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Required Lokomotor Robot Habilitation and Rehabilitation for Children with Cerebral Palsy During Sleep

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Abstract
The subject of the research is habilitation during slow sleep phase (SSP) ensured by a biotechnical system "child – locomotor robot". The child is cast into slow sleep phase (SSP) by exposure to monotonous action of the locomotor robot thus creating movement stereotypes during recurrent day sessions.

1. Introduction

Over the recent decades new rehabilitation methods have evolved that are based on exposure of patients to external energy in special brain conditions. *Leon Sazbon* successfully developed rehabilitation of adult patients in vegetative state (2001). Patients with paediatric cerebral palsy (PCP) aged between 1.5 and 6 years should not be included into this brain state group, besides patients in this group lack muscular and controlling activity and movement stereotypes. The process of habilitation becomes possible only if the imperative acceleration of a child's locomotor activity is applied through exposure to external energy. The locomotor robot makes it possible to ensure controlled external energy and information flows. Sleep is characterised by inhibition of the organism's active exchange with the surrounding environment. Sleep makes the child available for corrective intervention.

2. The Method

By means of monotonous locomotory actions of robot on a child, the latter is brought into the slow sleep phase (SSP), creating the stereotypes of motion during numerous daily sessions.

Functional essence of the author's method comes down to the use of external energy for activation and normalization of main systems of the body. External energy supplements the internal energy on micro- and macro structural level of the body and provides the patient with possibility of self-recovery [1].

The ideology of the method is basing on realization of the PROCESS OF DISINTEGRATION of mutual interference between the executive periphery and the CEREBRAL STRUCTURES, which contributes to the ESTABLISHMENT OF NEW REFLEX CONNECTIONS, which are consolidated in the process of treatment. The process is carried out with the use of new class of auxiliary technical aids: abilitation locomotor robots.

The philosophy of the method: motion is treatment, wherefrom a necessity directly follows to solve two biomechanical problems on macro level: verticalization of the patient's body and forcing the patient to walk.

Walking process is accompanied by reduction in the difference "pathology (of natural type) – norm (of artificial type), since the sensor correction is realized by a complex (not single but more types of sensors) of motion reflex mechanisms at the spinal level while brain participates in these processes indirectly and passively. This fact allows to compensate the deficiency of muscle activity (DMA) and the deficit of controlling activity (DCA), not depending directly on the degree of brain pathology (i.e. on the type of disease, in particular).

