal range (probably due to scoliosis) throws the patient back in her success by 4 days (as indicated by the dashed lines) in addition to the lost 8 days of therapy. With the relief of the pain by jumping in rotation on the springboard at least 400 times per day, the therapy could be resumed. After a few days of supported running (Fig. 66E,F) free running was achieved (Fig. 66G). The backwards extrapolation of the running curve seems to indicate a fusion with the walking curve. Similar origin of the walking and running curves suggests a similarity of the reorganization with ontogenesis (Fig. 64). Only 3 measuring points were obtained for running up the staircases post-lesion.

ways better than that of walking. With the ongoing intensive training (6 times per week, 2 times per day), the dynamics of the running could strongly be enhanced (Fig. 66I), so that after 6 weeks non-rhythmic movements could additionally be trained (Fig. 66K). The walking in mountains (Fig. 66L,M) should be useful to train the modification of stereotyped movement patterns.

An extrapolation of the curve for running backwards indicates a similarity between walking and running, as the curves for walking and running seem to have the same origin (Fig. 67), as if walking and running were generated by the same neuronal network and very similar network states. In this case, the curves for walking and running during reorganization show similarity to ontogenesis (branching of walking and running, Fig. 64), which supports an earlier assumption that there are some similarities between ontogenesis and reorganization following CNS lesion.

At the beginning, the coordination between arm and leg movements was difficult for the patient during walking, but not during running. The patient said herself during running: ‘The arms are moving by themselves in the right way during running’. The patient enjoyed running very much (speed ecstasy), and the running exercise lead to a faster improvement of the walking performance and therefore quality of life.

After 45 days the results of the therapy were already quite good (Fig. 66I-M). But the treatment was intensively continued to improve the urinary bladder function. Because of the lesion of the conus medullaris atonic bladder with incontinence developed. The autonomic nervous system seems also to be organized by rhythm coupling, rhythm training can thus be expected to improve urinary bladder functions indirectly, by interlacing neuronal networks or network states. First signs of recovery of the pelvic floor muscles (together with sphincters for guarding continence) were recognized, which fitted the loss in sensitivity (loss of sensitivity of the right dermatomes S2-S4, mainly preserved sensitivity of the left sacral dermatomes), even though motoric and sensoric losses often do not coincide. A quick reorganization of the sacral micturition centre was necessary to eliminate the anatomical basis for reoccurring bladder infections (no or only little function of the pelvic floor and sphincters, no complete emptying of the bladder, detrusor-sphincter-dyssynergy), to avoid repeated administration of antibiotics, the patient showed hypersensitivity to (Fig. 66H, reddish colour of the face), and to prevent bacteria from colonizing the foldings of the bladder epithel. Ascending kidney infections were previously the factors limiting the life of patients with spinal cord lesions. The patients feel the loss of continence, followed by the loss of sexuality and locomotion and occurring pain problems as the biggest losses with respect to the quality of life.

After 90 days of intensive therapy the patient became continent, even though the feeling of bladder filling was still far from normal. Bladder infections did not occur any more. The intensive therapy (including the training of different kinds of movements) was continued to further improve bladder functioning, to get back more sensitivity in the sacral range (with the improvements of the neuronal network organization), and to improve regulatory functions of the spinal cord to prevent re-growth of the ependymoma. MRI (magnetic resonance imaging) taken half and one year after the surgery showed cysts in the lower spinal cord. There was no indication of regrowing ependymoma or enlargement of the cysts. After one year the patient went back to school and she now behaves as a normal teenager. She, e.g. is fond of dancing. The sensitivity in the sacral range improved slightly during the year, but is still not normal. Urologists report that sensitivity improves slowly but continuously over years. The patient is now back to normal life [135]. - The opinion of the rehabilitation department of a wellknown hospital 2 months after the operation was that she should be glad if she can stand on her own feet again and can walk a bit.

Case 2: *A tetraparetic patient re-learned running one year after the accident [131]*

One year after the accident, a 56-year old tetraparetic patient (sub C4/C5, the patient could walk with some balance problems) re-learned free running and other movements during a 6-week training by jumping on a springboard (opposite phase coupling of spinal oscillators), running under 20 kg weight reduction and other movements [131]. The number of jumps per series increased from 50 to 300 with ongoing therapy. Each series of jumps was terminated by a block of the left knee due to pathologic simultaneous activation of knee flexors and extensors (spasticity). With ongoing jumping on the springboard, the pathologic neuronal network organization got reduced (longer series with the knee block occurring later), and the physiological movements (walking, running) improved. Most likely, the spinal oscillators improved in their functioning, since the variation of the jumping frequency decreased i.e. rhythmicity increased, and the jumping frequency increased. The running speed increased up to 8 km/h during 11 days of running, and kept increasing thereafter up to 9.3 km/h. By using co-movements of the legs, the patient re-learned swimming, whereas before this therapy he could hardly swim at all. Tetraplegics have little power in their arms because of the lesion of the cervical intumescentia. When closing the legs before flexing, the 'poor' leg also moved, and the patient was able to swim.

Case 3 and 4: *Tetraparetic patients re-learned running 5 and 10 years after the accident [193]*

Two patients (case 3 and 4) underwent an intensive oscillator formation (rhythm entrainment) and coordination dynamic therapy for 3 months, 5 and 10 years after their tetraparetic spinal cord lesion respectively. Both patients used sticks as walking support; one patient (case

3) used braces to support the feet for walking and sometimes used a wheelchair. The therapy methods included crawling, jumping on a springboard (Fig. 69B), walking and running on a treadmill (Fig. 68A), air-walking (3000 excursions/day; Fig. 68B,C), special coordination dynamic training using a device for performing coordinated arm, hand, finger, leg, foot, toe and three-directional trunk movements (2000/day; Fig. 68E,G,H), free walking and running (Fig. 69C), and climbing staircases up and down (Fig. 68D). All exercised movements improved during 3.5-hour training sessions per day, 5 times a week for 3 months. The patients did not need sticks and braces any more. The first free running was achieved after 34 days. Spasticity reduced, no overstretching of the knee occurred any more, and the movement performances became better, even though the walking and running patterns were still not normal. Because the therapy was started many years after the accident, it is concluded that the improvement has been due to the therapy and that CNS functions can be improved very late after a spinal cord lesion, even though it is believed that the patient's functions have reached a steady state. It is proposed that many years after different kinds of CNS lesions, the outcome of the injury suffered can be improved essentially.

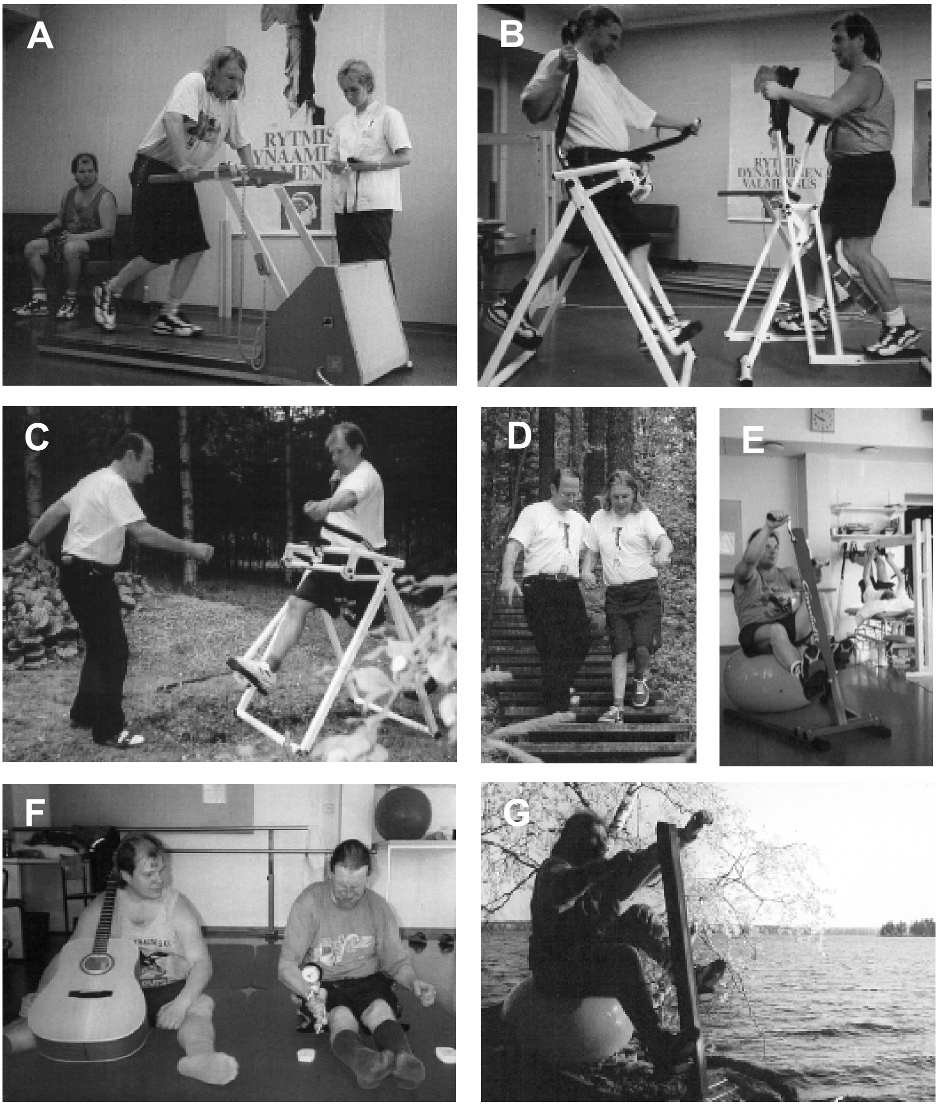
In a 40-year old patient 5 years after spinal cord lesion sub CV (case 3), the number of jumps in anti-phase per series increased from 20 to 600 in a somehow stepwise manner (Fig.69B). The mean walking speed over 26 m increased from 5.3 to 7.5 km/h, and the mean running speed increased from 6.1 to 8.7 km/h. The reduction of running and crawling times are shown in Fig. 69C,D. The hand grip power (Fig. 68F) of the right hand increased from 5 to 12 kg, and that of the left hand from 20 to 24 kg (Fig. 69E); physiological values are approx. 40 kg. The patient used auxiliary muscles to generate hand grip power, especially for the right hand. Because of shortend tendons and because of the dorsal flexion of the hand, the patient can also use arm muscles (auxiliary muscles) in addition to the hand muscles to generate hand grip power.

In a 38-year old patient 10 years after spinal cord lesion sub CVI/CVII (case 4), the number of jumps per series in antiphase increased from 50 to over 1100 (Fig. 70A), and was then kept at 500 per day so as not to overload the joints. The mean walking speed over 26 m increased from 6.7 to 9.3 km/h, and the mean running speed increased from 8.4 to 10.4 km/h (Fig. 70B). The hand grip power for the right hand increased from 30 to 33 kg and that for the left hand from 15 to 18 kg (Fig. 70C); no auxiliary muscles were used to generate hand grip power.

Even though the two patients seem to have suffered rather similar spinal cord lesions, the different recovery patterns of motor functions indicate different lesions and/or differently weighted regeneration processes. The running performance of the 40-year old patient (case 3)

Figure 68

Coordination dynamic therapy in two tetraparetic patients (lesion sub CV (case 3) and sub CVI/CVII (case 4), 40- and 38-year-old respectively) who re-learned running 5 and 10 years after the accident. A. Patient 3 is running on a treadmill. In the background patient 4 is giving the rhythm with a drum to improve the running rhythm of his colleague patient. The physiotherapist is measuring the running time and supervising the running. B. Patients during air-walking in interpersonal coordination. Even though the devices for air-walking had different properties and the patient on the right side (case 4) stoped the air-walking several times, they went each time again into interpersonal coordination. When the air-walkers were positioned so that the patients could not see each other, they did not go into interpersonal coordination. C. Air-walking: patient 4 at the beginning of the therapy. To enhance air-walking, the therapist (author G.S.) is giving interpersonal coordination stimulation by swinging his arms in coordination. D. Training of climbing up and down staircases in interpersonal coordination with the therapist (author G.S.). E. Re-learning of coordination dynamics of arms, legs and trunk. In the sitting position on the ball the equilibrium is additionally trained, and in recumbent position the coordination of fingers and toes can be trained in coordination with arm, leg and trunk movements.



Therapy in recumbent position is performed on an unsteady support construction since the proper device was not available at that time. F. Relearning of playing guitar (old learned movement for patient 4) and training to increase hand grip power (patient 3 just measuring hand grip power). At a later stage, hand and finger functions were mainly trained with the equipment shown in E. G, H. Training of coordination dynamics on a transportable coordination dynamic device in a nice surrounding to enhance motivation (at a lake, Vesijärvi at Pikonlinna, close to Tampere, Finland (G) and in front of the Acropolis of Lindos, Rhodos, Greece (H)).

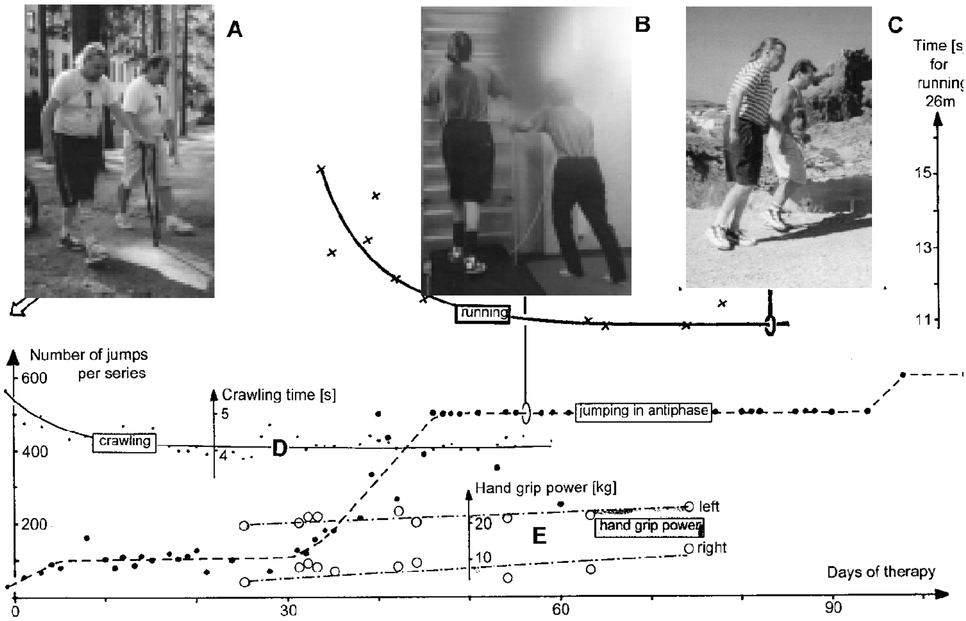


Figure 69
Improvement of motor functions due to a rhythm and coordination dynamic therapy for 3 months, 5 days per week and 3.5 hours per day in a 40-year-old tetraparetic patient (case 3) 5 years after a cervical spinal cord lesion sub CV. The outpatient (B) walked to the first therapy session with a stick and braces on the legs (A), and was able to run after the 3-month treatment without braces (C, in the background the Acropolis of Lindos). Progress in the reorganization of the CNS was partly quantified by the number of jumps per series (B), when jumping on a springboard in anti-phase (B, the mean of the first 3 series is drawn, when jumping several series at 1 min intervals), by the reduction of the fastest running times over 26 m (C) in a corridor, the reduction of crawling times over 5 m (D), and by the increase of hand grip power (E). Note that the number of jumps per series increased from 30 to 600 in a stepwise manner, which suggests the participation of different regeneration mechanisms. Note further that the grip power of the right hand was much smaller than that of the left hand, even though auxiliary muscles were used to generate power with the right hand.

was best at the highest speed, but the other patient (case 4) had the best running performance at lower speeds. In the first patient (case 3), the number of jumps in antiphase increased slowlier and in a stepwise manner, and in the second patient the number of jumps increased more quickly and not so much in a stepwise manner. It will be therefore quite difficult to pool such patients into groups for statistical evaluation, since the differences between their lesions turn only out during the reorganization of the CNS, and the therapy methods have to be adjusted to each special CNS lesion. From the research point of view, more can be learned when single patients are followed up carefully.

The dependence on the therapy time of the improvement of running and walking in case 3 and 4 shows the same pattern as in case 1 (and 2). Only the variation of the values is larger. It seems therefore that speed measuring is a rather unspecific parameter to quantify the improvement / restoration of the lesioned CNS. From the clinical point of view it is sufficient to have a reliable parameter to measure the improvement of CNS functions with ongoing therapy. From

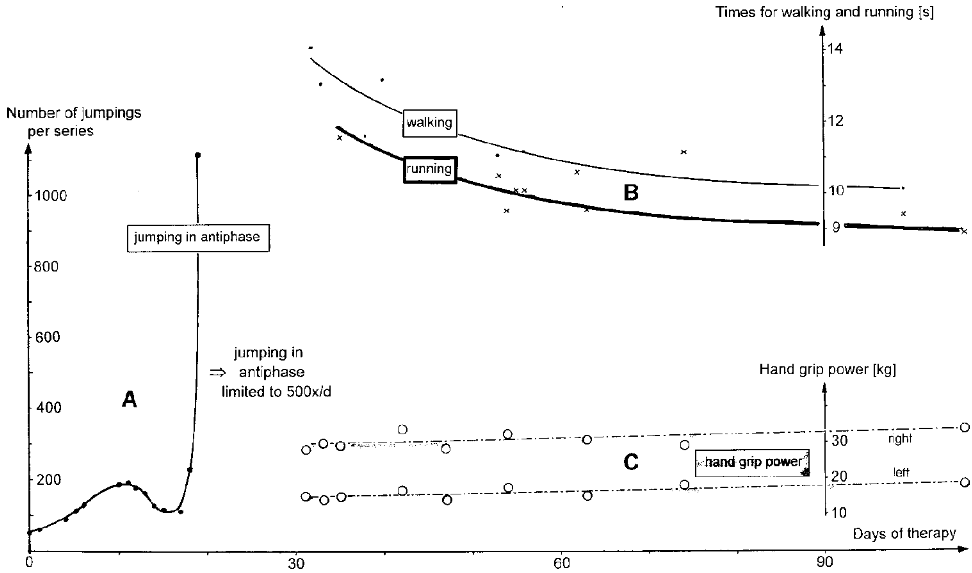


Figure 70A-C
Improvement of motor functions due to a rhythm and coordination dynamic therapy for 3 months, 5 days per week and 3.5 hours per day in a 38-year-old tetraparetic patient 10 years after a cervical spinal cord lesion sub CVI/CVII. The outpatient walked with a stick to the first therapy (Fig. 69A), and was able to walk and run (Fig. 69C) without the stick after 3 months of therapy (B). Progress in the reorganization of the CNS was partly quantified by the number of jumps per series (A), when jumping on a springboard in anti-phase (the mean of the first 3 series is drawn, when jumping several series at 1 min intervals), by the reduction of walking and running times over 26 m in a corridor (B), and by the increase of the hand grip power (C). Note that the number of jumps per series increased from 54 to 1120 (and was limited in further therapy to 500 to protect the joints) with a transient decrease around the 15th day of therapy, and not in a stepwise manner. The different increase of the number of jumps per series in comparison to those of the other seemingly similarly lesioned patient (Fig. 69B) suggests a different spinal cord lesion and/or differently strong contributing regeneration mechanisms. One possible difference is that during the 10 years after the accident more neurogenesis took place (and was not used) than in the patient where therapy was started only 5 years after the spinal cord lesion (Fig. 69).

the research point of view parameters are desirable which reflect different reorganization mechanisms, like neurogenesis, change of efficiacies of synapses, growth of axons and dendrites or membrane property changes. The plotting of the mean number of jumps per jumping series may provide some information about the mechanism of reorganization. The time period of 4 to 6 weeks (approximate plateau-times, Fig. 69B) is approximately the proliferation time for neurons during neurogenesis from stem cells. One can speculate that in the patient 5 years after the accident new neurons still proliferated during the therapy whereas in the patient 10 years after the accident, there were more neurons for a more efficient reorganization built, so that the improvement was mainly due to reorganization of the CNS neuronal networks. Another explanation for the difference is that different tracts in the spinal cord were lesioned, so that different kinds of reorganization in the spinal cord and in supraspinal centres took place.

It was estimated from MRI pictures of different longitudinal and transversal sections taken 10 years after the accident that in case 4, 70% of the spinal cord cross section was lost due to the lesion. At the lesion site the spinal cord was thinner and a large cyst was seen. In the more severe lesion of case 3, maybe only 20 % of the spinal cord cross section was left at the site of injury (no MRI could be taken because of metal in the cervical range). Monkeys were observed to manage to move if only 10% of the spinal cord was left if the lesion was rather balanced [30].

The traditional methods of neurorehabilitation believe to reached steady state within 2 years with respect to locomotion and hand grip power. It has been shown in the above two patients that both locomotion and hand functions can be improved with oscillator formation and coordination dynamic therapy even many years after the accident. There is therefore justified hope for 'old' spinal cord lesions.

Case 5: *A paraparetic patient re-learned running 14 years after the accident [136]*

A 39-year old female patient re-learned running (Fig. 44) in a few minutes time, 14 years after having fallen down a staircase and suffering a paretic spinal cord lesion sub Th12 [136]. Even though she had little skin and joints sensitivity left, she had no problem with the stability during running. When she changed the mode of locomotion from walking to running, she described the additional help she got from the spinal cord during running in the following way: 'The walking is hard, troublesome and sticky, but if I run, then I lift up'. Her face seemed to reflect the feeling, when the spinal cord supports her 'getting wings' during running. The stimulus for the walking and running was heel strike. The patient seemed to use the genetically predetermined step automatism of newborn infants, in which heel strike is the stimulus for inducing and maintaining the step automatism.

This case supports the data of case 3 and 4 concerning the late recovery of spinal cord lesions, and gives some functional indication that there is neurogenesis following spinal cord lesion which contributes to the mechanisms of reorganization of the lesioned CNS, because in a lesion sub Th12 the neuronal network in the intumescentia lumboscralis generating the walking and running pattern is assumed to be damaged. Even neurogenesis with a slow time-course should have had enough time in 14 years to build new neurons.

Case 6: *Recovery from plegic (complete) spinal cord lesion*

A 30-year old woman suffered a complete spinal cord lesion sub Th12 in an accident in the mountains. During the first year of rehabilitation, the lesion level lowered to sub L3. Two years after the accident she was able to cycle on a normal bicycle and walk a bit without sticks but wearing supports in the shoes.

Case 7: *Recovery from plegic rostral spinal cord lesion*

The most difficult CNS lesions to repair are the complete rostral spinal cord lesions and the very severe brain lesions, in which the patient stays permanently in vigilant coma. About the rostral complete spinal cord lesions will be reported in this section; about the treatment of patients in permanent coma will be reported below.

Tarmo, an 11-year old boy played in the forest and was shot by a hunter, who mistook him for a wolf. One bullet (grain of shot) went through the head and damaged the brain and one eye. A second bullet went through the rostral spinal cord and made him tetraplegic at the level of C3/C4. After two years, the patient could partly move the left shoulder, could move the right shoulder and had some little right arm function. Speech and breathing were impaired since the intercostal and most trunk muscles could not be activated.

Two years after the accident coordination dynamic therapy was started mainly by using the special coordination dynamic therapy device in the recumbent position. After 4 months of therapy (~ 4000 turnings per day supported by the farther), the complete spinal cord lesion turned into incomplete. Trunk and intercostal muscles could be partly used again. Now, the patient can partly move the trunk again, can breathe much better (no paroxysmal breathing any more; no repeated lung infections any more), and the speech has normal strength again.

Some signs of skin activity could be found down to the TH10 dermatome. The turning of the complete spinal cord lesion into an incomplete one is remarkable, as it is believed that the severe lesion is caused by the pressure wave accompanying the bullet rather than by the bullet itself. The therapy is continued.

Recovery of locomotor functions following spinal cord (and brain) lesions only occurs if the patients go on in training in the years following the accident, and they only become able to leave the wheelchair if they try hard and want to leave the wheelchair. With respect to patients with spinal cord lesions the task is to get the patients out of the wheelchair if possible and as soon as possible, and to make them walk and run again; in other words to cure rather than care.

67. Reorganization of the CNS following brain and other lesions: Case reports 8-26

Case 8: *Cerebral palsy*

Helen, an 18-year old patient with cerebral palsy, learned to walk again 18 years after a brain and brainstem lesion, after 2.5 months of coordination dynamic therapy. Apart from balance problems, the main drawback to re-learn walking was the very strong adduction of the thighs, which made jumping on the springboard, treadmill walking, air-walking and free walking impossible (the special coordination dynamic therapy device was not available at that time). The adduction was so strong that the knees could not pass each other during alternating leg movements. But by pulling the knees apart, jumping and walking was made possible, so that coordination dynamic therapy could be performed. With ongoing therapy, the adduction reduced, so that after 2.5 months of therapy alternating leg movements were possible without the knees touching each other. The lesioned CNS learned, 18 years after the traumatic lesion suffered at birth, to reduce adduction of the thighs to allow alternating leg movements. The improvement of alternating leg movements can be seen during jumping on the springboard (Fig. 71), during treadmill walking (Fig. 72) and during air-walking (Fig. 73); the result is that the patient could learn to walk (Fig. 74) [186].

In Fig. 71, the improvement of jumping on the springboard can be seen. At the beginning of the therapy, the knees were pulled apart using bandages, and were fixed as shown in Fig. 71A. With ongoing therapy, the adduction strength reduced, so that the mother could pull the knees apart (Fig. 71B) while the author (G.S.) supported the patient jumping in antiphase. The jumping in rotation on the springboard was hindered only little by the adduction (Fig.71C). In the background of Fig. 71C it can be seen how adducted legs can be pulled apart to allow treadmill walking. With further reduction of the adduction, no pulling apart of the knees was necessary any more. The light hitting of the knees during jumping in antiphase was damped by fixing soft material to the left knee (Fig. 71D). At the end of the therapy, the jumping in antiphase on the springboard was possible without any knee manipulations (Fig.71E).

The improvement of jumping in anti-phase varied quite much (Fig.71F) since the pathologic coordination dynamics established during the 18 years that passed after the lesion had to be substantially reorganized; a competitive interplay took place between the existing pathologic and to-be-re-learned physiologic coordination dynamic tendencies, giving rise to fluctuations in progress

Treadmill walking started later on also improved with ongoing therapy (Fig. 72). At the beginning the whole body was twisted very much during treadmill walking (Fig. 72A). Quite a lot of inward rotation of the knees can be seen in Fig. 72B.

In the background of Fig. 72B it can be seen how the women often transport their children with cerebral palsy. Often, they ruin their spines by carrying their children. It is unbelievable

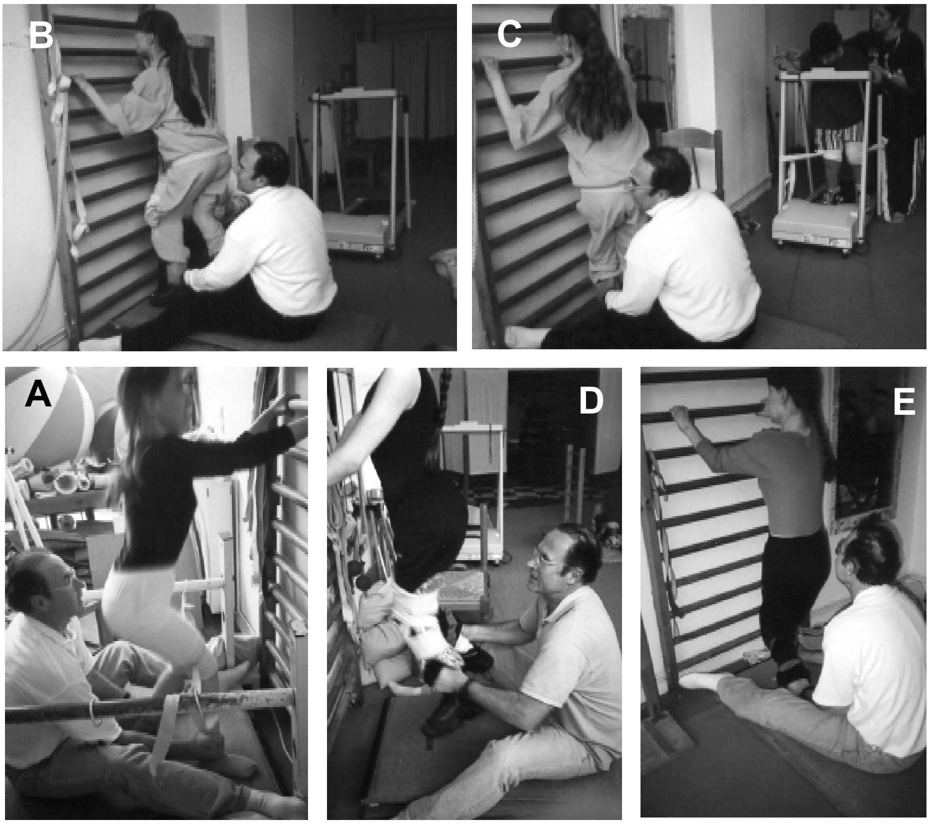


Figure 71A-E
Improvement of supported (by the author G.S.) jumping in anti-phase on springboard in an 18-year-old patient with cerebral palsy. A. Knees are pulled with bandages laterally to allow jumping in anti-phase. B. Less pulling apart of the knees is necessary to allow jumping in anti-phase; the mother takes care of the necessary pulling. C. Jumping in rotation needs no knee pulling. Notice that another child with cerebral palsy in the background is prepared for treadmill walking. The knees are pulled laterally to allow walking on the treadmill. D. Less lateral traction of the knees is necessary to allow jumping in anti-phase. The small bumps during jumping are damped by fixing some sponge-like material around the left knee. E. Due to the improvement of the CNS and muscle functioning, the knees are not hitting each other any more during jumping in anti-phase.

how much the mums can give mentally and physically to their children with severe brain damage, even though they get often only little back.

Fig. 72C, D shows how the 18-year old patient improved in treadmill walking. Walking barefoot on the treadmill seemed to improve the treadmill walking performance (Fig. 72E), because of the increased afferent input to the walking pattern generating network in the spinal cord. Because of the danger of an injury to the feet, especially during running, the barefoot treadmill exercise was only performed seldom. At the end of the therapy, the treadmill walking performance was already quite good. (Fig. 72F).

Since, during treadmill walking, the arms normally do not move in coordination with the legs (Fig. 72), air-walking has to be exercised in connection with the treadmill walking (Fig. 73) to train coordination between arms and legs. To make the exercise of air-walking

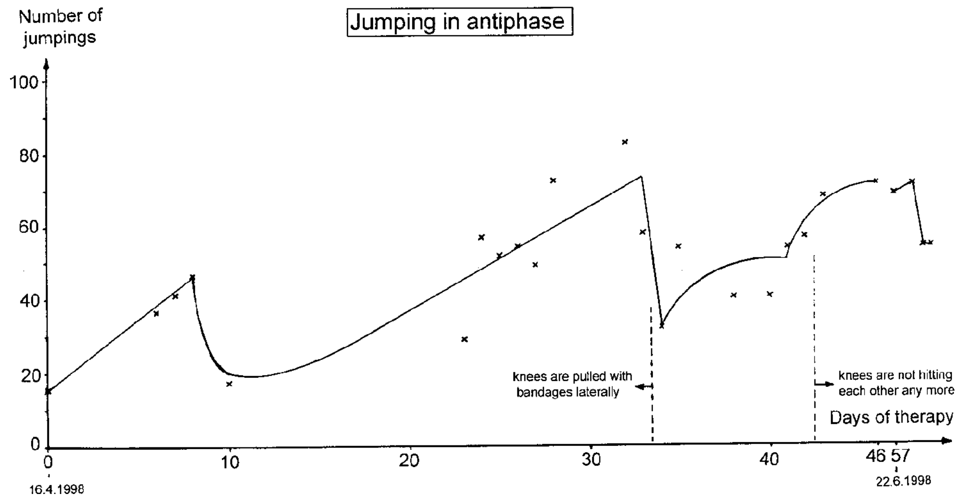


Figure 71F
Increase of the number of jumps in anti-phase per series with ongoing therapy; 18-year-old patient with cerebral palsy (Fig. 71A-E). Each value represents the mean of the first three series. Note the instability of progress, indicating that the existing inner coordination tendencies are in competition to the to-be-learned neuronal network organization.

possible, the same support strategy was used as for jumping on the springboard. First, the knees were pulled apart to allow air-walking (Fig. 73A) and then air-walking was possible without support (Fig. 73B,C), even though the knees were quite much inward rotated and the pelvis was very much forward because of little trunk stability. Towards the end of the therapy, the inward rotation of the knees reduced and the trunk stability improved (less forward bending) (Fig. 73D,E).

The similarities concenring the pathology of the movement (too strong adduction) in rhythmic, dynamic movements such as jumping on the sprinboard, air-walking and walking suggest that these different movements are mainly generated by similar network organizations in the spinal cord (and training contributes in a similar way to the reorganization of the CNS), and that the pathology of the movement is caused by the pathologic descending drive from supraspinal CNS parts. The case reports on the repair of spinal cord lesions indicate that the spinal cord (a phylogenetically old CNS segment) gets innate repair support; the case reports on the repair of brain (phylogenetically younger CNS segments) lesions point towards a need for strong instructive learning, since innate (genetic) repair support seemed to be week or not existing.

