

Application of interactive rehabilitation equipment for kinesitherapy of children with lower limbs dysfunction

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Analysis and modelling

ABSTRACT

Purpose: This article presents an innovative approach to the process of rehabilitation of children under 3 years of age. It shows a system supporting the process of rehabilitation based on cyclotherapy. This work presents a method of combining traditional cyclotherapy with stimulation of intellectual development of the child by means of using the Glenn Doman method or music therapy depending on the degree of intellectual development of the child. Rehabilitation will take place in the form of a play with the use of specially designed equipment.

Design/methodology/approach: This work reviews selected methods of improving the children's condition, which methods may be applied in interactive rehabilitation.

Findings: The combination of movement-based therapy with mental stimulation will make it possible to use the child's potential in a more effective way and quicken the process of rehabilitation.

Research limitations/implications: In further stages of works it is expected to make a prototype device that can be transferred to a public benefit organization or an organization of a similar nature in order to conduct researches within their own works.

Practical implications: The combination of movement therapy with psychological stimulation will exploit, to the maximum extent, natural abilities of brain development in small children. This is enormously important as it is often a factor that conditions the length and, first of all, the quality of life of the patients.

Originality/value: The device being developed will include all the most important factors that may affect the physical structure of children and their psyche, which can directly affect the improvement of their health.

Keywords: Biomechanics, Rehabilitation, Kinesiotherapy, EEG sensor

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1. Introduction

Biomechanics is an interdisciplinary field of science which enables the analysis of dynamic phenomena taking place in living organisms and is used to stimulate the activity and increase comfort of people with motor organs defects [1,2]. The group of motorically disabled children varies in terms of etiology and types of conditions as well as the scope of dysfunctions which determine the degree of the decrease of motor and psychophysical abilities. Motor development is one of the aspects of physical development of the child. As the child develops, diversification and maturing of their organs and bodily systems take place, new movements are developed which are later organized into more and more complex and targeted behaviour. The functions, specialization and coordination are improved by motor activity. Any movement limitations usually cause psychological consequences, especially in children, as movement is one of their basic developmental needs. Disability in one sphere of life always causes consequences in other areas. In case of the children with motor organ disabilities, similarly to the case of children suffering from cerebral palsy, some defects are irreversible [3]. However, there is a considerably big possibility to limit their negative influence on the child's life by means of applying a proper course of rehabilitation. The fundamental objective of rehabilitation is, in this case, activation and stimulation of the impaired lower parts of the body as well as improvement of the properly developing parts of the body, so that they can compensate for the shortages resulting from disability. What is also very significant here is the intellectual development of the child. In both cases, it is crucially important to start the process of rehabilitation as soon as possible, in the earliest stage of the child's life, in which the brain has the biggest capability to develop.

Treatment by means of movement constitutes the basis of kinesitherapy. Movement as a therapeutic means is able to affect all human organs. It stimulates biological processes and metabolism of all bodily systems, including the nervous system, which translates into reflex actions. It is recommended to apply movement as a therapeutic means in case of ascertainment of physical disability in patients. Therefore, the aim of kinesitherapy is to improve physical ability, increase the scope of movement and strength of muscles of the organ or limb whose functions have been disturbed [4]. In case of kinesitherapy of small children with motor organ defects, the basic problem is how to engage them in doing the rehabilitation exercises. Another aspect is the knowledge of psychomotor development of children as well as the fact that the therapy should take into consideration the structural and functional differences between the child's and adult's organisms. One should remember that the child's main motivation to exercise is the intrinsic willingness to play, gain pleasure and satisfy the need for movement. Therefore, first of all, the above-mentioned elements should be taken into account. The choice of possible forms or methods necessary in work with small children is conditioned, among other things, by the possibility of making contact with such children [4]. It is vital that in the rehabilitation process one should work not only at the child's body but also at their psychological development. That is the reason why it is so important to select an appropriate rehabilitation method in children's therapy, the method which can bring considerable therapeutic effects. Children tend to quickly give up classes which

seem boring and unattractive to them. On account of that, the applied equipment should encourage children to do exercises through playing. Rehabilitation of children disabled both motorically and intellectually is a multi-directional operation which consists in restoring the sick child to the possibly highest degree of ability to lead an independent life in society, ability to learn and develop substitute skills which may compensate for particular functional losses.

