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The concept of interactive rehabilitation device for children under the age of three

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Analysis and modelling

ABSTRACT

Purpose: This article presents the concept of an interactive rehabilitation equipment designed for children under 3 years of age with dysfunction of the lower limbs. Through the use of interactive play-boards and games not only will the children learn faster, but the whole process of rehabilitation will be really fun. Furthermore, the device can be connected to a computer or a special synoptic screen mounted on a special rack. Thanks to an interactive combination of the function of movement rehabilitation with mental stimulation of a child it will be possible to support the development of cognitive functions, cause-effect thinking, stimulation of the senses and to improve coordination and spatial orientation of the young patient.
Design/methodology/approach: The novelty of the station is combination of the traditional cycle-therapy with the Glenn Doman improvement method, or with music therapy, depending on the degree of disability of a child.
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: FMEA is a very important method which should be employed in companies f**Practical implications:** The researches from the broadly understood biomechanics that are carried out shall lead to a construction of a rehabilitation device designed for children under the age of three. 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, it should also be a market success by contributing to the effective rehabilitation of the considerable population of children who require such rehabilitation.
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; Modelling; Strength analysis

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1. Introduction

In the case of children's locomotor disability, as in the case of cerebral palsy, some damages are irreversible. However, there is a relatively large potential for reducing their negative impact on a child's life through the correct process of rehabilitation. In this case, the primary objective of rehabilitation is activation and stimulation of the damaged lower body and improvement of the properly developing parts of a body to compensate the

impairment-resulted shortages. The child's intellectual development is also very important. In both cases it is extremely important to start the process of rehabilitation at the earliest possible stage of a child's life, when the brain has the greatest capacity for development. Through these activities, the capabilities of mental and physical improvement of a sick child are used to the maximum extent. Hence, the process of rehabilitation should begin as soon as possible. Kinesiotherapy covers all issues related to the movement-related treatment. Movement as a therapeutic agent has the ability to exert impact on all organs of the human body. The indication for the movement as a therapeutic agent is a diagnosis of physical impairment in the patient. Thus, the aim of kinesiotherapy is to restore full physical ability, if that is possible with a given affection, or the maximum physical ability in cases of chronic conditions that may leave some irreversible changes [7,4]. In the case of kinesiotherapy of small children with impaired mobility, the basic problem is their involvement in rehabilitation exercises. Children have a tendency to quickly drop out of activities that seem to them boring and unattractive [9,11,15]. Therefore, devices used for this purpose shall be encouraging to perform exercises in the form of fun. Reduced psychophysical performance of children with disabilities means that they have difficulties in development, learning, as well as social adaptation to the environment. Early applied psychomotor stimulation may prevent, or at least reduce, the formation of pathological patterns of posture and movement. Rehabilitation of children must be tailored to their needs and, above all, abilities. It shall take into account the neuropsychological, movement and cognitive aspects. The main purpose of rehabilitation is to provide children with activities and skills appropriate for their age range. Properly conducted rehabilitation should become a part of everyday life of the child, their learning and fun. A choice of forms of work with a disabled child also depends on being able to establish a contact with such child who is capable of carrying out orders. It is often impossible or very limited, especially with the smallest children, and requires special methods of rehabilitation, using reflex actions. Rehabilitation cannot discourage a child to continue work and should not be associated with pain. From the medical point of view, the earlier the child starts the rehabilitation process the easier and faster it will be and will result in more successful treatment. Through the application of, from the earliest period of life, proper rehabilitation procedures and supportive devices, which are a very helpful in rehabilitation, it is possible for the rehabilitated children to master the skills such as independent walking, and thus to learn how to cope with basic activities of daily living, which shall improve their quality of life. The movement has an impact on both the part of the body that is trained and the entire human body, especially on the developing body [1,2,10,12]. Mainly due to the acquisition of more and more experiences and more complex motor skills, a child's psychical development is possible. The reciprocal influence of these two elements on each other is so great that in the earliest stage of life is hard to consider them separately, and they are always considered jointly as psychomotor development of a child. It should be emphasized that the most effective rehabilitation can be achieved through the use of various methods of improvement, while taking into account the needs of the child's development, such as a sense of security, love and belonging. It is therefore believed that the most beneficial course of children's rehabilitation, for example of children with cerebral palsy, takes place in a family environment. This is especially important for the rehabilitation of young children, therefore the designed rehabilitation device shall be performed in such a way as to enable a comprehensive rehabilitation and stimulate both physical and, above all, mental development of children, while allowing the implementation of the therapy by their parents and the immediate environment of the child, only under the substantive supervision of people educated in this direction. Development of an interactive device for the rehabilitation of physically and/or intellectually handicapped young children will enable the maximum use of the natural abilities of the brain development of young children [3,4,8,13-15].

