Overreaching in Coordination Dynamics Therapy in an athlete with a spinal cord injury

G. Schalow, I. Vaher, P. Jaigma

Summary

A motocross athlete suffered a clinically complete spinal cord injury (SCI) during competition. Although MRIs (magnetic resonance imaging) showed a complete spinal cord injury at the Thoracic 11/12 levels, surface EMG recordings indicated the survival of few tract fibres across the injury site. Six weeks after the accident the subject began intensive Coordination Dynamics Therapy (CDT) at an up-to-date therapy centre. The subject trained at his physical limits to induce structural and functional repair. Exercising at variable loads between 20 and 200N (on a special CDT and recording device) generated periods of overreaching and super-compensation. By plotting coordination dynamics values (kinesiology), including high-load exertion (200N) and hysteresis curves, periods of overreaching and super-compensation were made graphically visible. It was found that symmetrical improvements of central nervous system (CNS) functioning occurred during overreaching. Improvements in spinal cord functioning were achieved throughout one year of CDT in this chronically injured subject with an almost anatomically complete SCI. It is discussed that the measuring of CNS functions by means of recording coordination dynamics is a powerful and non-invasive tool ideal for exact quantitative and qualitative measurements of improvement (or change) in CNS functioning. Such diagnostics may be of particular importance in sport during training and before competition. Also, coordination dynamics might be used to measure the effects of prolonged exposure to reduced gravitational conditions on CNS functions, such as faced by astronauts.

Key-words: *Spinal cord injury – Athletes – Astronauts – Coordination dynamics – Overreaching – CNS – Self-organization – Symmetry – Gravity.*

Introduction

A movement-based, operative learning therapy, called Coordination Dynamics Therapy (CDT), has led to improve central nervous system (CNS) functioning after stroke (3), traumatic brain injury (4, 15), hypoxic brain injury (14), cerebellar injury (16-18), spinal cord injury (5, 8), cerebral palsy (12), and Parkinson's disease (10, 11). Because up to three years of therapy may be needed, with more than 20 hours movement therapy per week to achieve substantial clinical improvement (achieved by structural and functional repair of the CNS), the efficiency of the treatment is highly important.

An effective functional repair of the human CNS, especially of the spinal cord, can require substantial structural repairs. One assumption of CDT is that natural repair mechanisms are optimally activated when subjects train at their physical limits, including the building of new nerve cells and connections, and that new nerve cells functionally integrate into existing, but impaired neuronal networks. Substantial functional improvements achieved through CDT usage may support this assumption of CNS structural repair. This paper presents specific details we believe should be considered when training CNS-injured subjects at their physical limits. Overreaching and super-compensation (1, 2) of an athlete who

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Institute of Exercise Biology and Physiotherapy, Centre of Behavioural and Health Sciences, University of Tartu, 5 Jakobi Street, Tartu 51014, Estonia.

suffered a spinal cord injury during competition are quantified by coordination dynamics (6, 7, 16, 17) while training at his physical limits during CDT.

The CDT training of patients with spinal cord injury will be compared with those of uninjured athletes. In order to perform optimally, athletes must be adequately trained. However, if athletes train too intensively and/or too often, they may become susceptible to short-term and/or long-term decrements in performance, as well as a myriad of physiological, medical, and/or psychological symptoms related to overreaching and overtraining. Understanding the pathophysiology of this relationship, including its physiological and psychological markers, may serve to decrease the prevalence of overreaching and/or overtraining in athletes (1, 2).

This article presents similarities between the treatment of spinal cord injury and the training of athletes. It will be demonstrated that overreaching during training of athletes and patients can be assessed non-invasively by measuring the coordination dynamics of arm and leg movements. In athletes, when training at the limits, it may even be possible to predict the phase of super-compensation (following overreaching) where performance is optimal.

Method

Schalow: Coordination Dynamics Therapy (repair strategies)

Coordination dynamics therapy (CDT) is a movement-based learning therapy that improves the functioning of the human CNS following injury, malformation, or degeneration (17, 12, 21 (review article)). CNS-injured subjects are trained in movements that induce CNS repairs and restore its functions most efficiently. These movements can include automatisms (creeping, crawling, standing, walking, running, swallowing, and breathing), and deep-seated learned movements such as climbing staircases. CDT employs the following movements: 1) movements that the patients wants to re-learn for everyday life (such as walking), and 2) rhythmic, dynamic, stereotyped movements to repair premotor spinal oscillators (jumping on the springboard), and 3) precise, coordinated movements on special CDT devices, including: four-limb cyclical rotating movements with changing coordination patterns between arms and legs (Combo AG, Tugginerweg 3, CH-4503 Solothurn), and a self-made, four-limb neurowalker that facilitates *trot gait* and a device that imposes *paced gait* coordination (Ref. 19, following paper). CDT applied movements are derived from theory and human CNS measurements.

Single neuron level of preferential repair: Because of the impairment of the phase and frequency coordination between neuron firing (9, 20, 21), the patient has to train using many different very coordinated movements to improve intra-neuronal phase and frequency coordination and coordination between arm and leg movements. This can be achieved by exercising on special devices that generate exact coordinated movements, which the patient's CNS can adapt to. In this way the patient's CNS re-learns from movement-induced afferent input the exact phase and frequency coordination of neuron firing. When the movements are performed volitionally, the cerebellum will substantially contribute to the functional reorganization by comparing the efferent copy of requested movements with movement-induced afferent inputs, thus developing functional repair strategies for functional improvements (16).

