A New Rehabilitation Device for Balance Impaired Individuals

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Abstract: In the paper authors present a device designed to improve the rehabilitation process of people with balance impairment. The discussed device (JStep) utilizes a commercially available static standing frame (stander) modified in order to fit force sensing units under the feet and in the pillows around the hips of a patient. While executing rehabilitation tasks, the patient may compensate his balance deficiency by leaning on the pillows around his hips. Information about weight distribution between left and right leg together with the information about the force applied to the pillows supporting the patient's body is further presented on a display in front of the patient. Such a setup allows physicians to work with the patient while having direct information about compensation necessary for completing a task or gives the patient a visual biofeedback about how well he is doing the exercise. The system is based on an ATmega controller, load cells and analogue amplifiers. In this framework a case study is presented of a 16 y.o. patient with Cerebral Palsy affecting his cerebellum, labelled as ataxic Cerebral Palsy. Two exercise scenarios utilizing the proposed device are discussed and results of a 6-week exercise are further presented. They show a decrease in necessary compensation in order to maintain a standing posture as well as a better accuracy in achieving the desired force distribution between right and left leg while standing upright.

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1 INTRODUCTION

Keeping an upright standing position requires a cooperation of nervous, muscular, skeletal and fasciae systems and is based on the integrity of reactions, reflexes, tonus, sensory system information as well as the intellectual, emotional and social capacity (Horak, 2006)(Błaszczyk, 2004)(Matyja, 2012). Free body movements, walking and finally locomotion are the results of this complex task (Błaszczyk, 2004), and the capacity for free movement gives the feeling of independence and personal safety. It’s futile to try to pick one of the systems, as the most important as they are all directly responsible for completing the task and their functioning is mutually dependent (Horak, 2006)(Matyja and Domagalska, 1998).

For infants, the spinal cord and primitive reflexes are the first to develop with prevalence of the latter, after a short period of time after birth. Next, the righting reflexes emerge, which lead to the development of stability and equilibrium reactions at the age of 6 months (Matyja, 2012)(Gilfoyle et al., 1990). Integrity of those is essential (Batra et al., 2011)(Zafeiriou, 2004) and leads to a correct postural tonus in coronal, sagittal and transverse planes. Resulting postural reactions last for the whole life (Zafeiriou, 2004). The integration of postural reactions takes place in cerebral cortex whereas reticular formation is responsible for the control of the process together with basal ganglia and cerebellum (Hurło and Kowalski, 2003). Proper postural reaction gives the ability to coordinate the position of body segments in respect to each other, in order to maintain the desired position or to reclaim equilibrium in the presence of a gravitational force (Matyja, 2012)(Gilfoyle et al., 1990).

Ataxic Cerebral Palsy is one of the examples in which the development of a person's reflexes is stunted at some point and keeping a standing posture is often impossible. The lack of the skill of maintaining stability affects the possibility of social interactions. The lack of axial limb loading can lead to circulatory, respiratory, urinary and skeletal system

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dysfunctions (Drużbicki et al., 2013). Due to the complex nature of Cerebral Palsy, resulting mobility disorders have various forms.

It is important to differentiate between stability and equilibrium. Equilibrium is a state in which the adjustment of the position of body segments is a result of bringing the resultant of acting forces on the body down to a minimum. It is achieved by adjusting the proper tonus of the muscular system in a stationary environment (Błaszczyk, 2004). Whereas stability is the ability to maintain equilibrium in a dynamic environment where disturbances may occur (Horak, 2006)(Kuczyński et al., 2012).

In this paper we focused on the condition affecting a particular patient, so the proposed device is designed to meet the requirements of Ataxic Cerebral Palsy patient rehabilitation.

Various devices are used for maintaining an erect posture like: walking (walkers) and standing (standers, parapodia) assistance devices. They are usually modular with a wide base and support a patient in an upright position by various elements of the device. Walkers enable their users to move around. The parapodia can be of two kinds: static parapodium, which stabilizes the body of the patient in an upright position, and may provide support in the chest, hip, lumbar and knee areas, or a dynamic parapodium, which stabilizes a patient's body while allowing one to move around in limited space. Movement of the device is achieved here via repeated body movements from side to side.