2. Project and design assumption

Research concerns the interactive, stationary device of own design for kinesiotherapy of children with dysfunction of the lower limbs below the age of three. The set, which includes a special bicycle with a seat, gives the patient the possibility of preventive and corrective exercises, and mainly an opportunity to have a nice time. The recorded movement of the limb via the interface will induce specific reaction on synoptic screen connected to the steering wheel (Fig. 1 and Fig. 2).

Fig. 1. View of the multimedia display fixed on the handlebar, made in the graphic programme

The novelty of this device is combination of the traditional cycle-therapy with the Glenn Doman improvement method, or with music therapy, depending on the degree of disability of a child. Through the use of interactive play-boards not only will the children learn faster, but the whole process of rehabilitation will be really fun. Furthermore, the device can be connected to a computer or a special synoptic screen mounted on a special rack. A device attached to the computer/synoptic screen will work with feedback, i.e. the movement of the pedals will trigger a slide show, and lack of the movement will not trigger a further slide. Innovation of the device lies in the fact that children control images/slides on a computer screen through bicycling. Results of

their efforts visible immediately on the screen will mobilize young patients to continue working and thus the process will be much more effective than the traditional method (usually based only on the suggestions and motivation of sick children by their guardians or coaches). Small size of the device makes the rehabilitation possible to take place at home in front of the computer or TV, for example, while watching cartoons or educational programs. After dismantling the rack, the device can be used as a so-called "regular" recreation bicycle for children. In addition, it is also possible to attach a special guide at the rear seat to increase the control and child's protection while cycling, when the device is disconnected from the racks. The present device assumes the ability to use various devices ensuring safety of young patients and supporting their rehabilitation, such as stabilizers of the limbs and spine tailored to the size and degree of disability of a child (Fig. 3).

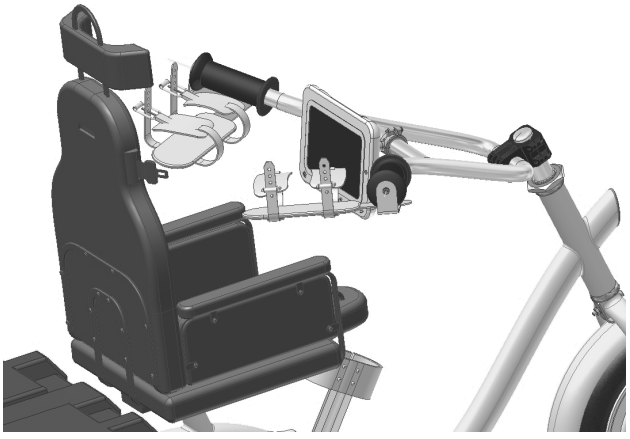

Fig. 2. View of the multimedia display fixed on the handlebar, made in the graphic programme

Fig. 3. The concept of the rehabilitation device

Furthermore, the device will be equipped with servomechanisms (Fig. 4), which will automatically support the work of a patient being rehabilitated.