Neural ensemble level of preferential repair: Because of the impairment of phase and frequency coordination between the firings of pre-motor spinal oscillators (20), the patient has to train using rhythmic, dynamic, stereotyped movements (like jumping on the springboard). This enables neural ensembles (the network oscillators) to improve their 'Eigenfrequencies' (individual members of the neural ensembles improve their coordination within the network oscillator, improving the network's unified function) and to improve phase and frequency coordination of firing with *other* neural ensembles and with other neurons that fire occasionally. This part of CDT was formerly referred to as "oscillator formation training."

Symmetry repair: Since movement symmetries (which structure the state-space of coordinated movement patterns (22, 23)) are impaired following injury, or in the pathologically functioning CNS, multiple symmetries must be retrained for repair (16, 17). The symmetries of pace and trot gait, which are mainly located in the spinal cord, are particularly relevant when using CDT following spinal cord injury. All movements should be performed in forward and backward directions for mirror-image symmetry repair.

Movement level of repair: Since movements are lost or impaired, patients must be trained to regain these movements. Movements should be predominately practiced that have the highest efficiency of repair given the patient's evolving condition. Since inborn 'automatisms' play a key role in human development, genetics probably support the repair of these movements. Learned automatisms (like climbing staircases), which have very high pattern stability in the CNS, are partly preserved in the CNS following injury. Further, automatisms probably require less volitional control for activation, thus requiring fewer tract fibres and fewer repairs. Automatisms therefore represent initial functional targets for re-activation through CDT. Automatisms like crawling, walking and running (4-limb movements) are integrative CNS activations that include substantial activation of breathing and circulation. Therefore, using these movements CDT facilitates learning transfer through integrative repairs of the CNS, leading to improvements in movement performance and functions. Movements such as running, or jumping on a springboard, improve vegetative functions, such as continence and sexual functions.

The human CNS is an open system. When training only one part of its neural networks the pathologic organization may escape to another part of neuronal networks (15). Integrative activations of the CNS have the best chance to 'catch' the pathologic organization and repair it, since activated movement patterns are very integrative (like running) and the movement induced afferent inputs are also highly integrative.

Coordination detector principle for repair: Since neurons work as coincidence, or more generally as coordination detectors, the threshold for action potential generation is reached earlier in the axon hillock for coordinated input than for uncoordinated input (see Fig. 4 of Ref. 24). Coordinated activation that spans the injury site will induce increased impulse traffic over the injury site, in the rostral and caudal direction, between the intumescentia cervicalis (where the stereotyped arm movements are mainly located) and the intumescentia lumbosacralis (where the stereotyped leg movements are mainly located). Surviving nerve fibres over the injury site can thus be optimally used for functional repair. To activate most (or all) of the spared tract fibres for functional repair, various precise coordinated movements must be exercised.

Structural repair: When training at the physical limits, the over-loaded nerve cells and connections at the injury site (seen from the functional aspect), will induce building of new nerve cells and connections (this is a hope and assumption that needs to be proven). The adequate stimulus for neurogenesis will probably be present where overloading is taking place. It therefore seems likely that neural structural repairs may involve specific activation mechanisms similar to functional (neural firing, i.e., phase/frequency) repairs.

In conclusion concerning CNS functional and structural repairs, the System Theory of Pattern Formation (applied to the injured CNS) provides a blueprint for understanding how the injured or pathologically functioning CNS can be repaired (17). In particular, the System Theory of Pattern Formation provides insights regarding the transference of afferent input from CDT into increased movement pattern stability, including positive effects on spasticity. The neurophysiology of the human nervous system (for review see Ref. 21) tells us what must be repaired in the injured human CNS and how to achieve the repairs.

For further information about CDT see References 12 ("Methods" section) and 17 (System Theory of Pattern Formation and Symmetry).

Measuring methods for diagnosis and quantifying progress

Standard methods of magnetic resonance imaging (MRI) and surface electromyography with differential input were used. The quality of CNS organization was quantified by coordination dynamics recording of arm and leg movements (kinesiology). One aspect of CNS organization is quantified by measuring the arrhythmicity of turning (df/dt; f = frequency), when exercising on a CDT device that involves rotating movements with changing coordination patterns between arms and legs. The best mean arrhythmicity of exercising over 1 min is used as the coordination dynamics value. Since coordination