Cyclotherapy is used to improve the movement, cardiovascular system and breathing by means of riding a rehabilitation bike. This therapy is used by patients with various motor affections, neurological affections, paresis after brain stroke and spinal cord paresis as well as balance disorders. This type rehabilitation is beneficial for balancing the psychic function and neurovegetative disorders as well as for reducing fatty tissue, without burdening a circulatory system excessively.

Rehabilitation of children must be tailored to meet their needs and, first of all, their abilities. It should comprehensively take into account the neuropsychological aspect as well as motor and cognitive aspects. The main goal of rehabilitation for the child is to acquire the skills and activities appropriate for their age group. Properly run rehabilitation should become a part of the child's everyday life, learning and playing. A selected method of work with the disabled child depends on the possibility of making contact with the child and their awareness of carrying out the instructions. This is often impossible or very limited, especially in case of small children and thus it requires the application of special rehabilitation methods making use of reflex activity. Rehabilitation should not discourage the child from further work and should not be associated with pain. Various types of devices applying modern technology are most helpful in realization of children's rehabilitation goals. Apart from serving their basic purpose, they also play a significant role in increasing the attractiveness of rehabilitation by awakening the child's interest and thus enabling longer execution of activities at a lower degree of fatigue.

The equipment presented in this work supports the children's rehabilitation process by 'play and learn' activities, in which the child is keen to participate. At the same time a psycho-motor stimulation of the body takes place. The main objective of such rehabilitation with the application of the proposed equipment is to stimulate the child's development within the scope of motor activities, concentration and cognitive functions, so that the child could achieve the best possible adaptation to normal life.

Currently, one can observe that there is no universal equipment either on national market or world market, which would be used in psycho-motor rehabilitation and encompass the following features: a stationary bike, a mobile bike, kinesitherapy joined with e.g. music therapy, Glenn Doman's method, SI, as well as other methods depending on individual approach towards the patient subject to rehabilitation, automatically aided work of the rehabilitated child by means of servomechanisms – a stationary version of the device, examination of the degree of the child's involvement in the rehabilitation process (EEG sensor).

Through interactive merger of the motor rehabilitation function with the stimulation of the child's intellectual development, which is planned to be applied in the designed equipment, it will be possible to support not only cognitive functions but also cause-and-effect thinking, stimulation of senses, motor coordination and spatial orientation. The idea of

interactive rehabilitation by means of turning rehabilitation exercises into an attractive play, presented in this article, is an innovative concept based on the synergic combination of kinesitherapy, neurophysiology and biomechanics [5,6].

2. Review of the selected rehabilitation methods

It is believed that frequency of rehabilitation exercises influences the efficiency of the rehabilitation process. However, one should remember that it is not only frequency and intensity that are of importance but also the quality of conducted exercises and, most of all, individual approach towards a rehabilitated patient, as the child's acceptance of given training often proves crucial to the success of the therapeutic process. There are many methods of rehabilitation of the children with motor disabilities. Each new method, being based on previous findings, takes advantage of the latest medical developments and becomes subject to further continuous improvements and modifications. This chapter presents selected methods of rehabilitation of the children with central nervous system disorders. Such methods may be applied in the process of rehabilitation with the use of the proposed interactive rehabilitation equipment.

2.1. Music therapy

A method which is more and more frequently used is music therapy which exerts therapeutic influence on the psychological and somatic sphere of the organism. Therapeutic properties of music have resulted in the application of music in many branches of medicine, where it supports and complements traditional ways of treatment. The potential of music therapy in children's rehabilitation is tremendous due to enhancement of the development of psycho-motor and socio-emotional spheres. Music therapy boosts therapeutic effects of physiotherapy and makes them more profound. The essential aspect of music therapy is creativity, which means that at every stage of human life it is possible to awake creative activity in humans, enriching thus their inner life, psyche and intellect. There are many divisions of music therapy dependent on the type of applied methods and techniques as well as people participating in the therapy. The basic division distinguishes two kinds: active and receptive music therapy.