Towards the end of the therapy free walking was achieved. At the beginning of the free walking period, the patient walked supported by her mother and the author (Fig. 74A), and later on with the support of the author only (Fig. 74B,C,D). At the beginning, when walking home from the physiotherapy practice (a walk of 1/2 h) with the author and the mother, the patient could mentally manage this new situation in the traffic of Athens only if the mother was no more than 10 m away. With further therapy free walking was achieved (Fig. 74D,E), so that it could be exercised in interpersonal coordination with the therapist (author G.S.) (Fig. 74F). In this training situation (Fig. 74F), the patient moved her arms in antiphase coordination with the legs, even though the trainer was performing in phase coordination of arms and legs. As pointed out earlier, the interpersonal coordination works in phase and in antipha-

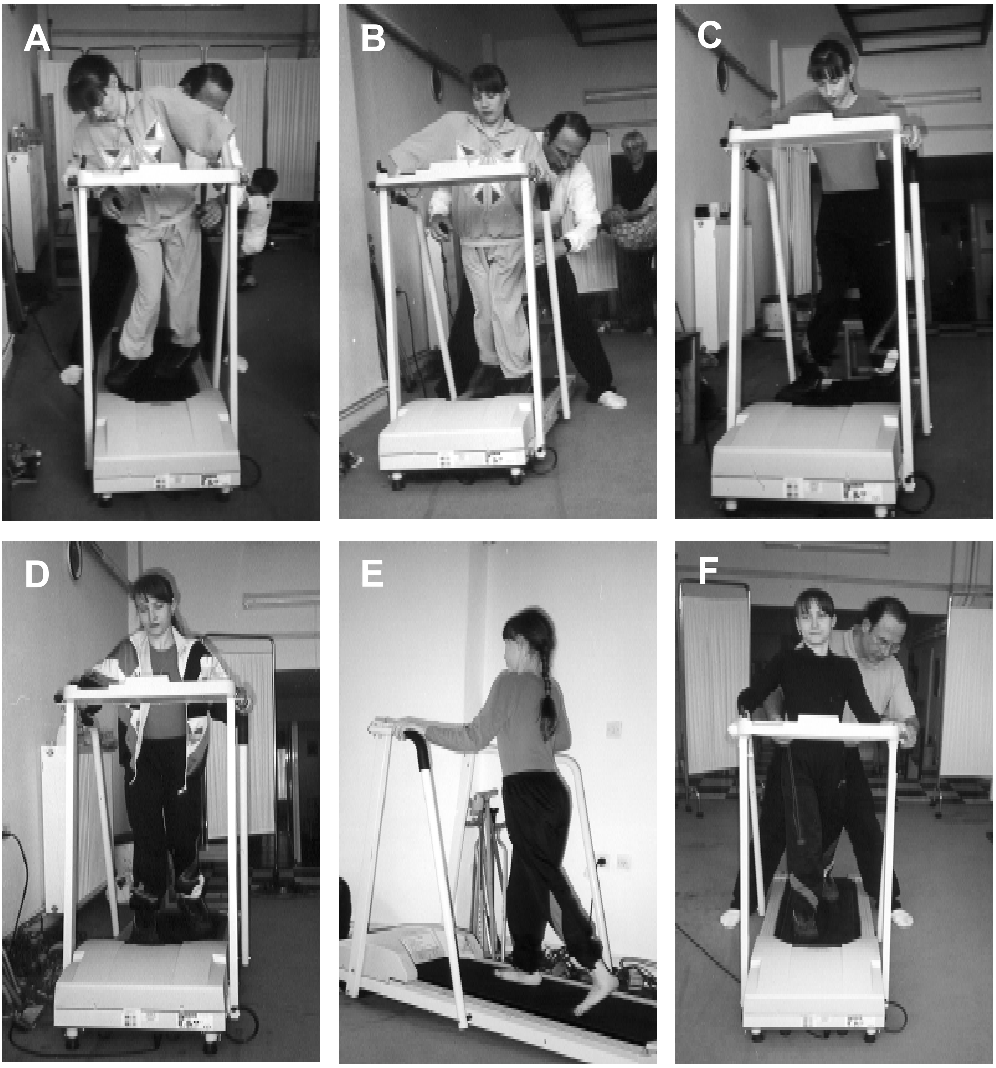


Figure 72
Improvement of treadmill walking with therapy in an 18-year-old patient with cerebral palsy. A, B. Begin of treadmill walking. Feet, legs and trunk are bent quite pathologically to allow walking. But still the knees are not touching each other. Note in B, how mothers in the background are often carrying their children with cerebral palsy; such carrying will on the long term ruin the spine of the mother. C, D. Improved walking on the treadmill; less bent legs and better trunk stability. E. Walking barefoot on the treadmill improves the walking performance because of an increased afferent input from the feet to the walking pattern generating network (relatively larger rather physiologic afferent input from the legs in comparison to the pathologic descending drive input to the network). Because of the danger of feet injury, especially during running on the treadmill, barefoot walking was only seldom trained. Note the sunken plantar arches which can also be improved by the CNS reorganization. F. Improved treadmill walking.

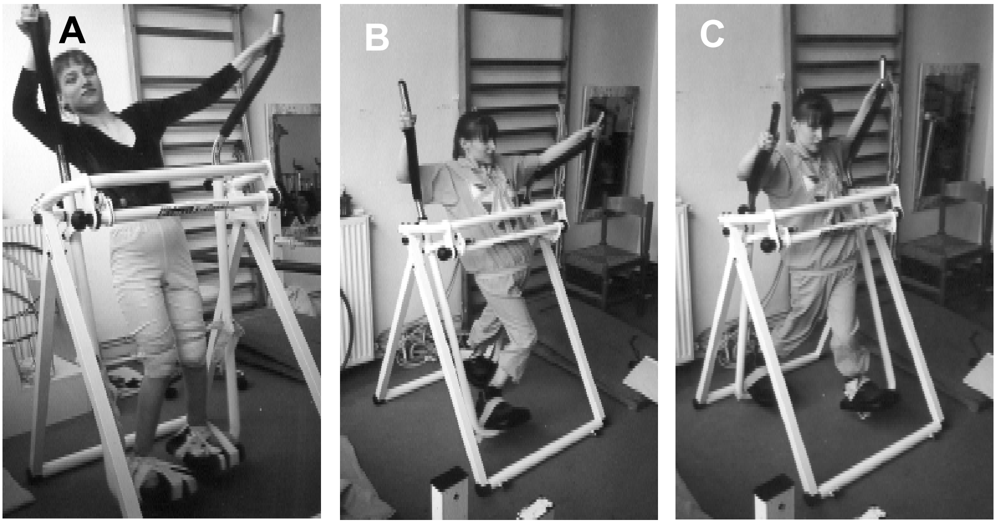


Figure 73
Improvement of air-walking with therapy in an 18-year-old patient with cerebral palsy. A. Air-walking is made possible by pulling the knees apart with bandages. B, C. With ongoing therapy, the knees are not touching each other any more, no support is necessary. The trunk (pelvis) is still very much forward and the knees are very much inwardly rotated. D, E. With further ongoing therapy a better trunk stability and less inward rotation of the knees are achieved.

se, and is in accordance with the coupling and drive of premotor spinal oscillators which takes place every 180°.

Since the patient had no problems with the coordination of arms and legs during free walking, it seems that the spinal cord was only little affected by the pathophysiologic supraspinal impulse patterns present over 18 years; as if the stability of the basic spinal cord self-organization were innate (genetic).

Moreover, it is interesting that the patient could keep balance during walking, but not during standing. When giving the patient slight support with one hand when standing, similar to the position in Fig. 74B, the therapist could feel how the patient's CNS was handling the balance problem: all the time the muscles for the finger movement were activated and deactivated to regulate stability. The fact that the patient could not keep balance when standing seems to indicate that the balance regulation via the feet was not organized sufficiently at the

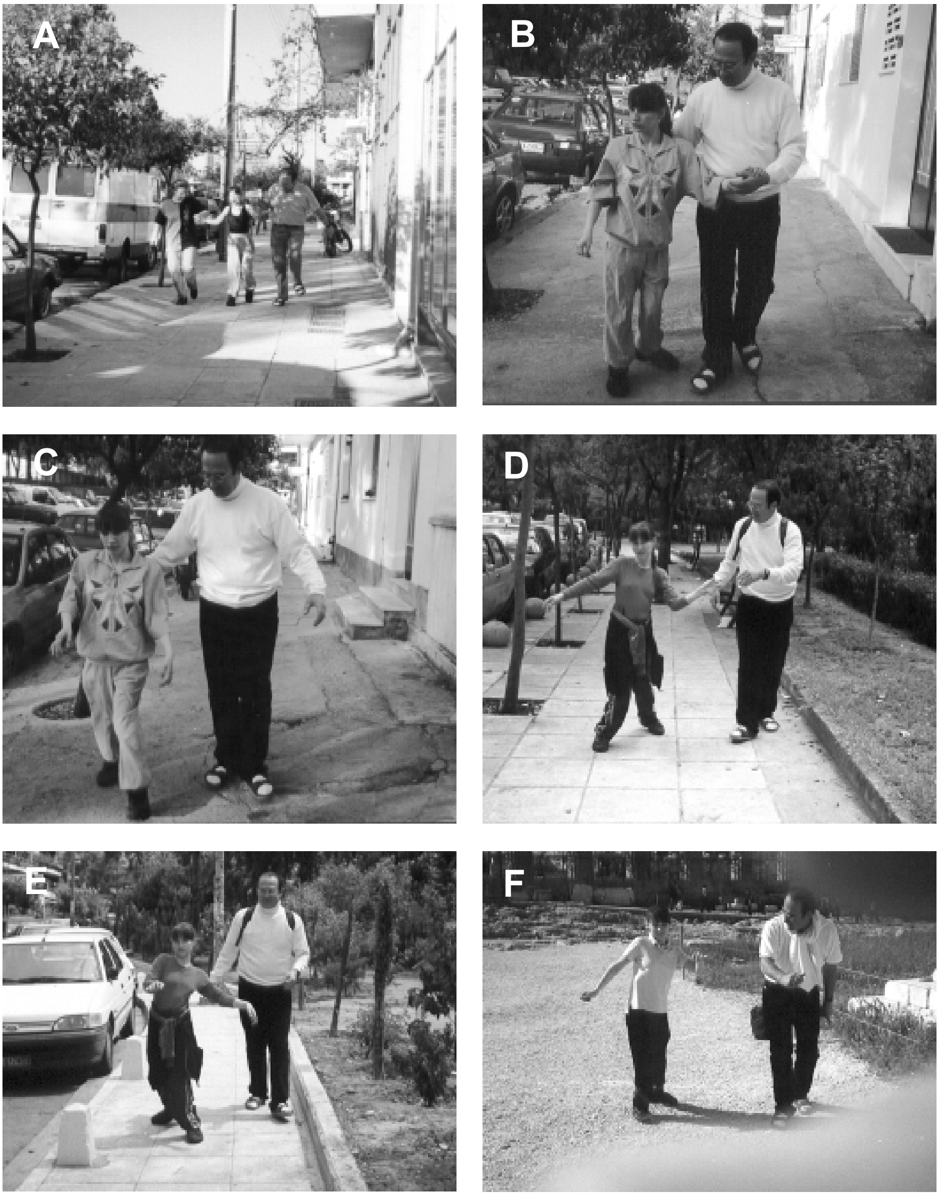


Figure 74
Free walking in the 18-year-old patient with cerebral palsy, even though she is unable to stand without support. A. Begin of walking with support from both sides (mother and author G.S.). Note the interpersonal coordination between the mother and the author, and the patient; the patient's foot movements are slightly delayed. B. Walking support by holding one hand and giving a touch support in the back. C. Walking with only touch support in the back. D, E. Free walking. F. Free walking in interpersonal coordination. In accordance with premotor spinal oscillator coupling data, interpersonal coordination between arms and legs needs not be in phase; interpersonal coordination also works in opposite phase. Note in D, E, F that the coordination of arm and legs of the patient is good, as if the self-organization of the spinal cord was somehow physiologic and the problems in walking arose from supraspinal centres. What cannot be seen is that the mother is not more than 10 m away (taking the photos).

end of the therapy time. But during walking, when more neuronal network parts of the CNS are activated, probably sufficient regulation was established in the neuronal networks to keep balance. Also, the kinetic energy vector built up with walking will have contributed to the enhancement of balance.

In accordance with the theory is further the fact that it was possible to improve locomotion in that patient without taking any specific muscle activation or motor program diagnosis into consideration. It is believed that the motor cortex knows about movements but does not know anything concerning muscle activation times. By teaching the lesioned CNS what to learn with the different treatment methods, the CNS changed its self-organization continuously in the direction that more physiologic movements were generated.

With an efficient therapy which takes into account the functioning of the human CNS, it was possible to make the patient walk in 2.5 months, which could not be achieved throughout her former life, and no orthopedic operation was needed to overcome the very strong adduction of the legs. A further improvement of the organization of her CNS to generate more physiologic movement is possible. It depends on her will to undergo a further intensive coordination dynamic therapy.

Case 9: *Cerebral palsy [135]*

Maria, a 10-year-old patient, was a good pupil attending a regular school, and communicated with the author in English. With the brain damage suffered at birth she was not supposed to ever be able to walk. The mother carried her therefore mainly on her arms during the early childhood (Fig. 72B, background) and ruined her own spine. The patient had some kind of Moro-reflex (alarm reaction) when the author saw her first.

The coordination dynamic therapy applied included treadmill walking (Fig.75A,B), air-walking (Fig. 75C,D), jumping on the springboard (Fig. 75E), later on exercising on the special coordination dynamic therapy device (Fig. 76), supported walking (Fig. 75F-I) and conservative physiotherapy.

At the beginning of the therapy, she was able to perform a few walking steps with little rhythmicity, no trunk stability and no contribution from the arms and hands to the movement (Fig. 75F). The arms and hands were hanging passively. With ongoing therapy the trunk stability improved; many more steps could be performed more rhythmically and the arms and the fingers started contributing to the walking (Fig. 75G) and were not hanging passively any more as in Fig. 75F.

But then, the patient refused to train any more with the author. She preferred to get the conservative physiotherapy only. When the author talked to the father, he replied that it was the same with him. The girl did not want to train with him any more. The reason was simple: the patient wanted to have an easier therapy, so she chose conservative physiotherapy. The author gave in as the patient was not cooperative any more. Then, 2 months later, the patient wrote to the author to Switzerland that she wanted him to come to Athens to get advice for the therapy. When the author met the patient with her parents again, the father informed him that he had been going on with the intensive therapy, even though his daughter did not like it. When he went on holidays with her, he carried a transportable treadmill to the holiday place, so that she could train every day. According to the father, the dynamic training also seemed to change her character to become more dynamic. Now she did not want to have it easy any more, she wanted to train hard to become a normal girl. It seems as if the mental functions had also improved. This character change is in accordance with the real meaning of tye term ‘dynamics’, which comes from the Greek word dynamikos, which means the ’soul and/or spirit’. The character getting more dynamic would mean that it is becoming more spirited.


A
B
C
D
E
F
G
H
I

From the human neurophysiology standpoint dynamic training means movements with velocity, changing acceleration and internal tension of limbs and muscles, which in turn means complicated rhythm coupling changes in the CNS, including relative coordination of different fast network systems and relative coordination of higher harmonics of the rhythms (according to Fourier analysis; see the theoretical section). The improvement of complex relative rhythm coupling contributed to the improvement of mental functions.

Now the patient herself also wants to train hard again. She also received some exercise on the special coordination dynamic therapy device (Fig.76). Her walking improved so that it became possible to walk for the first time with only the support of one hand (Fig. 75H). She felt very happy as, for the first time in her life, she could walk with an adult person by giving only one hand for support. Now she walked something like a normal child after the 9 months of therapy. After 10 steps however, the CNS could not support the trunk stability any more so that the one hand supported walking was over (Fig. 75I). The therapy is continued. There is little doubt that she will reach the free walking stage if she continues with the intensive coordination dynamic therapy.

Case 10: *Down's syndrome and myelomeningocele*

Clinical experience in neurorehabilitation shows that motor functions and speech can be improved in children with Down's syndrome (Fig. 77). As in brain lesions, more efficient therapy methods will faster improve the functioning of the malformated CNS. The child shown in Fig. 77 improved faster with the coordination dynamic therapy. Fig. 61 (and Fig. 108) illustrates the general idea concerning the improvement of CNS functioning. If the outcome with respect to the CNS functioning is determined by the innate network properties, the organization principle of the CNS (self-organization of neuronal networks) and therapy (and learning) methods to optimize and change CNS functioning, then genetically determined false organization should partly be repairable by therapeutical methods which reorganize the CNS. If for example, sets of first synapse efficacies are not good enough in parts of the network or

Figure 75

Improvement of locomotion in the 10-year-old patient with cerebral palsy. A. Walking on the treadmill with trunk support by her father. B. Patient walking at higher speed, just before getting unable to manage the speed any more. Note the fear in her face because she cannot manage. C. The patient during exercise on an air-walker adapted for children to learn coordination between arms and legs, which cannot be learned on the treadmill. A physiotherapist is supporting the first air-walker steps. D. Improved air-walking after some minutes. E. The patient during jumping in anti-phase on a springboard with trunk support given by the mother and leg support given by the author. The right hand of the patient is slipping from the wall bars. At that stage of therapy she had problems to simultaneously perform two independent volitional movements. Due to the brain lesion the substitute neuronal network organization of the brain cannot fully perform two independent movements. F. Supported (by the author G.S.) walking performance at the beginning; no trunk stability and no arm movement (the arms are mainly passive). G. At a later stage, the patient tries to help to keep balance with the arms during supported walking. Note the position of the fingers. H. First walking with one-hand support after half a year of coordination dynamic therapy. The patient is happy because it has been for the first time in her life that she could somehow walk like a normal child with an adult person. I. After 10 steps the trunk stability was lost, probably because the responsible neuronal networks could not generate the network state 'trunk stability' any longer. Note the fear in her face when unable to manage the walking performance. At birth, the patient was assumed to never come on feet; therefore the mother was always carrying her child in her arms and ruined her own spine.

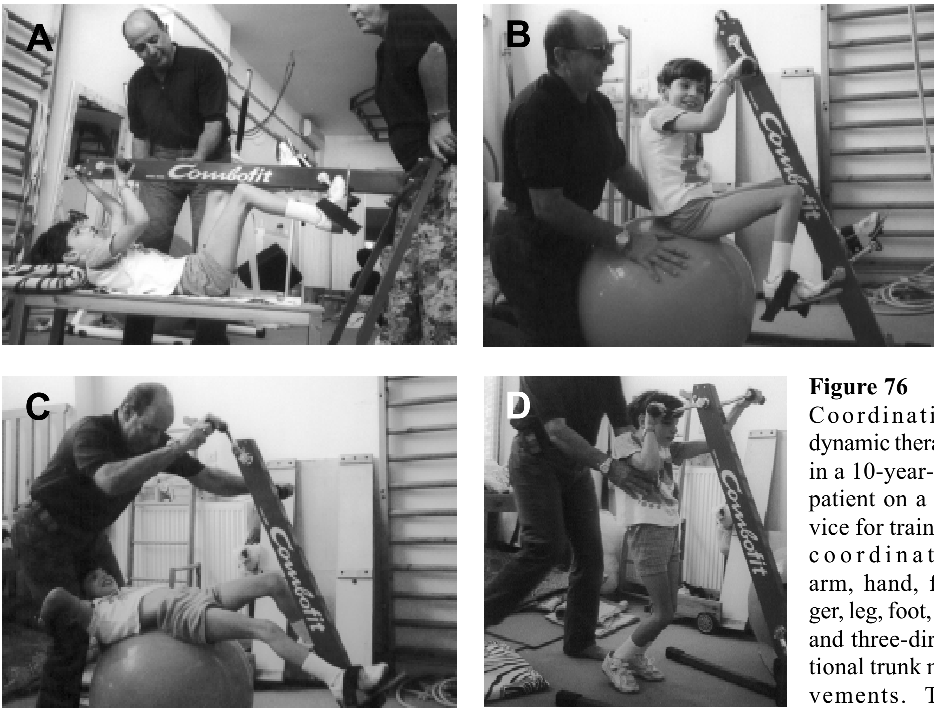


Figure 76 Coordination dynamic therapy in a 10-year-old patient on a device for training coordinated arm, hand, finger, leg, foot, toe and three-directional trunk movements. The father is helping or guarding her. A. Training in recumbent position (father and mother are holding the instrument). B. Movements in sitting position. C. The patient performs some stretching and has fun. D. The patient trains trunk stability.

parts of the networks are missing, then to a certain extent efficient neurorehabilitation methods can change the network organization to make the CNS function with more physiologic output.

Another explanation for the improvement in CNS functioning in genetic malformation is that repair genes may operate physiologically when activated by an adequate efficient therapy method such as coordination dynamic therapy. Two explanations are thus possible for the improvement of CNS functioning in genetic malformation, induced by adequate therapy methods: first, that nearly every falsely functioning CNS can be improved, including malformated neuronal networks; and second, even if impaired genes give rise to malformation of CNS organization, repair genes may still operate physiologically if activated. Work is in progress to show that also in myelomeningocele (malformation of spine and spinal cord) substantial progress can be achieved with coordination dynamic therapy. The results of the therapy will, of course, depend on the magnitude of the genetic CNS malformation.

Cases 11-13: Severe brain lesion

A. Quick recovery following severe brain lesion, when therapy is started at the vigilant coma stage

Three boys, 10, 12 and 14 years old, suffered severe brain lesions almost at the same time, two in a car and one in a bicycle accident. In the 10- and 14-year-old patients an intensive coordination dynamic therapy was started approximately 5 and 10 weeks after the trauma in vigilant coma stage. The two patients recovered inexpectedly early from the coma and progressed quickly in their recovery of motor functions so that they re-learned running after 4 months of therapy, even though their locomotor functions are still far from normal. The 12-

Figure 77
Mother with her child with Down's syndrome, training for the first time on an air-walker to improve free walking (treadmill-walking).

year-old patient did not obtain intensive coordination dynamic therapy, only conservative physiotherapy, because of many infections and complicated bone fractures, which were not invasively reconstructed. The patient recovered much later from the coma (6 months instead of 6 weeks) and has now very much extensor spasticity (Fig. 78E), shortened tendons, problems with several joints, quite much pain, weakend mental functions, grasp reflex in the right hand (Fig. 78F) and nearly no useful motor functions in the legs. It will be attempted now to apply the intensive coordination dynamic therapy with a delay of 5 months in comparison with the other two cases. It has to be seen whether the same therapy, even if delayed, can help to reach the same level of reorganization in the end. It is known that in brain lesions (and most likely in all CNS lesions, including spinal cord lesions) the therapy has to be started as early as possible following the trauma (maybe except for the first week) to avoid pathologic reorganization (for example, spasticity). The lesioned neuronal networks have to be instructed, as early as possible, by therapy how to reorganize themselves. Success of the therapy has been reported to depend critically on when the training begins. Overuse of an affected limb during the first week after the lesion can increase the volume of the lesion (perhaps by glutamatergic excitotoxicity), whereas overuse during the second week does not [40]. For several practical clinical reasons, in most severe accidents an intensive therapy can not be started earlier than after 1 or 2 weeks anyway. An intensive efficient therapy therefore has to start as early as possible, which means at the intensive care unit. The 3 cases will be reported in detail below, especially that of the 10-year-old patient, since most detailed data were available for him.

For an overall view of the progress 7 to 9 months after the lesion, all three patients are shown together in Fig. 78A. The two patients who obtained the coordination dynamic therapy for 6 months re-learned walking and running (Fig. 78A,B) and the mental functions improved to be not far from normal. The third patient who obtained no coordination dynamic therapy for the first 7 months following the trauma cannot walk or run but has to be carried from the wheelchair to the training device (Fig. 78C). He can hardly stand because of extensor spasticity (Fig. 78E) and suppination of the feet (Fig. 78G).

The improvement of running in the two patients who received coordination dynamic therapy is shown in Fig. 78H. For the 10-year-old patient the running times over 22 m reduced during 8 months from 14.4 to 5.2, and for the 14-year-old patient during 6 months from 18.5 to 6.4s (Fig. 78H). The jumping in anti-phase in the 10-year-old patient increased from 25 per series to over 250 per series, and in the 14-year-old patient from 7 to 55 with a delay of 3 months (Fig. 78I).

Figure 78
Three patients with severe brain lesions (10-year-old (A, left), 12-year-old (A centre, in the wheelchair pushed by the mother), 14-year-old (A, right)), 7 to 9 months following the lesion. The 2 patients who received coordination dynamic therapy for 6 months can walk (A) and run again (B), and the third patient who did not receive coordination dynamic therapy for 7 months following the lesion is still in wheelchair (A) and has to be carried to the coordination dynamic therapy device by the mother (C). In A, the mother is pushing the wheelchair with her child; the mother of the

The 10-year-old boy Benjamin was running during playing in the street and was hit by a car driving at 55 km/h, and thrown several meters through the air. The boy was pressed against an iron fence and suffered many injuries, including an open thorax injury on the right side and a brain damage of the basal ganglia domain (area = 4 cm x 3 cm) and the frontal lobe (Fig.79A,B). The patient was in coma for 2 weeks, and started then to react a bit when asked to respond. The physicians of the intensive care unit forecasted that he would be in vigilant coma for another 1 to 2 months. After 10 days of vigilant coma (Fig. 80A-C) (~ 4 weeks after the accident) coordination dynamic therapy was started in the recumbent position (Fig. 80D).

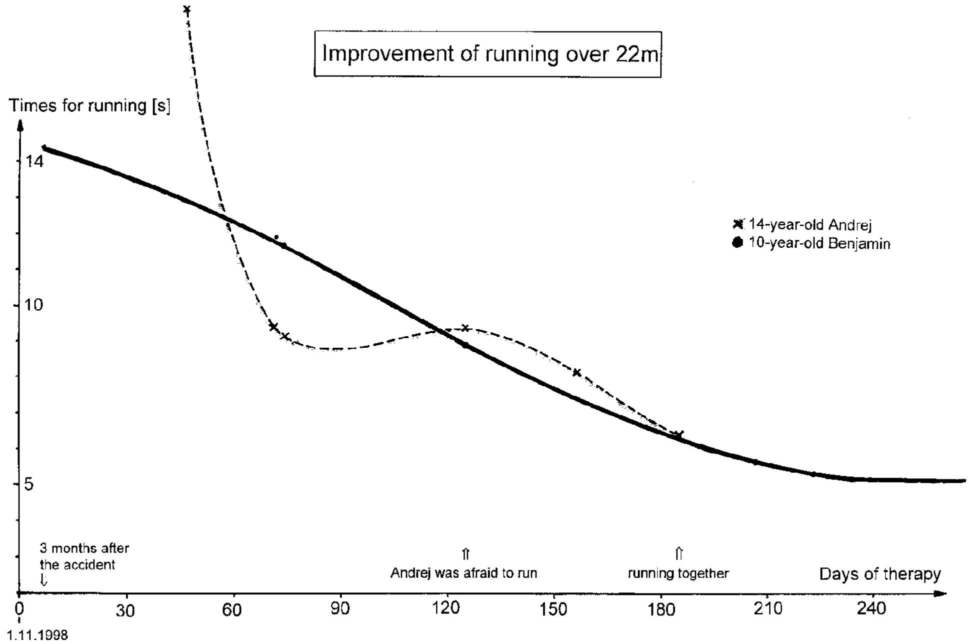


Figure 78H
Improvement of running times; the 10-year-old patient Benjamin (severe brain lesion due to a car accident) over 22 m (solid line), and the 14-year-old patient Andrej (severe brain lesion due to a bicycle accident; dashed line) with ongoing therapy. The running times of the 14-year-old patient transiently increased with ongoing therapy; the patient fell once during running and was then afraid to fall again.

10-year-old boy and the father of the 14-year-old boy are in the background. In B, the father of the 14-year-old boy is running, for safety reasons, along with his son and is running in interpersonal coordination. D. The 12-year-old Mario (right-sided hemiparesis; quadruparesis) during exercising on the special coordination dynamic therapy device. The right hand is holding the hand-hold quite strongly, probably because of the induction of the grasp reflex (F) in addition to volitional power. E. Extensor spasticity activated in the 12-year-old Mario; the extensor spasticity is only moderately hindering the therapy. F. During shaking both hands with the author, the patient develops relatively strongly the grasp reflex in the right hand (from the hand reaching position the hand slips into the position of holding the thumb of the author; it could be felt how the network organization slipped from the neuronal network state 'hand giving' into the network state 'grasp reflex' in similarity to Fig. 107). G. Suppination of the right foot during standing (Mario).

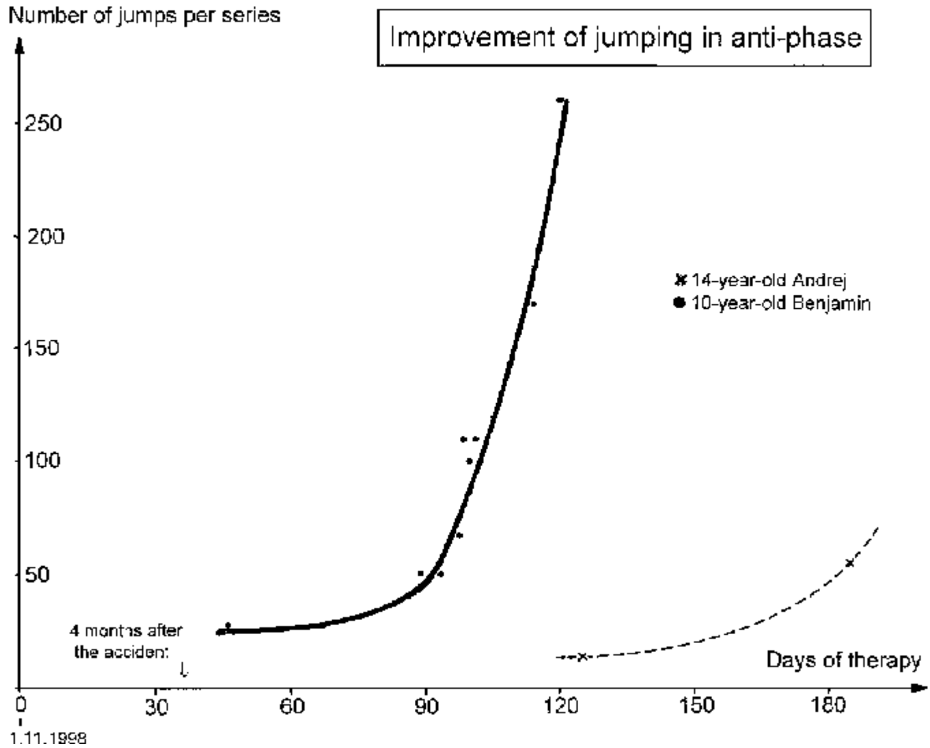
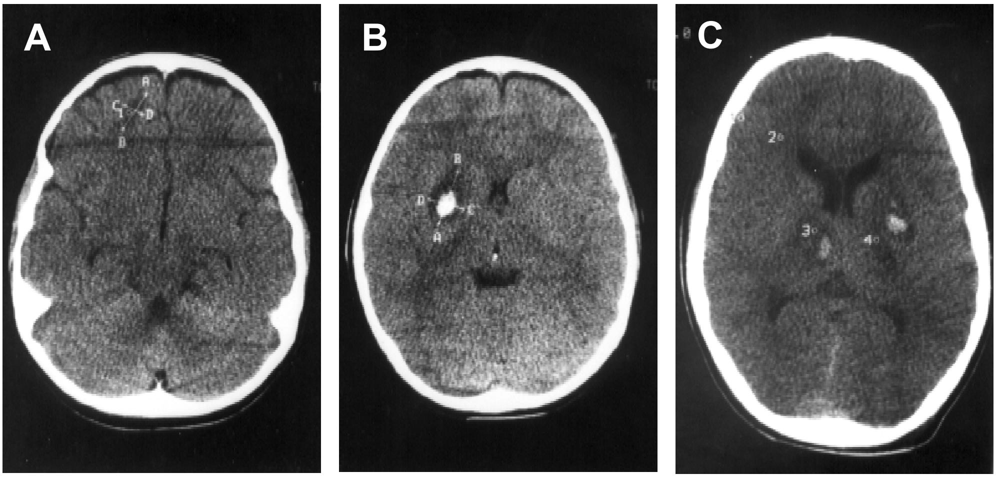


Figure 78I
Improvement of jumping in anti-phase on a springboard in the 10-year-old patient Benjamin with ongoing therapy (solid line). At the beginning, the jumping was manually supported. Andrej´s (the 14-year-old patient) first jumping is indicated. Note that the running (Fig. 78H) could be earlier performed than the jumping on springboard, suggesting that the running automatism is located more in the spinal cord or that the running automatism is less affected by the brain lesion than the jumping in anti-phase.

Especially treadmill walking supported by 4 persons seemed to frighten the patient (Fig. 80E). The patient seemed to develop left sided hemiparesis; the left arm and the left hand showed signs of spasticity. Due to a humerus fracture the shoulder joint could be moved only little. Even though the movements in the left arm and left hand seemed to be painful for the patient, he seemed to be cooperative. Because he could not speek, a safe communication was not possible. When the author (G.S.) left the patient after 3 days of therapy, he got some stroke units from the patient, which indicated that he was thankful for the therapy, even though the therapy caused pain. The coordination dynamic therapy was continued by a physiotherapist and the mother, herself a physician. After 3 further days the speech came back and the vigilant coma was over. The patient told now that he had indeed quite a lot of pain in the left arm and hand during the movements. But because he felt that the therapists and the mother wanted to help him, he helped actively during the arm and hand movements as much as possible, in spite of the pain and being frightened. The recognition of the reality (of the trauma) is still difficult for the patient. Often he says to his mother: ‘Mum, please wake me up, the dream is so terrible’. Depressive thoughts were opposed with an intensive therapy (what was anyway in the line of his neurorehabilitation), not to give the patient time to think his situation over, in similarity to the work therapy of neurotic patients. Further, training using a special coordina-



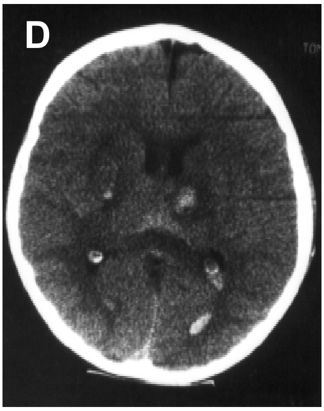
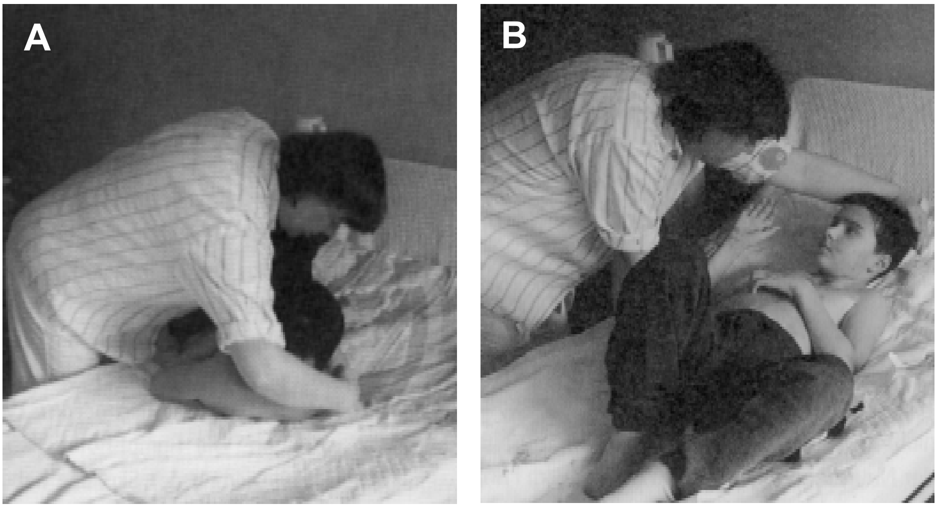


Figure 79
Computer tomographic pictures (CT's) of the 3 patients with brain lesions. A, B. CT's of the 10-year-old Benjamin 12 days after the accident, showing a lesion in the frontal lobe (A) and in the area of the basal ganglia (B). C. CT of the 14-year-old Andrej, 5 days after the accident. His brain lesions included contusion of the basal ganglia left, cerebellar swelling, contusion to the thalamus right, cortical contusion to fronto-parietal region right, contusion in the periventricular region frontal right, intraventricular bleeding, posthemorrhagical contusion in the basal ganglia left, atrophic cortical part of the brain in the fronto-temporo-parietal region right. D. CT of the 12-year-old Mario, 7 days after the accident, showing multiple brain lesions.

tion dynamic therapy device (Fig. 81C) seems to have a positive effect on the patient's mood (see also the poliomyelitis case). As turned out after the end of the vigilant coma, the patient indeed is hemiparetic on the left (with a slight quadruparesis), including spasticity in the left arm, hand and fingers and in the left sternocleidomastoideus muscle (pulling his head to the left side). The organization of the CNS improved continuously with the ongoing intensive therapy (6 times per week, several times per day).