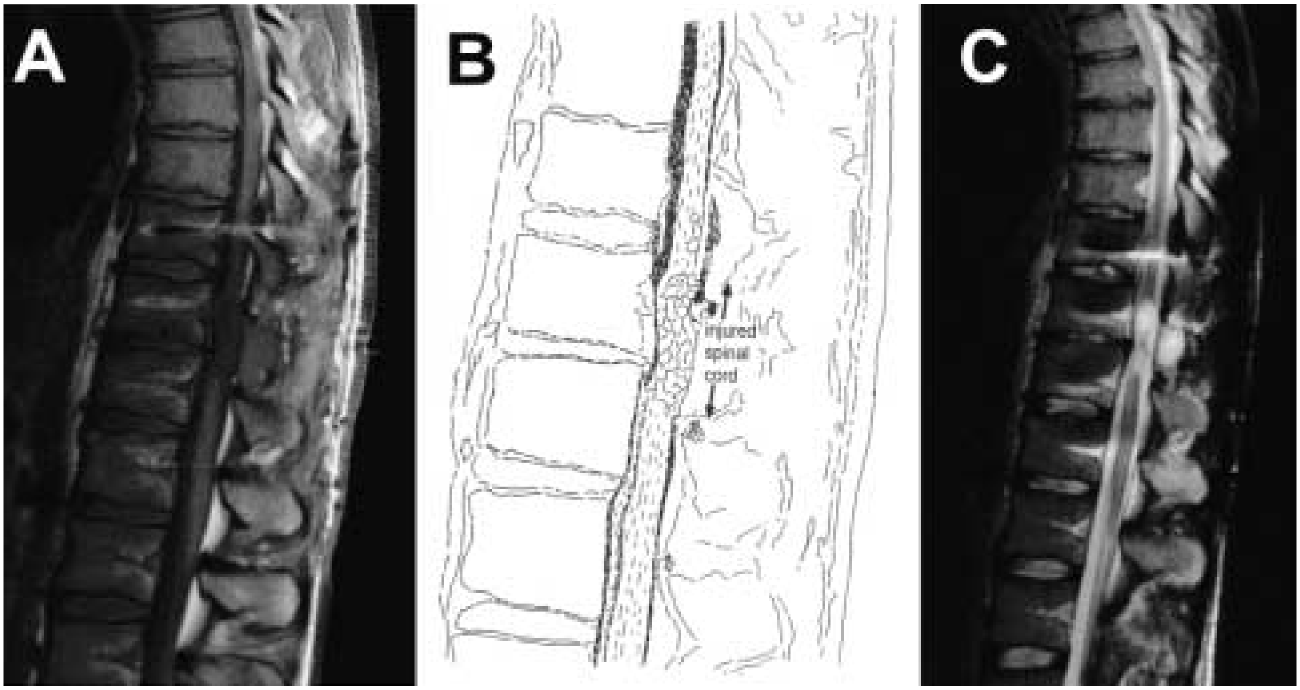

Fig. 1. – A. MRI of the patient with a spinal cord injury Th11/12 (T1). Over a length of 2.3 cm the spinal cord shows no healthy nervous tissue. B. Redrawn injured area (from A) to show more clearly the honeycomb structure. C. MRI in T2. In A,C artefacts present from the 4 titanium screws of the fixation.

between arms and legs change continuously between pace (camel walking, one side against the other side) and trot gait (dromedary, coordination crosswise) via intermediate coordination stages, where substantial supraspinal control is needed, large parts of the CNS are activated for evaluation.

Within the framework of the System Theory of Pattern Formation (applied to the injured CNS), coordination dynamics evaluates CNS functioning by measuring the stability of movement patterns (pictured in the attractor lay-out) by means of pattern change when exercising on a special CDT device that facilitates continuously evolving rotating arm and leg movements between pace and trot gait. The stability of different movement patterns are quantified by the arrhythmicity of exercising: Greater degrees of arrhythmicity characterize low movement stability; slighter degrees of arrhythmicity indicate greater movement stability. A healthy person can only crawl in pace or trot gait coordination, because these coordination patterns have a very high stability. Intermediate coordination stages between pace and trot gait have such a low stability that without learning or assistance they cannot be performed. But when exercising on the special CDT device for rotational movements in the sitting, lying or standing positions, a healthy person with a good functioning CNS can perform these intermediate coordination stages. The device's designed impositions of movement serve to minimize the degree of arrhythmicity between pace and trot gate, which assists the learning and improvement of movements. Therefore, it is easier for the body to adapt and adopt a movement, than to generate the movement spontaneously without help of the instrument.

Functional anatomy (MRI)

The patient showed clinical signs of a (functionally) complete spinal cord injury: no quantifiable motor functions below the injury level and no sensitivity. However, did the patient really suffer an anatomically complete spinal cord injury (or only an incomplete one)? An MRI (magnetic resonance imaging) was taken 6 months after the injury, at a time when the macrophages should have taken away the damaged nervous tissue and the extent of the injury should be visible. As Fig. 1A shows, the MRI indicates a complete spinal cord injury over a length

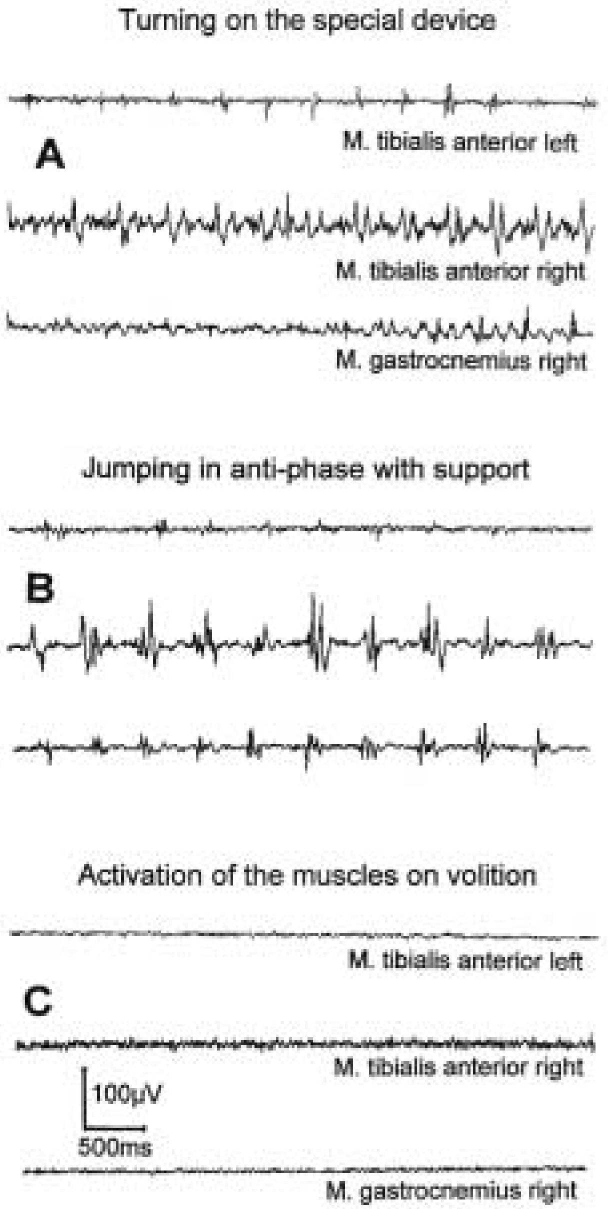

Fig. 2. – Surface EMG of the left and right tibialis anterior muscles and the right gastrocnemius muscle, performed when exercising on the special device for turning (A), when jumping on springboard in anti-phase (B), and when activating the muscles on volition (C). Note that the muscles cannot be activated on volition; but they can be activated during jumping and exercising on the special device for turning.

of approximately one vertebra (2.3 cm). In Fig. 1B a drawing of the MRI is performed to more clearly present the injured area of the virtual section.