3. The Results

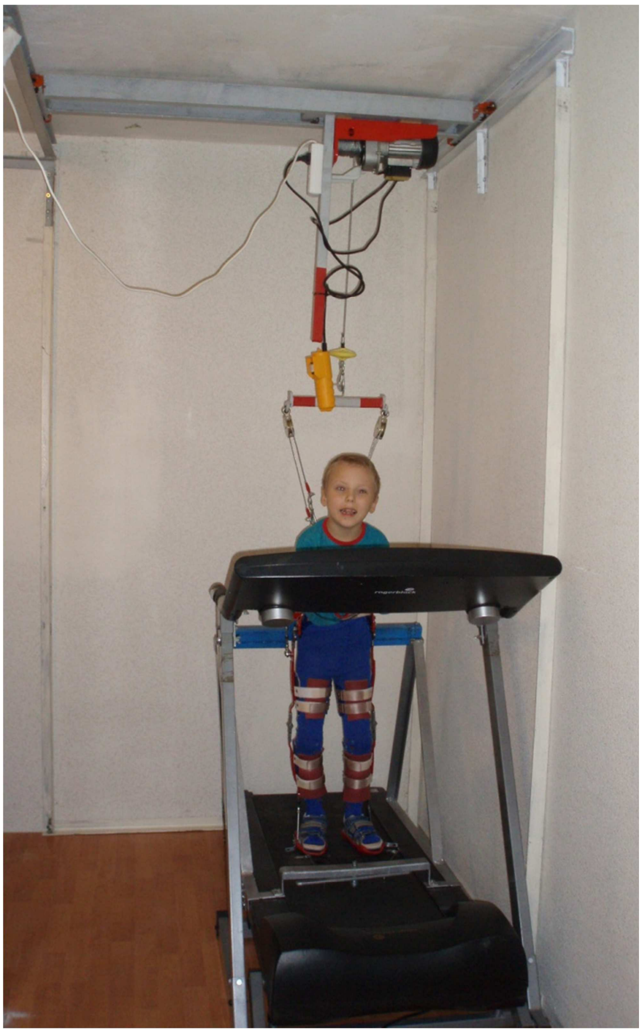

Fig. 1. Locomotor robot is used to position the electric telpher above.

Locomotor robot [2] is used, which consists of an orthotic reciprocal system (A) fastened at a given height to a patient's verticalization device (Б), which has an active horizontal mechanism. Both together, they are fastened to an electric treadmill (B). All three modules (A-Б-B) are mounted together inside a parallelepipedic frame (Г), in upper part of which a two-coordinate manual manipulator (Д) is mounted, on which an electric telpher (E) is fastened for vertical lifting of body and handle (P) for movement of patient in longitudinal and transverse direction. Upon delivery of external energy, the treadmill belt starts moving at adjustable speed due to the friction force of the treadmill against the soles of the reciprocal orthotic system. Simultaneously, a motor is switched on for oscillating movement of a rocker of horizontal reciprocal connection. Between left and right sole, a forced alternate pendulum motion of left and right leg begins in the orthotic system, thus realizing the locomotory action. Mechanical energy tracts transfer external energy to pivotally connected pelvic and chest parts of body and orthotic system of upper extremities, leading to forced, almost natural cinematically synchronous walking motions of all parts of human body (except head). Upon completion of the abilitation session, external energy is switched off, then the manipulator handle the patient at both sides. Snap hooks are used to fasten the left and the right cables that are mounted on the rocker (K), which at its side is suspended to the cable of the electric telpher, releasing the fastener of the orthotic system from the virtualizing device, lifting and positioning the patient besides the treadmill. Independent walking then follows, supported by the operator.

The locomotor robot carries out a mechanically forced motion of all body parts and induces a process that does not require a reconstruction in the central nervous system. Depending on the number of training sessions and their duration, a transfer is realized from the forced conditionally reflex activity to the unconditionally reflex activity.

The base for this transfer is formed at the microstructure level of motion control. It is established that in the phase of excitation (whether active or forced), the locomotor centres are relieved from inhibitory impacts and become available for corrective effects. Due to the connection between motoneurons of different muscles and muscle groups in spinal cord, the spinal interactions are realized in so-called neuronic pools, organizing the step-like rhythmic motions.

3.1. Verticalization

In the process of treatment by means of locomotor robots, orthostatic hypotension is not observed due to the functioning of the baroreflex and vestibular reflexes.

The following manifestations of the vestibular reflex and vestibular function resulting from the use of the reciprocal orthotic complex (ROC) are available for stimulation and study:

- vestibular nystagmus (generated during the process of the gyratory tests);
- statokinetic reactions of cross-striped external and oculomotor muscles;
- extrapolation of regularity (normal and pathologic) of vestibular nystagmus phenomena on activity of skeletal muscles.

The misbalance of paired interaction between the labyrinths is practically smoothed down, which leads to:

- smoothed asymmetry of statokinetic reactions;
- partial resetting of muscular tone;
- normalization of ratio between reactions of otolith organs at semicircular ducts;
- changes in behavior pattern of muscular tone;
- reduction in spasticity;
- reduction in rigidity;
- stabilized position of the common centre of mass due to reduction in frontal rocking when walking, typical for ICP patients;
- improved behaviour pattern of foot contact pressures with the use of bionic insoles and involvement of foot areas into supporting reaction during the heel-and-toe phase from the time of the front take-off till the end of the rear take-off;
- normalization not only of highly-automatic motilities but also of speech, intellect to a considerable degree, sharp increase in sensory ability;
- injured patients (backbone, spinal cord) are recovering faster and easier than patients with inborn diseases since the first ones possess the locomotory memory.