On the advice of the author, the parents refrained from botuline therapy to selectively reduce spasticity (by a blockade of the neuromuscular endplates in the domain of the application of the toxin for approx. 2 months), which was suggested by neurologist. With the early begin of an efficient intensive neurorehabilitation therapy the development of false organization of the CNS (spasticity) can be strongly reduced or abolished; there was therefore no indication for a botuline therapy.

After 3 months of coordination dynamic therapy, the functions of the paretic arm strongly improved. Thus, the physiologic network states have been strengthened (the corresponding attractor wells have deepened) and the pathologic network states have been weakened (the corresponding attractor wells became more shallow). Only if the left arm can fully be moved in coordination with the other arm and the legs (coupling of the self-organizing network for



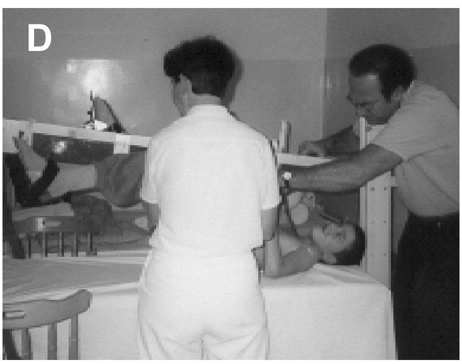


Figure 80
Coordination dynamic therapy applied to the 10-year-old Benjamin during the vigilant coma state 5 weeks following severe brain lesion. A. The patient is mostly carried by the mother (herself physician). Still insufficient head stability. B. The patient lifts the right hand to get the holding hand of his ‘Mum’. Obviously, he needs to feel his ‘Mum’ to manage anxiety generated by the false self-organization of the CNS. Left arm and hand in a spastic position. The mother is on the right side of the patient, to counteract spasticity of the musculus sternocleidomastoideus, turning the head to the left. C. The patient got the sedative hand of the mother. The expression of the face seems to be more relaxed; the patient can now look into the camera. Feeling the mother is not enough to reduce spasticity in the left arm and hand. The look of the patient shows similarity to that of a baby. The eyes seem to want to take in the ‘whole world’. If one compares the look of the patient with the look of a robot, the robot could say: ‘I need input to repair my neuronal networks and get them organized again’. With the coordination dynamic therapy on the special coordination dynamic device in D, the nervous system of the patient is supplied with the necessary space-time coordinated impulse patterns for the

the right arm and hand movement to the network organization of the other arm and the legs), the spasticity will reduce so much that non-rhythmic volitional movements of the left hand and fingers can fully be trained. By oscillator formation, coordination dynamic and conservative therapy the movements of the paretic arm and leg could be improved. Some movements achieved after 3 months of therapy are shown in Figs. 81A-G.

After 6 months of coordination dynamic therapy (7 months after the CNS lesion), the paretic arm further improved, the overstretching of the left knee reduced and the patient relearned running. The achieved progress is shown in Figs. 82C,83,84. It seemed that an essential step forward was achieved in the last 3 months of therapy, when the patient used the special coordination dynamic therapy device in the standing position (Fig. 82B,C). At the beginning the patient had again big problems in the left hand to hold the lever (Fig. 82B). But 6 weeks later, the function of the left hand improved (Fig. 82C). Several months earlier the patient had big problems to hold the lever of an air-walker (Fig. 82A). Even after 6 months of therapy the coordination dynamic therapy included creeping, crawling and running (Fig. 83).

When crawling with another girl (with a brain lesion suffered at birth), the left hand showed still some problems and limited the speed of crawling. But the crawling performance was much better than 3 months earlier, as can partly be seen by comparing Fig. 83B with Fig. 81B. Also, the 13-year-old girl with hemiparesis on the left side showed still a pathologic hand movement and positioning during crawling (Fig. 83B), even though she is the fastest runner in her class (normal school). It seems only to be possible to cure hand and finger functions completely, if the special coordination dynamic therapy device is used to improve the finger functions: single fingers have to be used to turn the lever. In this way each single finger is trained to move in coordination with arms, legs and trunk.

When the patient is giving the therapist the hand (Fig. 84A), the hand-holding is nearly normal (no palmar flexion of the hand). Even a slight dorsal flexion of the hand is already possible. When showing himself and the author clenched fists (Fig.84B), it can be seen that the hemiparetic left hand became quite good even though not normal. But sometimes still the left hand switched into a spastic position (Fig. 84C), probably partly now because it became a habit. The attractor state ‘spastic hand’ still exists, only the corresponding potential well has become shallow.

Even though the sensibility in the left arm, hand and foot improved, there is still quite a strong sensitivity disturbance in the left small finger. Interesting is the position of the left small finger (Fig. 84C). The abducted slightly flexed position shows very much similarity to the graceful position of that finger especially in women, when they hold a cup of coffee or a flower (Fig. 84D). The strange position of the small finger seems therefore to be a habitual position in humans which was freed by the CNS lesion.

reorganization of the neuronal networks according to the lesion of the CNS; the lesioned CNS is supplied continuously with the impulse patterns for physiologic organization of the CNS. D. The patient during exercising on the special coordination dynamic therapy device. The author (G.S.) is holding his hands during turning, so that the left hand does not slip from the handle, and to give emotional support. The physiotherapist is supporting a bit the legs. It turned out that following supported hand movement, the patient could, for a few seconds, better move the hands and arms. The paretic left hand slipped less often from the handle, probably because of reduced spasticity. The patient was suffering pain from stretching and moving hand, ellbow and shoulder joints. The device is a loose self-construction. E. The patient in vigilant coma during supported treadmill walking. The mother was supporting the body. Two nurses were holding the hands and the head, and the therapist was supporting the leg movements. The patient was crying, mainly because of fear, rather than because of pain.

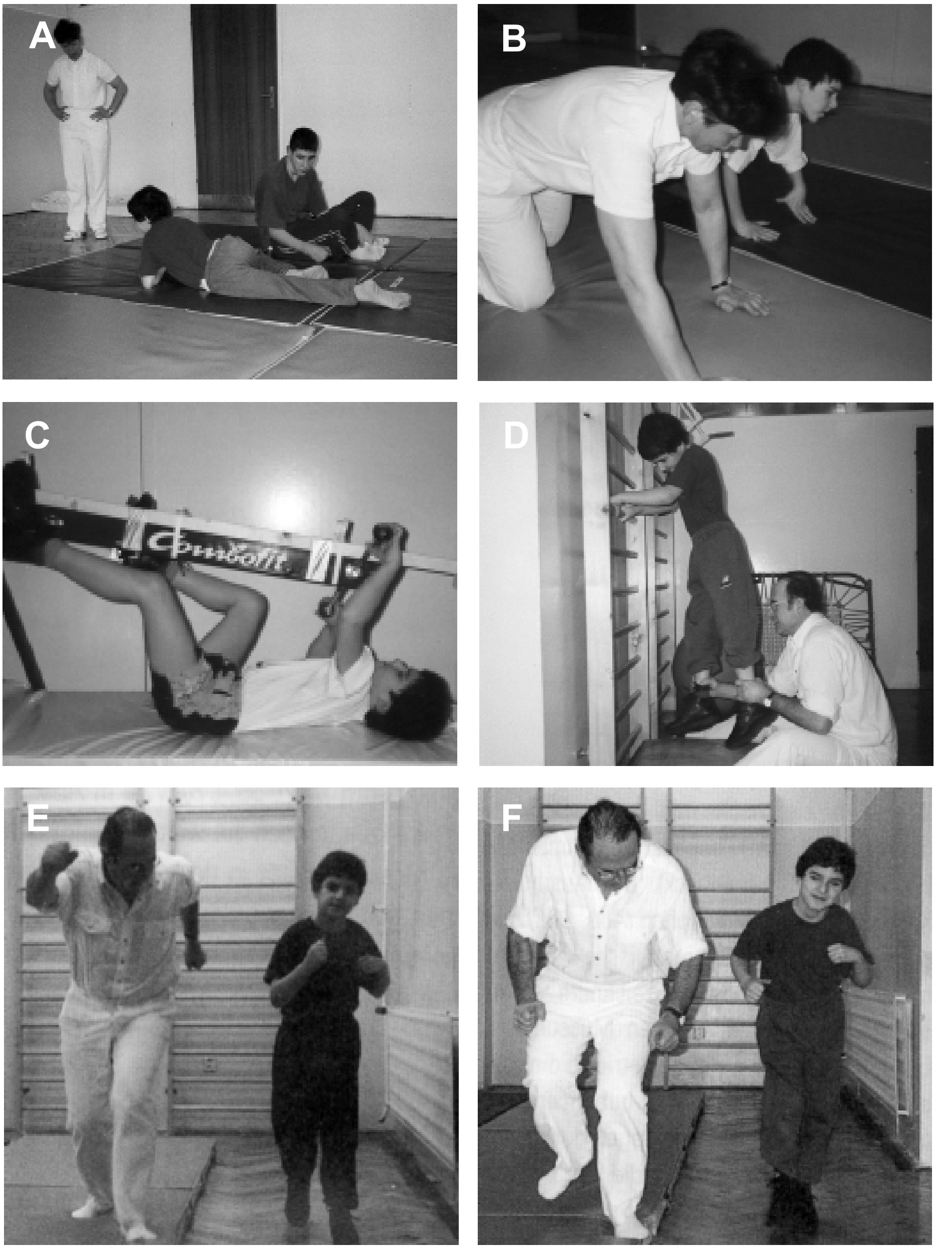
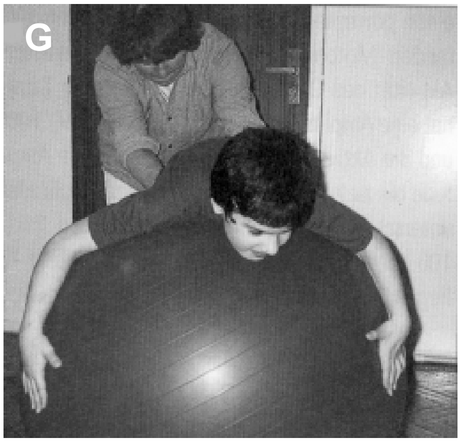


Figure 81
Movements achieved after 3 months of coordination dynamic therapy in the 10-year-old patient with severe brain lesion. A. The patient during creeping. The other 14-year-old patient, competing with him in the progress of getting more functions back, is watching him. B. The patient during crawling. The physiotherapist is crawling in interpersonal coordination to improve the crawling of the patient. Note that the left hand (and arm) of the patient is rather spastic, hindering rhythmic crawling. C. The patient during the training on the special coordination dynamic therapy device. The left rather spastic hand slips often from the handle in the upper position. The coordinated rhythmic hand movement is supported by repetitive volitional movements of the left hand to hold the handle. D. The patient during sup-



ported jumping on springboard. The left hand and arm are in spastic position. The head is turned to the left because of the left spastic sternocleidomastoideus. The left knee most likely overstretched. E. The patient during walking in interpersonal coordination with the author. Both legs and the right arm move in coordination with the arms and legs of the trainer. The left, still a bit spastic arm, moves only little in coordination. The left knee is overstretched. F. The patient during flexed walking (a kind of duck walking), in some interpersonal coordination with the therapist (moving also in flexed position during interpersonal coordination), to avoid overstretching of the left knee. The head is flexed to the left (paretic) side because of the spastic musculus sternocleidomustoideus. The left shoulder, ellbow and hand joints are more flexed than on the right side because of spasticity. G. The patient lying on the ball, supported by the mother. By comparison with the right hand it can be seen that the left hand (palmar) and the left fingers (flexed) are still spastic. The not visible left small finger cannot be moved on volition and is cold (impairement of somatic and vegetative nervous sytem divisions (impaired temperature regulation and/or blood supply)).

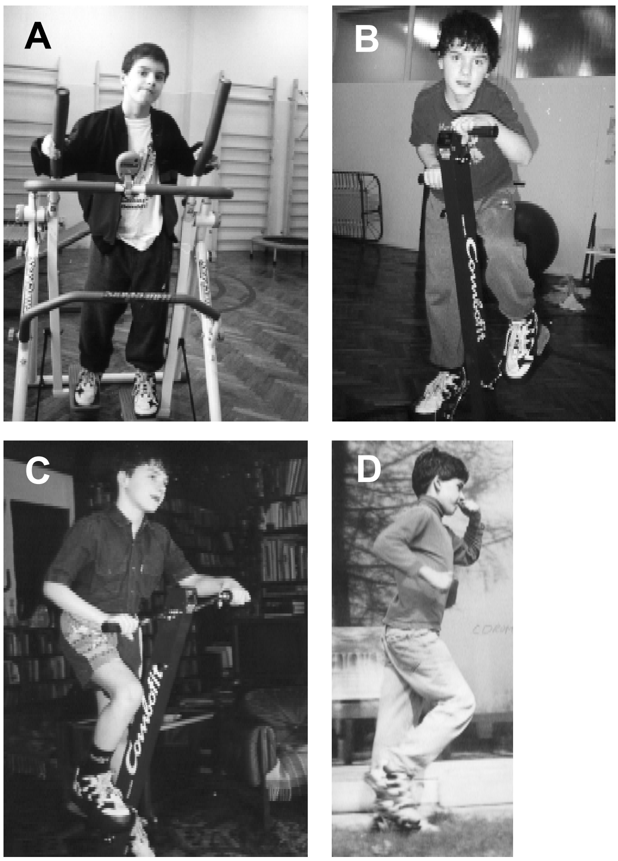


Figure 82
Improvement of hand and finger functions in the 10-year-old patient with severe brain lesion. In A, the patient is exercising on the air-walker after 3 months of therapy; in B and C exercises on the special coordination dynamic therapy device after 4 and 6 months of therapy are shown. Note the good positioning of the left hand and left fingers in C in comparison to those in A and B. D. Eight months after the accident, the function of the left hand during running is already quite good.

The improvement of motor function after 3 and 6 months of therapy can roughly be judged upon by comparing the jumping on the spring-board after 3 months (Fig. 81D) and 6 months (Fig. 83D). After 6 months of coordination dynamic therapy the patient needs no support any more when jumping in anti-phase, the left knee is not overstretched any more, the positioning of the left arm, hand, head (reduced spasticity of the musculus sternocleidomastoideus) and trunk are better - hemiparesis partly subsided.

With the improvement of the motor functions also the mental functions improved. His short-term memory became better. The short-term memory is still not normal because he often forgets what sentences he should translate, when translating 2 to 3 sentences from English to Slovak. He enjoys to go to school for a few hours per day. The improvement of the mental functions corresponds with the healthy looking face, as judged by the parents and the author. Whereas the face in Fig. 82A after 3 months of training looked not very healthy, the impression of his face after 6 months of therapy (7 months after the CNS lesion) is normal or nearly normal again (Fig. 84A,C).

After 6 months of therapy the patient can move the small left finger on volition, uses better the left hand, walks and runs distinctly better. Even though he is still a bit overstretching the left knee, he is not dragging the left leg any more, but is walking actively with both legs.

The 14-year-old patient Andrej was cycling down a steep hill, fell on his head and lost consciousness. He suffered many injuries including contusion of the lungs, obstructions of the airways due to facial and mandibular injuries and brain damage in the region of the right thalamus, the right fronto-parietal region, the frontal periventricular region and left basal ganglia (partly shown in Fig. 79C). The coma and vigilant coma stage lasted 2.5 months, that is 6 weeks longer than in the 10-year-old patient, where the therapy was started earlier.

Figure 83
The 10-year-old patient with severe brain lesion after 6 months of therapy during creeping (A), crawling (B), running (C) and jumping on the springboard (D). In A and B, the patient is creeping and crawling in competition with another girl with a brain lesion suffered at birth.

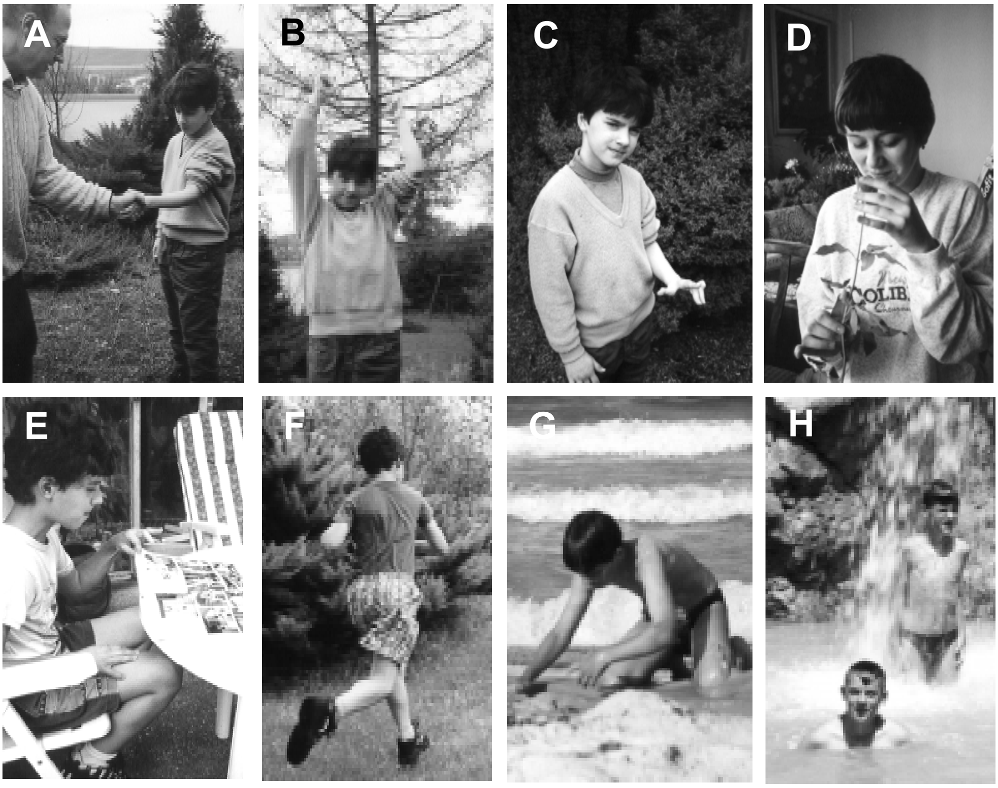


Figure 84
Hand and finger functions in the 10-year-old patient with severe brain lesion after 6 months of therapy (A-D). During hand giving, the left hand is no more in palmar flexion (A). When showing the clenched fists, the right hand and left hand positionings are similar (B). Sometimes the left hand and fingers still switch into spastic position (C). The volitionally uncontrolled small finger in C takes a position similar to the gracile finger positioning especially in women (D). Finger and posture functions of the now 11-year-old Benjamin one year after the accident (after 11 months of coordination dynamic therapy) (E-H). E. The finger functions are quite good again, when turning the pages of a journal. F. The patient during powerful running uphill in the garden; the posture is not fully physiologic in that moment. G,H. When playing on the beach with his brother, the patient assumes a quite good physiologic posture and when standing under a natural shower in Africa, his posture is symmetrical. Note in H the scar above the left mamilla (running laterally) from the open thorax injury (the patient was pressed during the car accident into an iron fence). The fractures and wounds healed up within 2 months; the restauration of the CNS functioning following severe brain lesion needed already more than one year.

Coordination dynamic therapy was started 2.5 months after the accident in the last phase of the vigilant coma state. When the author first saw the patient, the patient was aggressive, and the author even thought it was a hopeless situation to repair the lesioned CNS because the patient could hardly perform any coordinated movement and the speech was strongly impaired. But the parents wanted help, so the author advised them to start coordination dynamic therapy using the coordination dynamic therapy device (Fig. 85A) and treadmill. At the beginning, the patient had to be carried from the bed and the wheelchair to the training device. The progress in the beginning was slow. But with the improvement of motor functions and the vegetative functions (the strong sweating of the hands reduced) also the mental functions improved. The patient became strongly motivated to train hard to get healthy again. He started to like the author and could not remember any more that he had reacted aggressive at the beginning. It seems therefore that with the more integrated functioning of the neuronal networks, the CNS started to work on a mentally higher level. After 4 months of therapy, the patient could better run (Fig. 86E,F) than walk. After slipping once during running, the patient became afraid and his running was not as good any more (Fig. 78H). Some virus infections pulled him also back in the therapy. The therapy included also crawling (Fig. 85B), creeping (Fig. 85C,D) and rightening movements.

After 6 months of therapy, the functioning of the neuronal networks of the patient's CNS was very good in comparison to the following case in which the patient did not obtain any coordination dynamic therapy for the first 7 months, but was not as good as in the 10-year-old Benjamin, because of a later start of the coordination dynamic therapy, an illness, a complication with a bone contusion, suboptimal therapy, and of the unnecessary administration of botuline toxin, which disturbes the movement induced re-afferent input.

The improvement of CNS functioning with therapy in this patient can also be judged upon by the reduction of the palmar flexion of the right hand (Fig. 86B,C,D). But a good-bye photo after 6 months of therapy (Fig. 86A) demonstrates that the neuronal network organization generating movement, posture and hand function is influenced by somatic and mental functions. Even though the right hand and right arm functions are still strongly impaired, as can be seen during crawling (Fig. 85B) and giving both hands (Fig. 86B, still a strong palmar flexion of the right hand) on the good-bye photo the right hand was not palmar flexed (Fig. 86A). In the 10-year-old Benjamin, the hand function was better during crawling, was not far from normal when giving the right hand (Fig. 84A), but was a bit spastic on the good-bye photo

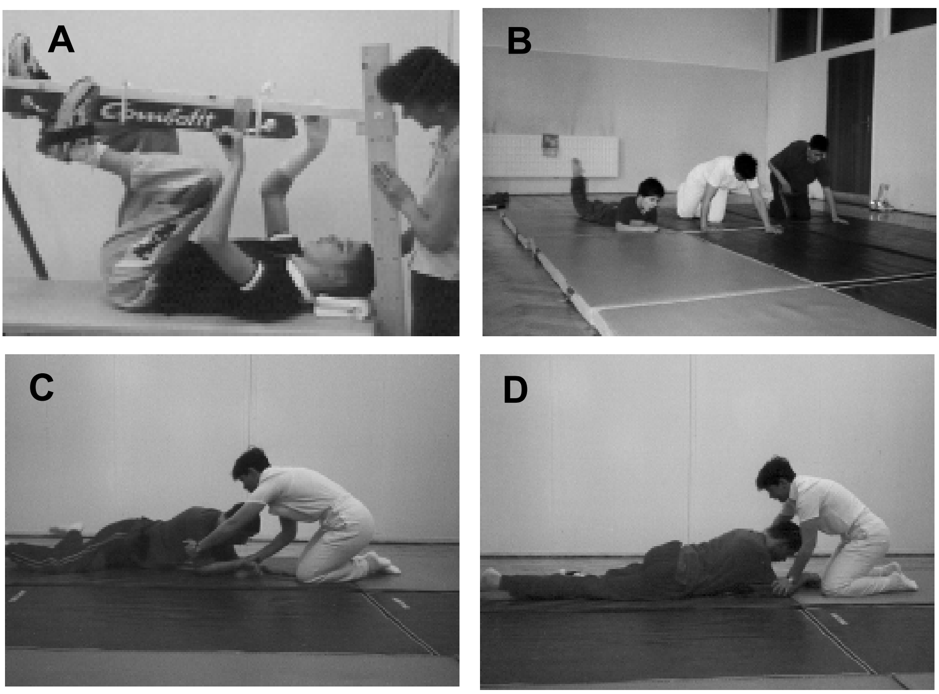


Figure 85
The 14-year-old patient Andrej with severe brain lesion during exercising on the special coordination dynamic therapy device (A), during crawling (B, problems in positioning of the right hand) and supported creeping (C, D). In A, the mother is supporting the construction.

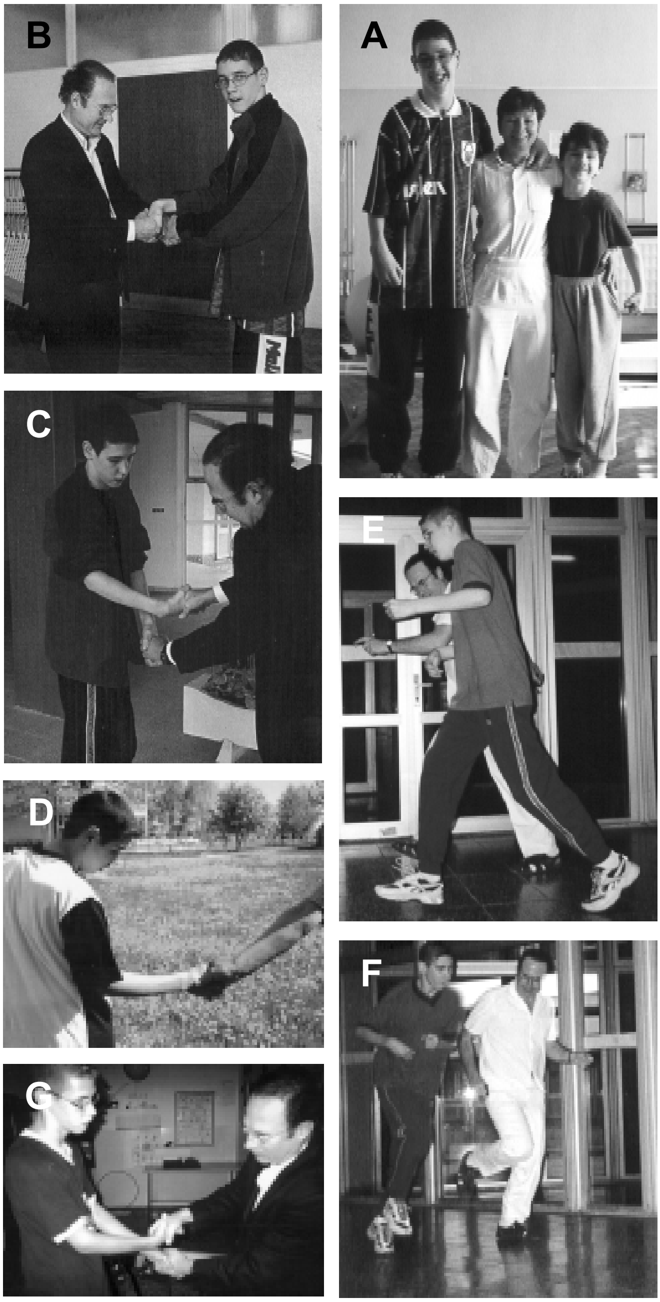


Figure 86 A - G
A. Good-bye photo, after 6 months of therapy; the 10- (left) and 14-year-old (right) patients with severe brain lesions and their physiotherapist. Note that in the 14-year-old patient the right 'bad' hand is not in palmar flexion, whereas the left hand of the 10-year-old patient is rather spastic. B, C, D. Hand giving with the author after 5 (B), 6 (C) and 7 months (D, one month after A) of therapy. Note the reduced palmar flexion in C, and no palmar flexion in D. E,F. Running after 3 months of therapy. G. Re-appearance of a slight palmar flexion one year after the accident, when replacing the coordination dynamic therapy transiently for one month by conservative treatement.

(Fig. 86A). The potential landscape for motivation and emotions after the CNS lesion [154] was in this emotional situation beneficial for the hand function in the case of Andrej but not for Benjamin (Fig. 86A). Interestingly, one month later it was possible to bring the right hand of Andrej in aligned position during hand shaking (Fig. 86D). The right hand could even be slightly flexed dorsally. Thus, the emotion with the present potential landscape for motivation and emotions [154] showed in this case a progress in the reorganization of the CNS which was possible without emotion only one month later.

The 12-year-old Mario had a car accident when cycling and suffered many bone fractures and brain lesions, when he came under the car. Because of many complications of the bone fractures and the brain lesions (additional subarachnoidal bleeding) and several infections, coordination dynamic therapy could be only started 7 months after the accident, even though the author was urging all physicians to start the therapy as quickly as possible. The coma and vigilant coma state ended 6 months after the accident, i.e. much later than in the two other cases where coordination dynamic therapy was started earlier. The motoric and mental situation is very much delayed in comparison to those of the other two patients, Benjamin and Andrej, 9 months after the CNS lesion. The patient has still to be carried from the wheelchair to the therapy device (Fig. 78C,D) because of strong extensor spasticity (Fig. 78E) and supination of the feet (Fig. 78G), and communication is difficult, even though the patient is friendly and cooperative (when the author is present).

After one month of coordination dynamic therapy, the motor and mental functions started to improve.

It can only be hoped that the lost early treatment can partly be caught up. It is argued in the literature that there is a time window for early treatment [40]. Even if this suggestion of the time window for early treatment were correct an early treatment is important for the following reason. If supervised reorganization is efficient and starts very early after the CNS lesion, then the reorganization goes directly from the neuronal network organization after the lesion towards the functioning with physiologic output (Fig. 108). But if such early therapy is not provided, the lesioned CNS organizes itself in a pathologic way because of missing supervised re-learning. Due to the pathologic functioning of the CNS, the mechanical properties of the body become pathologic: tendons shorten, muscles become spastic or atrophic, joints cannot be moved any more (pain) and the arms, legs, hands and feet often assume very unphysiologic positions so that it becomes difficult to use them for physiologic movements, and appropriate therapy can only be applied slowly and with many difficulties; then, the therapy is not as efficient any more. With these and other difficulties, the pathologically functioning CNS has to be reorganized in the direction of physiologic functioning. In conclusion, following CNS lesion the remnants of formerly physiologic functioning network parts are easier to organize for physiologic output than network parts which started to function pathologically. Even for the 10-year-old Benjamin it would have been probably better to start coordination dynamic therapy already 10 days rather than 4 weeks after the lesion. Even if tubes, wires and the necessary apparatus hinder intensive coordination dynamic therapy, intensive therapy has to be started as early as possible.

In severe brain lesions, bone and other reconstructions must be designed in a way to allow an early intensive neurorehabilitation. Bone fractures, for example, must be reconstructed invasively.

B. Stage of repair 1 to 2 years after the CNS lesion: Repair also in the case of delayed coordination dynamic therapy

The now 11-year-old Benjamin obtained a further optimal 6-month coordination dynamic therapy at home. The functions in the left arm and left hand further improved. He can walk and run better (Fig. 84F) after the further treatment. With the left 'bad' hand he can turn over pages of a journal (Fig. 84E). Benjamin is back to his old school in his old class (!) and is managing well. The strategy to first give priority to the re-learning of the motor functions before going back to school and giving in this way priority to the re-learning of the basic structures of the CNS with the improvement also of the short-term memory was right in this case. With the improvement of the motor functions also the higher mental functions improved, so that he could better manage at school. Benjamin is not far from normal again. With two hours intensive therapy per day, he will in a few years time be largely cured from his severe brain lesion.

Even though the running of the 11-year-old Benjamin is powerful again one year after the accident, as shown in Figure 84F, his posture during running is not fully physiologic. On the other hand, when playing with his brother on the beach (Fig. 84G) his posture is quite normal, and when standing under a natural shower in North Africa during holidays, his posture is symmetrical (Fig. 84H). It seems therefore that the patient is using the former pathologic posture now at least partly as a habit. The former attractor ‘pathologic posture with spasticity’ of the lesioned CNS is still somehow existing in the repaired CNS. But the patient has the possibility to switch on volition into the attractor state ‘physiologic posture’. The possibility to have a bistability of the two attractors, pathologic posture and physiologic posture, is found again below, when tackling idiopathic scoliosis in the case of slight disturbances of CNS functioning. 15 months after the accident, his CNS has still problems in organizing the trot gait coordination between arms and legs during crawling and during exercising on the special coordination dynamic therapy device. When falling, he is still not using protection reaction automatisms. The measured coordination between arms and legs is still not physiologic (Fig. 86L).

The now 15-year-old Andrej was receiving only conservative treatment for one month. His motor functions did not improve further during this month. The re-appearing slight palmar flexion of the right hand (Fig. 86G) may even indicate a loss of re-gained motor functions (a loss of re-learned functions was also found during the therapy of a caudal spinal cord lesion, when interrupting the therapy (Fig. 67)). With re-starting coordination dynamic therapy, the motor functions started to improve again.

Most interesting is the case of the now 13-year-old Mario. Six to eight months following the brain lesion (with no or only little conservative treatment) his motor and higher mental functions were in a seemingly hopeless condition. Because of only little or false organization of the neuronal networks, including different kinds of spasticity, false posture and positioning of leg and feet (Fig. 78E,G), he had to be carried by his mother (Fig. 78C). Still an intensive coordination dynamic therapy was started with him, including exercising on the special coordination dynamic therapy device in recumbent (Fig. 78D) and sitting position (Fig. 86Ka), and treadmill walking. Even though the patient was often crying, especially during treadmill walking (Fig. 86Kb,c), mainly because he was afraid (as he explained later on, when his mental functions had further improved), the neuropediatrician, the physiotherapist, the mother and the research worker (author G.S.) came to the same conclusion, namely that Mario has to exercise intensively, or he has nearly no chance for further essential improvement in the future.

One year after the brain lesion (after 4 months of rather intensive therapy) an essential progress occurred. The patient became able to walk a bit when supported (Fig. 86Kf,g). His hand functions improved, so that he could turn over the leaves of a journal and was able to write again (Fig. 86Ke). He is now motivated to exercise and he has the feeling that his functional state of the CNS is progressing (Fig. 86Kh). His higher mental functions also improved substantially. Eight months after the accident, the patient had problems to recognize the author. Twelf months after the accident, he even speeks some words in German to him (his native language is Hungarian). Mario is back to his old school, but two classes lower. The pupils and the teachers are giving him much help so that he can manage. Further progress depends on the intensity of the continuous coordination dynamic therapy. When Mario is separated from his mother for a longer period of time, he is so much stressed that he has problems to speek. If Mario is therefore treated further at the clinic, then his mother will have to be with him. 17 months after the brain injury he has still problems in organizing the different coordinations between arms and legs.