Even though the different virtual sections indicated a complete spinal cord injury (Fig. 1A, C), some surviving tract fibres likely remain intact at the injury site. This possibility stems from knowledge of peripheral nerve injury. If one squeezes a peripheral nerve with forceps so forcefully that it seems obvious that all nerve fibres are destroyed (one can look through the damaged nerve), still some fibres will remain intact. After fixating and staining a peripheral nerve so damaged, healthy fibres can be found that survived. Therefore functional measurements are needed to prove whether some intact tract fibres survived at the spinal cord injury site. In other words, it had to be proven functionally whether the spinal cord injury was really fully complete in this patient. This is because if there are some tract fibres left, then there are still running connecting fibres across the injury site and regeneration may be possible. A spinal cord cut with scissors (which would be a real complete spinal trans-section) may not regenerate.

Functional evaluation of the injury site by sEMG

Surface electromyography (sEMG) was performed after 4 months of CDT shortly after taking the MRI (Fig. 4). Recordings were taken from the tibialis anterior and gastrocnemius muscles (Fig. 2). No muscle activity could be seen when the patient tried to activate the muscles on volition (Fig. 2C). But when jumping on a springboard in anti-phase (with support by a therapist) or when turning on the special coordination dynamics therapy and recording device (for turning movements), these muscles were seen to be activated (Fig. 2A, B). Also while jumping in abduction and adduction, motor programs could be activated. Motor programs were best for jumping on the springboard in anti-phase. Therefore the recorded sEMG indicates that the thoracic spinal cord injury was very severe, but not absolutely complete. The MRI (objective measure) and the thorough clinical evaluation give therefore only approximate information on the degree of the spinal cord injury.

In comparison to a sEMG made 3 months earlier (one month after therapy begin) (not shown), a slight improvement could be seen in the motor programs. The left tibialis anterior muscle was activated only during the second sEMG recording. This indicates a bit of regeneration quantified by sEMG.

Movements supporting an incomplete injury and improvement

Improvement of motor functions could also be quantified, when the patient exercised on the special device for turning in the lying down position. The power of turning, when using only the legs (bicycle type movement), improved with therapy. At the beginning the patient could only turn against 20N, but later on could turn against 50N (Fig. 3). According to the spinal cord injury site (Th11/12), some parts of the abdominal muscles (inserting the pelvis) remained probably innervated and could be activated on volition. The improvement in muscle power still indicates a bit of regeneration or recovery.

Definition of overreaching and overtraining in sport

Overreaching: An accumulation of training and/or non-training physical stress resulting in a long-term decrement in performance capacity with or without related physiological and psychological signs and symptoms. Restoration of performance capacity may take several days to several weeks.

Overtraining: training at (or exceeding) ones physical limits without adequate rest, inducing general fatigue and muscle breakdown. Restoration of performance capacity may take much longer times (from several weeks to several months).

Overreaching and overtraining in neurotherapy: Has not been considered so far.

Results

A 34-year-old motocross sportsman suffered an anatomically complete (according to the MRI, see below) thoracic spinal cord injury (T11-12) during competition. Four weeks after the accident coordination dynamics therapy (CDT) was started in an up-to-date therapy centre. The patient was informed that at least 3 years of CDT are needed for a partial repair. From the beginning of the therapy it was obvious that the patient was willing and able to train at his physical limits. Low-load, high-load, and symmetry coordination dynamics were measured to insure that the subject trained at his limits without long term overloading. From high-load coordination dynamics hysteresis curves, generated by exercising at increasing and decreasing loads between 20 to 200N, it was determined whether the patient's CNS and body were overloaded. When the coordination dynamics values for decreasing loads became higher (worse) than for increasing loads, then the patient was exhausted. Since the patient had plenty of arm power, the coordination dynamics values for 200N were plotted, in addition to those for 20N (low-load test). 200N loads require that the legs be substantially used to reduce the load-stress. High load, 200N coordination dynamics values were therefore most characteristic for showing leg improvements in this patient.

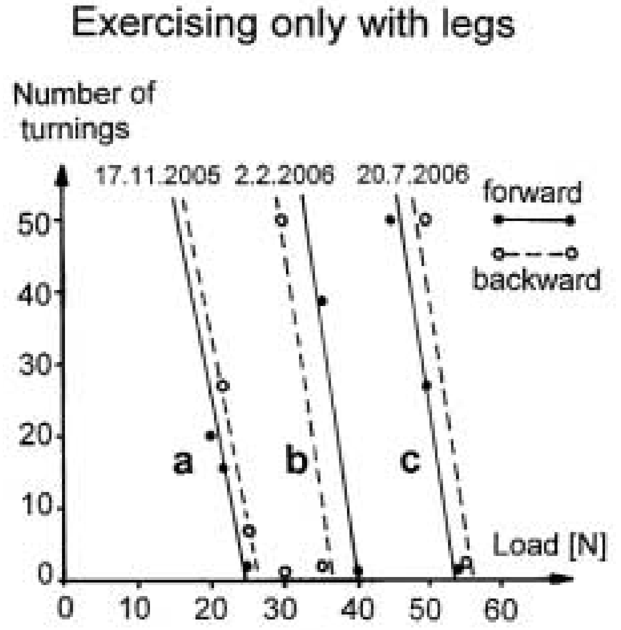

Fig. 3. – Improvement of leg muscle power with ongoing therapy. Increasing leg power is quantified by the increasing turning load in Newton when exercising only with the legs on the special coordination dynamics therapy device in the lying position. The number of manageable turnings depends critical on the load against of which the patient has to turn.