3.2. Forced Walking

When using a locomotor robot, the patient moves forcibly, which ensures:

- correct mutual arrangement of all body segments;
- non-crossing and non-twisting of lower extremities into waist, non-eversion and non-twisting of pelvis, spatial balancing of the whole body during the locomotions, changes in movement speed and correction of gait phases;
- strong reduction, up to elimination, of muscular atrophy, increase in volume and strength of muscles, bioelectric activity, acceleration of metabolism and other characteristics.

The first stage of SSP (drowsiness) rapidly passes into the second and third phase featured by occurrence of slow rhythmics of electroencephalogram in delta range with frequency up to 2 per second. Duration of one sleep cycle is average 1.5 to 2 hours, which fully coincides with the duration of the locomotor sleep (up to 2 hours). Initial provision of resonance processes requires the determination of the step length and frequency.

The step length ℓ[m] is determined by Gavanga&Margaria formula at walking speed on the treadmill $V_m \leq 2.7$ [m/s], $\ell = 0.362 + 0.257\ V_m$. It depends on the belt speed and between-centres distances on the rocker of the left and right brace.

The step frequency on the treadmill at average speed $V_m \leq 2.7$ [m/s] is determined by Gavanga&Margaria formula f [1/s]= V_m: $0.362 + 0.257\ V_m$. Minimal speed of the robot belt is 0.1 [m/s].

Approximate frequency band is presented in table below.

Table 1. *The step frequency on the treadmill.*

V_m [m/s]	0.1	0.25	1	1.38
f [step/s]	0.24	0.6	1.36	2

Fatigue of the child does not influence the step length and frequency since the robot maintains constant the movement parameters.