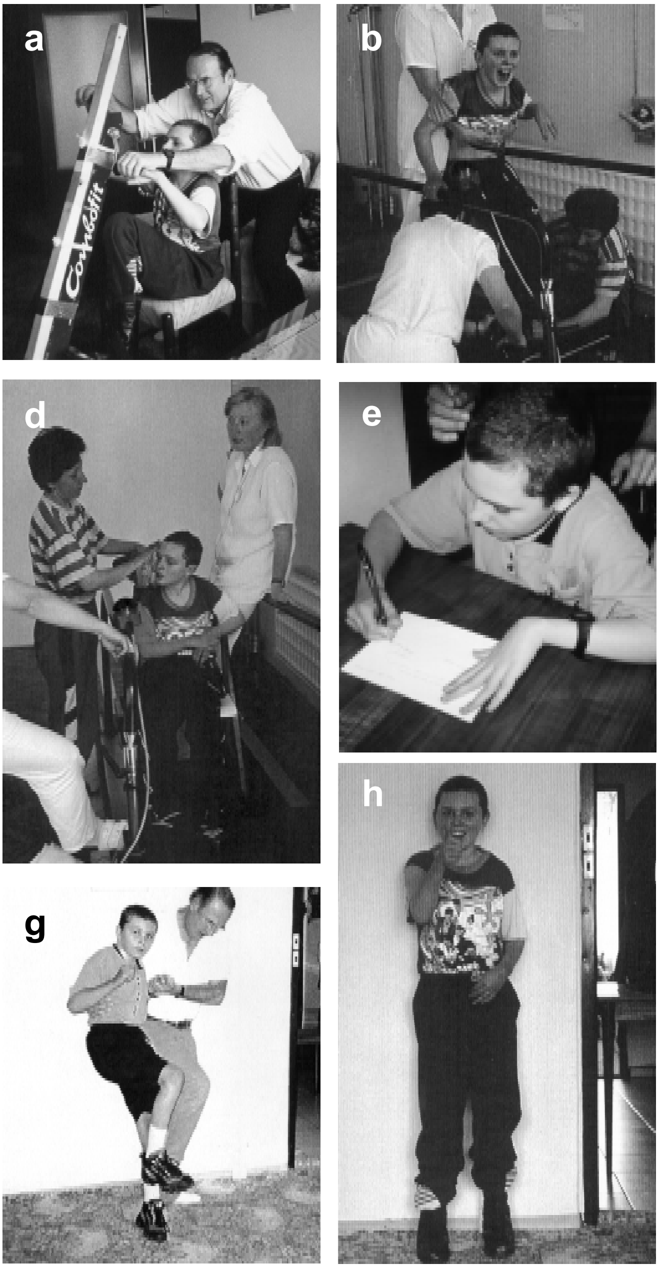



Figure 86 K
Delayed improvement of the functioning of the lesioned CNS in the 13-year-old patient Mario with a left-sided hemiparesis (and quadruparesis). a. The patient exercising on the special coordination dynamic therapy device in the sitting position. The author (G.S.) gives hand support, so that the left paretic hand does not slip from the handle. The support is given to both hands, to induce co-movement in the left hand of the patient. b,c,d. The patient during exercising on the treadmill, supported by the physiotherapist, the mother and the chief physician. In b, the feet are supported, whereas they are not in c. In d, the patient recovers from stress and fear. The exercising on the treadmill was a burden to all, because of the crying of the patient (he was afraid). e. The patient is able to write again. f,g. Supported walking with the mother and the author. Barfoot walking is possible (f), even though the left foot is in a quite pathologic position (suppination plus plantar flexion). Walking with shoes seemed to be beneficial for the walking performance (g), as if the additional skin afferent input from the feet, due to wearing the shoes, induced a better walking performance. The high lifting of the right knee indicates probably a partial induction of the stepping automatism. h. Patient in standing position, supported by the wall behind him. Also the higher mental functions improved in the patient; he has himself now the impression, that he is making progress in re-learning old functions: the patient is putting up the thumb without instruction.

The case report of the 13-year-old Mario shows that, even when the early coordination dynamic therapy is missed, there is still hope that CNS functions can substantially be improved. Only, the therapy is more difficult to perform because of the pathologic organizations which have taken place in the CNS in the meantime. The pathologic neuronal network states, which express themselves by spasticity, false positioning of body parts and maybe epileptic seizures, make the reorganization of the CNS more difficult and cause partly pathologic movement induced re-afferent input. A further important point is that also continuous, intensive and early adequate therapy and not only differences in the brain lesion are crucial for the outcome of similar severe brain lesions. If the therapy had not been continued 8 months after the accident, then the patient Mario would not have made that substantial progress!

C. Diagnosing coordination dynamics

The progress in the reorganization of the lesioned CNS cannot only be judged upon by the improvement of movements but also by directly measuring the coordination dynamics. Macroscopically, the impaired firing of the CNS neurons with relative phase and frequency coordination can be seen in arrhythmic movements when training on the special coordination dynamic therapy device. The change of the coordination between arms and legs from easy (pace gait and trot gait) to difficult (intermediate coordinations between pace gait and trot gait) and backwards opens up the possibility to measure the average organization of the hu-

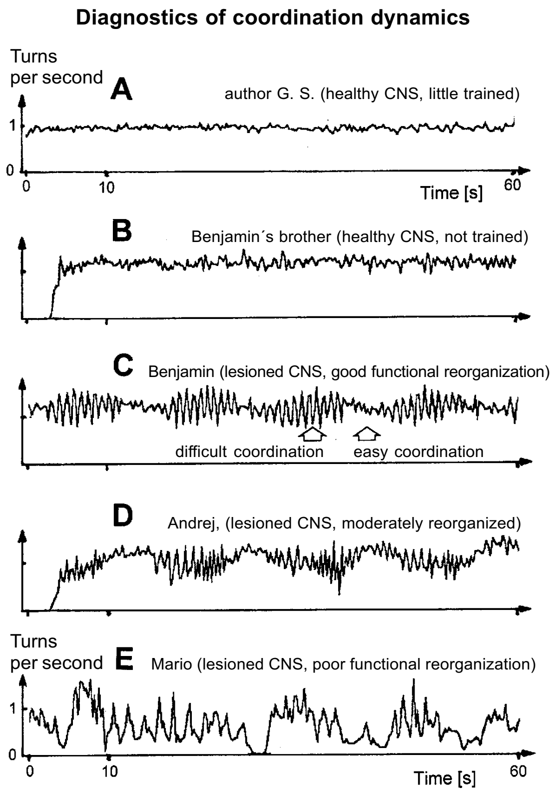


Figure 86 L
Measurements of physiologic and pathophysiologic coordination dynamics. A. Easy (pace gait and trot gait) and difficult coordination (intermediate coordination between trot gait and pace gait) can be performed by a healthy person without loss in rhythmicity. B. A person with a not specially trained CNS can almost equally well perform both the easy and the difficult coordination. The variability in the speed of turning is a bit bigger and equally distributed. C. The trained lesioned CNS is able to generate easy coordination without deficits in the rhythmicity (small variations in the velocity), but can only generate the difficult coordination (intermediate coordination between pace gait and trot gait) with loss in rhythmicity (large variation in rhythmicity of the turning velocity; patient Benjamin). Macroscopically, the poor relative coordination of the neurons in the CNS in phase and frequency causes a large variation in rhythmicity for the difficult coordination. What results is the typical pattern of continuously changing small and large velocity variations. D. For even more strongly deteriorated coordination dynamics (patient Andrej) a larger variability in the rhythmicity and varying volitional drive is observed already for the easy coordination. The typical pattern of continuously alternating large and small variations in rhythmicity due to the continuous changing from easy to difficult coordination and backwards (C) has been changed. E. For a very bad CNS organization, the turning becomes completely arrhythmic (patient Mario), and the patient sometimes stops turning during the performance of difficult coordination.

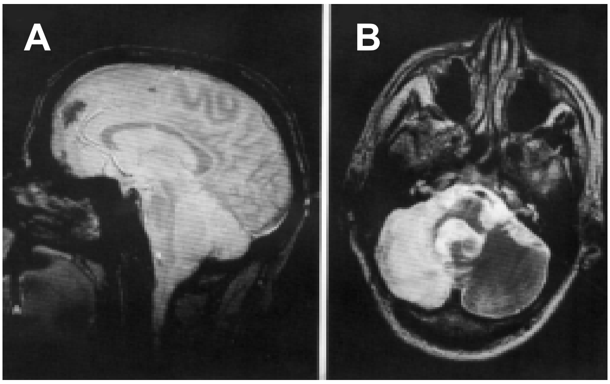


Figure 87
Magnetic resonance imaging (MRI) of the brain of the 58-year-old patient following severe brain lesion suffered 4 years ago. The cerebellum is destroyed to approximately 60% (B, light parts of the cerebellum) and there is loss of brain tissue in the frontal lobe (A, dark areas of the forebrain): cystic scar substance deficiency in the right cerebellar hemisphere, the vermis of the cerebellum (impaired balance), and the right middle peduncle of the cerebellum down to the right lateral pons (impaired planning and design of the movements; impaired input from premotoric areas, e.g., area 6). Small substance deficiency in the right frontal paramedian area (diameter approximately 1 cm). Small cortical lesion in the gyrus frontalis superior.

man CNS non-invasively. The measurements illustrated in Figure 86L show that the coordination dynamics is best for the patient Benjamin, less good for Andrej, and poor for Mario. The measurements of coordination dynamics are in accordance with the measurements of the movement functions. The measurement of coordination dynamics turns out to be an additional important diagnostic means, which can even be used for immobile or even uncoscious patients (patients in permanent coma; Fig. 103F).

Case 14: *Bilateral cerebellar lesion*

A now 59-year-old patient suffered severe bilateral cerebellar lesion (Fig. 87) when falling out of an unprotected window of a hotel 4 years ago. The formerly intelligent patient was a dynamic person as may be judged from Fig. 88A. After the lesion, the impression of his face became different (Fig. 88B). With the improvement of the CNS functioning the dynamicity of the face improved again (Fig. 88C-H).

When the author met the patient 3.5 years after the accident, the patient could walk a bit without help like a pinguin (Fig. 90A,B), but he had big problems to keep balance when standing or walking. The patient could not combine different automatisms for moving about. When the patient was sitting on a chair at a table, his arms and hands were mostly hanging down in a useless position. They were not prepared for action and brought in the appropriate position. Only when he gave himself the order to use the hands or another person gave the order, he brought the hands and arms in a functional position, like using them for safety reasons or putting them on the table. The patient did not show protection reaction when falling, and he was not making any gestures with hands and arms when speaking. When the patient wanted to go to another room, he could not combine the movements of getting up from the chair, turning to the desired direction and starting to walk to the other room. He was getting up too slowly and forgot to use the arms and hands. Then, he was changing slowly, with difficulties, the direction of the body, and then he was moving like a pinguin with no continuous movements to the other room. The patient had generally lost the ability to recruit and combine complex automatisms including gestures. He lost the readiness to manage actual situations. This can nicely be understood with the readiness to brake in a dangerous traffic situation. An experienced driver gets automatically ready to brake, i.e. to put the foot on the pedal and getting mentally prepared when a dangerous situation occurs, like if a ball or a child appears. When a child appears running without looking over the street the driver can quickly brake. Such protection,

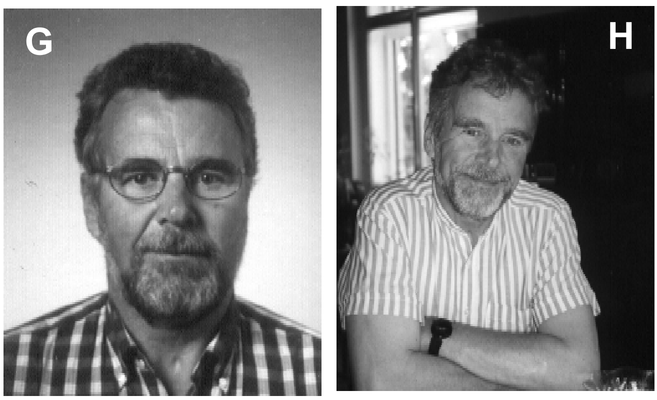


Figure 88
Changes in the appearance of the face due to reorganization of the CNS. Prior to the brain lesion (A), the face of the patient looks dynamic. Three months after the brain lesion (B), the higher mental functions seem to be strongly impaired. With ongoing recovery from the brain lesion after 7 (C), 10 (D), 19 (E), 20 (F), 40 (G) and 48 (H) months, the mental functions seemed to improve as suggested by the appearance of the face.

readiness and functional automatisms are essential in life to keep the brain free for volitional tasks which start out of automatisms. The loss of recruitment of such automatisms to combine them with other automatisms and volitional movements puts a big burden on the patient's 'brain' (see below). Because the centre of gravity of the patient's body was too much backwards, there was always a big danger that he may fall backwards. He was not able to bring his weight to the forefeet so as to fall forward rather than backwards. Further, his extensors were too much activated, which could even be seen on his fingers when playing piano (Fig. 92A, B).

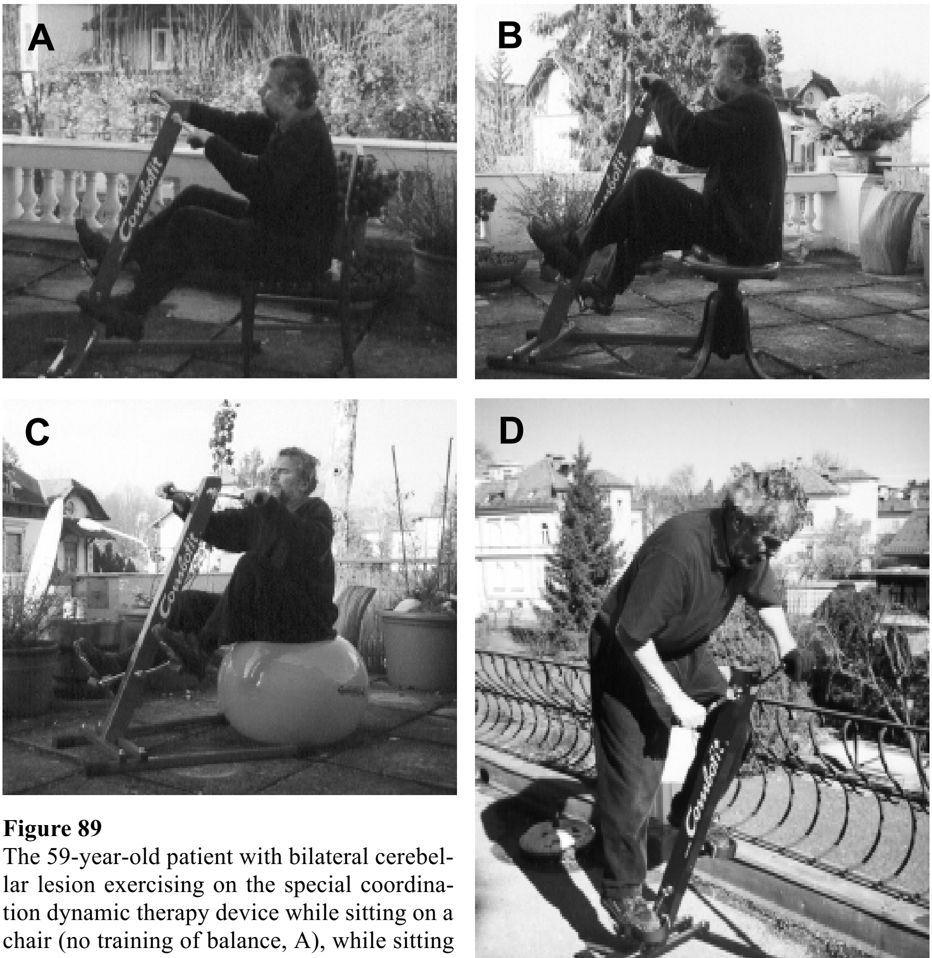


Figure 89
The 59-year-old patient with bilateral cerebellar lesion exercising on the special coordination dynamic therapy device while sitting on a chair (no training of balance, A), while sitting on an air cussion (exercising simultaneously a bit keeping balance, B), and while sitting on a ball (training coordination and balance, C). In D, coordination dynamics is exercised in the standing position (position with most integrative activation of the CNS including the strong activation of the balance keeping circuitry). The difficulty of the performance increases from A to D. At the beginning of coordination dynamic therapy, exercising on the special coordination dynamic therapy device was only possible in the sitting position (A), after 4 months of therapy also in the standing position (D).

His wife claimed that he was not as intelligent as before as he seemed to recall always good arguments from his long-term memory established before the lesion, but seemed to be unable to manage normal practical things of the momentary situation like very old people do. There was no power in his body mentally and physically, and he accepted most of the things of his surrounding.

When an intensive coordination dynamic therapy (Figs. 89,90) was started, he accepted it and he was in favour of it. With the ongoing therapy the patient became more dynamic and he really wanted the intensive therapy to substantially improve the organization of his CNS.

When the therapy was started it turned out that he could walk (Fig. 90C) and run (Fig. 90D) quite well on the treadmill. But he was nearly unable to walk without support. He moved slowly like a pinguin (Fig. 90A,B). The therapy included treadmill walking and running (Fig. 90C,D), air-walking, free walking (Fig. 90A,B), exercising on the special coordination dynamic therapy device first in the sitting (Fig. 89A,B,C) and later on also in the standing position (Fig. 89D),

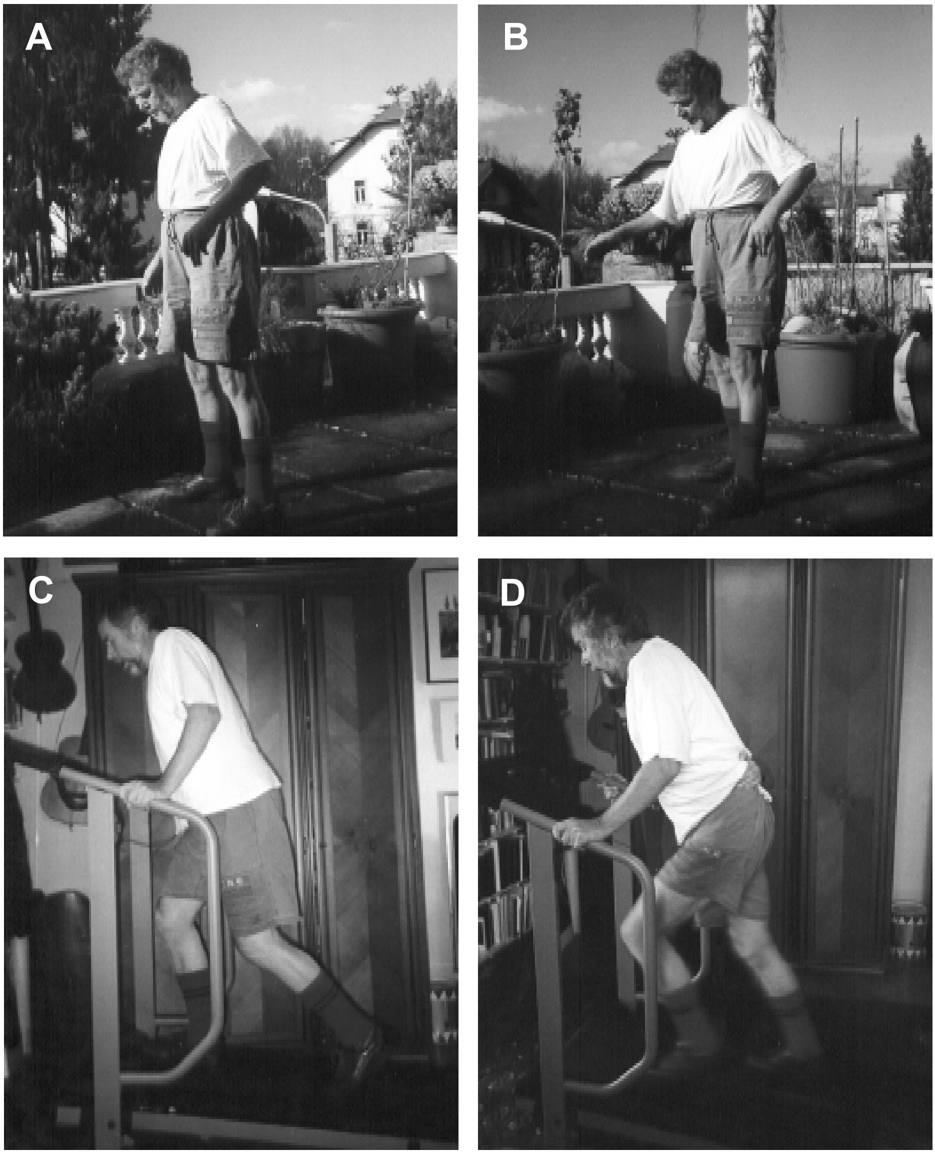


Figure 90
The 59-year old patient with bilateral cerebellar lesion during free walking: pinguin-like walking with small steps and at a very low speed (A,B), during walking on the treadmill (C, speed = 3.5 km/h) and during running on the treadmill (D, speed = 6.5 km/h). Note in D the stressed face of the patient, even though he is being supported by his wife. Note further that the patient in A and B (walking like a pinguin) is too much backwards (the point of gravity is more on the heel than on the center of the foot or the forefoot).

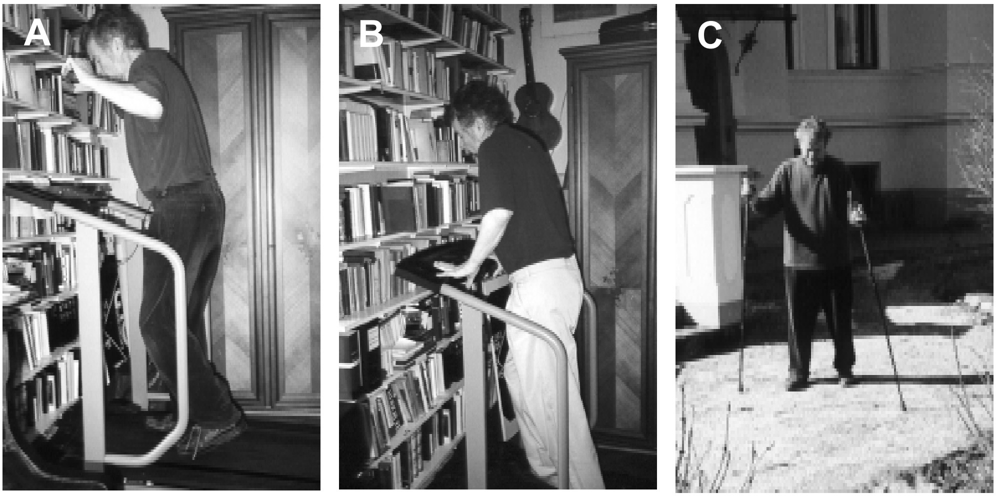


Figure 91
Balance training on the treadmill (A,B); the 59-year-old patient with bilateral cerebellar lesion. By starting with supported treadmill walking at a speed of 1.6 km/h and lifting one hand (A) or reducing the hand support finger by finger (B), the patient trains the keeping of balance and tries to bring the comparably good supported treadmill walking performance to not supported treadmill walking to avoid the pinguin-like free walking. In C, the patient is walking outside the flat with sticks to avoid using the wheelchair.

Figure 92
The 59-year-old patient with bilateral cerebellar lesion during integrative coordination dynamic therapy representing a combination of exercising of coordinated motor, speech and visual functions. A. The patient playing piano. Both hands move in symmetry. In this way the 'bad' left hand is coupled to the 'good' right hand. The patient is singing simultaneously a song to coordinate the speech muscles with the movements of the fingers. B. The patient playing piano and singing in interpersonal coordination with

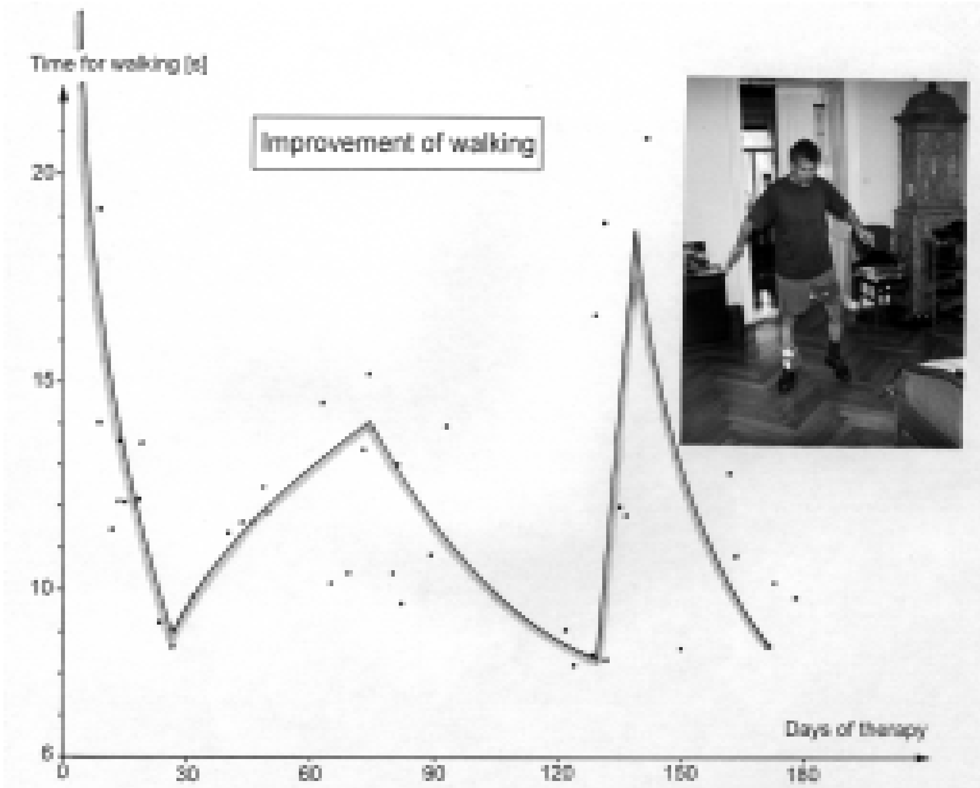


Figure 93
Walking times over 8 m in the bedroom with ongoing therapy; the 59-year-old patient with belateral cerebellar lesion. Note that the improvement of walking is very instable, indicating that the inner existing coordination dynamics tendencies are in competition with the to-be-learned neuronal network organization induced by the coordination dynamic therapy.

conventional physiotherapy, coordination dynamic therapy on the piano (since he used to be a good piano player before the CNS lesion, Fig. 92A,B) and speech therapy (Fig. 92C).

The main drawback in his social life were impaired walking with the balance problems, impaired speech (scanning speech, no problems to find words), loss of the dynamic character and reduction of the ability to solve problems.

After 5 months of coordination dynamic therapy, free walking (Fig. 93), keeping of balance and speech improved and the patient re-learned chest swimming. Even though the patient could swim he could drown. When he was walking in a swimming pool and fell backwards, he

a musician to further improve the organization of the CNS. The forefeet also move rhythmically in coordination with the music to expand the activated integrated functions. Note that, while playing piano, the fingers of the patient are more stretched than those of the musician, playing in interpersonal coordination, which also indicates that extension predominate in the patient. C. The patient during speech therapy performed simultaneously with coordinated arm and leg movements to harmonize the descending activation system and to make the speech (and the moving of the arms and legs) more continuous. D. To enhance the coordinated rhythmic visual input given by the rhythmically moving hand and feet in the field of vision, a flashing lamp is mounted on the therapy device. The patient moves his legs and arms automatically in relative coordination with the rhythm of the flashing light.

was not able to get quickly enough into the swimming automatism, which is in accordance with the difficulty of his CNS to combine different movements and automatisms.

To further improve the walking (to get rid of the pinguin walking on the long-term), the patient had to walk on the treadmill with the support of his hands, and then he had to reduce the support by lifting one hand (Fig. 91A) (or both hands) and getting it (them) moved in antiphase or by having the hands in front of the body during treadmill walking and trying to reduce the hand support by lifting finger by finger (Fig. 91B). To avoid using the wheelchair when covering longer distances rather fast, sticks were used (Fig. 91C). The speech therapy was combined with motor learning in two ways to activate the CNS as integratively as possible. First, during speech therapy the patient had to exercise simultaneously on the special coordination dynamic therapy device (Fig. 92C). To include more strongly coordination with vision during the motor learning, a flashing lamp was mounted on the device in the field of vision (Fig. 92D). The patient had also to train to speak as quickly as possible. The speech therapy combined with exercising on the special coordination dynamic therapy device had two immediate advantages in the short-term memory of the the patient´s CNS: a more continuous speech (more harmonic speech activation) and a transient normalization of the hypersecretion of the salivary glands (transiently improved functioning of the vegetative nervous system). The second way to combine motor learning with speech therapy was to play piano with both hands in symmetry and in interpersonal coordination with a musician (Fig. 92B). The patient had to give rhythm support with the feet. When training by himself, he was, e.g. playing with both hands in symmetry the song ‘Guten Abend, gute Nacht ...’ and was singing the song simultaneously (Fig. 92A). It has been assumed that singing is more distributedly organized and stored in the CNS than speech and is therefore less impaired due to the CNS lesion. It has been reported that languages learned later in life are stored differently from the mother tongue [65]. It is generally known that following brain lesion, singing is less impaired than speech.

The most marked progress achieved so far has been that the patient’s speech has become more regular and more precise (probably due to a better coortdination of the muscles involved in speaking) and the improvement of higher mental functions. A glance in his eyes as a sign of mental excitement occurred more often, and the patient became more active in solving problems in actual situations.

Interesting were the answers the patient gave when asked whether his mental functions are the same as before the CNS lesion. The patient answered: 1. His mental potency is the same as before the CNS lesion if in recumbent position at his home on the couch (no need to use higher mental functions to induce, maintain, controll and terminate motor functions (volitional and automatic)). 2. If he moves he has to use parts of his brain (higher mental functions) for the motor functions. 3. His self-confidence is reduced, because he cannot walk and speak well. His behavior is not dynamic any more, because he had to adapt his intentions to the motor possibilities left after the CNS lesion. If he wants to get a certain thing from another place of the flat, then he starts first to think about the tremendous motor tasks he has to perform to get the thing, and often he gives up the task. But if his motor functions worked sufficiently automatically again with safety so that he had not to think about them, then he would be more active and he would become more dynamic again. This is what has been predicted from the theoretical neurosciences: when re-learned motor functions become automatic, then the ‘brain’ becomes free for higher mental functions [63].

If the patient is right, what is likely, then he is still not back to his old mental power. Firstly, he must re-learn to combine (interlace) different automatisms and volitional motor functions, and secondly, he must re-learn to recruit or activate his higher mental functions again. Interestingly, after running on the treadmill, when sitting on a chair for rest, he was more active in speaking, his eyes had a higher glance and the motor functions and automatisms seemed to be better coordinated or higher activated. As if the running (coordinated movement, highly activated integrated functions of the CNS) were beneficial for activating higher mental functions. This would support, in this case, the idea that higher mental functions and coordination of motor tasks are more dependent on the extent of activation of integrated coordinated neuronal networks of the CNS than on the activation of localized brain parts. The descending drive from higher to lower mental functions is created by the activated integrated neuronal networks. In the CNS there is no conductor (as in an orchestra) who would activate, maintain, control and terminate the integrated action of the different network parts of the CNS; rather, in the CNS it is the mutual coordinated influence as between the members of an ensemble making chamber music to generate the spirit of their music and to activate, maintain, control and terminate it.

After one year of coordination dynamic therapy, the patient´s speech and higher mental functions further improved. His walking further improved but with big variations (Fig.93). Probably, a competitive interplay took place between the existing pathologic coordination dynamic tendencies in the lesioned CNS and the to-be-re-learned physiologic coordination dynamics organization. With the improvement of the CNS organization also the processing of the afferent input improved. A transient drawback for the time being is that with the improvement of the sensitivity also the pain perception improved. After falling down with no protective automatism, pain occurred which strongly disturbed his walking (and increased strongly spasticity) because the CNS just manages to generate a bit of walking with no safety margin and, a bit of pain in the knee had a strong inhibiting effect on the walking performance and, consequently, on the balance. With further improvement of the coordination dynamics of his CNS and the healing of the knee, the pain problem will subside to become a normal control function in the body.

Case 15: *Poliomyelitis*

A 37-year old patient had poliomyelitis 36 years ago. She became paraplegic sub Th10 and also the right arm was affected (slight quadruparesis). After a period of 36 years with absolutely no signs of activity in the leg muscles, coordination dynamic therapy was started to learn her walking. Following 4 weeks of therapy (3-5 times per week, 3.5 hours per day) first signs of muscle activation were observed. After 3 months of therapy, leg movements were observed for movements where little muscle power is needed. One of the first possible movement positions is shown in Fig. 94A. The applied coordination dynamic therapy was performed in the recumbent position with a special device to especially train coordination dynamics (Fig. 94D). The patient was now able to perform, on the special coordination dynamic therapy device, an average of 12000 turns (~ 6 hours) per day, five times per week. First regained electrical muscle activity could be recorded from previously plegic muscles (Fig. 95A). In Fig. 94D, the patient is shown during therapy with the surface electrode cables. After preamplification (1000x), the electromyographic (EMG) activity is shown on an oscilloscope screen. In Fig. 95A, a plot from the oscilloscope is shown. The lower trace shows the activity of the musculus biceps brachii, the upper trace represents the electrical activity of the musculus quadriceps femoris (vastus medialis). The amplitudes of the electromyographic activity of the biceps brachii and quadriceps femoris differ by approximately a factor of between 10 and 100, suggesting a principal type difference of the innervating motoneurons. It is difficult to explain such an EMG amplitude difference by muscle atrophy since firstly, such a difference would not be expected to be that big and secondly, the reinnervated muscle fibres had been trained intensively for the previous 3 months.

Probably, the reactivated muscle fibres of the previously plegic legs are activated by α_3-moto-

Figure 94
First movements the 37-year-old patient can make with muscle activity regained in leg and hip muscles (with ongoing therapy) after poliomyelitis, which left no muscle activity below Th10 for 36 years. A. After 3 months of therapy swinging of the right leg and foot in the wheelchair is possible (at this time the EMG recording shown in Fig. 95A was taken). B. Standing a few seconds with strong support at the wall bars. C. After 7.5 months of therapy the patient can go two steps backwards, if she can support herself (at this time the EMG recordings shown in Fig. 95 B to F were taken). D. Author (G.S.) taking EMG recording, while the patient is exercising on the special coordination dynamic therapy device. Surface electrode wires (indifferent recording) can be seen with preamplifiers besides the oscilloscope (top of the picture). Upper trace: quadriceps femoris; lower trace: biceps brachii.

neurons innervating red muscle fibres (ATP-ase type I). This is likely since the α_3-motoneurons are small and do generate only small muscle action potentials (Fig.9, page 139 of Ref. [131]). This amplitude argument is supported by the reorganization argument. Because the α_3-motoneurons (S) or the oscillatory firing subneuronal α_3-networks are activated polymodally, they are more interlaced with other subneuronal networks (higher connectivity) in the CNS than, for example, α_1-motoneurons (FF) which innervate white muscle fibres (ATP-ase type IIB). Due to the destruction of motoneurons and network parts by poliomyelitis, in the reorganization and regeneration process induced by the intensive coordination dynamic therapy the surviving α_3-motoneurons are expected to become recruited first during the establishment of new muscle function.

Also, in the 30 year-old patient with a clinically complete spinal cord lesion sub Th12 (case report 6), the muscle action potentials had only very small amplitudes in those muscles reactivated with the lowering of the lesion level from Th12 to L3. Among motoneurons which survived the spinal cord lesion in the lesion area, those motoneurons were reactivated first which are supposed to have the highest connectivity, namely α_3-motoneurons.

The EMG recording after 3 months from reactivated muscles of the poliomyelitis patient points towards reorganization induced recruitment of motoneurons surviving after poliomyelitis rather than neurogenesis of motoneurons in the spinal cord.