Fig. 4 shows the coordination dynamics values for 20N (lower trace) and for 200N (upper trace). Schematic hysteresis curves are attached to the 200N curve to indicate whether the patient was exhausted or not.

Low-load coordination dynamics values improved (became smaller) quickly and remained constant once the patient reached very good values. The subject's coordination dynamics value of 1.5 s^{-1} for low-load

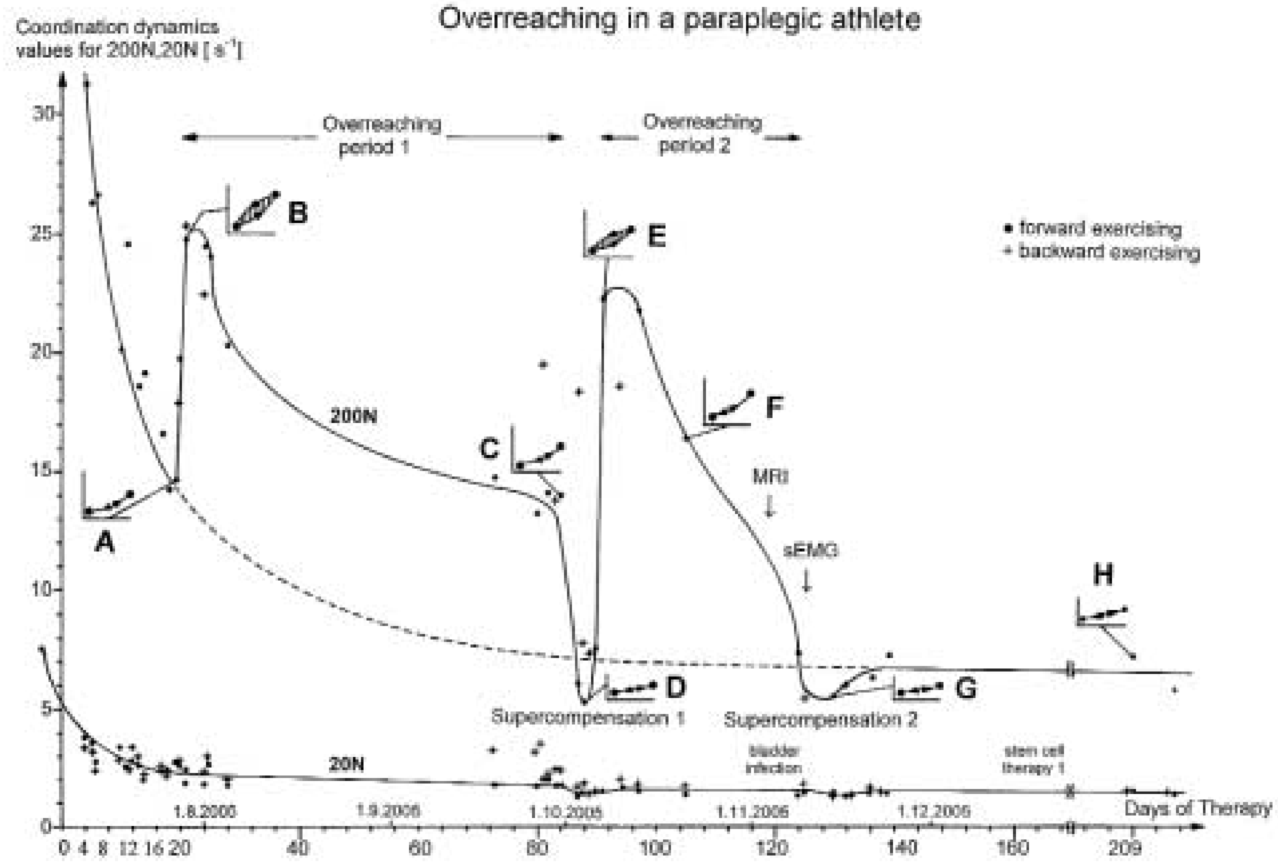

Fig. 4. – Low-load (20N, lower trace) and high-load (200N) coordination dynamics values in dependence on days of therapy for forward exercising. Dashed line indicates improvement of 200N-coordination dynamics values without overreaching. A-H, schematized hysteresis curves (for increasing and decreasing load) to show exhaustion; details of the hysteresis curves are shown in

exercising was much better than that of a healthy person (around 5 s^{-1}), when training the first time (6). Therefore, the low-load coordination dynamics curve failed to provide therapeutically instructive information.

Coordination dynamics measurements for quantifying improvement of CNS functioning and periods of overreaching and super-compensation

The curve obtained from coordination dynamics values for loads of 200N reveal characteristic changes. First, coordination dynamics improved substantially because measured values sharply declined. This improvement may have continued with ongoing therapy (indicated by the solid and dashed lines) if there would not have been overloading or overreaching intermediately (Fig. 4). The hystereses curve in 'A', attached to the 200N-curve does not indicate overloading. But when pushing the patient to the limits with high-load exercising, the coordination dynamics values increased strongly and the hystereses curve shows exhaustion (B). Even after 2 months of therapy the coordination dynamics values for 200N were still very high, but the hystereses curve (C) does not show any more overloading. At that point the coordination dynamics values improved strongly (the values reduced strongly) and gave rise to a super-compensation period with very good performance. During this super-compensation (period 1), the coordination dynamics values were extremely good. The hystereses curve (attached to the 200N-curve) does not show (of course) overloading (D).