Active music therapy, commonly used in children's music therapy, aims at general activation of the child. It can take place in two areas: music production, i.e. creative and artistic work, as well as in music reproduction, i.e. performance. It makes use mainly of instruments, voice and movement. Improvisation is an important aspect here, both in the scope of playing instruments as well as in vocal and motor exercises. Tasks which have to be performed by means of an instrument, vocally or motorically as well as drawing or painting to music are all of spontaneous character. They are improvised artistic activities which in the process of music therapy are considered in therapeutic categories and consist in expressing oneself independently of any artistic conventions.

Receptive music therapy consists in listening to music pieces in a free way, without suggesting any meaning to patients, or in a task-oriented way, providing patients with specific associations and then making them elaborate on evoked images and emotions. Such classes allow the therapist to monitor individual members of the group and facilitate diagnosis of their needs. Receptive music therapy for children consists in the following: listening to songs sung by the therapist or children themselves, listening to instrumental music and listening to artistic music of an illustrative and curricular character suited to children's age and perceptive capability.

Receptive music therapy develops in children perceptive abilities vital for the development of speech and reasoning. It forces children to concentrate and mobilize their imagination. It sparks sincere, open reactions as well as reveals problems and needs which would not have been revealed if it had not been for music. Music therapy develops sensitivity and ability to appreciate aesthetic dimension of music as well as expands emotional intensity. It develops the love of music by teaching children to recognize the character of music pieces, the tone of instruments and basic features of sound.

Depending on affections and disabilities, music therapy may play different roles. The most important one is psycho-motor rehabilitation of the child, assistance in compensation for shortages resulting from disability, reduction of negative effects of affections, stimulation of child's brain development, activation of cognitive processes, stimulation of child's imagination, creative thinking, ingenuity and self-activity, release of feelings, assistance in expression of emotions, relieving stress and psychological tension, increase of self-esteem and creation of a positive self-image, assistance in making interpersonal contacts, providing the patients with positive aesthetic and emotional experiences, development of new interests, learning how to relax, rest and organize leisure time. In children's music therapy the sound material should not be limited to traditional music, understood as songs or music pieces. A wide scope of other acoustic phenomena may be used, for instance, the sounds of nature like birds' songs, animal sounds, the swoosh of the forest, sea, wind, everyday sounds such as cracking, rustling, sounds of traffic, human voices, including sound-imitating effects. Adaptation of movement to the character of music creates favourable conditions for the improvement of mind functions, i.e. ability to focus attention, power of observation, memory, reflexes. Moreover, it develops spatial orientation and ability to quickly react to stimuli [7,8].

2.2. Glenn Doman's method

The Glenn Doman method, also called the Philadelphia method, consists in children's early rehabilitation which aims at making the healthy, uninjured part of the brain take over functions of the injured part. The concept of intelligence is of prime importance here. At the same time, it is emphasized that the brain grows and develops in a perfect way when, apart from its individual capabilities, it is maximally stimulated to develop movement, speech and manual skills. The chief assumption of the method is the determination of abilities and possibilities of multi-directional influence in four areas:

- the sphere concerning motor development which aims at teaching the child how to move around in an independent way, or at least develop some forms of movement;
- the sphere encompassing the influence on the physical development of the organism by means of proper development of cardiovascular and breathing systems;
- intellectual development aiming at constant improvement of intellect. Influencing this sphere consists in intense multi-sensory stimulation by feeding 'intelligence bits' by means of a specially devised teaching programme;
- social development preparing the patient to live in the society by means of teaching the rules and standards of social coexistence and looking after the patient's emotional development.

The essence of Doman's method is the stimulation of brain by means of appropriate signals. The method consists in the realization of a special developmental programme, which is tailored to meet the specific current needs of the sick child. The programme focuses on the developmental aspect – it includes exercises rehabilitating both physical and intellectual spheres.

The human brain may be compared to a computer - which is totally dependent on the amount of data it has stored in its memory. Each fact stored in the computer is called a 'Bit of Information'. Glenn Doman decided to call facts remembered by children and adults as 'Bits of Intelligence'. The amount of data collected in the computer is called a database. The same name 'Database' was applied by Glenn Doman to the facts stored by the human brain. Obviously, the facts in themselves do not constitute intelligence, however, make the foundation on which intelligence is built. A Bit of Intelligence is an isolated piece of information possessing essential features, i.e.: it is precise, it faithfully renders details, it is separated, individual, without confusing background, it is unambiguous and precisely named, it is new, it is the first time the child has seen it, it is big and due to that distinct and clear.