For the time being, neurogenesis induced by intensive coordination dynamic therapy seems impossible in this patient. The time needed for neurogenesis is in the range of 6 weeks (personal information). Then, the axons of the newly built motoneurons would have to grow down the nerves to the muscles which would need a time of approximately a year, since axons grow approximately 1 to 2 mm per day. And then, functional motor endplates would have to be built. Improvement of motor functions in the legs due to therapy-induced motoneuron neurogenesis can therefore be expected within one to two years with ongoing therapy. But it

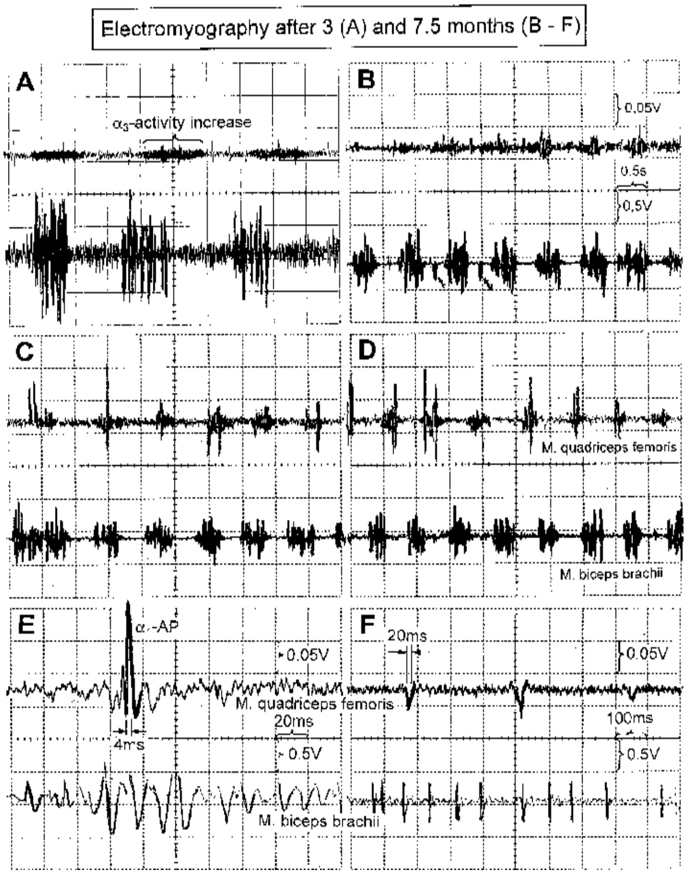


Figure 95 A-F Electromyography (EMG) taken in the 37-year old patient after 3 (A) and 7.5 months (B-F) of coordination dynamic therapy, from a reactivated muscle (quadriceps femoris, right); poliomyelitis 36 years ago, in comparison to a muscle which was only little affected by poliomyelitis (biceps brachii, right). A. EMG plot of the oscilloscope. The amplitude of the EMG activity of the biceps brachii (lower trace) is nearly 100 times larger than that of the quadriceps femoris (upper trace). The EMG activity of the quadriceps femoris is probably recorded from red muscle fibres (S) (low AP amplitude) innervated by α_3-motoneurons, and the EMG activity from the biceps brachii mainly represents the white muscle fibres (FF) (large AP amplitude) innervated by α_1-motoneurons (for further reasoning, see text). B,C,D. Rhythmic activity of the musculus quadriceps femoris can be identified if the patient is exercising quickly on the coordination dynamic therapy device. The more dynamically activated (fast turning) α_1-motoneurons (identified by the large EMG amplitude and the short action potential duration, see E) still activate the FF-type muscle fibres (ATPase type IIB) irregularly, as can be seen from the irregular rhythmic EMG activity of the musculus quadriceps femoris. Even in the musculus biceps brachii the rhythmic firing is still not fully physiologic; in B, two additional action potentials (APs) are marked with small arrows. E,F. EMG recording during non-rhythmic activation. In the recording in E (top trace) a muscle action potential is marked with α_1-AP, which has a comparably large amplitude and a short AP duration (4 ms), probably being a potential from an FF-unit (ATPase type IIB), which is activated by an α_1-motoneuron. There are therefore also electromyographic indications for reinnervation of the musculus quadriceps femoris by fast growing and therefore early reinnervating α_1-motoneurons. In F, the muscle APs with a long duration (20 ms, top trace) give further indication that motor unit APs are built and established, since the motor endplates (of the few hundred muscle fibres of a motor unit) are still firing irregularly and giving therefore rise to muscle APs of long duration. Note that the muscle action potentials of the musculus quadriceps femoris (top trace) have a much smaller amplitude than those of the musculus biceps femoris, since the amplification is 10 times larger (0.05 V instead of 0.5 V) than for the biceps brachii.

might well be that, in the preceding 36 years following poliomyelitis, new motoneurons were built and axons and dendrites grew out from the soma and formed connections but were not used so far, because no effcient effective therapy was performed. The 'adaptive machine' CNS was not forced to adapt (reorganize) to the instructions given by the therapy. A healthy child who does not attend school and who does not learn will also not learn how to read and to write and will not learn mathematics and physics, even though the CNS is offerering all opportunities for learning.

With ongoing therapy the power in the leg muscles improved. For the first time, she could stand on her legs (Fig. 94B,C), perform the therapy additionally in the sitting position, could stay a bit in the upright position when supporting herself (Fig. 94B, no full power in the left arm and hand), and can perform two steps backwards when supporting herself (Fig. 94C).

After 7.5 months of therapy, new EMG recordings were taken to see whether there were electrophysiological signs of further reinnervation.

The recorded electromyographic activity 7.5 months after the beginning of the therapy is shown in Fig. 95 B-F. With rhythmic dynamic movements (quick turning of the leavers) also rhythmic EMG activity of comparably high amplitude was recorded from the former plegic quadriceps femoris muscle (Fig. 95B-D, upper trace). The large amplitude and the short duration of the newly occurring muscle action potentials (APs) point towards an activation of FF-type muscle fibres (fast fatigue; ATPase-type IIB), activated by α_1-motoneurons (Fig. 21). From frog experiments it is known that the thick fast conducting axons are the first to innervate the muscles during ontogenesis [102] and quickest to regenerate following denervation [78]. The additional appearance of FF-type muscle APs with ongoing therapy suggests therefore that a regeneration process is taking place. This explanation is supported by the observation that, in this patient, the proximal muscles regained function earlier than the more distal muscles. During the process of regrowing of motoneuron axons of a certain type the proximal muscles will be reinnervated first because they are closer to the spinal cord. The muscle APs with long AP duration (Fig. 95F, 20ms) further suggest that new motor units are built, because newly formed motor endplates will fire iregularly first, and will give rise to motor unit APs of long duration. Further, the irregular appearance of muscle APs in the previously plegic leg muscles indicate that new synapses in the spinal cord are built, because they will also fire irregularly first. The electromyographic picture thus suggests reorganization of the CNS and a reinnervation of the previously plegic muscles. If the patient who had suffered severe poliomyelitis could be made walking again a few steps, the clinical consequence would be unbelievable: poliomyelitis can partly be cured even after 36 years; there is neurogenesis in the human adult spinal cord, if the neurogenesis and neuron cell proliferation is activated or used efficiently and adequately; and substantial reorganization of the CNS is also possible following poliomyelitis. Since neurogenesis in adults is assumed to be a slow process, and new blood vessels have to be built and joints have to be made working, etc. (the patient was affected by poliomyelitis at an age of one year!), further progress will take a long time.

After 17 months of therapy, more leg muscles were re-innervated and the power in the reinnervated muscles improved. She can now exercise on the special coordination dynamic therapy device only with the legs against resistance. The two possible explanations are that there were firstly quite a lot of remaining motoneurons left after poliomyelitis (even though there was abolutely no function in the legs) or secondly some motoneurons have been newly built.

The intensive coordination dynamic therapy of the poliomyelitis patient is continued. It is not clear whether she will be able to walk again, even though her motor functions are continuously improving. Nevertheless, she will win anyway with the therapy as already after 4 weeks of therapy the vegetative functions in her legs (blood supply, trophic) improved. Her higher mental functions also improved: she feels better in her nervous system and she has no states of anxiousness any more. Before the therapy she became anxious when she was under the shower and she was afraid lo leave her village with her car.

Case 16: *Treatment of a patient with a spinal cord and a brain lesion*

A 23-year-old paraparetic patient (sub Th11) and with an additional lesion of the left frontal lobe underwent coordination dynamic therapy to re-learn walking (Fig. 95H-M). The patient had extensor and flexor spasticity. The EMG motor program was strongly pathologic; many spinal oscillators were out of full volitional control (EMG evaluation). The jumping on a springboard was blocked by the extensor spasticity. After performing 1 to 3 movements of walking or running (or crawling), the spasticity released, so that supported walking and running and free crawling could be used for the reorganization of the neuronal networks of the spinal cord and supraspinal centres. The patient could run under 13 kg weight reduction (Fig. 95I) better than walking (Fig. 95L).

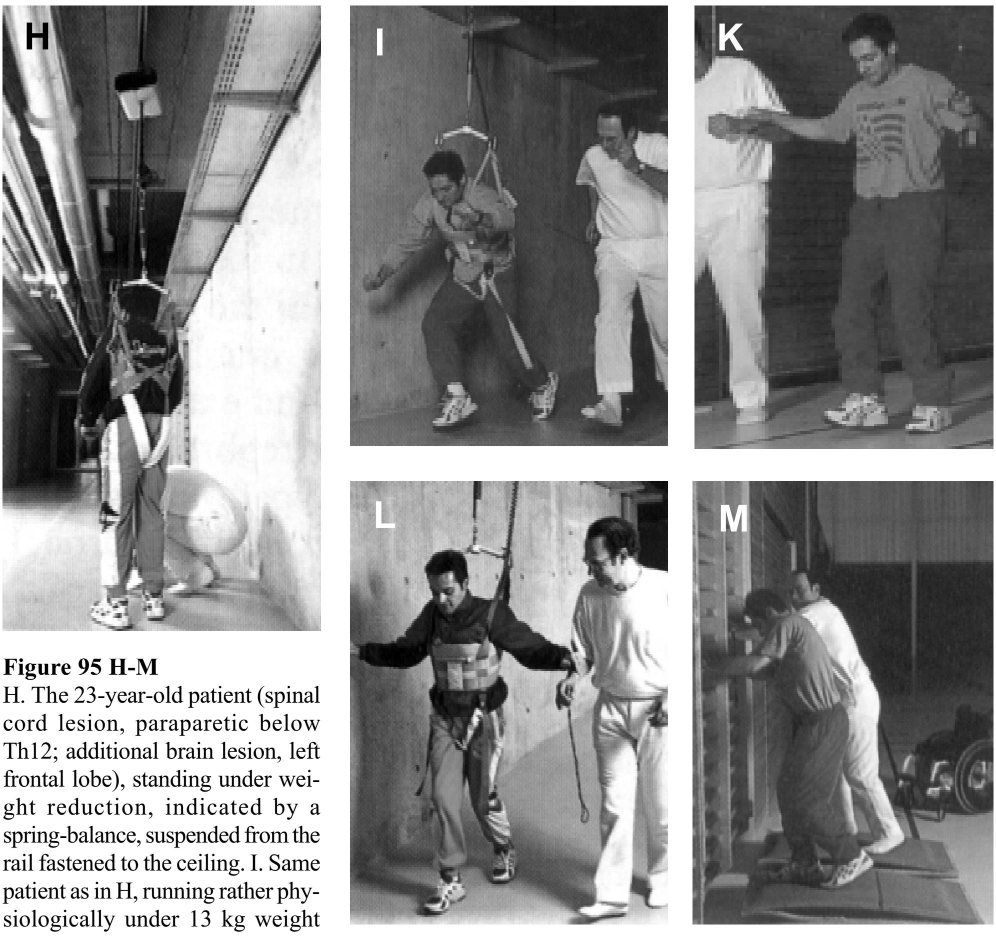


Figure 95 H-M
H. The 23-year-old patient (spinal cord lesion, paraparetic below Th12; additional brain lesion, left frontal lobe), standing under weight reduction, indicated by a spring-balance, suspended from the rail fastened to the ceiling. I. Same patient as in H, running rather physiologically under 13 kg weight reduction. Note that he has no problems with the stability compared to walking (K, L). K, L. Same patient as in H, I, walking with little weight reduction and without weight reduction, but with some support of the therapist to provide for stability. The patient is walking with slightly flexed knees to avoid overstretching of the right knee. M. Same patient as in H, while jumping on springboard. Oscillators and pattern generators of the legs are coupled in ‘anti-phase’.

The quick break of spasticity with 1 to 3 movements suggested that spasticity was partly generated by the lesioned frontal lobe in cooperation with the reticular formation, since in animals cooperation of regulatory influences from the forebrain cortex (and the cerebellum) with the reticular formation were observed to be of utmost importance for motor control. The existence of more rapid mechanisms of activity focussing in the neuronal apparatus of the reticular formation, which may become effective already upon the first or second stimulus, was suggested by cyclic changes of the threshold of reticular neurons in relation to a certain source of afferent activity.

After six weeks of exercising, walking, running and crawling (and other movements), the spasticity was so much reduced that the patient became able to break spasticity to jump on the springboard (Fig. 95M). With the breaking of the frontal lobe-induced spasticity, typical problems in locomotion of pure spinal cord lesions occurred in the poor leg, such as pathologic activation of the musculi tibialis anterior, extensor digitorum longus and extensor hallucis longus. This preliminary case report suggests that the rhythmic dynamic stereotyped movements which are especially genetically predetermined in the neuronal network organization of the spinal cord (walking, running, crawling) are an easy start to reorganize neuronal networks of the CNS following brain lesions, with little network reorganization necessary.

Case reports 17-20: *Scoliosis*

In 90% of cases, scoliosis is called idiopathic [25]. An important factor is supposed to be a changed innervation of the muscles, which shifts the state of equilibrium [25] dynamically. Assuming that a portion of the idiopathic scolioses is caused by a slight pathologic organization of the neuronal networks of the spinal cord, then the following can be reasoned: Due to an asymmetric right-left activation of the back muscles asymmetric right-left tension will act on the vertebrae and will draw the spine into a scoliotic curvature.

A tight corset reduces the lateral curvature of the spine and stabilizes the posture, but the cause for the scoliosis, namely right-left imbalance of muscle activation has not been resolved. From the mechanical point of view, active and passive three-directional rotational move-

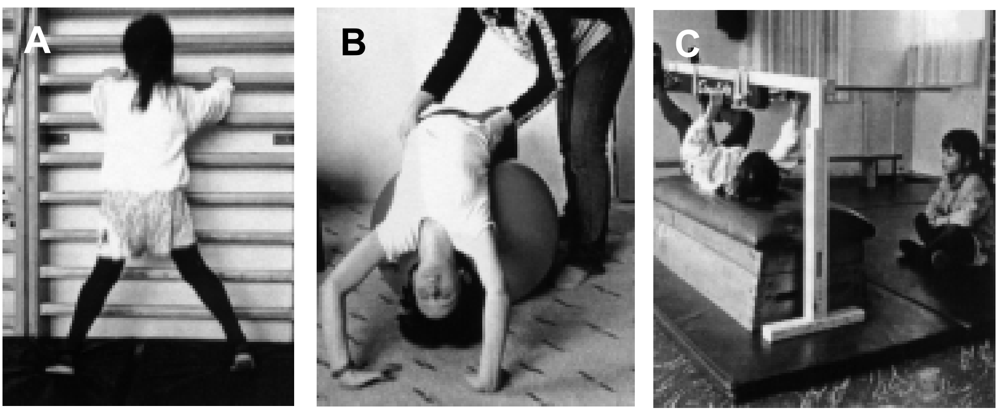


Figure 96
A. A twin jumping in abduction-adduction. Note that the right leg and arm are more abducted. The transient switching (unvolitionally) into other jumping modes are not shown. B. The 15-year-old patient with scoliosis lying on a ball. Note her bending of the trunk. C. Twins during coordination dynamic therapy. One twin is exercising, the other one is watching. The sitting position of the watching twin is beneficial to organize (and establish on the long-term) a symmetric network state of the CNS, because hands, arms and legs generate symmetric simultaneous afferent input from touching each other and induce co-movement in the sitting position.

ments of the trunk can be expected to reduce the scoliotic curvature of the spine. Using coordination dynamic therapy in which primarily rotational movements of the trunk are coordinated with arm and leg movements, the scoliotic curvature of the spine should be reduced actively. Upon an improved self-organization of the neuronal networks of the spinal cord, the too little activated back muscle groups will be activated stronglier, so that the tensions acting at the spine becomes more equal; consequently the scoliotic curvature of the spine should reduce at least during active posture. Rotational movements of the trunk will reduce the lateral curvature of the spine from the mechanical point of view (passive reduction of the lateral curvature) which works in most types of scoliosis and will act to actively reduce scoliosis in cases where scoliosis is caused by a pathologic organization of the CNS. In the latter case, the improvement of the symmetry in the self-organization of the spinal cord neuronal networks (and partly higher centres) will activate the back muscles symmetrically, will make the back muscle mass symmetric, and will make the tensions on the vertebrae symmetric so that the lateral curvature of the spine and the scoliotic form of the thoracic cage will reduce.

Irregularity upon jumping on springboard, for example in abduction (Fig. 96A) and adduction, and irregularity in the postural behavior when lying on a big ball (Fig. 96B) support the assumption that in idiopathic scoliosis, there is a slight pathologic organisation of the CNS, mainly in the spinal cord. This pathologic organization may be of genetic origin, because monozygotic twins (Fig. 96C) had both right-left asymmetry (for example, during jumping in abduction - adduction (Fig. 96A)), were switching between jumping modes when exhausted, like jumping in symmetry, jumping in anti-phase and jumping in abduction twice (phase jump by 180°), and both had scoliosis. Even in healthy individuals one can often observe that the organization of the CNS is not optimal. When normal persons performing fittness training on the special coordination dynamic therapy device, the turning of the levers backwards is often irregular, indicating suboptimal coordination of arms and legs; after exercising a few times a few thousand turns, the backward turning becomes also harmonic: the exercised coordination becomes more optimized. It is therefore likely that in some cases of idiopathic scoliosis, asymmetric right-left coordination of the spinal cord neuronal networks is the cause for the lateral curvature of the spine.

Figure 97
Sculpture of an ancient Greek. National Museum, Athens, sculpture No. 2585. Note the positioning of the body which may be due to scoliosis or to the beauty standard of that culture which may induce scoliosis. Note further that the gracefullness of the woman’s body is strongly enhanced by the foldings of the thin skirt, only partly reproduced by the picture.

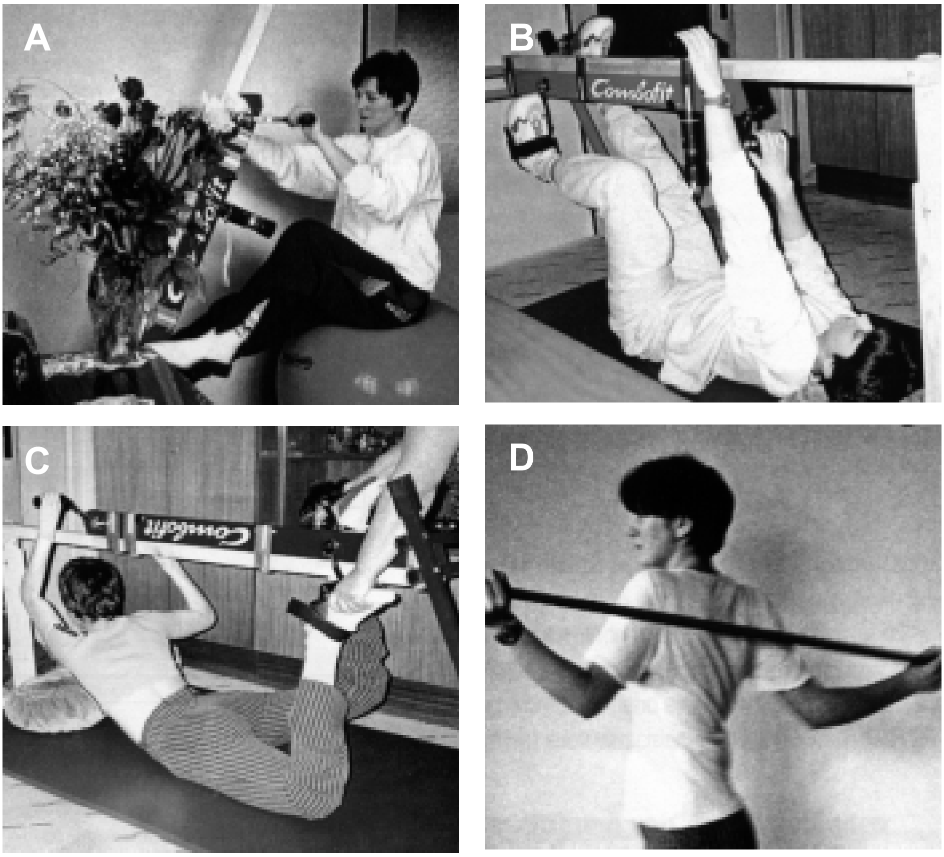


Figure 98
Some exercises included in the coordination dynamic therapy to reduce idiopathic scoliosis. A,B. Therapy on the special coordination dynamic therapy device with a ball and in recumbent position. The flashing light was used to improve eye function simultaneously by expanding integrative network activation. C. Coordination dynamic therapy in hyperextension; it was not beneficial in this case because of a slight kyphosis in the lumbar range. D. Rotational movements with a stick.

A 19-year old female patient with scoliosis involved in 20 therapy sessions (for approx. 30 min each) on the special coordination dynamic device in 7.5 months. In spite of the low number of therapy session the scoliosis improved. Before treatment, she had pain in the back because of the scoliosis. After the treatment she still has pain in scoliotic position, but the pain subsides during active improved posture.

In cases when the vertebrae are not sticking together and when there are no rigid blocks built in parts of the spine, there may be an active position of the trunk where the spine has little lateral curvature and a more passive posture where there is lateral curvature of the spine. Such more physiologic and pathophysiologic postures may be observed when lying on a ball (Fig. 96B). Normally, X-ray scans can not provide information about the curvature of the spine due to the different network states of the CNS. They just show the positioning of the spine when the picture was taken. The scoliotic curvature of the spine may be even related to a graceful positioning of the body. The posture of the sculpture of an ancient Greek (Fig. 97) may be a result of scoliosis or of a deliberate graceful posture of the body. The organization of the CNS is influenced by the history of the CNS and by the culture of the society. But in severe cases of scoliosis, there are mostly also deformations of the whole thoracic cage and other parts of the skeleton.

Three female patients between 13 and 15 years of age were in a rehabilitation hospital to treat their severe scoliosis. An intensive therapy was applied including conservative treatment and coordination dynamic therapy. When the therapy was stopped for organizational reasons after 2 to 3 months, the lateral curvature of the spine has been reduced in all three patients.

In the 15-year old patient, intensive coordination dynamic therapy was continued at home for 3 further months including exercises like those illustrated in Fig. 98.

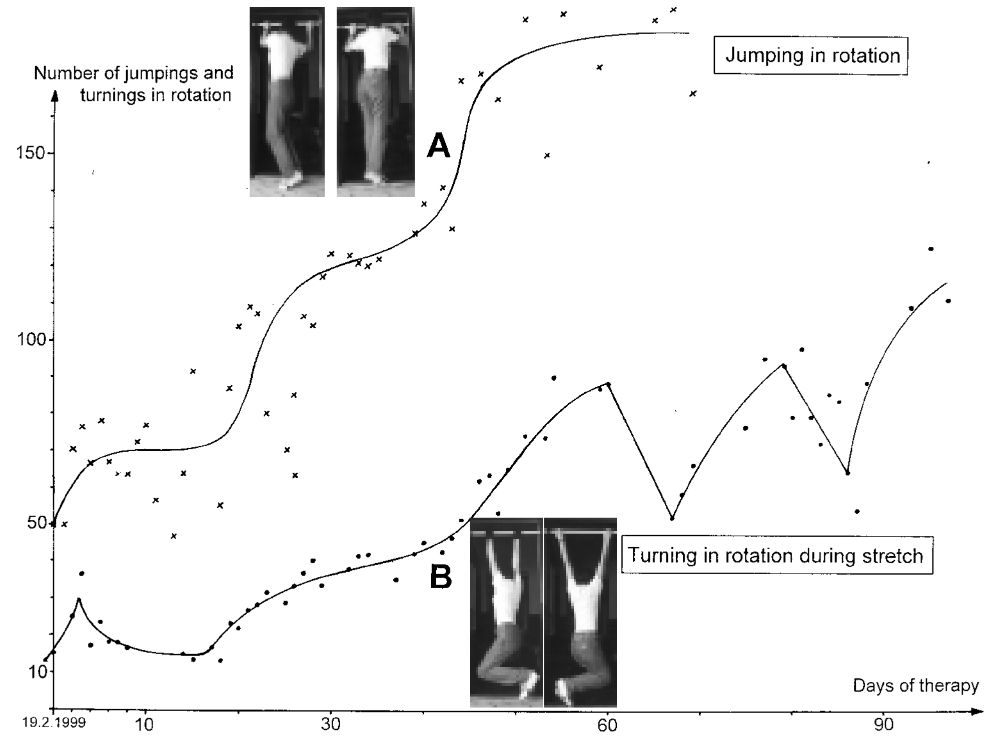


Figure 99
Increase in the number of jumps in rotation (A) and of rotational turns during stretch (B) in dependence on the days of therapy. Each dot or cross represents the mean of 3 movement series. The scatter of the data is partly due to pain occurring in the hands and the abdomen. Note the fluctuating increase in B, which may indicate that the inner existing coordination dynamics tendencies are in competition with the to-be-learned neuronal network organization.

When exercising rotational movements with a stick (Fig. 98D), the turning angle to the left was smaller than the one to the right. A right-left difference in the rotational movement is typical for scoliotic patients and is due to the scoliotic deformation of the spine and the costal frame. During the therapy, the turning to the left was emphasized. But when the patient jumped in abduction-adduction (like in Fig. 96A), also irregularity of these movements occurred. This irregularity in the rhythmic movements cannot be attributed to the scoliotic deformation of the spine and the thorax, it is an indication of a suboptimal organization of the CNS. The argument of suboptimal organization of the CNS is supported by the loss of anxiousness before darkness with ongoing therapy. All her life, the patient became afraid when the light was switched off in her room. She could tolerate darkness only when her mother was present. After 6 months of therapy, she lost that anxiousness. Also, the poliomyelitis patient lost anxiousness with ongoing therapy (see above).

The improvement in two rotational movements is shown in Fig. 99. The stepwise increase in the number of successive movements shows some similarity to the stepwise increase in movements during the process of reorganization of the lesioned CNS [133] (see also Fig. 45B).

With ongoing therapy, the scoliosis improved further. In Fig. 100, the improvement of the shape of the spine after six months coordination dynamic therapy can be seen. The scoliosis of the spine and in consequence also the scoliotic shape of the costal frame reduced due to therapy. The curvature of the spine (measured according to Cobb [74]) reduced from 13 to 8° [189].

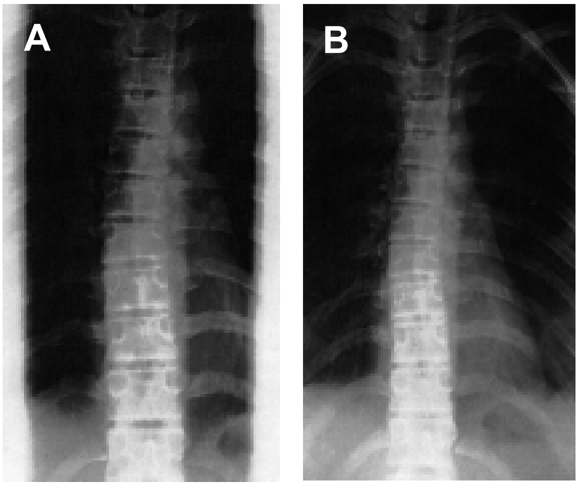


Figure 100
X-ray pictures of scoliosis before (A) and after coordination dynamic therapy (B).

Case 21: *Co-movement in vision*

A 14-year-old patient was hit by a car and suffered a brain lesion with hemiparesis on the left side. During three months of coordination dynamic therapy, she re-learned to walk and run (Fig. 101A). Because of the brain lesion, the vision was impaired and she had left-sided mydriasis.

The improvement of CNS functioning can also be seen in the improvement of the facial impression after one month (Fig. 101B) and two months (Fig. 101C) of therapy.

In Fig. 101A it can be seen that the running performance seemed to be nearly normal. This was probably due to a rather balanced lesion of the CNS and/or that she used to exercise 400 m running before the brain lesion. So far, it seems that individuals who used to be quite athletic before the

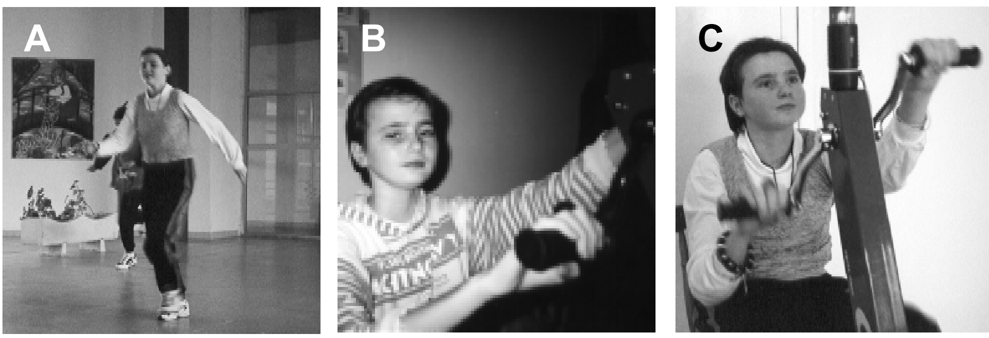


Figure 101
The 14-year-old patient with a right-sided brain lesion (the reddish scar can be seen in B, C) re-learned running (A) thanks to coordination dynamic therapy. B,C. Training on the special coordination dynamic therapy device with (C) and without (B) flashing light. Note the improvement in the facial expression with therapy from B to C.

brain lesion recover better. There may be two reasons for a better recovery from brain lesion. Firstly, athletes can understand better that they have to exercise hard to become better and that they are more motivated to do the necessary training. Secondly, it could be that in athletes the movements are additionally stored in a more integrative way so that with a localized lesion the integrated storage is not so much affected than the localized storage, in some similarity to the storage of languages where mother tongues are stored differently than languages learned later in life [65].

The main interest in this case was whether it might be possible to induce co-movement in the motor functions of the eye to achieve equal diameters of the pupils (in the short-term memory) on both sides during exercising on the special coordination dynamic therapy device. After turning the hand levers 1000 times in synchrony with the flashing light (f ~ 2.1 Hz) mounted on the coordination dynamic device (Fig. 101C), the pupils became transiently equal and responded equally to mainly direct light flashes. Therefore, as could have been expected, also the motor functions of the eye perform co-movements.

Case 22: *Cerebral palsy*

The 13-year-old Karolin suffered a brain lesion at birth with left-sided hemiparesis. When the author (G.S.) saw Karolin for the first time, she could walk and run, but she did not move her left arm during pathologic running performance. With a few months of half-optimal coordination dynamic therapy, including exercising on the special coordination dynamic therapy device (Fig. 102), the walking and running performance improved in general and the left arm is now moved in coordination with the other arm and the legs. Also, the left hand and finger functions improved, even though being still far from normal (Fig.103A,B). Pushing simultaneously keys (Fig. 103A,B) to improve, by co-movement, the function of the left fingers will not be as efficient in learning as learning finger function on the special coordination dynamic therapy device, because the latter training is more integrative. If Karolin goes on in training the movements of the left hand and fingers in integrative coordination with the movements of the right hand and fingers, the legs and the trunk (Fig. 102) for a few months (a few thousand turns per day), then the left hand and finger function will become rather normal. The father is already now proud of his daughter as her left leg looks also beautiful and not atrophied any more.

Case 23: *Recovery following brain lesion of moderate severity*

The 9-year-old Jakub fell 5 m down from a balcony and suffered a brain lesion of moderate severity (temporobasal). While in coma, he was transferred to the intensive care unit (Glasgow coma scale 7, decortication rigidity, several contusion oedema and bleedings). The boy recovered after 4 weeks from the coma (hemiparesis, quadruparesis) and was then carried by his mother from the wheelchair to the special coordination dynamic therapy device for therapy. With the rather optimally applied coordination dynamic therapy, the patient was sent home 3 months after the accident. Among other functions he re-learned to walk and run (Fig. 103D), and was able to fight with his therapist (Fig. 103E). The fast progress in the repair of the lesioned CNS points towards a rather balanced lesion.

Cases 24-25: *Improvement of CNS function in very severe brain lesion (permanent coma)*

When patients with brain lesions do not recover from coma, they are attended at home by their parents or in certain other places. The ‘school-medicine’ has given up such patients. But still it may be possible that some of these patients could be made to recover from coma. Of course, when the brain damage is so severe that it is close to brain death, then the chance for recovery will be very small or none. Since there is indication that patients wake up quicker from coma when subject to coordination dynamic therapy (case reports 11-13), more patients can possibly be made to recover from vigilant coma with the coordination dynamic therapy. Tears appearing in the eyes may be a response of such patients to outside stimulation. But even efficient therapy will need a long time for recovery because of the severe brain lesion.

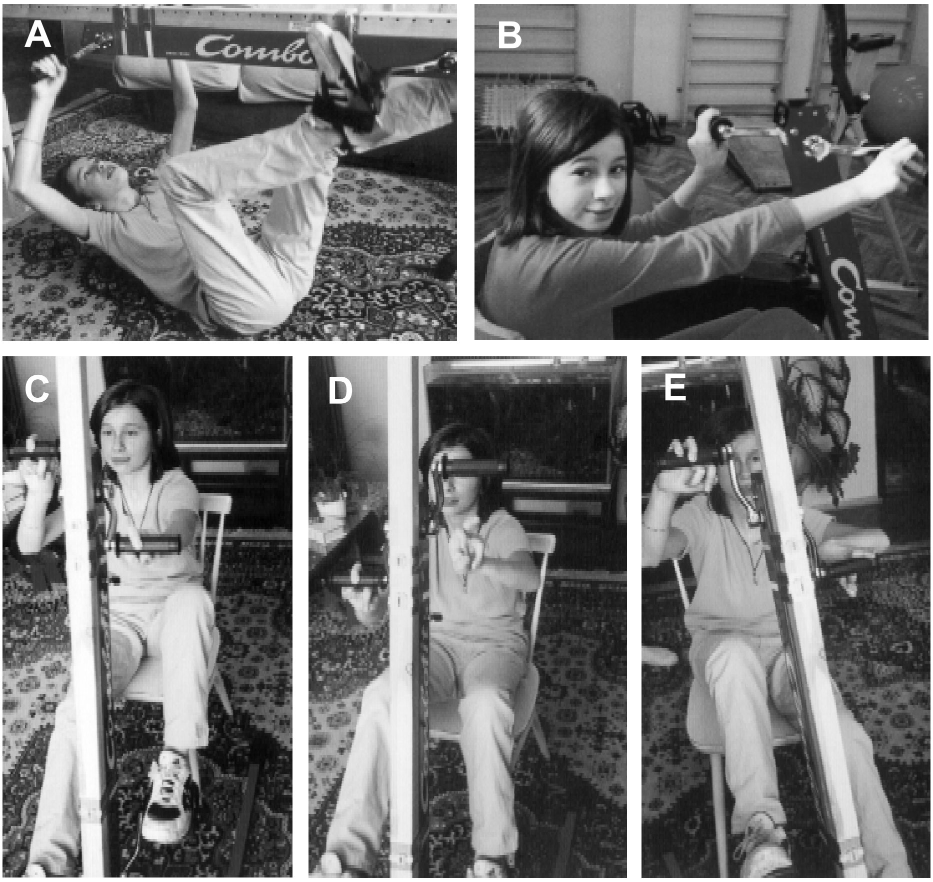


Figure 102
Exercising finger, hand, arm, leg and trunk functions on the special coordination dynamic therapy device in the 13-year-old patient with CNS lesion suffered at birth. A,B. Training in recumbent and sitting position. C,D. Training the middle fingers. In D, the left finger is slipping from the lever. The continuous volitional attempt to keep the middle finger in place, also trains volitional movements in addition to the stereotyped movements. Volitional and stereotyped movements are trained in this way simultaneously. By turning the levers with the two small fingers, the pathologic posture of the left arm, hand and fingers becomes obvious. F. The necessity of improving the left hand and finger functions becomes also obvious during eating. The left hand is in palmar flexion and cannot hold the knife in the appropriate position. The left hand could also not hold the fork in the way the right hand could do. G. During washing hands, the patient has to try to move the hands symmetrically, so that the left hand can learn from the right hand by co-movements (coupling of right and left premotor neuronal networks).