With a second pushing of the patient to the limits, the coordination dynamics values increased strongly (got worse) (Fig. 4). The hystereses curve again shows overloading (E). With the reduction of the load, the hystereses curve shows no overloading any more (F), even though the coordination dynamic values were still very high. However, a second period of super-compensation occurred, resulting in another strong reduction of coordination dynamics values. During this second period (Period 2) of super-compensation the hystereses curve again indicate no short-term overloading (G).

With ongoing therapy, 200N-load coordination dynamics values slowly declined further and the hystereses curves showed no exhaustion (H). The patient felt a bit tired during these overreaching periods. Blood pressure measurements in the morning did not show higher values than in the evening, which would have indicated an overloading. It was noted that in both periods of super-compensation overreaching (or overloading) was over (quantified by the hysteresis curves C and F in Figs. 4, 5) prior to sharp declines in coordination dynamics values. The disappearance of overloading in the hysteresis curves before strong reductions of the coordination dynamics values for 200N may indicate that at least two mechanisms were working in the patients' CNS during overreaching. The details of the hysteresis curves of Fig. 4 are given in Fig. 5 (with corresponding 'A' to 'F').

Periods of increased coordination dynamics values for 200N lasted approximately 72 and 32 days (Fig. 4). According to the definitions in sport (see Method section) the first long period of increased coordination dynamics values would indicate overloading and the second shorter period may indicate overloading or overreaching. But in the case of spinal cord injury, the length of overreaching and overloading periods may be different (longer), since only a part of the body is working properly and at least a part of the CNS (caudal spinal cord) is functioning pathologically. Also repair mechanisms may work more slowly, especially shortly after injury. Since the blood pressure in the morning was not higher than in the evening, it is likely that both periods were signs of overreaching and not overloading.

Symmetry improvement of CNS functioning achieved by overreaching

The primary goal of training the patient at his phyical limits was to enhance functional repair and to induce structural repair. It may therefore be possible to find CNS improvements in this patient that were induced by overreaching. Following the periods of overreaching, super-compensation occurred. In that period the patient could perform the coordinated movements very well and he felt very good. An athlete's performance would be optimal at during this period. Since periods of super-compensation were brief, they may not indicate repair. The second period of overreaching lasted shorter, although coordination dynamics values for 200N more sharply increased. This shorter overreaching period may suggest partial repairs.

Prior to the first period of overreaching (period 1), coordination dynamics traces for 200N show no sign of symmetrical impairment between forward (Fig. 6A) and backward exercising (Fig. 6B). However, when the patient became overloaded one day later, coordination dynamics traces reflect increasing and decreasing arrhythmicity of turning, which differed for exercising in the forward (Fig. 6C) and backward direction (Fig. 6D). This indicates symmetrical impairment. The smallest arrhythmicity of exercising (highest stability of movement pattern) lies for forward exercising to the left of the trot gait coordination (K) (φ = -60°) and for backward exercising to the right side of the trot gait coordination (φ = + 70°) as indicated by arrows in Fig. 6C,D. Forwards and backward exercising under overreaching conditions therefore made a symmetry impairment of CNS functioning visible.

During super-compensation period 1 and before the second overreaching period (period 2), the coordination dynamics traces show no rhythmic changes of pattern stability for forward (Fig. 6E) and backward exercising (Fig. 6F) and thus no more symmetry impairment (as expected). During the overreaching period 2, the coordination dynamics values for 200N are strongly enhanced again, but no rhythmic changes of the arrhythmicity of exercising and no symmetry impairment can be seen (Fig. 6G, H). It seems therefore that during the overreaching period '1' a symmetry improvement took place in CNS functioning.

In conclusion, training at the limits (quantified by periods of overreaching and supercompensation) led to qualitative improvements in CNS functions in this severely injured patient (sportsman) with a functionally complete spinal cord injury, whose injury also appeared (by MRI) to be anatomically complete. Whether overreaching induces substantial structural repairs needs to be demonstrated.