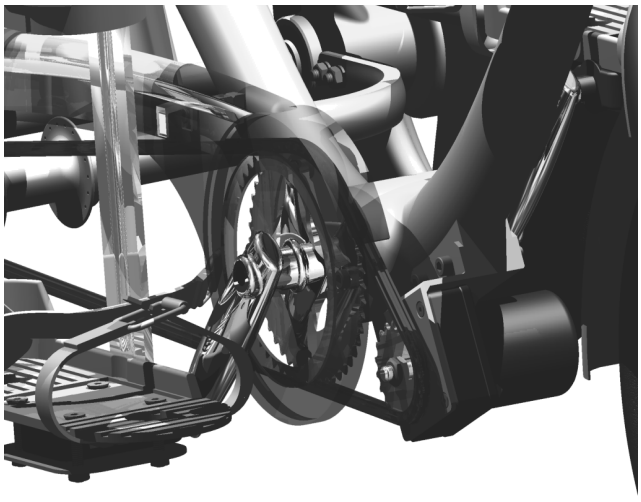

Fig. 4. View of servomechanisms used

Such a solution will allow the implementation of the so-called passive exercises (i.e., movement of pedals will be enforced automatically). It is also assumed to install on a steering wheel, as an option, the special brackets to stabilize the patient's hands. Through the interactive combination of the features of movement rehabilitation and stimulation of intellectual development of a child, which is planned to be used in the designed device, it will be possible to support the development of cognitive functions, cause-effect thinking, stimulate the senses and to improve coordination and spatial orientation. A physiotherapist will be able to choose the appropriate device parameters depending on the degree of disability of a child. At the first stage of the study a 3D model of the device was created. Then, a strength analysis of selected structural elements was performed in order to verify the project and design assumptions. These calculations will be used to optimize the design, especially in terms of minimizing the weight of a device [5]. In parallel with the process of creation of the mechanical part of a device, work on the synoptic screen programming and development of play-boards and interactive games will take place.

At each stage of works the consultations with the rehabilitation centers will be carried out to verify the structural and functional characteristics of the device.

The end result will be a set for rehabilitation of children under the age of three, which will consist of:

- a prototype mechanical device muscle- and/or servomechanism-actuated,
- microcontroller with sensors that allows wireless transmission of information on parameters describing the movement to the touch screen or PC computer,
- computer program containing relevant interactive play-boards and/or games.

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 [16-18]. 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 5 was developed.

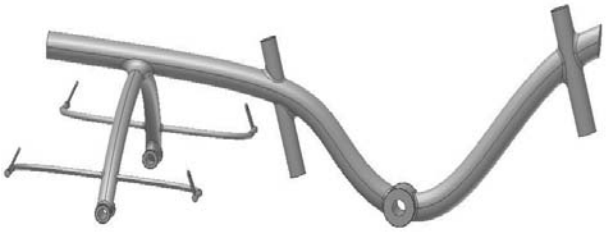

Fig. 5. The concept design made in the graphic programme

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.

3. Strength analysis

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. In the paper used SOLID187 Element Description. The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. 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 6 and 7 a graphic representation of the loads applied for the two options is presented.

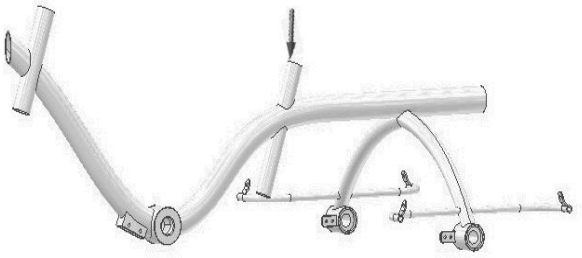

Fig. 6. The method of applying force to the frame 300 N

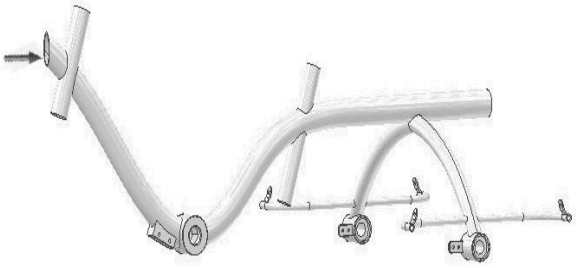

Fig. 7. The method of applying force to the frame 600 N

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.