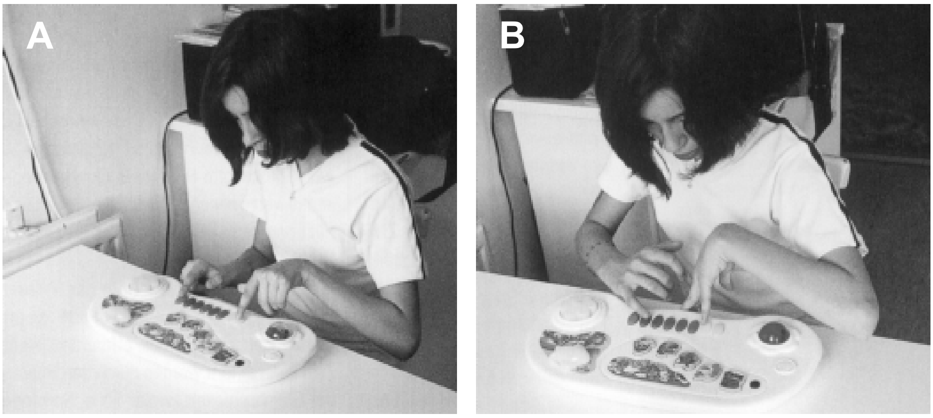


Figure 103 A, B
Thirteen-year-old patient with a CNS lesion suffered at birth, during exercise to re-learn the simultaneous pushing of keys by pushing repeatedly keys with right and left fingers. In A, the index fingers and in B, the small fingers are used. Note the false positioning of the left hand and left fingers.

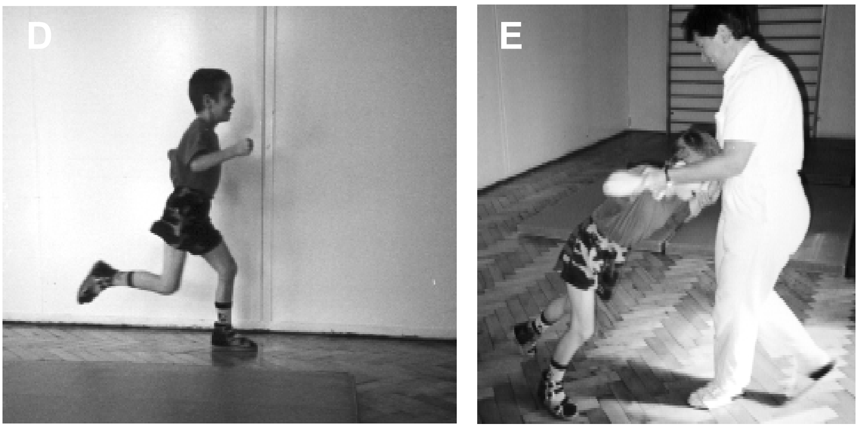
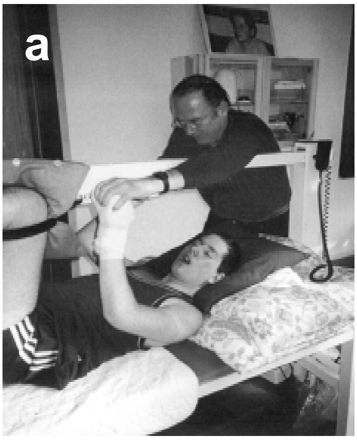


Figure 103 D, E. Reorganization of the CNS in a 9-year-old-boy having suffered a brain lesion of moderate severity when falling 5 m down from a balcony. D. The boy during running. The left arm is still not in the appropriate backward position. No overstretching of the knee any more. E. The patient feels so strong again that he likes it to fight with the therapist.

Improvements of the presently existing coordination dynamics in the CNS of the coma patients can be measured as coordination dynamic therapy goes on (Fig. 103Fb).

In two coma patients undergoing coordination dynamic therapy, 18 [194] and 25 years of age, being in coma for 2.5 and 5 years respectively, the impression of the face seemed to improve more after about 1500 supported turns on the special coordination dynamic therapy device than would come from purely enhanced blood circulation.

Especially in the 18-year old patient a transient improvement of the vegetative functions could be seen. At the beginning of the exercises the mouth was open, as always. After a few hundred turns, clonus in arms and legs and salivation appeared. When reaching about 1000 turns, the cloni reduced and disappeared, as did salivation, the mouth closed and the face looked quite healthy. When this therapy session was terminated after 1500 turns, the mouth



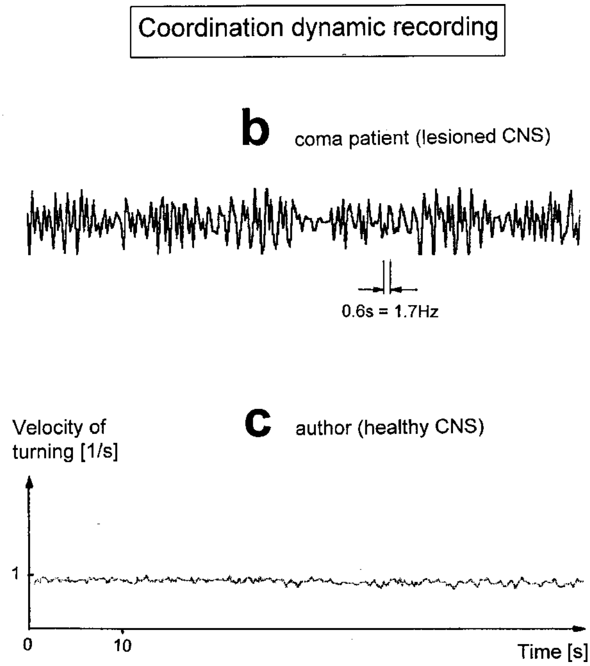


Figure 103 F
a. Coordination dynamic therapy applied to the 18.5-year-old patient being in vigilant coma for 2.5 years (the patient was hit from the back by a drunken car driver). The therapist (author G.S.) is moving the levers of the device (upper part). A picture of the patient before the brain lesion (mainly brain stem parts) is positioned above the head of the therapist. b. A registration of the coordination dynamics during exercising on the special coordination dynamic therapy device. Rhythm changes of the coordinated movements can be recognized from approximately 0.1 Hz to 1.7 Hz (frequency range of α_3-oscillators and one tremor rhythm); the coordinates are the same as in c; mean turning velocity ~ 1/s. Coordination dynamics from a healthy person (author G.S.) for comparison.

opened slowly again. If the closing of the mouth is taken as an indicator of an improved CNS functioning, then during that therapy session the coordination dynamics of the CNS transiently improved. But since the patient was receiving a by far suboptimal therapy for the 2 years following the accident, the severely lesioned CNS may have adapted in a very pathologic way. Instabilities of CNS functioning are expected to occur with ongoing therapy, because of the competitive interplay between the patterns to be re-established and the intrinsic pathologic coordination dynamics. Transient loss of functions has to be expected.

When performing coordination dynamic therapy with the now 18-year-old Georg on the special coordination dynamic therapy device in recumbent position, the levers had to be moved by the therapist (Fig. 103Fa), because coma patients are unable to exercise alone. When moving the pedals or levers, the therapist can feel the improvement of CNS organization in the short-term memory, when turning becomes transiently easier (reduction of spasticity and/or increased volitional help by the patient) during a session of a few thousand turns. Such improvement in (motor program and) CNS organization can be measured and quantified (Fig. 103Fa) by the coordination dynamics, measured using the equipment. The observed rhythms of impaired coordination of arms and legs (Fig. 103Fb) may reflect themselves in face and eye muscle movements.

The coordination dynamics of a person with a physiologically functioning CNS (of the author G.S.) is shown in Fig. 103Fc. The coordination of arms and legs is that good that the turning speed of pedals and levers is rather constant with little variation only. When turning the levers and pedals, with the coma patient´s hands and feet attached to (Fig. 103Fa), the measured coordination dynamics (Fig. 103Fb) is the sum of those of the coma patient and the therapist. Since variations of the rhythm due to the therapist can be neglected in comparison to those of the patient, the coordination dynamics in Fig. 103Fb shows the coordination dynamics of the patient. Many rhythms can directly be seen in the coordination dynamics of the coma patient Georg (Fig. 103Fb). A Fourier analysis may be helpful to quantify the contributions of different rhythms of premotor spinal and other oscillators.

Computer programs evaluating the average coordination dynamics of arms, legs and trunk, can essentially measure nicely the change of the coordination dynamics in the patient, when changing from the pace gait (both legs on one side move together) moving to the trot gait (legs move in diagonal pairs) moving. The pace gait crawling is the more easy (less differentiated) neuronal network organization during development than the trot gait crawling, since normal children learn mostly first the pace gait crawling (before the trot gait crawling). Bobath stated that more differentiated and difficult functions and tasks are learned later by the child (see under Bobath). That trot gait neuronal network organization is more difficult to perform by the lesioned CNS than the pace gait organization is in accordance with the bimanual coordination task of Kelso and co-workers. It can be observed in many patients with CNS lesion. For slow free or treadmill walking, they can move trot wise. For higher walking speeds a phase transition occurs from the trot gait network organisation to the pace gait organization, that means the patients change their arm (and trunk) moving with increasing speed during walking (or running) from the trot to the pace gait manner. Also in the coma patient Georg the pace gait neuronal network organization was easier to perform.

Humans with a healthy functioning CNS or suboptimal functioning CNS show no or only little coordination problems when changing from trot gait to pace gait coordination.

E. Comparison between reorganization strategies in man and enhancement of neurogenesis and cell proliferation in mouse and rat

68. Running and other neurorehabilitation methods enhance neurogenesis and cell proliferation in mouse and rat

Running, exercising on the special coordination dynamic therapy device and other coordinated rhythmic movements have been reported to restore somatic, vegetative and higher mental functions in lesioned CNS in man [131-136]. Such functional reorganization therapy will induce a host of structural changes, probably including neurogenesis and cell proliferation [136] in the CNS. There is no direct evidence that intensive coordination dynamic therapy induces neurogenesis; neither is there evidence that it does not. But two clinically complete spinal cord lesions became incomplete due to intensive coordination dynamic therapy for 3 and 6 months (not included in the case reports); the poliomyelitis patient and a patient with a damaged conus medullaris recovered unexpectedly well so far. The substantial recovery of also these patients makes it likely that there is also neurogenesis in parts of the adult CNS other than the hippocampus.

Since reorganization therapy can certainly also be applied in minor CNS lesions (and genetic malformations), and even the seemingly normal functioning CNS can be optimized in its functioning by coordination dynamic therapy (see the above case reports on scoliosis), it is not astonishing that also not lesioned CNS in rats and mice can be optimized in its functioning by running and other methods used in neurorehabilitation, especially because laboratory animals do not have enough exercise to optimize their CNS functioning because of their housing (no species-specific housing).

Anyhow, the reports that motor learning enhances adult neurogenesis and cell proliferation [169-171] in the hippocampal formation of rats and mice are very interesting because they support the data concerning the reorganization of lesioned human CNS. Some conclusions on adult neurogenesis induced by neurorehabilitation methods are summarized below and compared to strategies used in neurorehabilitation of patients:

1. Proliferation and survival of newly formed neurons can be affected by training methods (so-called experience) in mice and rats (in the hippocampal formation), especially in cases of suboptimal CNS functioning due to non-use. Proliferation and survival of newly formed neurons was assumed to also apply in neurorehabilitation.

2. The survival rate of labeled neurons was more than two times longer in animals which had learned the hippocampus-dependent task than in those learning a similar but hippocampus-independent task. With respect to applicability to humans, this probably means that a lesioned part of the CNS has also to be activated during therapy to be repaired. When training very integrated CNS functions the chance is biggest that the lesioned CNS parts are included in the network activation and that these neuronal network parts are also functionally connected to the healthy network parts.

3. It is important to distinguish between effects on the formation of new neurons and effects on their subsequent survival. New neurons may be more sensitive than more mature neurons to the effects of activity, and it is possible that the period of maximum sensibility may begin shortly after the neuron is formed. This argument shows similarity with what has been

found e.g. in the frog nervous system: Those motoneurons survive which have established appropriate successful synapses in the periphery (the trophic substance and the appropriate activity from the corresponding motoneuron [78,102] (in similarity to Fig. 21) is needed for the survival and functioning of the muscle fibre, and in turn for the functional proliferation of the motoneuron). For patients with CNS lesions this may mean that there may be a time window for a successful reorganization of the CNS [40] with respect to neurogenesis. The case reports on the partial recovery from severe poliomyelities after 36 years and the late recovery from spinal cord and brain lesion following therapy weakens that argument.

4. Voluntary exercise of mice in a treadmill increased cell proliferation, cell survival and net neurogenesis. Motor learning may be a specific stimulus for epigenic neurogesis. This is what the practical experience with the patients suggests: for a success in reorganization to be achieved there must be more than just reorganization of the lesioned CNS. New neurons are needed in some critical parts (for example connecting parts) of the neuronal networks destroyed. Free and treadmill running was used in patients, if possible, for the reorganization of the lesioned CNS.

5. Activity alone is not an adequate stimulus for adult hippocampal neurogenesis. This argument is fully in line of the coordination dynamic therapy and is of immense consequence for the methods applied in neurorehabilitation. It is of importance what methods are used for an efficient supervised learning and re-learning and what neuronal network parts are activated during the exercise. The successful therapy methods to induce neurogenesis in rats and mice were movement functions induced by integrative neuronal network activations, such as running, rather than just the movement of one limb or training a static posture. The survival of newly generated cells was even shorter in running (56%) than in enriched mice with enriched environment (85%), suggesting different long-term effects of these behavioral protocols [169].

6. Involvement of the hippocampal formation in learning: Direct association between hippocampus-dependent learning and neurons generated in the adult hippocampal formation.

7. Stressful experiences known to increase levels of adrenal steroids and hippocampal glutamate release, diminish the proliferation of granule cell precursors in the dentate gyrus of adult tree shrews and marmorset monkeys. Continually diminished production of new cells resulting from chronic stress or corticosterone treatment may contribute to performance decrements in hippocampus-dependent tasks under some conditions. Performance decrements were also observed in some patients when they experienced stress. When walking or running at one minute interval a certain distance, the walking or running performance and time (speed) improved due to improvement of the corresponding network states in the short-term memory before getting worse again due to exhaustion. If a person whom the patient did not like or who caused stress to him was watching the walking or running performance, then the walking or running times were drastically prolonged. If a beautiful woman was watching a male patient, the performance times were better due to an increased motivation.

Several of the conclusions arising from the training induced neurogenesis in rats and mice [169-171] are similar to the conclusions extracted from the progress data on the re-organization of the lesioned CNS, when performing coordination dynamic therapy [132-140,186-189,193,194]. The animal data suggest that adult neurogenesis is one strategy in the host of structural changes taking place during the reorganization of lesioned CNS, induced by supervised motor learning. By combining data on the organization of the human CNS [105-131] and data of theoretical neurosciences [63,145,146,172-176,190,191] with clinical practice, it turns out that new simple diagnostic means could be found to asses the state of the integrated functions of the CNS. For example, when a patient jumps in abduction-adduction and switches transiently into the in-phase or anti-phase jumping mode or performs a phase jump by 180° (jumping successively two times in abduction) (Figs. 55,96A), then the organization of the CNS needs therapy to improve the self-organization of the CNS, because the transient shift to another network state is an indication for the loss of stability of network states, including enhanced fluctuation [172]. The measurement of rhythmicity upon performing coordinated movements on the special coordination dynamic therapy device offers the possibility to measure the coordination dynamics of patient´s CNS and to follow up improvements in the organization of the lesioned CNS more directly (Figs. 113, 114, 117-119). A further correlation between the concepts of theoretical neurosciences, the results from neurorehabilitation therapies, and the data from animal experiments which simulate as much as possible clinical settings, would be in the interest of patients, because this might throw additional light on what neurorehabilitation methods, strategies or beliefs get support from animal data and theoretical neurosciences. Already the above comparison shows a similarity between animal data on adult neurogenesis and cell proliferation and practical human data extracted from the organization and re-organization of lesioned CNS, and is therefore satisfying.

In spite of the similarities between some principles of re-organization of the CNS it should be borne in mind that animal data are still far away from human reality if it comes to brain lesions, speech therapy, keeping eqilibrium (bipedal locomotion), hand and finger functions, continence, scoliosis, poliomyelitis suffered long years ago, spasticity, shortened tendons, pain and repair, beginning of therapy at the coma stage up to decades after the CNS damage. Motivation and interpersonal coordination are difficult to apply in rats and mice with CNS lesions.

Brain research including human CNS research with treatment of patients can become a powerful research branch. It is an old idea that CNS functioning can be studied if the CNS has been lesioned since what can be studied are the appearing deficiencies. New is that with efficient therapy methods available, we now can learn about the functioning of the (human) CNS by repairing it by re-organization (re-learning). Further, all what seems to hold for the repair of the CNS by re-learning seems to also hold for the normal CNS including the improvement of higher mental functions. Genetic malformations can partly be repaired by learning. The epigenic learning possibilities seem to be much greater than assumed so far. A further improvement of learning efficacies and possibilities depends on the further understanding of the organization and reorganization of the human CNS. The 'spirit' in the CNS may become free from the inherited possibilities (genetic background). Already the poet Goethe was suffering when getting older, by the fact that his brillantly functioning CNS will be lost with his death. But unlike in science fiction where robots may quickly start to think and become creative, an essential improvement in the functioning of the human CNS needs very much time and a strong will to learn and re-learn.

F. Re-learning in severe CNS lesions

69. Learning of a bimanual coordination task by synchronization to a visually specified phasing relation, studied as a dynamical process in healthy volunteers

Kelso, Zanone, and Schöner [63,172-176] studied learning of a bimanual coordination task (synchronization to a visually specified phasing relation) as a dynamical process over several days of practising a required phasing pattern. Learning was defined as a relatively permanent change in behavior in the direction of a to-be-learned pattern induced by the learning method (so-called behavioral information). The behavior was quantified by probing the attractor layout of the volunteer's behavioral coordination dynamics (expressed through a collective variable, relative phase) before, during and after practice. Depending on the relationships between the initial coordination dynamics (so-called intrinsic dynamics) and the pattern to be learned (which acts also as an attractor of the coordination dynamics toward the required phasing), qualitative changes in the phase diagram occurred with learning, accompanied by quantative evidence for loss of stability (phase transition). The nature of change due to learning (e.g. abrupt vs. gradual) arose from the cooperative or competitive interplay between the pattern to be learned and the intrinsic dynamics. If the pattern to be learned coincides with the intrinsically stable patterns, then cooperative processes dominate, performance will improve rapidly, and no phase transition is initially predicted. If the patterns to be learned conflict with the initial pattern intrinsic dynamics, then, as the strength of memorized information increases, the less stable pattern will lose stability, and a phase transition will be seen.

During the task learning, a specific modification of the intrinsic dynamics is learned. Before learning of a new task the behavioral pattern dynamics is in an initial state. Each individual possesses his or her own intrinsic dynamics, which may reflect contribution from ancestry (innate) and prior experience. By determining the phase diagram prior to any practice, it is possible to identify individual constraints that may exist before the learning process begins. The dynamics of the learning itself may be evaluated by probing the phase diagram in time as practice proceeds. The evolution of the learning process, seen as a specific modification of the intrinsic dynamics may be studied directly. With learning the already organized structure, being the basis for the behavior before learning, evolves toward new (or different) forms of organized structure being the basis for the behavior including the newly learned tasks. The learning in the model system of Zanone and Kelso can be seen as quantitative change in the phase diagram.

70. Re-learning of motor and vegetative functions by manual and visual coordination of hand, arm, foot, leg and trunk movements with movements offered by mechanical devices in patients with CNS lesions

The re-learning of motor, vegetative and higher mental functions by coordination dynamic therapy following CNS (and PNS) lesions can also be seen as a dynamical process in principally the same way as learning in not lesioned CNS, but complicated by CNS lesion. The re-learning of functions following CNS lesion is complicated by at least five factors: (1) The individual's intrinsic dynamics varies from patient to patient with CNS lesion much more than between healthy volunteers because of the lesion. (2) The efficacy of the re-learning methods is essential. With inefficient learning methods nearly no progress will be achieved if the CNS lesion is severe. (3) The increase of the efficacy of re-learning functions, seen as a dynamical process, should be studied or understood at the macroscopic level (coordinated movements of arms, legs or fingers; lesioned CNS parts, practical aspects), at the level of neuron assemblies (for example, loss of self-organization of premotor spinal oscillators, increase of fluctuation of relative phase relations between the oscillators; entrainment for recovery), and at the level of the single neurons. (4) The integrativity of the re-learning process (increase of coordinated activated CNS neuronal network organization) must be considered to increase the rate of learning, to improve higher mental functions and to build up a somehow functioning CNS following severe lesion. (5) The movement induced re-afferent input and regulation loops during re-learning have to be considered to increase the rate of re-learning.

1. *Individual´s intrinsic dynamics and CNS lesion.* The individual´s initial state of the behavioral pattern dynamics is given by the pattern dynamics before the CNS lesion and the pattern dynamics following the CNS lesion. The changes of the pattern dynamics due to the CNS lesion are that strong that the individual's initial state of pattern dynamics before the learning is mainly determined by the lesion. The learning is now seen as a long-term modification of the intrinsic dynamics, determined by the CNS lesion, towards the individual's behavioral pattern dynamics before the CNS lesion (Fig. 108). If we assume that the behavioral patterns are also stored more integratively, then the remaining parts of the CNS structure, giving rise to the individual's pattern dynamics before the lesion, are partly preserved stored in the dynamics of the still functioning CNS parts after the lesion. But the organization of the patterns are pathologic because of the lost integrativity and the lost (destroyed) CNS parts and, consequently, the lost timing of firing of neurons. By efficient integrative learning methods a specific long-term modification of the intrinsic dynamics is performed towards the pattern dynamics before the lesion. The re-learning process induces a host of structural changes probably including neurogenesis and innate repair mechanisms in some CNS parts. The essential structure of the CNS after re-learning will be different from the structure before and after the lesion, only the behavioral patterns should become as similar as possible to those before the CNS lesion.

2. *Efficacy of methods used for re-learning.* Which learning methods are efficient and integrative enough to 'reconnect' different CNS network parts remaining after the lesion or what learning methods can re-establish integrative functions of the CNS? What training methods can efficiently change behavioral pattern dynamics? Those learning methods are efficient which take into account the organization principles of the CNS itself. If we know how the human CNS organizes itself, then we may see possibilities to change the self-organization, which means to reorganize the CNS. Evidence has been provided that, in a part of the CNS, namely the lower spinal cord, neuron cell assemblies do self-organize according to the afferent input (Fig. 14) and that these assemblies, called premotor spinal oscillators (Fig. 21), interact with each other by relative coordination, i.e. by relative phase and frequency coordination (Figs. 34-39). Re-learning of the impaired coordination dynamics, namely re-learning of relative phase and frequency coordination lost due to the lesion, should be an efficient way of re-learning. It has to be seen what learning methods do best materialize the re-learning of the lost phase and frequency coordination.

3. *Top-down or bottom-up approach to increase the efficacy of therapy methods.* By understanding the re-learning of relative phase and frequency coordination at the macroscopic, the assembly (and the afferents giving rise to their drive) and the single neuron level, it may become understandable why coordination dynamic therapy and oscillator formation therapy are efficient learning methods for re-learning.

Macroscopic level: If the patient uses the special coordination dynamic therapy device, where the movements of arms, hands, legs, feet and trunk are coordinated up to a few milliseconds, then the CNS can re-learn to coordinate the movements by adapting to the movements actively (supervised learning). Healthy children for example, who have not been crawling during their develoment (learning to optimize the coordination) will have later on problems with the coordination of arms and legs. But the re-learning of functions in the case of a lesioned CNS must be strongly supervised because the pattern dynamics in the lesioned CNS is so instable and disorderded that a change of attractor states occurs too easily and movement network states often slip into pathologic attractor states (spasticity). If a child with a not optimally functioning CNS at birth (Fig. 96A) is jumping in-phase, the jumping can transiently switch into the anti-phase jumping or other jumping modes. Zanone and Kelso [63,172] state that a phase transition from the easy in-phase to the difficult anti-phase movement (from the easier to the more difficult task) has never been observed in healthy volunteers. Transient phase transition from the in-phase movement to the anti-phase movement can be observed in individuals with lesioned CNS (Figs. 55,96A). A healthy subject can perform such jumping mode change on volition only with a high concentration. The unvolitional transient switching from the in-phase movement to the anti-phase movement can actually be used for the diagnosis of unphysiologic integrated motor functions of the CNS.

Assembly level: The evidence for self-organization of premotor spinal oscillators (a certain kind of assemblies) and their modification in organization due to changing afferent input (used here as a model for human CNS functioning) has been reviewed in the theoretical part.

Evidence has been provided for premotor spinal α_2-oscillators building up an external loop (via the γ-loop) to the periphery and for the secondary muscle spindle afferents and the γ-efferents being included in the rhythmic firing (Figs. 37,38). Because of convergence and divergence of γ-efferents and spindle afferents the coordination dynamics is given by the coordination dynamics of many spinal oscillators (Fig. 39) firing in coordination with the muscle spindles in the periphery (Figs. 31-36). Even though the skin afferents do strongly modulate the coordination dynamics of the premotor spinal oscillators (Fig. 37), including phase resetting, in healthy individuals the action potentials of naturally functioning premotor spinal oscillators and muscle spindle afferents fire in relative coordination up to a few milliseconds (HT6, Fig. 34). Therefore, the entrainment of an ensemble of premotor spinal oscillators towards re-learning of more specific coordination dynamics (more specific oscillator frequencies and more specific phase relations among them) will be strongest when muscle spindle afferents and efferents (motor control learning) and tract fibres for volitional activation (motor learning) are provided by coordinated and rhythmic activation (at the eigenfrequencies of the premotor spinal oscillators). Exercising on the special coordination dynamic therapy device will activate rhythmically and coordinate up to a few milliseconds the muscle spindle afferents (proprioceptors) and efferents in arm, hand, foot, leg and trunk muscles so that the premotor spinal oscillators are entrained at their eigenfrequencies up to a few milliseconds. Therefore, by turning the levers rhythmically with a frequency around 1 Hz, the premotor spinal oscillators are entrained, even though the individual is not noticing very much of this motor learning procedure. After approx. 1000 turns, a healthy individual will feel more comfortable in his CNS because of an optimized organization of the CNS or part of it in the short-term memory.

Single neuron level: Evidence has been provided that, when motoneurons are not integrated in a self-organized premotor spinal oscillator for low activation, they fire occasionally (Figs. 9-13) partly in coordination with other premotor spinal oscillators. Therefore, also

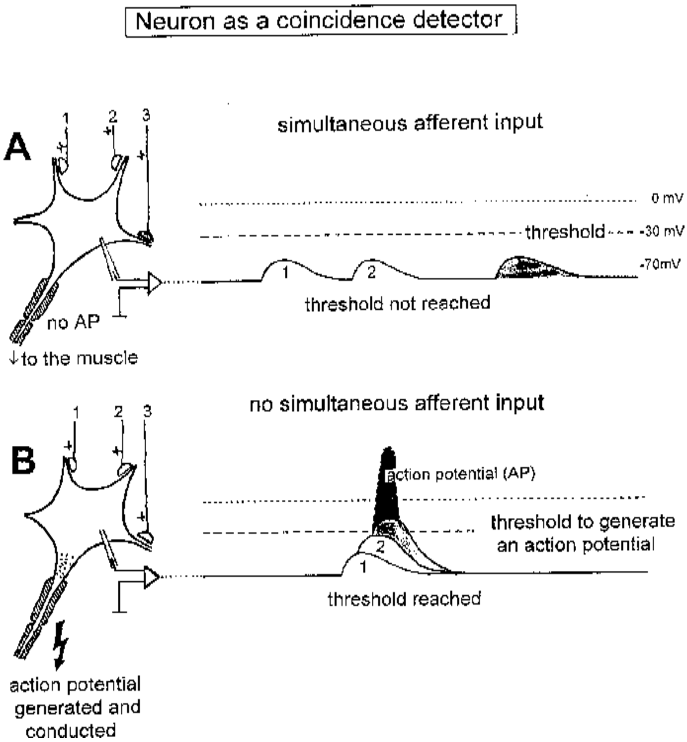


Figure 104
Neuron operating as a coincidence detector. A. Afferent input is not reaching the cell soma at the same time. No action potential (AP) is generated, because the threshold is not reached. B. The action potentials in fibres 1, 2 and 3 are reaching the dendrites approximately at the same time. The postsynaptic potentials add up and the threshold is reached at approximately -30mV, and an action potential is generated at the axon hillock and conducted along the axon. Coordinated afferent input may thus induce or enhance communication between neuronal network parts following CNS lesion.

coordinated firings between single neurons, not organized in an assembly, is essential for the human CNS. If single neurons (here motoneurons) do fire partly in coordination with oscillators, they probably also fire in relative coordination with other neurons. The recruitment of motoneuron firing in man according to the size principle was shown to be rhythmic with an approximate frequency of 0.3 Hz (Figs. 9-13,15). An easily observable coordination will be synchronization. Since at least some neurons act as coincidence detectors (Fig. 104), including the motoneurons, synchronized afferent input (as a special case of spatio-temporal coordinated input) will reach faster the threshold for axon excitation than non-coordinated input. Therefore, space-time coordinated excitations between neurons of the CNS should be more efficient than non-coordinated excitations for re-establishing neuron-neuron correlation. Spatio-temporal correlations can be assumed to be important for self-organization of cell assemblies in re-stablishing integrated functions of the lesioned CNS. Singer [145,146] forwarded the idea of the saliency of connections for synchronized afferent inputs to build up cell assemblies. It is very likely that space-time coordinated afferent input enhances the saliency of network connections between interlaced networks, i.e. it enhances the saliency of the integrated functions of the CNS.

4. *Integrativity of re-learning.* In severe CNS lesions integrated functions are impared which can e.g., be seen from uncoordinated movements or not moving of arms and legs and fingers, uncoordinated urinary bladder functions (dyssynergy of the urinary bladder) or too little controlled salivation. The intrinsic dynamics of the lesioned CNS has to be entrained to specific coordinated tasks to enhance the coherence of firing between the subsystems (coordination dynamic therapy) and to enhance the coherence of firing of the neurons in the subsys-

tems (oscillator formation therapy). The more integrative the performed coordinated tasks, the higher the coherence in the whole CNS. The weaker the cooperative and competitive bonds between network parts or subsystems, the greater the variability between the subsystems (e.g., loss of specific phase relation between premotor spinal oscillators) and the greater the instability of attractor states (e.g., switching between different jumping modes will occur unvolitionally). The bonds between network parts, subsystems or cell assemblies weakened by the CNS lesion have to be strengthened by entraining the intrinsic dynamics towards more coherence of the subsystems by enhancing of the weakened bonds by movement induced coordinated re-afferent input. In severe CNS lesions only efficient learning methods including integrativity, rhythmicity, repetition, reinforcement, observation, instruction, interpersonal coordination and motivation have a chance to change the intrinsic coordination dynamics of the CNS substantially. Since certain stable pattern (e.g., spastic states) will loose stability, nonequlibrium phase transitions will take place and can transiently make the patient's movement functions worse with ongoing therapy.

5. *Regulation loops and rate of re-learning.* To improve movement, vegetative, and higher mental functions, the integrative learning methods must be efficient. Zanone and Kelso [172] follow perception-action pattern learning in learning a bimanual coordination task, where the visual afferent input is mainly used for learning; when it comes to re-learning in severe CNS lesions all possible afferent input have to be used to increase the rate of re-learning. Especially the benefit from the muscle spindle afferent input will be considered, because the muscle spindles are the most complicated receptors, they can be regulated by the CNS via the γ-loops; human static and dynamic γ-motoneurons and the primary and secondary muscle spindle afferents have been shown to play a substantial role in the relative coordination between the different kinds of motoneurons (Figs. 31-38).

Even though the spindle afferents and the oscillatory firing motoneurons fire already in relative phase and frequency coordination for the control of non-rhythmically working muscles (sphincter muscles to secure continence), the rhythmically performed coordination tasks will enhance the re-learning of relative phase and frequency coordination among motoneurons by the spindle afferents more strongly than by other receptor afferents, because the muscle spindle afferents are included in a network of regulation loops (γ-loops) (Figs. 31-33, 37-38). Rhythmic skin afferent input, caused by repetitive pin-pricking of sacral dermatomes, induces phase resetting and transient synchronization among motoneurons and spindle afferents (Fig. 37B, Figs. 3,4 of [129]) and will entrain premotor spinal oscillators, but is not directly, or only little involved in the regulation of the pattern dynamics in a certain movement pattern. Urinary bladder stretch receptor afferent input shows a relative frequency coordination with α_2-premotor spinal oscillators (Fig. 36 K,M) as the secondary spindle afferents (Figs. 35,36), but the urinary bladder receptors are not a part of regulation loops either. Thus, muscle spindles seem to be of a special importance for (motor and motor control) learning especially as they can be innervated also by sympathetic fibres [86] and, maybe, by parasympathetic fibres [125]. The learning in motor-learning (and motor control learning) may be already essentially transfered or generalized to the sympathetic or parasympathetic nervous system network divisions at the muscle spindle level.

The training on the special coordination dynamic therapy device with the coordinated movements of finger, hand, arm, foot, leg, and trunk combined with speech and vision exercises will involve many muscle spindles of the human body and will increase the rate of motor learning. But other receptor afferent inputs are also important. Pain afferent input can, e.g. relatively block a movement. A patient with a paraparetic spinal cord lesion reported that he could not walk because he had no feeling in the left ankle joint. The missing afferent input from the ankle joint blocked his leg movements. But when he learned to replace the joint feeling of the left ankle joint by the feeling of the left hip joint which was induced in the same movement, then he could walk. The movement block was eliminated. Therefore, to increase the rate of learning in severe CNS lesions to improve the functioning of the behavioral intrinsic pattern dynamics, the movements and learning tasks have to be as integrative as possible and should include as much as possible coordinated afferent inputs. The self-organization of neuronal network patterns for movements are induced by the impaired volitional descending activation patterns and the movement induced re-afferent input. If the movement induced physiologic re-afferent input (made physiologic by movement support of the therapist) is enhanced, then the physiologic impulse pattern contribution from extero- and intero-receptors will be relatively larger than the impaired volitional activation patterns (from the lesioned brain) in the process of self-organization and the re-learning of the intrinsic pattern dynamics of the lesioned CNS toward intrinsic pattern dynamics with physiologic output (for example, physiologic functions) should be faster. The efficacy of re-larning of the lesioned CNS increases with the exactness and intensity of the coordinated movement induced re-afferent input.