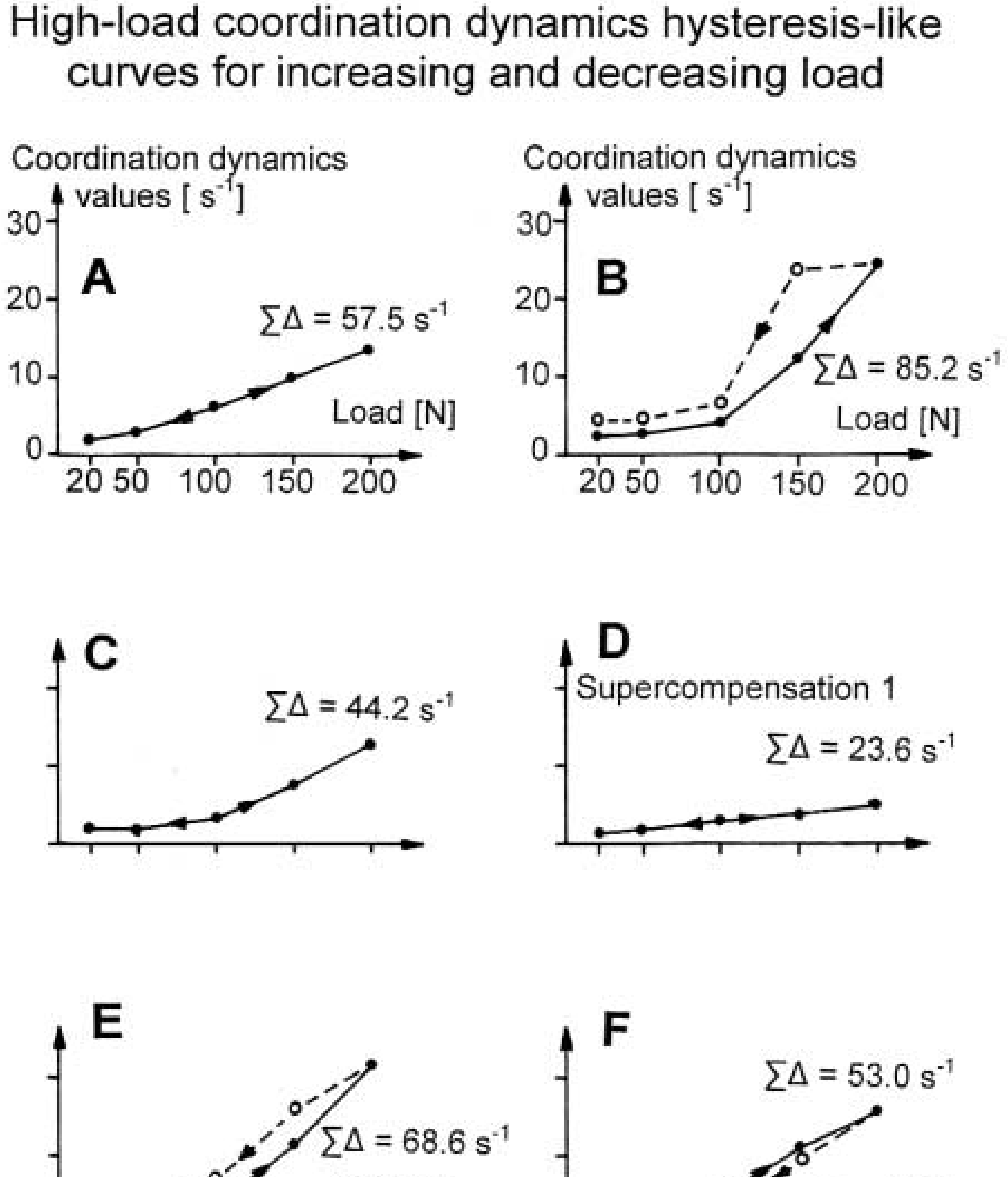

Fig. 5. – Periods of overreaching, supercompensation, urinary bladder infection, and first stem cell therapy are indicated.

Fig. 5. – Shape of hysteresis curves in dependence of overreaching and supercompensation. Note that during overreaching (B, E) the coordination dynamics values are higher for decreasing load than for increasing load (indicating exhaustion). Note further that during supercompensation (D, G) no exhaustion occurs and also the sum of the coordination dynamics values (ΣΔ = Δ20 + Δ50 + Δ100 + Δ150 + Δ200 + Δ150 + Δ100 + Δ50 + Δ20 + Δ20) for increasing and decreasing load are lowest.

