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An innovative system for interactive rehabilitation of children at the age of three

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ABSTRACT

Purpose: The article discusses the assumptions and a concept of a system aiding progress in rehabilitation by stimulating a child's senses through image and sound. A special rehabilitation device comprised of a training bike with a chair and a synoptic screen enables the patient to perform prophylactic and corrective exercises. Brain activity measurement with an EEG sensor is used as a function steering the rehabilitation process.

Design/methodology/approach: The article discusses a method of combining traditional cyclotherapy with the stimulation of a child's intellectual development with the Glenn Doman rehabilitation method or with music therapy depending on the degree of a child's intellectual development.

Findings: Combination of the traditional cycle-therapy with music therapy or Glenn Doman's method in rehabilitation of small patients will help to maximize the children's activity and their involvement, which at this stage of development is possible only by giving rehabilitation exercises an attractive form of plays and games.

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 in order to conduct researches within their own works.

Practical implications: The proposed device should be very effective in the rehabilitation process, even for the youngest children, and due to its relatively simple modular construction and the possibility of cooperation with many plays and games.

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; Modelin

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

The significance of correctly conducted rehabilitation becomes very important for children aged under three years. It is vital that the means and methods of rehabilitation are chosen optimally according to the criterion of accomplishing, potentially, rapid progress in the process of a motor organ's rehabilitation. From a medical perspective, the earlier starts a child's rehabilitation process the easier, faster and more successful, in therapeutic terms, it is. Children undergoing rehabilitation are capable of acquiring, through using correct rehabilitation procedures and rehabilitation devices aiding such procedures from the earliest stage of life, e.g. such skills as independent walking, hence they can learn to manage the basic daily activities, which improves the standard of their life [2-4,6].

Persons suffering from motor organ dysfunction (with the constrained efficiency of upper extremities, lower extremities or vertebral column) represent nearly a half of Poland's population of the handicapped persons. Admittedly, therefore, one can claim that motor organ dysfunctions represent, apart from other types of impairments, the most frequent cause of disability in Poland and in the world. A group of motorically impaired children is very diverse for its etiology and type of impairment and scope of dysfunction with those factors conditioning a degree of diminishing the motoric and psychophysical abilities to undertake individual activity. In case of a motor organ's impairment of children, just like in case of infantile cerebral palsy, certain damages are irreversible. Relatively extensive possibilities exist, however, to reduce their adverse impact on a child's life through the correct rehabilitation process. The basic purpose of rehabilitation in such case is to activise and stimulate the damaged lower parts of the body and to rehabilitate the parts developing correctly so that they compensate the deficiencies resulting from the impairment. A child's intellectual development is also crucial. It is of great importance in those two cases to commence the rehabilitation process at the earliest possible stage of a child's life when the brain has the greatest development abilities. Through such measures, an impaired child's psychophysical rehabilitation abilities are exploited to the maximum. For this reason, a rehabilitation process should begin as early as possible [2,5,10,16].

Kinesiotherapy encompasses all the issues related to movement therapy. Movement, as a therapeutic agent, is capable of interacting with a human being's all organs. Movement, as therapeutic agent, is advised when the impairment of a patient's physical efficiency is identified. Kinesiotherapy's task is to restore full physical efficiency, if possible for a given disorder, or to restore maximum physical aptitude in case of extensive disorders and those remaining certain irreversible changes. In case of Kinesiotherapy for small children having their motor organs disadvantaged, the main issue is to engage them in performing rehabilitation exercises. Children tend to quickly resign from exercises that seem boring and unattractive to them. Hence, the devices used for this purpose should encourage exercises carried out through playing [11,12,15].

Handicapped children having their psychophysical efficiency reduced have difficulties in their development, learning and social adjustment to the environment. Psychomotor stimulation is applied at an early stage may prevent or at least lessen the pathological patterns of posture and movement. Children's rehabilitation needs to be accommodated to their needs and, first of all, abilities and should take into consideration, in a versatile manner, the neuropsychological, motoric and cognitive aspect. The primary goal of rehabilitation for a child is to acquire the activities and skills appropriate for his or her age group. If directed correctly, rehabilitation should become part of a child's everyday life, learning or playing. The method of work with a disabled child is dependent, among others, on how possible is to establish a rapport with the child and his or her awareness of the instructions carried out. It is frequently impossible or limited, especially with infants, and special rehabilitation methods employing reflex activity need to be used. Rehabilitation must not discourage a child from further work and should not be associated with pain. Diverse technical aiding devices are very helpful in accomplishing a child's rehabilitation goals. The devices not only fulfil their basic tasks resulting from their intended use, they are also important in rendering rehabilitation more attractive thus strengthening an individual's attention and allowing to carry out different activities for longer with less fatigue.