Bits serve the purpose of conveying specific facts. The bits are created by using very precise drawings, illustrations or photographs which are presented to the child in a proper way. The Intelligence Programme is based on very short-timed information input, however, frequently repeated during the day. One uses mostly sensory channels of hearing and sight. The materials are adapted to the child's individual needs or are of a more general nature, depending on the degree of the child's intellectual and physical development [9].

2.3. Sensory integration method

The method of sensory integration, was developed by a psychologist, special pedagogue and occupational therapist Jean Ayres in the United States in the 1960's, who formulated the theory of sensory processing disorder, further confirmed with numerous tests. The author noticed that sensory processing disorder affects postural reactions, muscular tone, motoric planning, speech development, behaviour, emotions and cognitive functions. In case of deficit, excess or shortage of stimuli, the formation of proper sensory integration is impossible and the development of appropriate motoric reactions and behavioural manners is disturbed. Initially, the method was used in therapy

with children with learning difficulty but now it is used as one of complex therapeutic methods aimed to help children with psychomotor retardation [10].

The process of sensory integration consists in ordering sensory impressions to be able to perceive and interpret surroundings as well as to learn and react adequately to a given situation. The stimulation of senses and stimuli generated during movements stimulate the formation of nerve connections of impulse integration and their assimilation by the mind. Body movement and coordination constitute the basis for the formation of intentional and precise movements. As sensory processing improves, the child masters, among others, the awareness of their body and surroundings as well as the ability of self-esteem, self-control, concentration, proper lateralisation, ability to learn and think abstractly. The purpose of therapeutic management of sensory integration disorder is the normalisation of the reception of tactile stimuli and the normalisation of muscular tone, regulation of balance, reconstruction of body schema, improvement of visual-motor coordination, improvement of auditory perception, motoric planning and orientation in space. The therapy of sensory integration has the form of a controlled game in which children willingly participate [11,12].

2.4. EEG Biofeedback

The therapy known as EEG Biofeedback (EEG - electroencephalograph, *biofeedback* - biological feedback) is a method of harmonising brainwaves - enhancing the potential of mind. The method of EEG Biofeedback was developed at NASA in the USA in the 1960's to improve the training of airmen and astronauts and optimise such cognitive functions as concentration, memory efficiency, creativity, organisation and planning. The development of EEG Biofeedback was also contributed by medical, psychological and pedagogical research on stress, behavioural therapy and learning. During a training session, the patient had on their head sensors receiving signals of brain bioelectric activity. Afterwards, the signals were analysed by computer programmes. A person being trained can see the course of their brainwaves converted to the image of a videogame on a screen. The trainee controls the videogame using their mental activity only, without any devices. The process of learning of appropriate brainwaves (desired for the optimum brain activity) becomes automated during repeated training sessions, in which desired states are rewarded with a sound signal, success in the videogame or a tactile signal. In this manner brain learns to "enter" and "remain" in desired states of awareness without further assistance of equipment, in everyday life. On a monitor the therapist can see an EEG curve, power spectrum and classification of brainwaves in appropriate bands. The therapist also sets a corrective report, objectives of training and can monitor the course of the latter. After the completion of the whole training session, composed of 10 3-minute partial training sub-sessions the therapist prints out results obtained by the trainee. By means of the EEG Biofeedback method the trainee learns the activity of their brain and how to positively change the patterns of generated brainwaves (reinforce desired and inhibit undesired ones). The processes of neurotransmission in the human brain translate to behaviour because the cortex functions as the centre of mental and

behavioural regulation. The Biofeedback-based training can strengthen or weaken communication between various areas of the cortex, which translates to significant and long-lasting psychophysiological processes.

The EEG Biofeedback method is one with no side effects and can be applied in both adults and children. The EEG Biofeedback training improves concentration, quickens thinking, enhances creativity, memory, mood, self-esteem and sleep as well as teaches relaxations. The method is safe, pleasant and, as a videogame, has no side effects, provided that is conducted by competent therapists and supervised by a physician. Each session of training is monitored by a computer and its results can be printed out in a cumulative form [13-15].