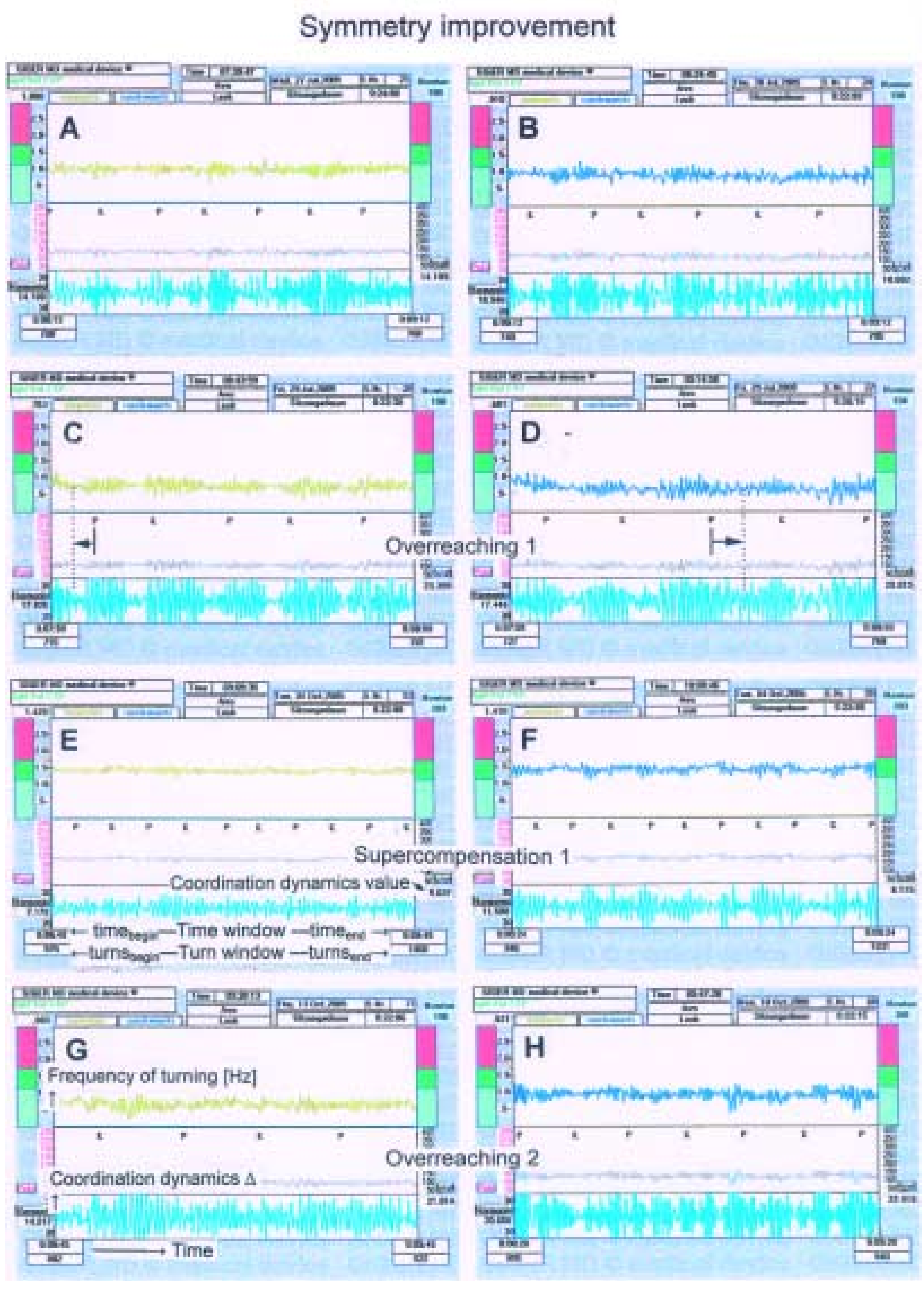

Fig. 6. – 200N-Coordination dynamics 1 min-traces before overreaching period 1 (A, B), during overreaching 1 (C, D), during supercompensation period 1 (E, F), and during overreaching period 2 (G, H). Note the improvement of symmetry impairment of CNS functioning between forward and backward exercising from C, D to E, F. Forward exercising = A, C, E, G; backward exercising = B, D, F, H.

Discussion

Overreaching during coordination dynamics therapy

When administering coordination dynamics therapy to patients one tries to achieve functional and structural repairs. A basic assumption in this therapy is that all repair mechanisms are activated by training at the physical limes, including the formation of new nerve cells and the building of new neural connections in the adult CNS. While training at his limits a spinal cord-injured athlete displayed physical characteristics of overreaching, as occurs in athletes while training for sports. In this patient, overreaching while training led to improved CNS functioning. Symmetries improved during the first period of overreaching. It remains to be determined whether substantial building of new nerve cells can be induced. The slight improvement in motor functions may indicate a slight increase of functional connectivity over the injury site.

Since the coordination dynamics hystereses curves for increasing and decreasing loads (Fig. 5) were better than those of uninjured athletes (7), it is proposed that functional repairs achieved these functional improvements.

Coordination dynamics measurements to measure overreaching in patients

Figure 4 clearly shows that overreaching (or overtraining) can be measured non-invasively during training periods on the special coordination dynamics therapy and recording device. When exercising on the special device, the quality of CNS functioning can be evaluated by the arrhythmicity of exercising. Interestingly, the patient's perceptions about his performance during low-load and high-load testing mostly correlated with measured values of coordination dynamics.

Diagnostic tool to measure overreaching in sportsmen

In order to perform optimally, athletes must be adequately trained. However, if athletes train too intensively and/or too often, they may be susceptible to short-term and/or long-term decrements in performance capacity (1). Overreaching is often considered as a normal outcome for elite athletes due to the relative short time needed to recover (approximately 2 weeks) and the possibility of a supercompensatory effect. Presently it is widely accepted as impossible to discern acute fatigue and decreased performance (experienced from isolated training sessions) from states of overreaching and overtraining. This is partially the result of a lack of diagnostic tools (2). However, it is shown in this paper that coordination dynamics measurements can be used as a tool to measure overreaching and overtraining. Moreover, although it has been published that CNS functioning can be improved in athletes (Fig. 5 of Ref. 7), which may optimize their physical performance, this knowledge has thus far remained overlooked by coaches and athletes. CDT and coordination dynamics measuring may provide a practical means for optimizing an athlete's mind/body connections.

Necessity to diagnose CNS functioning of astronauts in space

Training diagnostics, including coordination dynamics measurements, may be of importance not only for sportsmen before competition but also for astronauts spending long intervals in space without gravity. The vestibulocerebellum, responsible for keeping the balance (i.e. for coordination of the muscle activations for posture and movements against gravity (16, 17)), is very poorly activated. The lack of the activation of antigravity system and their coordination with movements may affect the integrative functions of the CNS, including higher mental functions in the long term. The precise monitoring of CNS functioning simultaneously with up-to-date fitness training programs on earth and in space may optimize CNS functioning of astronauts on earth. In space coordination dynamics training and measurement would reveal CNS functional changes due to the lack of gravity and provide diagnostics tools for counteracting these effects.

Stem cell therapy

Figure 4 shows how the CNS of the patient improved with ongoing therapy. The progress was mainly achieved by an optimisation of the functional reorganization of the injured CNS. Little contribution for these repairs are likely to have come from structural repairs, meaning the building of new nerve cells and/or new connections. What can be achieved by a functional re-organization was brought about by this movement therapy. Strong improvements below the injury site in this patient, who has a rather complete spinal cord injury, can probably be achieved only by building of new nerve cells and new connections and by their functional integration into the existing injured neuronal networks. This patient would therefore be an ideal patient to prove whether a stem cell therapy induces the building of new nerve cells and connections in man, leading to substantial improvements of leg functions.

Against the advice of the authors, this patient went for stem cell therapy after 6 months of intensive coordination dynamics therapy. The following paper (19) will report the results of a stem cell therapy and coordination dynamics therapy when administered to this patient.

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Address reprint requests to:
Giselher Schalow
Dr. med. habil., Dr. rer. nat., Dipl. Ing.
Untere Kirchmatte 6
CH-6207 Nottwil
Switzerland

www.cdt.host.sk
g_schalow@hotmail.com