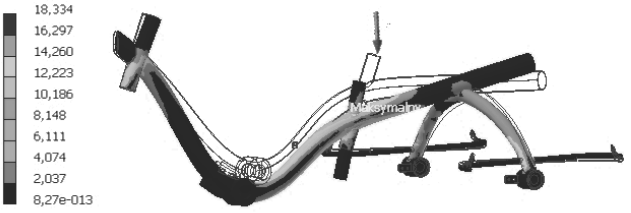

Fig. 8. Distribution of reduced stress according to von Mises's hypothesis 300 N

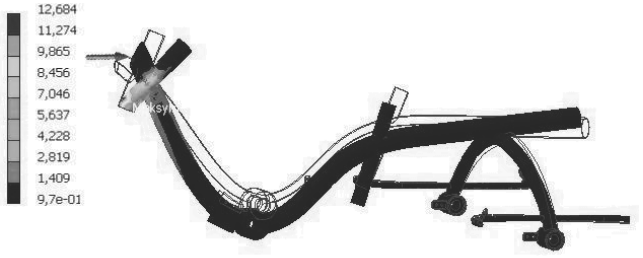

Fig. 9. Distribution of reduced stress according to von Mises's hypothesis 600 N

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

- Fig. 8 – 18.3 MPa;
- Fig. 9 – 12.7 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. 10 – 19.4 MPa;
- Fig. 11 – 21.6 MPa;
- Fig. 12 – 7.1 MPa;
- Fig. 13 – 9.2 MPa.

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

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

- Fig. 14 – 0.8 mm, in the upper part of the handlebar joint with the frame;
- Fig. 15 – 0.5 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.

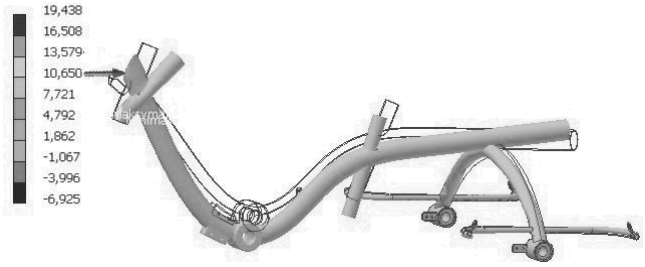

Fig. 10. Distribution of principal stress according to von Mises's hypothesis 600 N

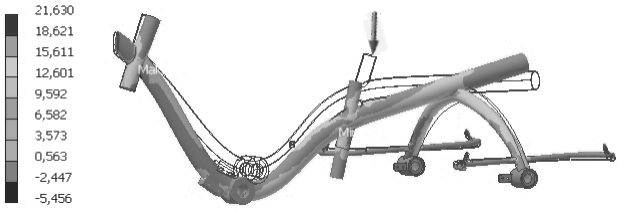

Fig. 11. Distribution of principal stress according to von Mises's hypothesis 300 N

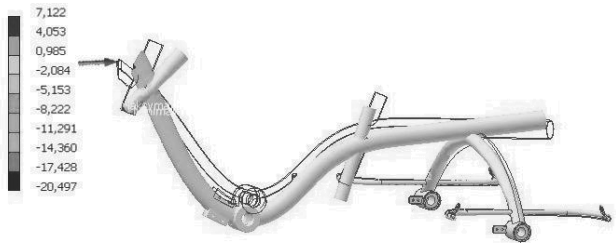

Fig. 12. Distribution of principal stress according to von Mises's hypothesis 600 N

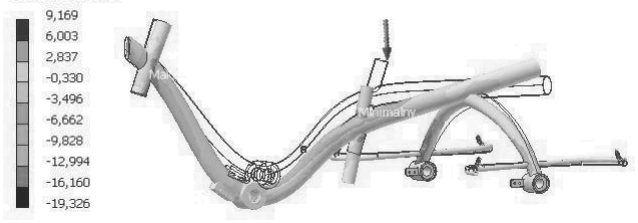

Fig. 13. Distribution of principal stress according to von Mises's hypothesis 300 N