Cyclotherapy is used to improve a motoric activity, a circulatory system and breathing by riding a rehabilitation bike. This type of therapy is used by persons with different motor affections, neurological affections, with paresis after brain stroke and spinal cord paresis and with balance disorders. This form of rehabilitation is beneficial for balancing a psychic function and neurovegetative disturbances and for reducing fatty tissue, without burdening a circulatory system excessively.

To sum up, one can claim that there is a shortage of universal devices at the domestic and world market used in Kinesiotherapy, combining the following features:

- a stationary bike;
- a mobile bike;
- kinesiotherapy merged with, e.g. music therapy, with the Glenn Doman method;
- automatically aided work of a rehabilitated child with servomechanisms - a stationary version of the device.

A rehabilitation method aided with a stationary training bike features multiple advantages quantified above, however, satisfactory progress in rehabilitation depends on a child's involvement. Without stimulating a child's attention appropriately, one's involvement lessens quickly as a child becomes quickly bored with repetitive rehabilitation exercises. The article discusses the assumptions and a concept of a system aiding progress in rehabilitation by stimulating a child's senses through image and sound [8]. The achievements of the contemporary multimedia contents presentation techniques with an intelligent system controlling rehabilitation intensiveness and child concentration measurement have been applied for this purpose. A portable, ergonomic EEG brainwaves measurement system has been used to identify a patient's engagement level. Movement therapy combined with psychic stimulation enables to utilise maximally the natural development abilities of small children's brain, which is very important as it is frequently a factor conditioning the length and, most of all, quality of such patients' life.

2. System assumptions

A traditional cyclotherapy method coupled with an intelligent multimedia contents selection system based on measuring a child's concentration level through analysing EEG brainwaves has been applied in the child motor organ rehabilitation process. A mechatronic circuit was used for setting a frequency and load level for a muscular and skeletal system. The circuit incorporates a DC motor and a speed and torque adjustment system. Fig. 1 shows a general layout of the system assisting a child's motor organ rehabilitation.

The key element in the structure of the system shown in Fig. 1 is a patient, i.e. a child under three years of age. A child is subjected to the following external influence: multimedia content is conveyed through the organs of vision and hearing, a muscular and skeletal system is activated through the rotational movement of the bike pedals A brain activity measuring system has been employed in order to control, in an intelligent manner, a small patient's engagement in the rehabilitation process. A child's concentration level is assessed based on the curve of EEG brainwaves produced. The resultant concentration level is used, at a further stage, as feedback in a control loop for modifying multimedia contents and a load on the joints coming from the forced movement of the training bike pedals. The limb movement being recorded with a motor control circuit will produce a relevant response on a synoptic screen connected to the master control unit.

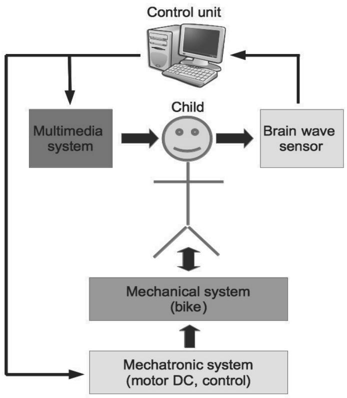

Fig. 1. General layout of the system assisting a child's motor organ rehabilitation

The device is innovative for its combination of traditional cyclotherapy with the Glenn Doman rehabilitation method or with music therapy depending on a child's disability level. The interactive boards will not only allow children to learn faster but will make the whole rehabilitation process a real fun. The results of small patients' efforts displayed immediately on the screen will encourage them to continue practising and hence the rehabilitation process will be much more effective than the traditional process (usually based on suggestions merely and motivating a sick child by his or her caretakers or trainers).

The interactive merging of a motoric rehabilitation function with a child's intellectual development rehabilitation will enable to aid the development of cognitive functions, cause and effect reckoning, senses stimulation and will also improve motoric coordination and spatial orientation. A physiotherapist will be able to choose adequately the device parameters according to the child's disability level.