Co-movements. The induction of co-movements by synchronized or coordinated afferent input at the appropriate movement cycle emphasizes the importance of considering also the movement induced re-afferent input when re-learning movement (and other) functions following CNS lesion. Since co-movements (Fig. 53) in some patients are an all-or-none phenomenon and can also be felt by healthy individuals, the theory on movement control in man must be able to explain co-movements. By closing the legs before flexion during chest swimming (Fig. 53A-F; in-phase co-movement), the not or only little movable leg was made moving by the synchronized afferent input to the pattern generating networks of the right and left leg by increasing the coupling between the premotor spinal oscillator networks for the right and left leg and, maybe, by additional phase resetting (Fig. 37B; induced by the closing of the legs) which enhances the symmetry so that the attractor network state swimming with both legs was established (stabilized). The reduced activation of the networks for the poorly functioning leg from supraspinal centres in spinal cord lesion was compensated for by the increased coupling between the networks, activating the right and left leg.

When inducing higher-order co-movements during exercising on the special coordination dynamic therapy device (Fig. 53G,H), probably the essential movement induced coordinated re-afferent input is coming from the muscle spindle afferents of arms, legs and trunk. Afferent input from joint, skin and other receptors will contribute.

71. Possibilities of enhancing the rate of re-learning following CNS lesion by increasing the coordinated re-afferent input

To increase the integrativity of learning and the rate of learning of the intrinsic pattern dynamics in severely lesioned CNS the re-afferent input coordinated up to a few milliseconds has to be increased. In this way, the saliency of weak bonds between partially disconnected network parts will incease and also the relative contribution of the re-afferent input in relation to the impaired volitional impulse patterns for the self-organization of the pattern will increase. When exercising on the special coordination dynamic therapy device, possibilities are given to enhance the visual, skin re-afferent and auditory input coordinated up to milliseconds.

Visual input: During the treatment of the patients with CNS lesion reported above, it was possible to increase the quality of performance and speed of movement by interpersonal coor-

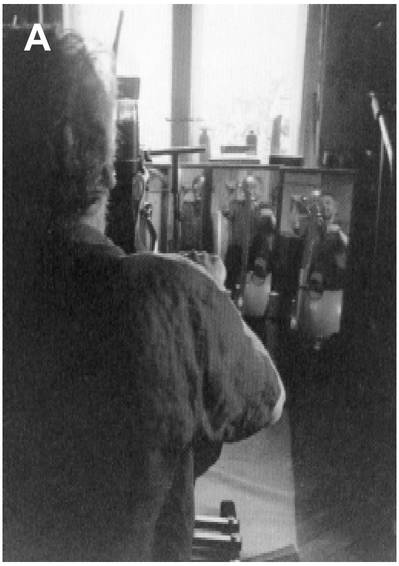


Figure 105
A patient with severe cerebellar lesion during more integrative coordination dynamic therapy (A, indoor; B, outdoor). The direct visual input ($\varphi = 0°$) is increased by a lamp flashing in coordination with the movements. The mirror picture input ($\varphi = 180°$) enhances premotor neuronal network organization because of the two driving phases of premotor spinal oscillators.

dination. The therapist (author G.S.) could, e.g., draw the patient into a more physiologic walking pattern (Figs. 66E-G; 68A-D; 74F; 81E, F; 86E, F). But the patient also happened to draw the therapist into his pathologic movement pattern (lagging with one leg) if the therapist concentrated too much onto the patients lagging leg. This mainly automatic coordination between the therapist and the patient was due to the visual input from the moving legs. The movement help obtained during interpersonal coordination can be experienced when watching own walking in a mirror or when walking or marching (soldiers) together with others.

Watching the turning of the levers when performing exercises on the special coordination dynamic therapy device will improve the pattern dynamics in the short-term memory. With a lamp or a light emitting diode in the field of vision, flashing in coordination with the arm or leg movements (Fig. 92D, 101C), the synchronized first-order visual information (luminance) is enhanced. When seeing oneself in several differently positioned mirrors during coordination dynamic therapy, the second-order visual input feedback information (contrast) is also strongly enhanced (Fig. 105). When wearing additionally bright colors, the visual system gets altogether input variations in luminance, contrast, color and motion. When the patient has the moving arms and legs and their mirror pictures in the field of vision, the premotor spinal oscillators get simultaneously in-phase (direct picture) and anti-phase (from the mirror picture) afferent drive via the brainstem and higher centres. Premotor spinal oscillators have been shown to get, for somatic activation, afferent input drive at two times per oscillation cycle (Fig. 38, [130]). Having also the mirror picture of movement in the field of vision will additionally enhance the drive of the premotor spinal oscillators. Since most likely, the visual system processes luminance and contrast by two processing streams [179] and both processing streams are activated with the additional devices affecting the visual system, there should be further enhancement in the rate of re-learning intrinsic dynamics, generating physiologic movement patterns. Unclear is where the patient should direct his visual attention to. One possibility is to focus the centre of sight on the light in one distant mirror (luminance) (and seeing the original light unfocussed and doubled (squinting)) and to have the visual attention changing between the moving arms and legs in the mirrors. The neural correlate of the ability to precisely direct visual attention to locations other than the centre of vision has been reported [180].

Skin afferent input: Automatic stepping in newborn babies (Fig. 43) is induced mainly by the heel strike, i.e. by afferent input from the feet. Motoneurons innervating the external anal sphincter are activated to fire oscillatory to subserve continence by the afferent input from the anal canal (with an anal catheter positioned). Additional repeated touching or pin-pricking of sacral dermatomes (frequency of pin-pricking ~ 1 Hz), especially inside the anal reflex area, induced phase resetting of oscillatory firing motoneurons and increased the frequency of motoneuron firing (Figs. 37, 38). Additional coordinated rhythmic input should therefore further enhance the rate of re-learning physiologic movements by phase and frequency entrainment, at least among premotor spinal oscillators. When turning the levers of the special coordination dynamic therapy device, coordinated rhythmic re-afferent input is especially induced in hands and feet and will reach the premotor spinal oscillators for phase and frequency entrainment. An additional skin afferent input can rhythmically and coordinatedly be induced, when the patient exercises on the special coordination dynamic device in water (Fig. 106). Water moving at the skin will additionally induce coordinated skin afferent input. If the water is warm, is moving or contains minerals, additional effects may be achieved such as additional reduction of spasticity due to the warmth of the water.

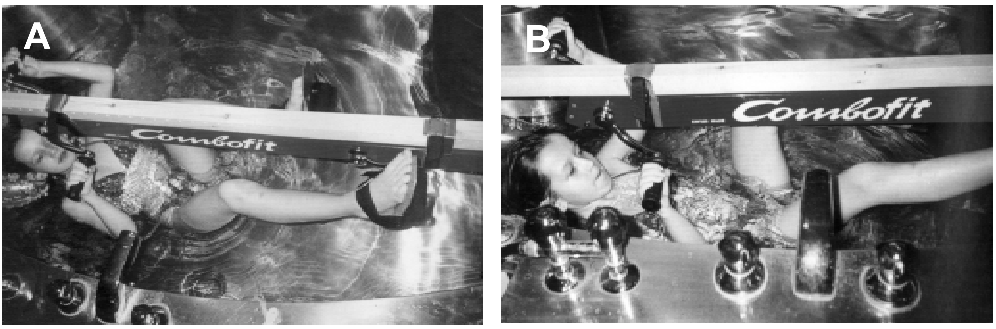


Figure 106
A patient with scoliosis during coordination dynamic therapy in water to enhance re-afferent input. The position of the patient has to be improved.

Auditory input: Music is able to evoke powerful emotions. Music was therefore used to motivate patients to exercise more. March music was sometimes used to let the patient move according to its rhythm. Music can also be applied directly to the body via the bones in similarity to the auditory perception of the fetus in the womb (the mother´s voice with its specific frequency characteristics is a very old learned perception and should be helpful to draw a patient out of the coma). However, there has not been a satisfactory possibility so far to use auditory input as an additional input in coordination with motor functions in connection with the visual input to incease the integrativity of the coordinated re-afferent input. If, for example, the flashing light was accompanied by sounds, the therapy became mostly unpleasant for the patient. No practical application of music to evoke powerful motivation and to enhance the rhythmicity in coordination with motor functions and visual input has been found so far, even though horses switch easily into the rhythm of waltz and soldiers may enjoy marching when they like the march music. Many people perform fitness training with music. But when the motor functions are heavily impaired, moving in a coordinated way with the rhythm of the music is not simple.

The patient with the bilateral cerebellar lesion and frontal lobe lesion was musical and had a good ear for music even after the CNS lesion, and he was the only patient who always used music directly for the therapy. The patient played piano in interpersonal coordination with a musician, was singing the played music, moved the feet in coordination with the rhythm and played with the right and left hand in synchrony (Fig. 92B). But firstly, not all patients are very musical, and secondly, the patient became often depressed because his fingers could not translate any more his feeling of music to the piano and back to his ears because of the CNS lesion.

Sounds are nevertheless suitable to enhance the re-learning of motor functions. The synchrony of afferent inputs to the CNS can be enhanced by using the comparison of two sounds to enhance co-movements and to improve in this way the functions of the left 'bad' fingers by coupling them to the right 'good' fingers, as an example (Fig. 103A,B). Auditory perception discriminates more exactly than visual or sensory perception, whether keys are pushed simultaneously (the patient could hear only one sound = synchronous key pushing) or not (two sounds were heard). But the re-learning of single finger functions is still more efficient when exercising finger functions on the special coordination dynamic therapy device (Fig. 102).

72. Transferability of learned pattern dynamics from one task to another

A very important question is how much of a learned (movement) pattern will generalize to other (movement) patterns that have not been practiced or could not be practiced easily such as continence functions of urinary bladder and rectum.

Transfer of relative phase symmetry. Zanone and Kelso [172] follow from their bimanual coordination task that by re-learning a new phase, the preexisting preferred relative phasing patterns, defining the intrinsic dynamics, are modified in the process of learning a new phase. By creating a novel attractor at a to-be-learned one, the pattern will generalize to other patterns that have not been practiced at all. Zanone and Kelso [176] suggest that the relative phase symmetry (e.g. $\varphi = 270°$) to the one learned (e.g. $\varphi = 90°$) can become an attractor of the patterns dynamics. Such result suggests that dynamical principles, such as preservation of symmetry, may be relevant to the transferebility to other tasks [192]. In-phase and anti-phase (movement) patterns constitute stable collective modes of nonlinear coupled oscillators and probably reflect a quite fundamental way to coordinate individual components (oscillators), whose behavior evolves in time. But Zanone and Kelso built theoretical understanding of intrinsic pattern dynamics on symmetric bimanual coordination tasks. It may therefore be expected that the theory gives preference to symmetry. In our recent studies concerning human neurophysiology the preference of in-phase and anti-phase movements is based on the macroscopic observation that coordinated, rhythmic, dynamic, symmetric movements are more or less generated in the spinal cord. E.g., a newborn baby can step automatically (Fig. 43); synchronized or coordinated afferent input induces co-movement (Fig. 53), etc.

The fact that in-phase and anti-phase patterns constitute stable collective modes of nonlinear coupled oscillators and may reflect a fundamental way to coordinate individual oscillators to generate movements, gets stronger support from the measurements on premotor spinal oscillators, subserving mainly continence functions. These premotor spinal oscillators have mostly two driving phases, 180° apart, and they activate continence muscles not involved in rhythmic, symmetric movements.

Transfer of integrative coordination dynamics (transfer of space-time correlated interplay between neurons and neuron assemblies). The most important question is, how much of a re-learned motor function is transfered to the improvement of other movement functions. How much of a re-learned motor pattern generalizes to other behaviors. Zanone and Kelso argue that the preservation of symmetry may be relevant to the transferability to other tasks.

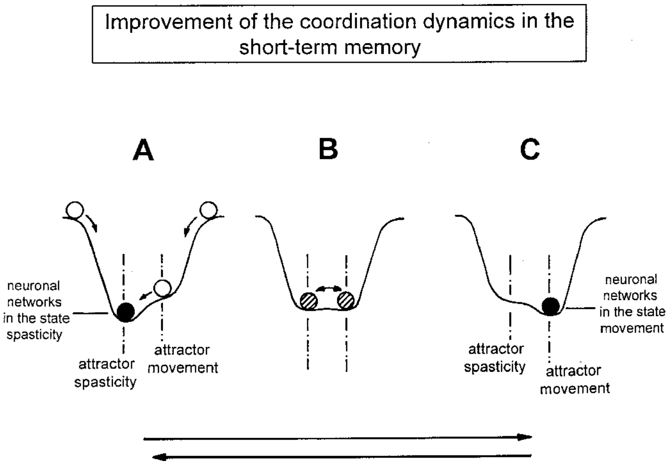


Figure 107
Improvement of coordination dynamics, visualized by a ball in a potential landscape, in the short-term memory during exercising integrative coordinated movements. The unstable physiologic attractor state movement can be improved even though being close to the pathophysiologic attractor state extensor spasticity. A. The attractor extensor spasticity is so deep that the neuronal network organization settles into the spastic state (represented by the black ball rolling into the bottom of the hole). The attractor coordinated movement of arms and legs is too shallow, so that the network organization movement slips always into the attractor state spasticity. When the patient tries to perform a movement such as walking, extensor spasticity would immediately occur and block walking. B. By performing instrumented supervised learning, i.e. movements on the special coordination dynamic therapy device with a movement coordination of up to a few milliseconds, the attractor movement becomes deeper and the attractor spasticity more shallow. A switching of the network state between spasticity and movement can occur. When a therapist helps the patient to perform the movements on the special coordination dynamic therapy device by holding the hands of the patient on the levers, he can feel that the hardness of turning the levers reduces and the movement becomes easier to assist. C. After performing approximately 1000 turns on the special coordination dynamic therapy device, the attractor coordinated movement becomes transiently deeper than the attractor spasticity. The network captures now the movement state. A therapist, supervising the movements of the patient on the device can feel now that the movement becomes easy to perform. The patient would feel that the spasticity reduced, so that he can now use better his remaining volitional power, which was counteracted before by spasticity. Children often start to smile or to laugh, when spasticity reduces, because they have a better feeling in their CNS. The reduction of spasticity is indicated below the potential wells by an arrow from left to right. After stopping the movement on the device, spasticity slowly reappears within minutes up to a few hours, which is indicated by the backward arrow below the potential wells from right to left. The fact that the neuronal network system (arrow) does not exactly return to the baseline (hysteresis) indicates a bit of learning in a longer-term memory. In the time window of reduced spasticity (improved network organization), volitional movements or automatisms can be performed by the patient and exercised, which were blocked before by spasticity.

The measurements on premotor spinal oscillators in the caudal spinal cord and the progress achieved in the re-learning of motor and other functions in patients with CNS lesion indicate that the re-learned coordination dynamics in substantially activated neuronal networks is transfered in the activated neuronal networks to other motor functions. This is supported by the findings that neurogenesis and neuron proliferation in mice and rats is induced in those CNS parts (proved for the hippocampal formation) which are substantially involved in the process of learning [169]. If it is the integrative coordination dynamics, i.e. the space-time correlated interplay between the neurons, including different kinds of neurons, what is transfered during re-learning, then static postures and space-time non-correlated movements (non-rhythmic movements) will have a low efficacy with respect to re-learning, because - for the entrainment of timing of firing between neurons (repeated activation of synapses in integratively activated neuronal networks) - little is learned during static postures or training of individual arms and legs (see A new start after the Bobath therapy).

Building up of differential stability of a physiologic pattern state close to a spastic state by coordinated afferent inputs. The exact timing of movements or afferent inputs is also important with respect to the differential stability of physiologic and pathophysiologic pattern organization. If an attractor of a certain spasticity is deep and large in the attractor layout and the attractor for the physiologic movement is small and shallow (Fig. 107), then only with the exact timing supervised by a device will it be possible to get into the attractor state for physiologic movement. Repeated exercising on the device will increase the strength of memorized information (entrainment of the timed firing of activated neurons) for the physiologic movement. The physiologic movement will become a stable pattern and the pathophysiologic state (spasticity) will loose stability and its occurrence will reduce.

G. Summary of the theory of coordination dynamics of the lesioned human CNS

73. Basis for the coordination dynamic therapy

Due to the 4 new developments in human neurophysiology mentioned, it is possible to reorganize the lesioned or functionally impaired human central nervous system (CNS). The four new repair-related concepts are:

1. The CNS is viewed as a neuronal network which organizes itself. The organization can be changed by re-learning.
2. The self-organization is based on a relative (specifically changing) phase- and frequency coordination of rhythmically firing subneuronal networks and single neurons.
3. Neurogenesis and functional cell proliferation is induced and controlled by learning. Methods for re-learning basic CNS functions use especially rhythmic, dynamic, coordinated movements.
4. It seems from the success in re-learning movements, vegetative and higher mental functions in patients with CNS lesion that the human CNS has a second integrative strategy to learn, re-learn, store and recall network states.

The lesioned human CNS can be repaired by re-learning of partially lost phase and frequency coordination through coordinated rhythmic movements. The severely lesioned CNS can only efficiently be repaired if integrative, coordinated functions are re-learned. The re-learning of relative phase and frequency coordination of the lesioned CNS can be achieved by:

1. Using special coordination dynamic therapy devices which offer exact phase and frequency coordination up to a few milliseconds for re-learning.
2. The training of automatisms, postures and old learned movements which are only little impaired in their functioning by the lesion.

Rather than asking what is the best method to re-organize the lesioned CNS we should ask what method is most efficient in re-organizing the lesioned CNS by re-learning. The increase of the rate of re-learning is determined by 4 factors:

1. The exactness of the coordination of the performed movements during the therapy, to functionally reconnect disconnected network parts to recouple arms or legs that cannot be moved.
2. The increase of the integrativity of the coordination dynamic therapy, which increases the number and complexity of simultaneously exercised phase and frequency coordinations and makes it possible to re-learn integrative functions such as the higher mental functions.
3. The enhancement of the movement induced re-afferent input to strengthen the physiologic self-organization of the lesioned CNS and its communication with the environment.
4. The increase of the intensity of the therapy to force the ‘adaptive machine’ CNS to adapt.

74. Coordination dynamics: some terms

The theory of self-organization and pattern formation in nonequilibrium systems [63,172-178,191] builds upon the concepts of synergetics [190]. Patterns of coordination are viewed in terms of their nonlinear dynamics. The patterns of coordination are characterized by low dimensional collective variables or order parameters whose dynamics are function-specific. Observable patterns of coordination are mapped onto attractors (see below) of the order parameter dynamics. Biological boundary conditions act as parameters on the collective dynamics. Several coordinative patterns can coexist under the same condition (multistability). Loss of stability leads to switching of patterns and gives rise to nonequilibrium phase transitions. Fluctuation and differential stability govern the switching dynamics among multiple coordinative patterns. If a certain coordinative pattern has a very high stability, it may seem as if this pattern is 'hard wired' and is generated by a pattern generator. If the coordination dynamics is not specified by the constraints to a particular pattern (spontaneous pattern formation), it is called intrinsic dynamics. The pattern in that concept that emerges is a direct consequence of cooperative and competitive interactions between the intrinsic dynamics, the intensional pertubation (intentional impulse patterns) and the extrinsic dynamics (movement induced afferent input).

If $\mathbf{x}$ is a characteristic collective variable, describing the dynamic pattern, then $\mathbf{x} = \mathbf{x}(t) = \mathbf{x}_t$, where t is time and $\mathbf{x}$ obeys the dynamical law $d\mathbf{x} / dt = \mathbf{f}_{intr} (\mathbf{x}_t$, parameters, noise) (the right side is called vector field). Special solutions to this equation are called attractors if they are asymptotically stable; all neighboring solutions converge in time to the attractor solution. Attractors play a key role in the modeling process because the behavior of the collective variable in time may be mapped onto attractors. The attractor basin is defined as the set of all initial points from which trajectories converge to a given attractor.

In learning a bimanual coordination task by synchronizing finger movements to a visually specified phasing relation, the coordination dynamics is captured through a collective variable, the relative phase, φ. With the equation for the order parameter $d\varphi /dt = - \partial V /\partial\varphi$ and the potential $V = -a \cos(\varphi) - b \cos(2\varphi)$ (Fig. 54), the behavior of the system can be visualized if φ is identified with the coordinate of a particle that moves in an overdamped fashion in the potential, V.

In a theoretical analysis of the patterns of interlimb co-ordination in the gaits of quadrupedal locomotion, the collective variables are given by three relative phases that describe the coordination patterns of arms and legs. Gaits were classified by their symmetry properties, which can be expressed as invariances under groups of transformations [174].

In the severely lesioned CNS only many collective variables (control parameters) can describe the coordination dynamics, and multistability may be large among attractor states. To increase the differential stability of those attractor states of subnetworks which give rise to physiologic movements (Fig. 107), supervised learning using the special coordination dynamic therapy device may be necessary.

75. Theory of coordination dynamics of the lesioned human CNS and re-learning

The key concepts to repair the lesioned human CNS are to discover the functional organization of the human CNS under physiologic and pathophysiologic conditions, and to reorganize the lesioned CNS for physiologic functioning. Self-organization and pattern formation (collective effects of firings of many neurons) was explored in a part of the CNS, namely the spinal cord, by measuring (1) phase and frequency coordination between α- and γ-motoneurons and secondary muscle spindle afferents in normal individuals and in patients with CNS lesions [107,115,116-121,123,128-131], and by (2) extracting knowledge on CNS organization from the lesioned CNS of patients [137-140,186-189,193]. By improving physiologic functioning of the lesioned CNS by a coordination dynamic therapy [137-140,186-189] in patients in the short-term memory and in the long-term memory (reorganization) the progress of re-learning was analyzed. Because of measured phase and frequency coordination in the process of neuronal network organization in man, the theory of coordination dynamics is used for re-learning motor, vegetative, and higher mental functions. The re-learning (repair) is seen as a change of the existing inner coordination dynamics tendencies after the lesion (with no or only pathologic functioning of arms, legs and trunk) to achieve CNS coordination dynamics which will generate again physiologic movements, vegetative and higher mental functions (Fig. 108). The change of the coordination dynamics is achieved by the coordination dynamic therapy which uses the strategies (1) of accurate movements coordinated up to a few milliseconds by supervised instrumented learning to reconnect functionally disconnected neuronal network parts (Fig. 104), (2) of increasing the integrativity of coordinated movements or behaviors to repair integrative CNS functions like higher mental functions, (3) of enhancing movement induced afferent input to stabilize physiologic network states of the lesioned CNS and to destabilize pathologic network states like spasticity by offering more physiologic afferent input to the lesioned neuronal networks for physiologic self-organization, and by supplying - through instrumented, coordinated movements - physiologic regulation (motor control) to the networks by using the receptors of the periphery, especially the secondary muscle spindle afferents, and (4) of going to the limits of exercising by increasing the intensity of the therapy to force the 'adaptive machine' CNS to adapt.

The self-organization of neuronal network parts and its evolution with time (coordination dynamics) is realized by interrelating (of firings of motoneurons) the existing inner coordination dynamics tendencies of the network (tendencies of phase and frequency coordination), the intentional impulse patterns and the afferent input from the periphery including movement induced re-afferent input. Network parts are functionally connected or interlaced by network communication including regulatory processes with other network parts and the periphery.

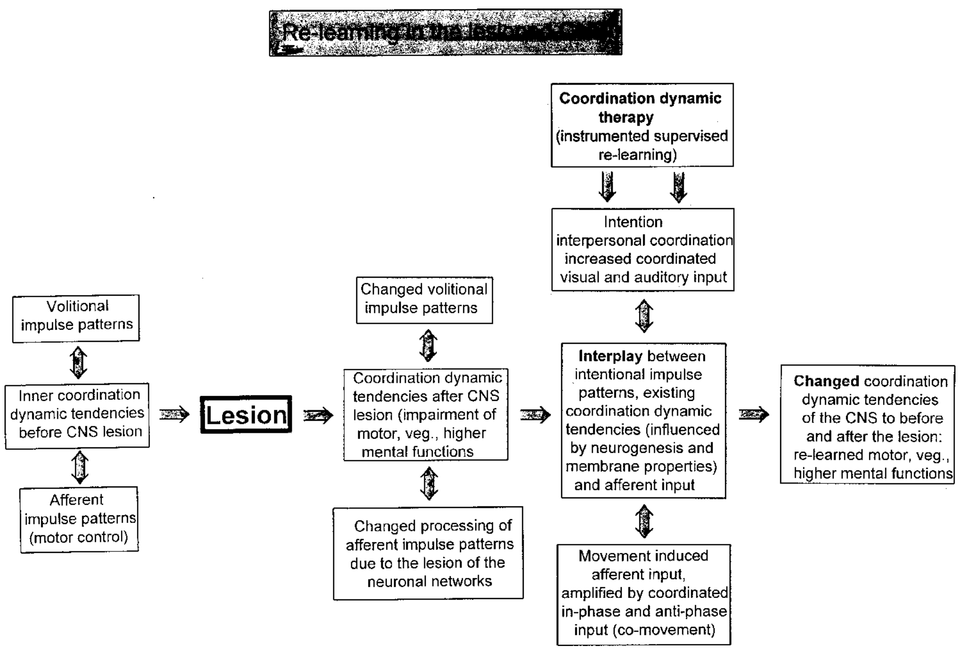


Figure 108
Layout of the re-learning of CNS functions following lesion in the concept of coordination dynamics.

The link between neuronal activities and movements resides in collective effects (pattern formation) at the microscopic level that create macroscopic order and disorder. Coordination can be observed and measured (1) between the moving of arms and legs (Figs. 109-114, 117-119), (2) in the motor programs of muscle activation in electromyographic (EMG) recordings [131], and was measured (3) as relative coordinated firings between premotor spinal oscillators (assembly level) and single neurons (Figs. 31-39).

Following CNS lesion, coordination is partly lost at all levels of observation (macroscopic level (Fig. 86L), assembly level (Fig. 47C), single neuron level (Figs. 12,13), motor control level (regulation loops, clonus)). The intrinsic dynamics of the neuronal networks, as measured by phase and frequency coordination of firings of neurons, shows poor coordination. By exercising on the special coordination dynamic therapy device, i.e. by instrumented supervised motor and motor control learning, phase and frequency coordination can be re-learned (Fig. 108) and the re-learned coordination measured (Figs. 86L, 109-114, 117-119). Since the neuronal networks of the CNS communicate via receptors with the environment, the coordination upon performing coordinated movements reaches the neuronal networks via regulatory loops (for example, external oscillator loops or γ-loops). The relationship between the coordination dynamics of arms and legs and the coordination dynamics of premotor spinal oscillators partly induced by secondary muscle spindle (joint and other) afferent activity constitutes a relationship between macroscopic and assembly level. Therefore, the networks of γ-loops or external loops of premotor spinal oscillators establish with other regulatory loops a connection between the macroscopic and the neuronal assembly level.

The macroscopic competition between a physiologic attractor state (e.g., running) and a pathologic attractor state (e.g., extensor spasticity) may be seen at the premotor network level as the competition for different coordinations among the impulse patterns of α- and γ-motoneurons, interneurons and muscle spindle and other afferents.

Relative coordination does not mean approximate coordination, but means specific changing coordinations among single neurons or assemblies. The coordination dynamic therapy improves the precision of relative coordination in CNS neuronal networks, i.e. the exactness of evolving changes with the time of coordinated firing among neurons.

Following CNS lesion, the coordination dynamics substantially changes. If, in a severe CNS lesion, therapy is started too late, the impaired neuronal networks adapt by themselves in an uncontrolled way. The CNS networks will then nearly always generate also pathologic neuronal networks states, which give rise to different kinds of spasticity, unphysiologic posture and unphysiologic hand and leg positioning (Fig. 78).

In re-learning of old learned functions two kinds of changes of the existing coordination tendencies may occur in the cooperative and competitive interplay between the pathologic inner coordination tedencies and the pattern formation tendencies induced by the afferent impulse patterns from the periphery, induced by the therapy. Firstly, when the re-learning involves a shift of preexisting attractive states, mainly cooperative mechanisms become involved, and parametric changes in the coordination dynamics correspond to adjustment of actual phase relations between the spinal oscillators and neurons within the same coordination strategy in the premotor network. Secondly, when the necessary re-learning requirements differ strongly from the existing coordination tendencies, competitive mechanisms may induce loss of stability (seen as enhanced variability in the progress of the re-learned task) and/or attraction of the re-learned movement to an underlying coordination tendency. Examples of the latter are the slipping during leg movement into extensor spasticity or slipping, when giving the hand, into the grasp automatism (Fig. 78E,F,G).

Whereas analysts of motor behavior consider motor control to be distinct from motor learning, motor control and motor learning is used when performing coordination dynamic therapy. When the patient tries to adapt his motor behavior to the coordination dynamic therapy devices, he uses the motor control (materialized by afferent activities of muscle spindle, skin, joint and other receptors) for re-learning. But when the hand partly slips from the lever and the patient tries to grip additionally the lever at the appropriate moment when the fingers starts to slip, then he exercises motor learning in addition to motor control learning.

So far, improvement of the organization of the lesioned CNS has been measured indirectly by the improvement of movements. E.g., to measure the changes of the coordination dynamics during re-learning, walking or running speed was used (Fig. 78H). But by measuring the coordination dynamics (rhythmicity) of arms and legs during exercising on the special coordination dynamic therapy device, it is possible to measure more directly the changes of the organization of the CNS with ongoing therapy (Figs. 114, 117-119).

Parametric changes of coordination dynamics, namely mainly the cooperative interplay, and dramatic changes, namely the more competitive interplay between the intrinsic dynamics and the to-be-re-learned coordination dynamics, were observed in patients. When coordination dynamic therapy was started soon after the CNS lesion, mostly smooth curves of improvement of movements were observed (parametric changes, see Figs. 67, 78H). When the therapy was started long after severe CNS lesions, often instabilities in the movement progress were observed (dramatic changes, see Figs. 71F, 93, 99). It seems therefore that when coordination dynamic therapy was started long after a severe lesion, false established coordination dynamics had essentially to be reorganized and a mainly competitive interplay took place between the existing pathologic and the to-be-re-learned physiologic coordination dynamic tendencies. The competitive interplay with the instabilities occurring in the network organization reflected itself in the instability of progress, which means that the performance of a movement (e.g., walking) can transiently become worse.

76. Transfer of learning

Kelso, Zanone and Schöner [175,176] evaluated changes of the intrinsic coordination dynamics tendencies during learning of coordination tasks in non-lesioned CNS by measuring the dynamics of the relative phase during the performance of bimanual coordination tasks, including the measurement of non-equilibrium phase transitions from anti-phase to in-phase movements when increasing the frequency of performance. By analyzing different bimanual coordination tasks, they tried to analyze the transfer of learning from a learned new coordination task to another not trained coordination task.

During coordination dynamic therapy of the lesioned human CNS, it has so far been only partly possible to measure the changing momentary intrinsic coordination tedencies during re-learning at the different levels of description (level of movements, assembly level (premotor spinal oscillator level), single neuron level). The improvement of the coordinated movement of an arm, finger or leg can be measured. The improvement of the average coordination dynamics when exercising on the special coordination dynamic therapy device can be used to quantify the improvement of the inner coordination tendencies on the macrsoscopic level (Figs. 114, 117-119). By performing electromyography, the coordinated firing of premotor spinal oscillators can be measured. Therefore, re-learned coordination can also partly be measured additionally on the assembly level and single neuron level.

With respect to re-learning of movements after CNS lesion using coordination dynamic therapy or other re-learning methods the question is important what is being re-learned by improving the coordination dynamics in the patient. What is transfered for the improvement of the general coordination tendencies, if a certain movement is exercised and re-learned. In patients following CNS lesion phase and frequency coordination among premotor spinal oscillators was shown to get partly lost. The oscillators have partly lost their rhythmic properties, α- and γ-motoneurons changed their recruitment in the occasional firing mode, control of spinal oscillators was partly lost, and the phase relations between spinal oscillators, γ-motoneurons and secondary muscle spindle afferents were partly lost. It seems therefore that the coordinated firing of the neurons in the lesioned CNS get partly lost with respect to time and space (loss of physiologic CNS organization) as is communication with the environment (partial loss of motor control). When the specific property of the lesioned CNS 'timed firing in space' of its neurons (phase relations between the firings) is partly lost, then the timing of firing of the neurons has to be re-learned.

If the CNS has only been affected by a minor lesion, then the CNS may be able to repair itself (re-learning by itself). But if a patient suffered a severe CNS lesion, the CNS cannot repair the basic functional structure by itself, as experienced from improving functions in patients with severe CNS lesions. Instrumented supervised re-learning can offer the lesioned neuronal networks dynamic physiologic sets of phase relations, evolving with time, for re-learning. It seems therefore that the phase relations between the firings of the different neurons have to be re-learned for different (movement) patterns for re-learning the general improved functioning of the CNS, because descending impulse patterns and afferent impulse patterns from the periphery contribute to the 'timed firing' of neurons. How the relative coordination evolves over time via relative phase and frequency coordination between the component neurons can directly be seen in Figures 31 to 39 for the premotor spinal neuronal network. The coordination dynamics is being re-learned by re-learning the appropriate phase and frequency coordinations among the firings of the neurons, evolving over time. The collective effects of many firing neurons resides in the collective effect of relative coordination of many phase relations. The self-organization of the assembly 'premotor spinal oscillator' is achieved by the timed firing of the component neurons activated by descending impulse patterns (volition or intension) and/or afferent impulse patterns from the periphery.

Dynamic neuronal network organization does not only mean evolution of the network organization over time (flow of a vector field) but additionally means that also movements of arms and legs are performed with high positive and negative accelerations, so that the CNS is activated as integratively as possible. Also, those phase relations are activated and re-learned which are only activated when fast changing movements are performed. Such dynamic activation of the system will also give rise to higher order rhythm couplings and will also activate strongly the fast systems in the neuronal networks. With respect to the premotor spinal network this means that also many (dynamically responding) α_1-motoneurons and primary muscle spindle afferents are activated.

During the process of re-organization of the CNS, when performing coordination dynamic therapy, the timing of firing of neurons (phase entrainment between neurons or between different neurons in an assembly) and premotor spinal oscillators (phase entrainment between assemblies) of different neuronal network parts with similar and dissimilar functions, and the timing of firing of the different CNS parts is re-learned. The phase relations with an exactness of up to a few milliseconds offered by supervised re-learning (Fig. 34) seem to be crucial for re-connecting of network parts (Fig. 104) to improve the integrative functions of the CNS.

The question could be put forward, what is being re-learned for walking when the patient is exercising on the special coordination dynamic therapy device, because the movements seem to be quite different. It seems that the overlap in the intrinsic coordination dynamics tendencies, i.e.

the overlapping of the activated performed phase relations of the two movement patterns over time is re-learned for walking. The overlap of the activated coordination dynamics tendencies is transfered from the task of turning levers and pedals to the task of walking. This view is supported by the experience that about 1000 turns on the special coordination dynamic therapy device will make walking and running easier in normal individuals and in patients with CNS lesion.