3. Design of equipment for assisting the process of psychomotor rehabilitation

3.1. Structural foredesign

It was suggested that the improvement of child's motor organs should combine the traditional method of cyclotherapy coupled with intelligent selection of multimedia contents based on the measurement of child's concentration degree, on the basis of the EEG analysis of brainwaves. A system for presetting the frequency and degree of burdening the musculoskeletal system is a mechatronic one. The system is composed of a DC motor and system for controlling speed and torque. Such a solution enables carrying out the so-called passive exercises (i.e. the movements of pedals will be forced automatically). An optional solution also includes special holders mounted on the steering wheel (to stabilise the subject's hands). By means of the interactive combination of the function of motoric rehabilitation with the stimulation of the intellectual development of the child, as is planned to be applied in the equipment being designed, one will be able not only to improve the development of cognitive functions, cause-and-effect thinking, sensory stimulation but also to enhance motoric coordination and spatial orientation. The physiotherapist will be able to properly adjust the parameters of the equipment in relation to child's disability degree. The equipment presented offers the possibility of applying various devices ensuring the safety of little patients and additionally assisting their rehabilitation e.g. limb and spine stabilisers in sizes adjusted to child's size and degree of disability. The patient is subject to the following external effects: multimedia contents are communicated through the senses of sight and hearing, the musculoskeletal system is activated by the rotation of bicycle pedals. In order to intelligently control the degree of the little patient's involvement in the process of rehabilitation, the brain activity measuring system has been incorporated in the structure. On the basis of the EEG course of brainwaves, one can assess the child's degree of concentration. The concentration-related information is further used as feedback in the loop of control of changes of multimedia contents and changes of burdening of joints enforced by the movements of exercise cycle pedals. The motion of the limb registered by the motor control system will evoke a specific reaction on the synoptic screen connected to the central control unit.

3.2. Equipment characteristics

In order to maximise the effects of synergy of multimedia techniques coupled with a mechatronic system in the process of rehabilitation it was necessary to develop an algorithm for preparation and carrying out of exercises. Figure 1 presents the algorithm of configuration and carrying out of cyclotherapy assisted by multimedia.

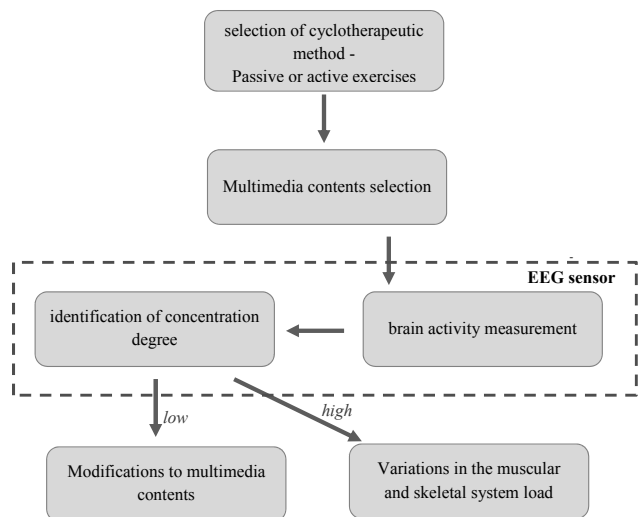


Fig. 1. The algorithm of configuration and carrying out of cyclotherapy assisted by multimedia

The algorithm presented in Figure 1 is composed of the following functional modules:

- **selection of cyclotherapeutic method** - the basic function of the module is to identify an appropriate programme of exercises directly corresponding to the child's health. The therapist can choose between two types of exercises. The first one consists in pre-setting constant rotation speed of pedals thus enforcing the movement of the patient's legs. The second type consists in a gradual increase in the burdening of motor organs, resulting from increasing momentum of pedalling-opposing resistance.
- **selection of multimedia** - the selection of exercises is followed by the selection of displayed multimedia materials. The selection of rehabilitation-assisting interactive programmes depends on child's brain damage degree and their cognitive ability. Interactive exercise programmes are stored in a database.
- **brain activity measurement** - in order to determine the child's involvement in the process of rehabilitation, it is necessary to measure brain activity. The measurement is based on the EEG recording of brainwaves. The system used for the aforesaid measurements has been developed by NeuroSky company and incorporates sensors measuring electric potential in the head and an appropriate microprocessor system processing obtained data.