3. Interactive rehabilitation method algorithm

A management algorithm for preparing and performing exercises was established in order to achieve the maximum synergy effects of multimedia techniques coupled with a mechatronic system in the rehabilitation process. Fig. 2 presents an algorithm for configuring and performing cyclotherapy aided with multimedia techniques.

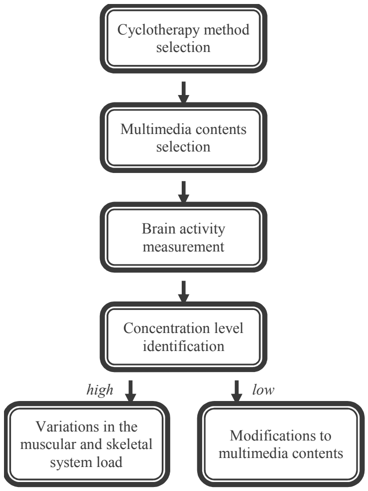

Fig. 2. An interactive cyclotherapy configuration and control algorithm

The two following function blocks can be distinguished between for the algorithm presented in Fig. 2

- cyclotherapy method selection - the block's basic function is to identify an adequate programme of exercises according to a child's health condition. Two types of exercises are expected. The first type of training is to set constant rotational speed of pedals and thus force a patient's legs movement. The other type is to gradually increase a load on the motor organ resulting from the rising resistance against pedalling.
- multimedia contents selection - after selecting the type of exercises, the type of audio-visual material should be determined. Depending on the extent of damage to the child's brain and his or her cognitive abilities, interactive, rehabilitation-aiding programmes are selected. The interactive exercise programmes prepared are stored in a database.
- brain activity measurement - brain activity is measured to identify the extent of a child's involvement in the rehab programme by recording EEG brainwaves. An innovative system by NeuroSky [14] consisting of sensors measuring electrical potential on the head and a special microprocessor data processing circuit was used.
- concentration level identification - it is crucial to interpret EEG brainwaves correctly to achieve feedback to the system controlling the progress of rehabilitation exercises. A NeurSky EEG sensor features a concentration or boredom level identification algorithm incorporated into the microprocessor circuit. According to the result obtained, a decision is made on modifying multimedia contents or changing a load on the muscular and skeletal system.

4. Hardware and software architecture of the system

A hardware and software device specification was established to ensure the proposed functionality of the interactive rehabilitation system for children under 3 years of age. Fig. 3 presents a three-dimensional virtual prototype of a training station.

Fig. 3. Virtual prototype of a training station

The key device components include: a tricycle, a driving and control system, EEG sensor, stationary computer and a multimedia contents display.

4.1. Tricycle

Analysis of the needs of children with disabilities and a review of market available vehicles intended for the rehabilitation of these children allowed to develop project and design assumptions, and consequently to create four concepts of frames of the bike proposed. A very important assumption is the minimum weight that would facilitate comfortable use of equipment by the patients as well as physiotherapists. Small weight of the proposed device significantly reduces the effort required to put the vehicle in motion. Another important factor that was taken into consideration when designing this type of equipment for younger users was safety of use. Using the device should be completely safe and should not pose a health risk to the person operating the equipment. An important issue is also a design that would not make any problems when mounting and dismounting a bicycle by a child. The design of rehabilitation equipment should also be characterized by simple design solutions, and, where possible, the use of the generally available elements that do not require special processing [7,18,19,21]. Moreover, the device must be designed in an attractive way that encourages exercises, while the operation should be easy and pleasant. Taking into consideration the project and design assumptions related to the project of a device, an optimal frame structure as shown in Figure 4 was developed.

This concept involves the construction of a frame of pipes with circular cross-section. By increasing the rigidity and structural stability in areas particularly vulnerable to loads, the cross-section of pipes was changed to oval.

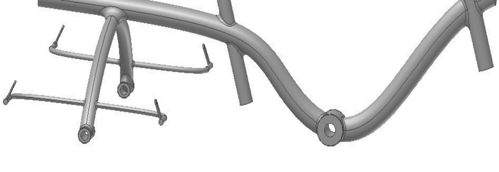

Fig. 4. The concept design made in the graphic programme

The most problematic part of every bicycle is its frame. It must carry the greatest loads in the entire assembly and is the most sensitive to damage of all types. Henceforth, the strength analysis was performed for the frame structure. The material selected for the frame is aluminium 6061 T6. Strength calculations were carried out in accordance with PN-EN 14765:2007 standard concerning children's bicycles, defining that the structure strength calculations shall be made for two load options. In the first case the force of 600 [N] was applied to the frame rake, whilst in the second the force of 300 [N] was applied to the seatpost perpendicular to the ground. In Figures 5 and 6 a graphic representation of the loads applied for the two options is presented.