When connections between neuronal network parts are destroyed by a lesion or are impaired, e.g. by demyelinisation, mutual phase relations between neurons will have changed dramatically. The re-learning of the collective effects of timed firing of neurons (pattern formation) includes therefore also the building up of new connections between network parts. A host of structural changes, including neurogenesis, cell proliferation and changes of membrane properties, will make contributions to the adjustment of the timed firing of neurons in the different parts of the CNS.

Competitive and cooperative mechanisms can only be re-learned (and measured) in relation to existing coordination tendencies, before, during and after re-learning, making the individual learner rather than the group or the species the significant unit [176]. The instantaneous coordination dynamics can be measured when exercising on the special coordination dynamic therapy device (Figs. 114, 117-119).

77. Interplay with genetics?

Interesting and important in the process of re-learning by the coordination dynamic therapy is that so far, no unphysiologic movement patterns have ever been produced if the supported and/or supervised exercised movements were physiologic. No drifting into obscure patterns has ocurred. Apart from some instabilities, the pathologic movements always gradually or suddenly changed in the direction of physiologic movements. It seems therefore as if the re-learning was supervised to go in the direction of physiologic movements. Maybe, the same mechanism is at work which is responsible for the primary organization of the CNS during ontogenesis. A genetic support in the control of the process of re-learning seems possible. The influence learning methods have on neurogenesis and cell proliferation in animals [169-171] supports that view. The observation that also improvement in the physiologic functioning of the CNS can be achieved in children with Down's syndrome (trisomy 21) if coordination dynamic therapy or conventional therapy is applied seems to contradict genetic guarding in the process of re-learning. However, different participating genes may cooperate in a different way during ontogenesis and repair, and ontogenesis may be rather pathologic because of the genetic defects, whereas the therapy induced genetically guarded repair mechanisms are mainly physiologic.

The understanding of the interrelationship between learning and re-learning methods and the host of structural changes taking place in response to them, including neurogenesis, cell proliferation, neurite growth, membrane property changes and synapse efficiacy changes, will not only bring further insight into the functioning of the human CNS, but will also give a further basis for improving the efficiency of learning and re-learning methods. From the peripheral nervous system in animals it is known that only those motoneurons survive during development, which make functional contact in the periphery [102].

78. Conclusion

Based on early pharmacotherapy [14,83] in spinal cord and brain lesions to reduce the self-destruction of the CNS, on new measurements in the PNS providing more knowledge on the self-organization and coordination dynamics of neuronal networks in the CNS, on regenerative capacity by neurogenesis and/or axonal regeneration [4,545,51,75,157,166,167], and on the demonstrated higher plasticity following rhythmic, dynamic, coordinated (and other) movements in a quantified intensive therapy, it could be shown that substantial recovery is possible in patients with spinal cord and brain lesions.

Even if new drugs are able to substantially enhance the regenerative capacity of the human CNS, it should be borne in mind that most likely, the growth of neurites is unspecific, which means that a reorganization (tackled in this vertical review) of the regenerating CNS is still needed to probably transform mass contractions into useful movements.

Researchers from theoretical and computational neurosciences have been attacked for not measuring on human CNS. Firstly, this argument holds for many researchers working on the CNS. Secondly, comparative measurements in animals and humans are needed so that knowledge obtained from animal studies can be transposed to humans and that human medicine can benefit from animal research. A cooperation of researchers from several fields is needed, including those from the clinical field. Actually, for the time being the major problem with respect to neurorehabilitation seems to be that new knowledge on neuronal network plasticity and regenerative capacity is to be brought to the patient. Theoretical modeling without including hard human data is an empty exercise, a mere theory. So is collecting facts in the absence of any understanding of the basic operating modes of the human CNS [63].

It has been shown that somatic, autonomic and higher mental functions of the lesioned CNS in patients can be repaired using the knowledge of four new developments in neurosciences, namely (I) the concept of self-organization of neuronal networks, (II) the concept of rhythmic firing of subneuronal networks and of the rhythm coupling (relative coordination of phase and frequency) of these rhythmically firing networks, (III) the concept of regeneration including neurogenesis in adult patients with CNS lesions, and (IV) the concept of integrative learning, re-learning after CNS lesion, storing and recalling, which follows from the case reports and further practical experience with patients with CNS lesions. With the newly developed oscillator formation and coordination dynamic therapy using also oscillator-theory-based equipment, the reorganization was so efficient and its extent so large that in some patients the goal of the neurorehabilitation 'Cure rather than care' has been reached. With the strategy in mind to reorganize the CNS as integratively as possible by means of special coordination dynamic therapy devices, the higher mental functions improved with the motor functions in severe as well as in minor CNS lesions, leading to the conclusion that higher mental functions may substantially be enhanced by integrative coordination dynamic therapy.

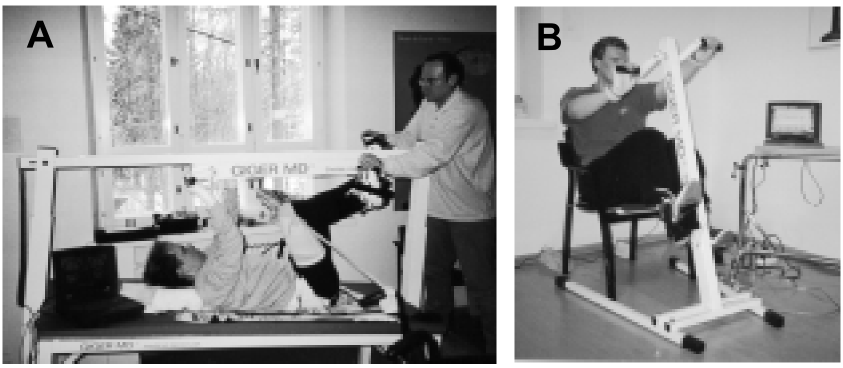
The spirit generated in the neuronal networks of the CNS may get released from the genetically determined network structure. There is no more the question whether the spirit can ever understand the functioning of the neuronal networks of the CNS which generated it; rather, we should ask if the spirit can understand how it is generated in the networks; then it may develop further, with sufficient motivation and appropriate learning methods, to become released from the genetically pre-determined neuronal network.

H. Coordination dynamic therapy update

The coordination dynamic therapy is used to treat patients with CNS lesions. Therapists using the method ask for the scientific basis of their applied treatment, but they also wish to see the up-to-date application of their instruments and performances they use. Such wish is in the interest of the patient; therefore, an update of the coordination dynamic therapy has been added here at a time when this paper was already in press.

79. Measuring the organization of the human CNS: Diagnosing coordination dynamics

The integrated organization of the human CNS can be quickly, cheaply and non-invasively measured when the patient is exercising on the special coordination dynamic therapy device in the lying (Fig. 109A), sitting (Fig. 109B) and partly in the standing position (Fig. 109C). False organization of the neuronal networks with respect to relative phase and frequency coordination of the firing of neurons generates macroscopically arrhythmic movements when turning on the special coordination dynamic therapy device. The relearning of phase and frequency coordination of the firing of neurons is achieved by trying to turn rhythmically on the device. The macroscopic phase coordination (absolute coordination parameter) is given by the device, and the macroscopic frequency coordination (relative coordination parameter) is given by the turning speed



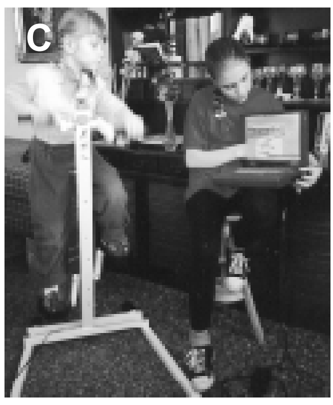


Figure 109
A. The 36-year-old patient with a spinal cord lesion due to hemorrhage exercising in the lying position on the special coordination dynamic therapy device; coordination dynamic diagnosis is performed at the same time. At the beginning of the therapy, the patient needed assistance to perform movements coordinated up to milliseconds in the lying position. B. The apparently tetraplegic patient during the training in the sitting position. He still has problems with the right hand to hold the handle. The coordination dynamic recordings on the computer display shows large variations. C. Coordination dynamic diagnosis can also partly be performed in the standing position. The layout shown can be used to compare different patients or to follow up a single patient. The special coordination dynamic therapy device is a product by: Combo AG, Postfach 146, Tugginerweg 3, CH-4503 Solothurn, Schweiz, Fax +41326219745.

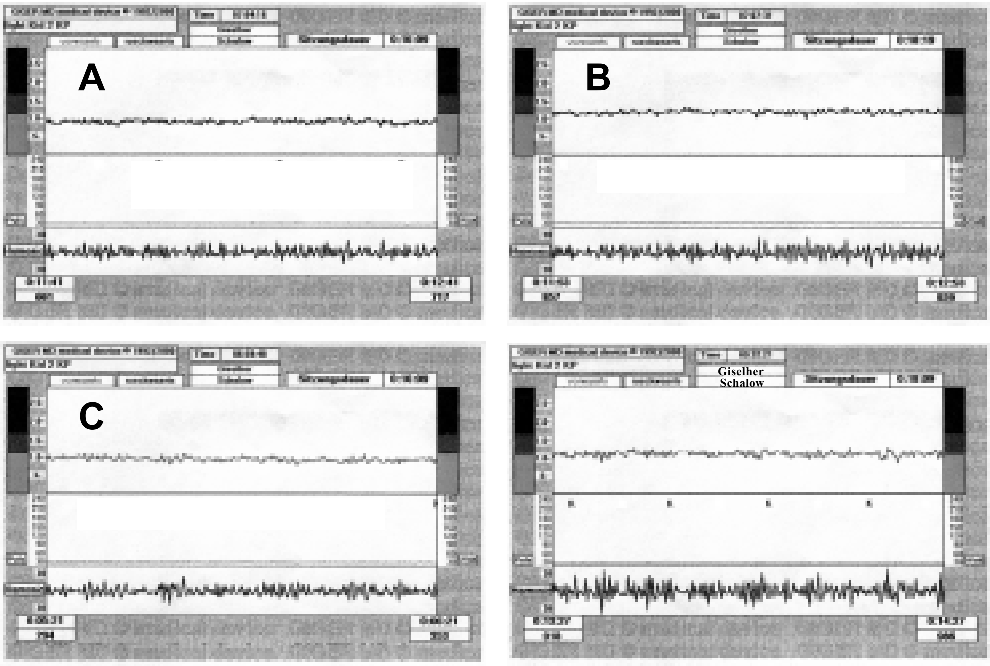


Figure 110
A. A coordination dynamic recording from a healthy slightly trained CNS (author G.S.), during the turning in backwards direction on the special coordination dynamic therapy device. The upper trace shows the turning velocity (approximately 1 turn per second); little variability can be seen. The pulse frequency (middle trace) has not been measured. The lower trace shows the changes in velocity (acceleration). This more sensitive trace with respect to arrhythmicity shows also comparably little variation. B. After exhaustion and/or stress the variability of bouth traces increased. C. For forward turning, repeated increases in the variability of rhythmicity occurred for the difficult coordinations; pace gait and trot gait coordinations (easy coordinations) were realized with the device. D. After exhaustion and/or stress the variability of rhythmicity for the easy and difficult coordinations increased.

(~ 0 to 3 Hz; ~ 1.5 Hz). By changing continuously from easy coordination (pace gait = arm and leg on one side move together; trot gait = arm and leg move in diagonal pairs) to the difficult intermediate coordinations and backwards, the CNS relearns the timed firing with respect to phase and frequency coordination by changing from easy to difficult coordinations and backwards. The arrhythmic movements are quantified by the variation of the turning velocity and more sensitively by the variation of the change of velocity (acceleration).

In Figure 110 a coordination dynamic recording of a healthy CNS (author G.S.) is shown. The velocity trace and the more sensitive acceleration trace show only little variation for turning backwards (Fig. 110A); the CNS is able to generate both easy and difficult coordinations. When the author turns forward (Fig. 110B), the variation for the difficult coordinations becomes bigger. His CNS has more problems to generate macroscopic coordination for the difficult coordinations when turning in forwards direction. After sleeping for 3 days only 3 to 4 hours per night and driving at least 10 hours per day (at the end a few black outs appeared), the author´s CNS had more problems to generate macroscopic coordination because the variation of the rhythmicity increased approximately 80% or 60% when turning forwards (Fig. 110D) or backwards (Fig. 110C) respectively. Interestingly, the stressed and/or exhausted CNS could only generate coordination with increased variability of rhythmicity for both movements. The relation betwe-

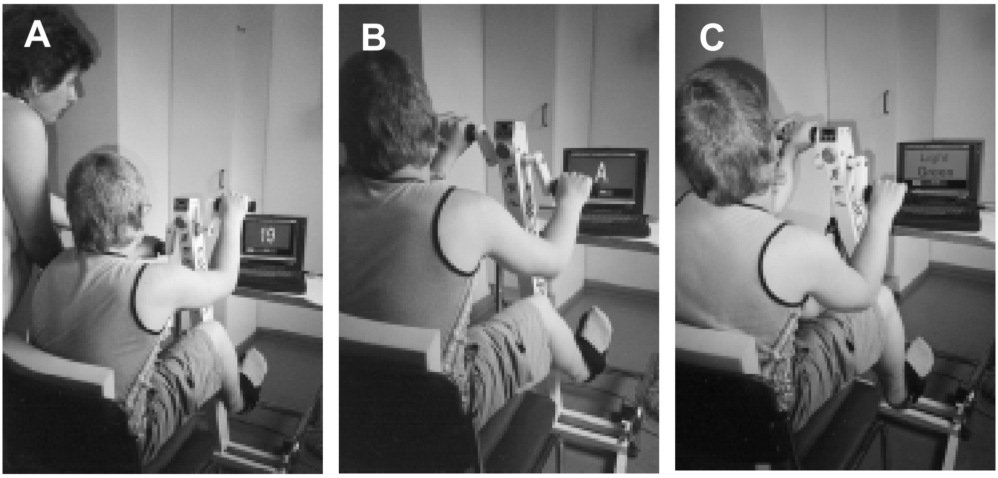


Figure 111
A. The twelve-year-old patient with a hemiparesis on the left side during coordination dynamic therapy with his mother. He had to say the numbers as they appeared on the screen (coordination with the movement). B. The patient had to speak the letters (here, the alphabet backwards) as they appeared. C. The patient had to tell the colors when appearing. D. Recording of the coordination dynamics.

en the variability for easy and difficult coordination seemed not to have changed. After 3 days of normal life the amplitude of the variation returned to normal values.

Three physiotherapist concentrated on the exercise on the device. Their amplitudes of variation were as big as the one of the author´s stressed CNS. Thus, even though they performed many movements per day during their work with patients, their organization of the CNS was not optimal. Therefore, when measuring the progress of the organization of the CNS we have to follow up every patient separately rather than in groups, because the organization of the CNS of healthy humans differs from person to person, and the organization of the lesioned CNS varies even more dramatically from patient to patient, as will be shown below.

80. Integrated coordinated activation of speech, vision and audition in a brain lesioned patient during performing coordinated movements (case 26).

Based on the principle that the coordinated activation of the CNS has to be as integrated as possible, the coordination dynamic therapy has been extended to include speech and vision.

Four years ago, the now 12 years old Andreas was riding a bicycle in the street and was hit by a car, suffering severe brain lesion. He became hemiparetic on the left side, his vision and his higher mental functions are impaired. The left optic nerve was pressed and damaged. With flashing light both pupils react, but when the right eye is covered, the left pupil is not or only very little reacting (co-movement of the left pupil).

Coordination dynamic therapy was started 4 years after the accident. In addition to performing coordinated movements, the patient had sometimes to count numbers (Fig. 111A), speak letters (Fig. 111B) and realize colours (Fig. 111C) as they appear on computer display (the computer is connected to the special coordination dynamic therapy device), that means in

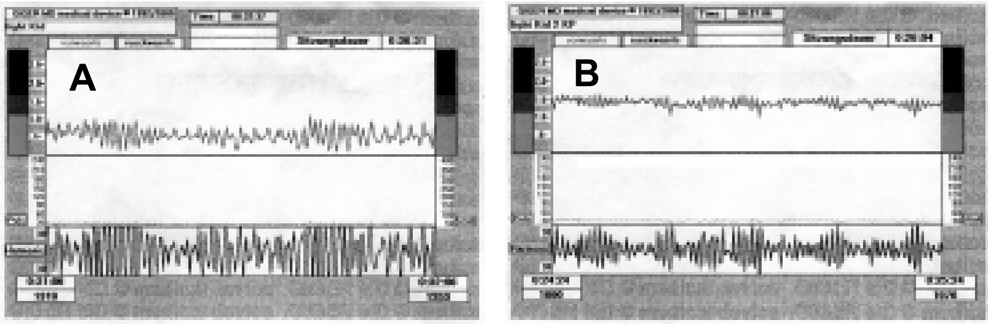


Figure 112
A. The recording of the coordination dynamics of the twelve-year-old hemiparetic patient before the coordination dynamic therapy, 4 years after the accident. Notice the large variation in the amplitude of rhythmicity. B. After 2 months of therapy, the rhythmicity of turning increased (reduction of variability). Rhythmic changes of the variability of rhythmicity appeared rhythmically with time on the record (ordinate, from right to left = 1 min (24.24 to 25.24)).

coordination (up to milliseconds) with the movements of arms and legs. The therapist (the mother) was helping with the timing of the speech and was reducing the palmar flexion of the hand and increasing the arm flexion (Fig. 111B,C) at the same time. After 2 months of therapy the arm and leg movements improved. The progress in the organization of the patient´s CNS was quantified by recording his coordination dynamics (Fig. 111D). Before the therapy the coordinated movements were rather arrhythmic (Fig. 112A). Already after 2 months of therapy the coordination dynamics improved substantially (Fig. 112B); the variation in rhythmicity decreased. But the coordination dynamics is still far from being normal when compared to that of a healthy person (Fig. 110A). The variation of rhythmicity is far more complex; it cannot only be described as small for the easy and large for the difficult coordination. Sometimes, also the easy coordination was difficult to perform by the patient. Only a detailed analysis including Fourier analysis will bring further insight into the pathologic functioning of the lesioned CNS. The therapy is continued.

In another 51-year-old hemiparetic patient (stroke, right sided) with a strong impairment of speech, the coordinated spelling of letters shown on the screen (like in Fig. 111B) made the patient speak again the letters M, N, R and Z after 1.5 hours of coordinated speech therapy.

It seems therefore that the coordinated activation of movements, vision, speach and audition is beneficial for the functional reorganization of the lesioned CNS.

81. Reduction of spasmolytica in spinal cord and brain stem lesion (case 27)

A 36-year-old patient (Fig. 109A, 113) had an accident during riding a bicycle and suffered a spinal cord lesion sub C4/C5 and partly sub C2 due to hemorrhage. The brain stem seemed to be partly also lesioned by the bleeding, because the patient had an unusually strong spasticity in arms and legs (in spite of a spasmolytic having been administered), and his breathing was impaired. Two years after the accident coordination dynamic therapy was started. Three months of coordination dynamic therapy (4 to 6 hours per day) resulted in a reduction of the spasmolytic drug from a very high dosis (120 mg Baclofen per day) to zero.

After 5 months of little progress (apart from the withdrawal of the spasmolytic), the patient´s movement functions suddenly made a step forward. The patient can now turn 4500

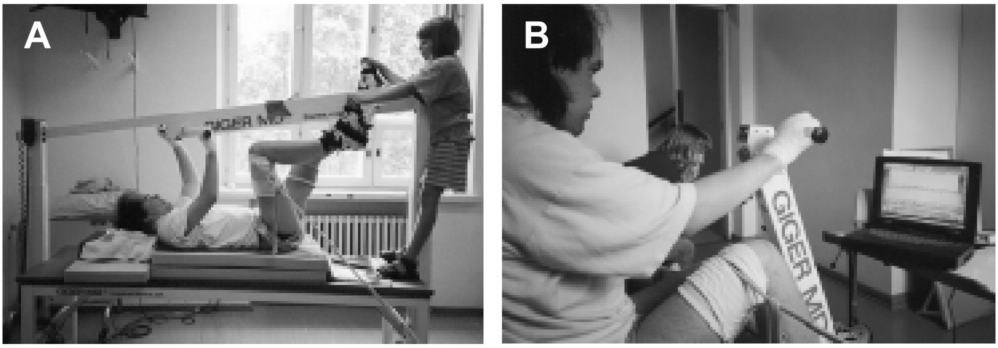


Figure 113
A The 36-year-old patient during spasticity reduction in the lying position. The position of the arms and hands can be adjusted by two motors the device is equippped with. To loose not all volitional power by fighting against spasticity, the movements are first supported (by one of his daughters). When the family is around the patient, he is in a good mood and optimally prepared for hard exercise. B. After reduction of spasticity (A), the patient is exercising by himself in the sitting position. He watches his coordination dynamic recording. In the background his wife can be seen who helps by supporting his legs.

times per day by himself in the sitting position, while before the sudden change he only managed 1000 turns. At the beginning of the therapy he only managed to perform a few turns by himself in the lying position (Fig. 113A). The sitting position became possible (Fig. 113B) because of the reduction of pain and hypersensitivity in the sacral range, especially the sacral skin. Probably, the pain subsided because of a better processing of the afferent input in the neuronal networks as a result of the improvement of the CNS organization. The hands have still to be fixed. With the hands not fixed with bandages and held to the handles, the therapist can feel the improvement of the movement state because approximately after 10 turnns the patient manages to hold the handles partly himself. Of course, the patient always tries to help volitionally to perform the movement. The therapy is continued.

In this case, the learning-therapy was superior to pharmacotherapy, and the side effect was an increased fitness.

82. Diagnosing complete and incomplete spinal cord lesion (cases 28, 29)

A 28-year-old patient with a complete thoracical spinal cord lesion sub Th7 started coordination dynamic therapy 3 months after the spinal cord lesion and became incomplete following 5 months of coordination dynamic therapy. After 9 months of the therapy, he could move the legs in coordination with the arms during swimming and could take the crawling position and move the right leg forwards. The coordination dynamic recording from before the therapy is shown in Fig. 114A, that taken at the time when he turned incomplete (approx. 8 months later) is shown in Fig. 114B. It can be seen from Figure 114 that the spinal cord lesion has become incomplete: during the therapy, the arms and legs started to move in changing coordination on the equipment (Fig. 114B) whereas this could not or only little be observed before (Fig. 114A). This means that the intumescentia cervicalis started to communicate with the intumescentia lumbosacralis, which means that a functional connection across the spinal cord lesion area was established. The comparable large variation in the rhythmicity is partly due to the right stiff elbow joint which hindered the right arm movement.

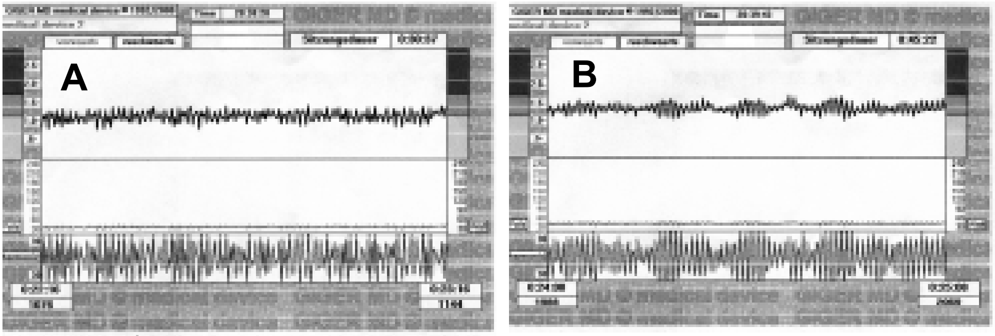


Figure 114
Coordination dynamic recordings from a 28-year-old paraplegic patient (lesion sub Th7) before (A) and after 5 months of coordination dynamic therapy (B) exercising on the special coordination dynamic therapy device, on the average 12,000 turns per day and 6 days per week. Notice that the lower trace showed no or only little continuous rhythmic changes before the treatment (A) and showed rhythmic changes in the amplitude after 5 months of therapy (B).

Figure 115
Improvement of movements in a 25-year-old patient with a clinically complete spinal cord lesion sub C4/5 during 5 months of coordination dynamic therapy. The first own movement to cross distance was creeping with big effort (A; the author G.S. is creeping in interpersonal coordination). After 5 months of therapy, the patient manages to stay on his feet by supporting himself with two arms (B) or even with one arm (C). In B, C, the author is checking that the knee and the trunk do not touch the wall bars and that the knees are slightly flexed. Remember that tetraparetics have little arm and hand power because of the lesion of the intumescentia cervicalis.

The continuous changing of the amplitude of variation of rhythmicity during the exercise on the special coordination dynamic therapy device is a diagnostic measure for the completeness or incompleteness of a spinal cord lesion.

Another 25-year-old patient suffered a clinical complete spinal cord lesion sub C4/5. 7.5 months after the lesion, coordination dynamic therapy was started. During 5 months of therapy, the patient´s lesion became essentially incomplete. First, the patient could creep a bit with big effort (Fig. 115A). After a while, he could creep easily, managed to crawl, and after 5 months he could train in the upright position and stand by supporting himself with two arms (Fig. 115B), with one arm (Fig. 115C) and without any support later on. The knees were not

Figure 116
A 25-year-old formally tetraplegic patient (spinal cord lesion C4/5) during training on the special coordination dynamic therapy device in the lying position to enhance especially trunk stability. A therapist is helping to increase the rotational movements of the trunk. The hands are fixed to the handles and the legs are brought in the physiologic position by support.

overstretched during standing, that means that he was not using extensor spasticity (spastic crutch) or overstretched knees for standing. The patient was exercising quite a lot the coordination of arms, legs and trunk in the lying position to enhance trunk stability. The rotational movements of the trunk were sometimes supported by a therapist (Fig. 116) to enhance the movements, because tetraplegics have little arm and hand power due to the partly distroyed motoneurons and the neuronal networks in the intumescentia cervicalis.

A comparison of the coordination dynamic recordings before (Fig. 117A) and after two months of therapy (Fig. 117B) shows an improvement in the organization of the CNS. As soon as after two months of therapy (Fig. 117B), the coordination dynamics was nearly as good as that of the author (G.S.; Fig. 110). Thus, the functional reorganization of the patient´s lesioned CNS was already very good after two months of therapy. The continuation of the therapy was therefore designed to induce neurogenesis, cell proliferation and neurite growth with respect to functional reorganization. The good coordination dynamics illustrated in Figure 117B is not astonishing since the patient used to be a very good hockey player before the accident and it seems that athletes have a better prognosis when performing coordination dynamic therapy. The coordination dynamic recordings before the therapy (Fig. 117A) suggested that the the patient had likely suffered an incomplete spinal cord lesion and that he may be able to get onto

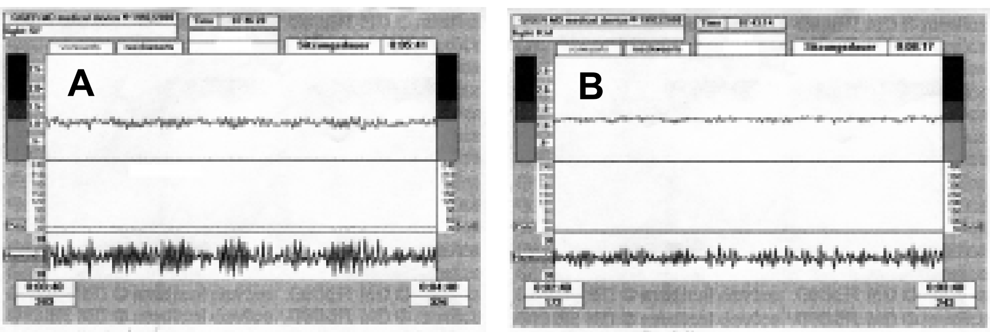


Figure 117
Recordings of the coordination dynamics from a tetraparetic patient (spinal cord lesion sub C4/5) before coordination dynamic therapy (A) and after 2 months of therapy (B). Notice that the coordination dynamics improved substantially with therapy. The recording in A suggested that the patient´s lesion is most likely incomplete (also supported by the fact that he could move 3 toes on one foot a few millimeters) and that he has a reasonable good prognosis to walk again.

his feet again after an intensive long-term therapy. This prognosis encouraged the patient to start the therapy.

83. Coordination dynamic diagnosis in cerebral palsy and stroke (cases 30, 31)

A 28-year-old female patient with a brain lesion since birth (CP) improved her arm and leg functions after 2 months of coordination dynamic therapy. An improved pattern of coordination dynamic can be seen when comparing post-therapy (Fig.118B) to pre-therapy records (Fig. 118A). Before the therapy, she sometimes even topped turning when exercising on the special coordination dynamic therapy device (the upper curve reached the baseline = zero velocity; Fig. 118A). After 2 months, (Fig. 118B) there were no stops seen at the upper trace, and both traces suggest that the easy coordination could already be performed quite well, only the difficult coordination showed large arrhythmicity. The therapy is continued.

A 34-year-old stroke patient showed substantial improvement in his motor functions on the left paretic side, and there was also a substantial improvement in the coordination dynamics at the same time. The coordination dynamics before the coordinaton dynamic therapy

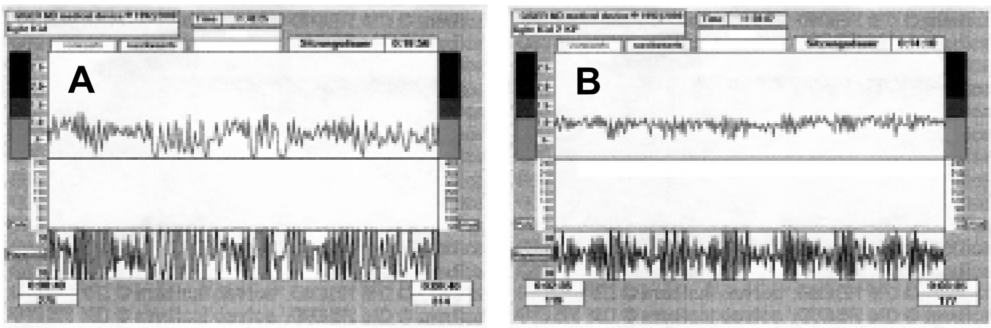


Figure 118
Recordings of the coordination dynamics of a 28-year-old patient with a brain lesion since the birth (cerebral palsy) before coordination dynamic therapy (A) and after 2 months of therapy (B). The variation of the rhythmicity amplitude reduced (improved) from A to B by more than 50% (upper (velocity) trace). The frequency of turning also increased. The measured improvement of the coordination dynamics was in accordance with the improvement of arm and leg movements.

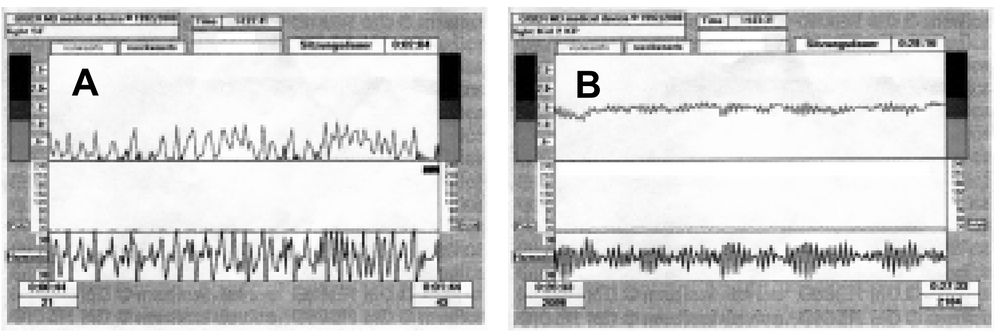


Figure 119
Recordings of the coordination dynamics of a 34-year-old female stroke patient before (A) and after 2 months of coordination dynamic therapy (B). The amplitude of variation of rhythmicity reduced by more than 60%.

showed irregularities with even some changes of the turning direction (Fig. 119A). As soon as after 2 months of therapy, the turning became more rhythmical and the frequency of turning increased (Fig. 119B). The complicated rhythmic changes in the amplitude variability of the rhythmicity (Figure 119B) suggest complex changes in the organization of the lesioned CNS; in other words, a competitive interplay took place between the existing coordination dynamics and the to-be-relearned movement patterns.

84. Anti-stress therapy in the space

Astronauts seem to have a shorter life expectation than average people. E.g., astronauts are known to develop irreversible osteoporosis. Their CNS is exposed to strong stress not only because of the unusual tasks but also because gettin a different afferent input due to the missing gravity and other changes as compared to the conditions on Earth. Partly, this stressful situation can be reduced by exercising on a special coordination dynamic therapy device which needs no gravity for training. Apart from keeping the body fit, the astronauts´ coordination dynamics could be easily measured on-line and digitized data could be sent to the control station. In this way, the terrestrial control station would have direct measurements available of the organizational state of the astronaut´s CNS. If the coordination dynamics becomes poor (cf. Figure 110B,D) due to too much stress and work and/or to little sleep, the astronauts could be instructed to sleep more and to get more coordination dynamic training.

85. The value of the coordination dynamic diagnosis

The recording of coordination dynamics provides information concerning the functional state of the CNS. The observed changes of CNS organization are of qualitative nature and allow follow up studies of the CNS of single patients. The order parameters for the integrated organization of the human CNS are the coordination dynamic parameters measured from the coordination dynamic recordings, for the moment including (1) the amplitude of variation of rhythmicity, (2) amplitude differences of rhythmicity between easy and difficult coordination, and (3) phase shifts of easy and difficult coordination.

The progress in the functional reorganization of the lesioned CNS of a patient cannot only be measured by the progress in performing certain movements (or EMG motor patterns), but also directly by the improvement of the functional reorganization. This diagnostic tool can also be used to measure the progress in other treatments, such as pharmacotherapy. The advantage of this diagnostic tool to measure the organizational state of the CNS of a patient or volunteer during treatment is that it is quick, cheap, healthy and non-invasive.

New measurements of phase and frequency coordination of single neurons and neuron assemblies are needed to assess the effects of the coordination dynamic therapy, and also diagnostics. Macroscopically a detailed analysis of the coordination dynamic recordings with respect to order parameters are needed to describe the changing integrated functions of the human CNS.

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The tremendous effort to get hold of recordings from brain dead individuals (HTs) should be emphasized. The clarification of the anatomy of the lower spinal cord and cauda equina in extreme detail [103,195,196] took 2 years to work in a pathology department. With 5 to 10 trials per successful case it was possible in 7 years to obtain

records from 7 HTs; when the brain death appears, the remaining functions of the body are mostly quickly lost; the 'best' cases were used for kidney explantation. In addition to obtaining permits from Ethical Committee and the relatives, every person involved had to be convinced about the necessity to do the recordings, which was difficult at the beginning of the research project. The mental stress when working with HTs was immense, especially when the author (G.S.) was attacked ethically. However, the successful outcome that nearly every malfunctioning CNS can substantially be improved in its organization roots in the high quality single nerve fibre action potential recordings from the HTs. Actually, the work on HTs and human cadavers was needed for the development of the single nerve fibre action potential recording technique in humans.

The case recports herein have been illustrated by many pictures, because physicians and physiotherapists recognize best the pathologic CNS organization they encounter in patients in pictures showing pathologic posture, arm, hand, finger, leg and foot positioning and movements.

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