- **identification of concentration degree** - in order to obtain feedback to the system of controlling the course of rehabilitation exercises, it is necessary to properly interpret brainwaves. An EEG NeuroSky sensor features an algorithm for identifying the level of concentration or boredom; the algorithm being built in the microprocessor system. On the basis of obtained results, one decides whether to change multimedia or the burdening of the musculoskeletal system.

3.3. Equipment characteristics

The equipment is composed of a tricycle, the system of drive and control, an EEG sensor, desktop computer and display of multimedia. In order to ensure the rotation of pedals with a pre-defined speed and desired resistance while the child is pedalling, it was necessary to apply a brushless DC motor with permanent magnets and an integrated controller of rotational speed and momentum. The torque generated by the motor is transferred to the chain gear of the exercise cycle, by means of a friction gear. The shaft of the motor is provided with a drum constituting a friction coupling with a wheel of the bike. A CAN-Bus interface installed in the motor enables information exchange with the control panel. The latter is used for selecting appropriate exercise programmes defining the adjustment parameters of the motor. The CAN interface can also be used to obtain information about the rotational speed of the rotor and current flowing in the motor windings. Knowing the ration of the friction and chain gear of the bike one can identify the speed at which the child pedals. Current flowing in the windings makes it possible to determine the torque generated by the motor. These two parameters are the basic elements of the rehabilitation-controlling system integrated with the system for presentation of multimedia. The basic function of the control system is to ensure constant speed of pedalling and control the torque of the motor, resisting the pedalling.

In order to identify the degree of child's concentration while carrying out rehabilitation exercises, it was necessary to apply an EEG-based monitor presenting brain activity. The monitor includes a MindWave [16] device based on NeuroSky-developed Brain-Computer Interface technology..

The Brain-Computer Interface [17] can be described as a device used for controlling a computer or another automatic device by means of electric signals produced by the nervous central system. The activity of the brain, related to the activity of neurons, comes down to the motion of charges generating electric and magnetic fields. The Brain-Computer Interfaces measure brain activity being a result of the user's intention. Appropriate sensors, located in selected areas of the brain, enable the examination of the electric activity of the brain [18].

The possibility of human communication with the computer only by means of signals coming directly from the brain was indicated by J. Vidal in 1973. It was only in the last decade of 20-th century, in several research centres all over the world, that the use of EEC (electroencephalography) in direct communication between the brain and the computer was attempted. Since 2010 it has been possible to observe the development of commercial equipment such as the brain-computer interface e.g. NeuroSky-manufactured MindWave or Emotiv EPOC. One of the most important elements of the equipment for interactive rehabilitation of children is a multimedia display (PC tablet). The tablet PC is a

personal computer inspired by the notebook but provided with a feature typical of palmtops i.e. a touch screen. The devices in question are equipped with many elements facilitating their use e.g. handwriting recognition functionality, screen keyboard or touch control functions.

The system of interactive cyclotherapy presented in this article incorporates an iPad tablet as the multimedia display. The basic purpose of the iPad application within the confines of interactive rehabilitation is to present films and educational games.

4. Conclusions

The article presents the combination of the standard cyclotherapy with the stimulation of child's intellectual development by applying Glenn Doman's method of improvement or music therapy, depending on the degree of the child's intellectual development. To this end, the equipment based on a tricycle for disabled children was developed. The games and educational programmes are used to distract the child's attention from boring and musculoskeletal system-burdening rehabilitation exercises. The brain activity measurements, carried out by means of the EEG technique, are used to identify the child's degree of concentration on exercises and to quickly react if the child becomes bored with the process of rehabilitation. The combination of movement-based therapy with mental stimulation will make it possible to use the child's potential in a more effective way and quicken the process of rehabilitation. The appropriate application of assistance helps the child learn to perform active movements and at the same prevents improper movements and normalises muscular tone.

It should be emphasized that the best rehabilitation results can be achieved by using various rehabilitation methods with simultaneously taking into account the child's development-related needs such as sense of safety/security, love and belonging. For this reason the most advantageous rehabilitation of children is that realised in their family environment. The latter remark is of particular importance in case of small children and therefore the rehabilitation device should be designed in the manner enabling all-embracing rehabilitation and stimulation of both physical and, first of all, mental development. It is vital that the therapy should be carried out by the child's parents and in the child's closest environment and only supervised and monitored by competent specialists.

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