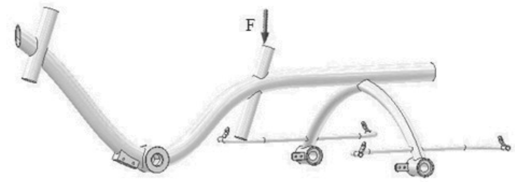

Fig. 5. The method of applying force to the frame 300 [N]

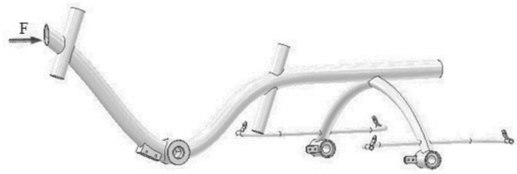

Fig. 6. The method of applying force to the frame 600 [N]

The analysed model was loaded with the force of 600 [N] in compliance with the standard and, moreover, it was supported in the fixing point of the front fork and fixing points of rear wheels, which were then deprived of all the degrees of freedom. The front frame section was not deprived solely of the degree of freedom along X axis (bicycle movement direction) in the fixing point of the front fork.

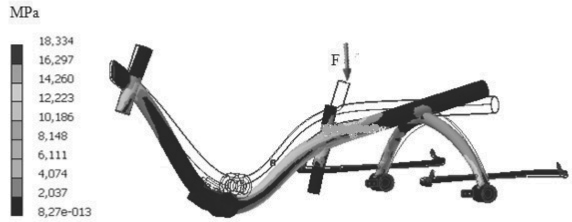

Fig. 7. Distribution of reduced stress according to von Mises's hypothesis 300 [N]

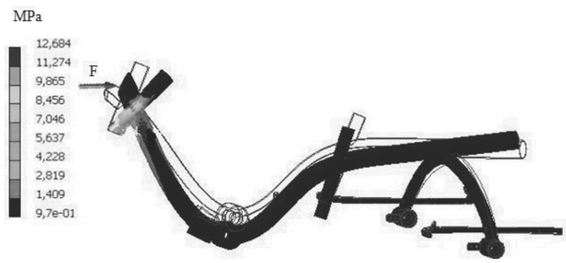

Fig. 8. Distribution of reduced stress according to von Mises's hypothesis 600 [N]

The maximum stress values obtained in the analysis process amount to respectively:

- (Fig. 7) 18.334 [MPa];
- (Fig. 8) 12.684 [MPa].

They do not exceed the acceptable value, which means that the requirement has been fulfilled.

During the analysis, the following maximum stress values were obtained for principal stress:

- (Fig. 9) 19.438 [MPa];
- (Fig. 10) 21.630 [MPa];
- (Fig. 11) 7.122 [MPa];
- (Fig. 12) 9.169 [MPa];

The stress values do not exceed the yield point for the aluminium alloy 6061.

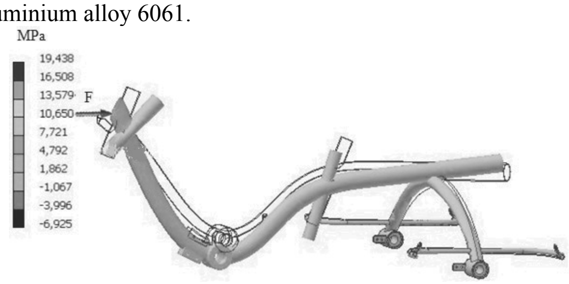

Fig. 9. Distribution of principal stress according to von Mises's hypothesis 600 [N]

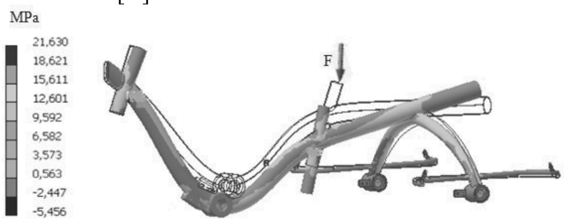

Fig. 10. Distribution of principal stress according to von Mises's hypothesis 300 [N]