Fig. 14. Strain map according to von Mises's hypothesis 600 N

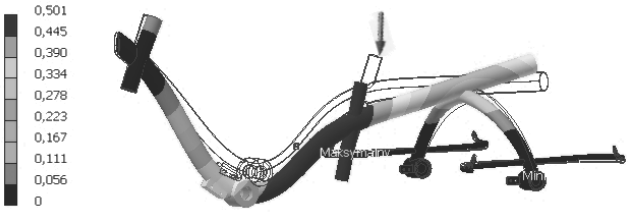

Fig. 15. Strain map according to von Mises's hypothesis 300 N

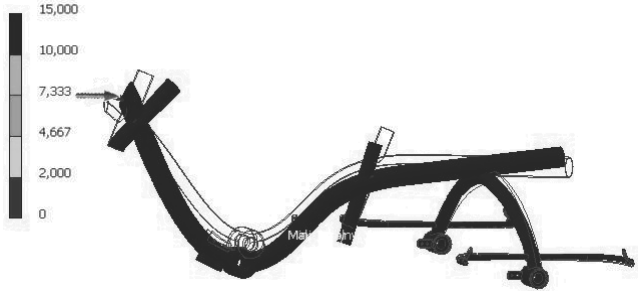

Fig. 16. Safety factor according to von Mises's hypothesis

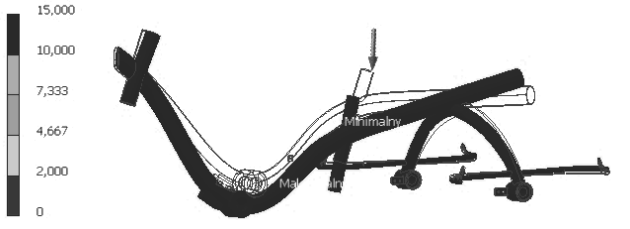

Fig. 17. Safety factor according to von Mises's hypothesis

4. Conclusions

A proposal of an interactive rehabilitation device cooperating with the computer is an innovative solution on the domestic market. It can be concluded that the proposed solution is a modern form of physical therapy, which combines traditional cycle-therapy with stimulation of the intellectual development of a child through the use of Glenn Doman improvement method, or music therapy, depending on the degree of disability of a child. Project documentation and a prototype device to assist treatment of the lower limbs defects of neurological and post-traumatic nature shall be performed within the scope of the further part of the works. Using an interactive connection of the functions of motor rehabilitation with mental stimulation of a child it will be possible to support the development of cognitive functions, cause-effect thinking, stimulation of the senses and to improve coordination and spatial orientation of the young patient. A physiotherapist will be able to choose the appropriate device parameters depending on the degree of disability of a child. Further studies will be conducted on a group of patients, which will allow for an objective evaluation of the device. Successful verification of the operation of the device shall allow its mass production. A solution of the task in question will allow to develop an innovative device that assists the psychomotor rehabilitation process of children with disabilities under the age of three. Rehabilitation will be based on a subconscious fun using specialized equipment while riding a stationary bike. In the course of therapy, a rehabilitated person will not get bored quickly, and thus will be more willing to repeat the recommended physical exercises, which is a very important factor for small children. In further stages of works it is expected to carry out design and construction works of the mechanical part, control system, preparation of play-boards and games, as well as to test the station and evaluate the effectiveness of rehabilitation methods. To sum up, the use of the device under consideration for rehabilitation of small patients can bring many tangible benefits, namely: increase of mobility of the joints, improvement of flexibility, elasticity of articular capsules and ligaments, improvement of blood circulation, strengthening of muscles, increasing their weight, maintaining correct length and flexibility of muscles, improvement of overall fitness and mental development.

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