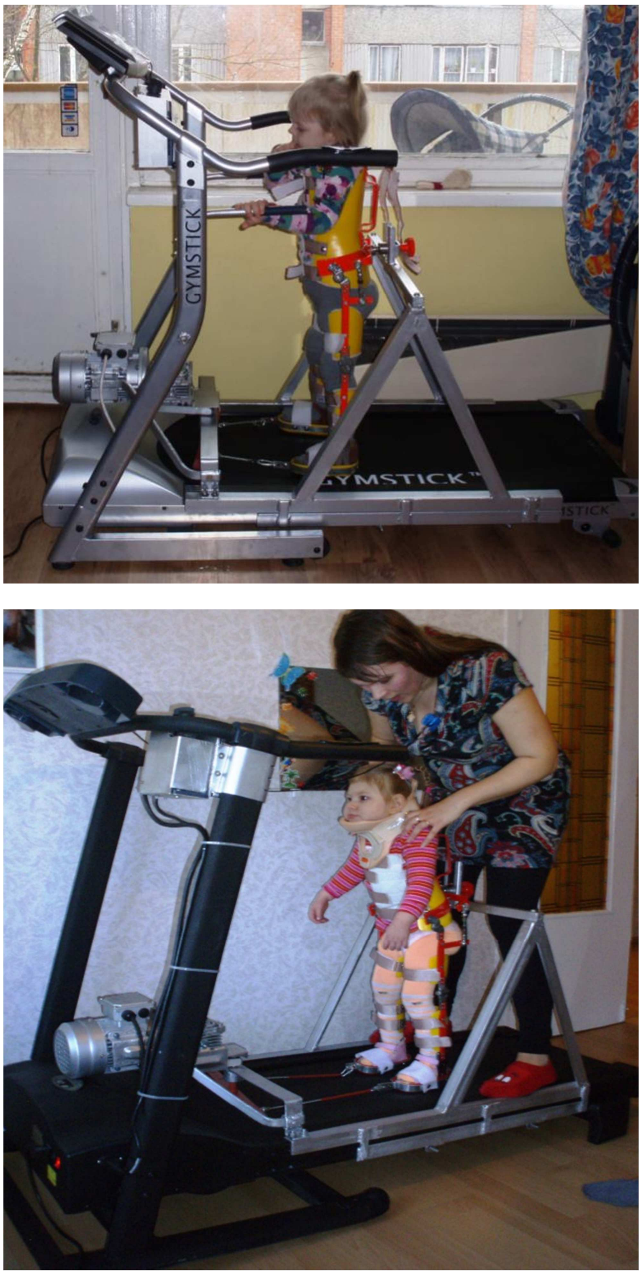

Fig. 2. *Options of locomotor robot and its home use.*

4. Discussion

Of principal significance are:

- Adequacy of external energy load with consideration of pathologic motional stereotype (synergy/synkinesis) formed in the patient as a result of disease; with a healthy person the change in position lying – sitting – standing leads to the increase in load along the gravity vector about 14-16 kgf under REST CONDITIONS and increases the metabolism by 0.8 – 2.5 [kJ/min].
- Use of active TREADMILL, movement at a speed up to

5 [km/h] (120 steps per minute) causes the growth in metabolism up to 26 [kJ/min] upon load 25 [kgf], and up to 38.8 [kJ/min] upon load 50 [kgf], that is in tens of times!

The biggest progress is observed at high treadmill speed.

Skeleton muscles are loaded from external energy via reciprocal orthotic system, and this process leads to: growing metabolism; pulmonary ventilation; thermoregulation; increased heart rate.

Independent walking causes:

- reduction in intensity of extrapyramidal and cerebellar symptomatology;
- correction of dysarthria;
- reduction in DMA and DCA caused by traumatic damages of spinal cord in the age 16-52.

The reason is in the “reminiscences” about walking, which are fixed in memory at different information storage levels.

The robot reduces the pathologic activity of the PROPRIOCEPTIVE INPUT and causes its gradual normalization, as well as ENSURES the optimal functioning of the EFFERENT (executive) ELEMENT of the locomotory-kinesthetic ANALYZER, thereby BREAKING the VICIOUS informational CIRCLE existing with such pathology.

Motor reflexes appear in children at sleep time while brain is functioning at a level corresponding to its lower phase of ontogenetic development. Considerable changes in sleep components are observed in the age up to 6.

Cerebral disease cause the long-term sleep disturbance – hypersomnia, which mainly manifests in episodes of daytime sleep-onsets (cataplexy). Idiopathic hypersomnia is featured by a daytime drowsiness, often with a syndrome of “sleepy intoxication”. These pathologic processes were also taken into consideration and used for clinical characteristics of the method.

During the period of “locomotory” sleep, an active inhibition takes place, coming from the brain stem. These changes, which are resulting from presynaptic and postsynaptic activity inhibition of gamma and alpha motoneurons, lead to reduction in muscular tone during SSP and sharp inhibition in muscles during the rapid eye movement sleep (REM).

The main components for the author’s method are the somatic vestibular reactions since they are evolutionally consolidated and ensure the preservation of spatial position of the body. Human spatial analysis is supplemented with visual (dimmed light during the sessions), proprioceptive, tactile, auditory analyzers (silence is necessary in the room). Monotonous effects upon the vestibular system reduce the thresholds of vestibulo-spinal reflexes of inhibition of sensory and vegetative manifestations.

5. Conclusions

Application of monotonous forced mechanical movement of all body parts triggers the process that does not require rebuilding of the central nervous system (CNS) but merely marks a transition from the forced conditioned reflex to unconditioned reflex activity. The basis for such transition is shaped at the level of microstructure responsible for locomotion control – at the (active or forced) muscle excitatory stage, locomotion centres are released from inhibitory influence and become available for corrective intervention. Due to the links among motor neurons of various muscles and groups, spinal interaction is launched in the motor neuron pools of the spinal cord, which creates rhythmical movement of the step motion pattern.

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