Fig. 11. Distribution of principal stress according to von Mises's hypothesis 600 [N]

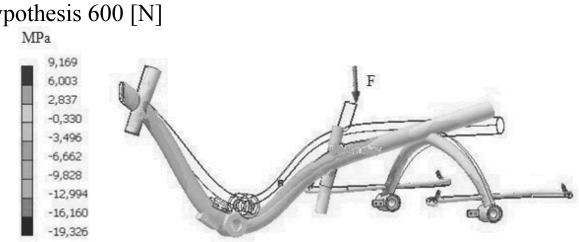

Fig. 12. Distribution of principal stress according to von Mises's hypothesis 300 [N]

Fig. 13. Dislocation according to von Mises's hypothesis 600 [N]

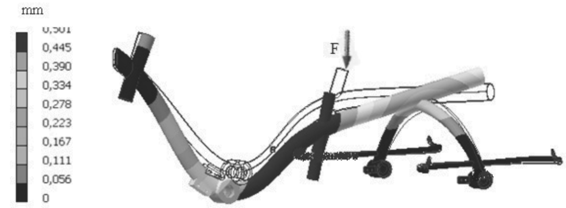

Fig. 14. Dislocation according to von Mises's hypothesis 300 [N]

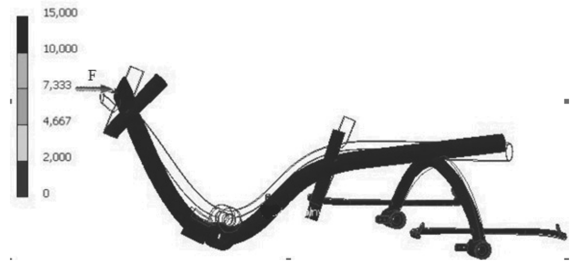

Fig. 15. Safety factor according to von Mises's hypothesis

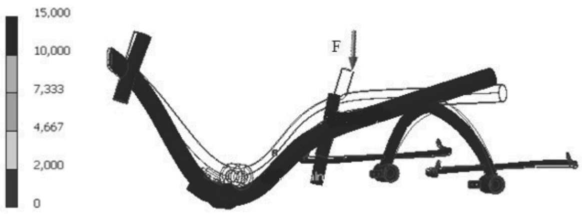

Fig. 16. Safety factor according to von Mises's hypothesis

The maximum dislocation in the model, as revealed by the analysis, amounts to respectively:

- (Fig. 13) 0.825 [mm], in the upper part of the handlebar joint with the frame;
- (Fig. 14) 0.501 [mm], on the profile at the seat fixing point.

The dislocation values obtained do not cause any hazard and do not impair the work of the assembly.

The minimum safety factor in the analysis carried out is 15 (Figs. 15, 16)

4.2. Driving and control system

A DC brush-free motor with permanent magnets with an integrated rotational speed and torque controller [13] was used to ensure the rotational movement of pedals at the set rate and appropriate resistance while pedalling, Fig. 17.

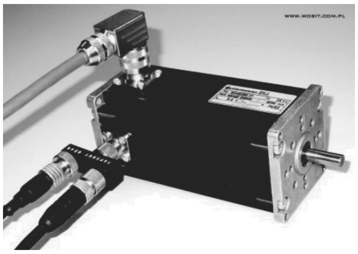

Fig. 17. DC brushless motor with permanent magnets [13]

The torque generated by the motor [13] is conveyed onto the rehabilitation bike's chain gear by means of a friction gear. A drum is seated on the motor shaft producing frictional contact with the bike wheels. Information with the operator panel is exchanged via a serial CAN - Bus link installed in the motor. The relevant exercise programmes are selected on the operator panel determining the motor control parameters. Information on the rotor's rotational speed and the current flowing in the motor windings can be accessed with the CAN link. A child's pedalling rate can be identified by knowing the total gear ration of the bike's frictional gear or chain gear. The current flowing in the windings allows to determine the torque produced by the motor. The two parameters are the basic elements of the system for controlling a rehabilitation process integrated with a multimedia contents presentation system. The key functions of the control system: ensuring a constant speed of pedalling and motor torque control generating resistance in pedalling.

4.3. EEG sensor

A brain activity monitor with the EEG diagnostic method is used to identify a level of child's concentration in practising rehabilitation exercises. A MindWave [14] device based on Brain-Computer Interface technology by NeuroSky is used for this purpose, see Fig. 18.

Fig. 18. MindWave Brain-Computer Interface by NeuroSky [14]

The Brain-Computer Interface [20] can be defined as a device whose task is to control a computer or another automatic device via electrical signals released by the central nervous system. Brain activity connected with working neurons consists in the movement of loads producing an electrical and magnetic field. The Brain-Computer Interfaces measure brain working activity resulting from a user's intentions. The relevant sensors arranged on the selected brain areas monitor the electrical activity of the brain.

J. Vidal suggested in 1973 that a human being can communicate with a computer via signals coming directly from the brain. It was not earlier than in the last decade of the 20th century, however, when attempts were made in several scientific centres across the world to use electroencephalography - EEG for direct communication between a brain and a computer. Commercial brain-to-computer interface-type devices have been constructed since 2010, e.g. MindWave by NeuroSky or Emotiv EPOC. Fig. 19 illustrates a functional concept of the brain-to-computer interface [17].

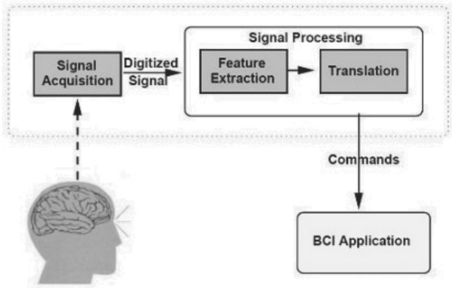

Fig. 19. Functional concept of the brain-to-computer interface [17]

4.4. Multimedia contents display

A multimedia, PC tablet-type, display is one of the key components of the device for the interactive rehabilitation of children [8]. A PC Tablet is a portable personal computer and is modelled on notebooks. A feature known from laptops has been added to it - a touch display. They have many convenient features, e.g. handwriting recognition, on-screen keyboard or a touch control feature. The most popular tablets support an iOS operating system by Apple (iPad) and Android Honeycomb by Google (e.g. GalaxyTab by Samsung). A market share of Apple tablets accounts for approx. 90%.

An iPad tablet was used in the interactive cyclotherapy system discussed in the article as a multimedia contents display [1]. Fig. 20 presents an overview of the iPad tablet.

iPad is a device launched to the market in 2010. It features a 10-inch touch screen and, in particular, enables viewing movies and photos and multimedia contents, i.e. games or interactive books. The tablet specifications: the device's key component is an A4 CPU specially constructed by Apple for this purpose compliant with ARM (Cortex-A8) architecture. The CPU is clocked with a 1 GHz clock, and incorporates an integrated PowerVR SGX graphics unit, a multi-touch 9.7 inch (190×130 mm) display with XGA 1024×768 resolution and Pivot function and a sensor automatically switching between landscape and portrait orientation. The above specification shows that iPad supports the creation of games and multimedia presentations with advanced graphics and sound effects and 3D graphics [1].

iPad's basic function for the interactive rehabilitation device project is to display movies and educational games. Fig. 21 shows an example of an educational game for children under 3 years of age employing advanced multimedia techniques in learning [9].

The idea of the game presented in Fig. 21 is that a child recognises sounds and assigns them to the applicable images. The game uses the voices of pets, vehicles, household appliances, weather effects or emotions such as laughter, cry or whistle.

Fig. 20. PC iPad tablet by Apple [1]

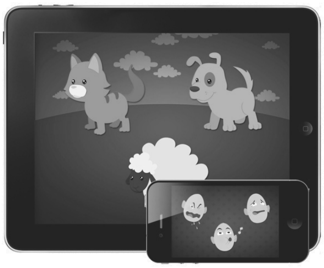

Fig. 21. Educational game for children under 3 years of age [9]

5. Conclusions

The article discusses an innovative approach to the rehabilitation process of children under three years of age. A device based on a tricycle adapted to disabled children has been developed for this purpose. An innovative element presented in the article is the combination of standard cyclotherapy with multimedia techniques. Educational games and programmes are used to divert a child's attention from performing boring rehabilitation exercises burdening a muscular and skeletal system. Brain activity measurement with the EEG technique identifies a child's concentration level on the exercises performed and fast response is ensured if boredom with the rehabilitation process increases. Movement therapy combined with psychic stimulation enables to utilise more effectively a child's abilities and accelerate the rehabilitation process.

Acknowledgements

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