Active forms of work with a patient held upright with a parapodium device usually focuses on activating their manual and cognitive skills. It is possible, because a parapodium allows the patient to free the arms from supporting the body, while simultaneously blocking their legs in most cases.

The available standers are very limited in their role as assisting devices for ameliorating stability or training correct gait patterns for patients with a GMFCS (Gross Motor Function Classification System (Palisano et al., 2007)) level of IV-V. Even the dynamic parapodium doesn't allow the patient to train their gait, because the movement of the device is achieved through a side to side rocking movement, which does not help with developing correct walking patterns. There are no strong arguments to back the thesis, that exercising with the use of walkers allows to minimise coordination dysfunction, which in turn would allow the patient to be able to retain their balance without the help of assisting devices (Livingstone and Paleg, 2016)(Paleg and Livingstone, 2015). Even though, a parapodium may be a good starting point for exercise which have a goal of getting to know the correct muscle tonus while in an upright position.

It is a common practice, that gait rehabilitation is performed with a help of balancing platforms and force platforms (Woollacott et al., 2005)(Shanahan et al., 2018). If the patient leans on the stabilizing device though, posturography with its CoP (Centre of Pressure) analysis does not provide correct results. There are just a few tools, which would help training and measuring stability based on the CoP for people, who need standing assisting devices to maintain an upright position (e.g. most of patients with a GMFCS level of IV-V).

An example of a device where designers reached beyond the goal of just keeping the patient upright is the static-dynamic parapodium BalanceReTreiner BalanceReTreiner (Matjacić et al., 2003)(Gałęcki et al., 2013)(Michalska et al., 2011). It allows to keep the patient in an upright position, while allowing for an inclination in coronal and sagittal planes for up to 10 degrees, where the inclination is assisted with a resistance from a spring. The feet of the patient remain attached to the floor. The device uses a visual feedback that shows the patient the current inclination of their upper body. Measurements of the inclination are registered via accelerometers. The patient is requested to control the inclination of the body, based on the direction and amount of inclination shown on a screen in front of him. The assessment of the patient's abilities is based upon the concordance of the directions and amounts of inclination requested by the program and executed by the patient. The patient's actual CoP is affected by a possible leaning on the device. There is no information gathered about the pressure applied by the patient to various parts of the device. Therefore the device does not allow to monitor the patient's CoP. Spring mechanism is the resistor for patient movements. Therefore, the force required to perform an inclination rises, as the inclination gets deeper. This behaviour is very different to what the patient experiences when he has no support from the device.

There is a lack of adequate rehabilitation devices, which would enable monitoring of forces necessary to compensate the disturbances of stability for individuals, which are not able to maintain an upright position without the aid of a physiotherapist and orthopaedic aids. This led authors to develop the idea of the JStep device described further in this paper.

This paper is organized as follows: the device construction and sensing system are described in Section 2; specific case study done with presented device and its results are described in Section 3; the discussion is presented in Section 4.

2 REHABILITATION DEVICE

The device was designed and built so that it provides a real-time visualisation of the body weight distribution between the left and the right leg. It also provides information about leaning of the patient on left, right and rear side pillow of a static parapodium. The device can be used as a rehabilitation exercise platform. The patient's goal is to follow a therapist's orders with visual information on the body weight distribution and the force applied to the supporting pillows of the parapodium. The design assures that the patient is safely held upright.

If the pressure applied to the supporting pillows is treated as a necessary help in maintaining stability, then the information about the usage of the supporting areas and the measured amount of pressure applied to them can be an additional tool for the therapist during stability exercises. The information about the amount of pressure applied to the base of the left and right foot allows identifying asymmetry of leg load.

This device is designed using basic and affordable electronic and mechanical elements in order to make it more accessible for potential patients.

2.1 Mechanical Platform

A static standing frame PJMS 180 (Figure.1, left) has been chosen as a platform to be modified in order to fit the sensors. It is a commercially available stander, already designed to be safe for the patient. It's crucial that the position/length of each component of the stander is easily adjusted, thus adapting the device to our needs with a reasonable amount of work.

The position of the two independently mounted platforms on which the patient stands can be shifted in coronal plane. Pillows on the sides of the stander, as well as the one in the front and in the rear hold the patient in the upright standing position. Those can be raised or lowered depending on the height of the patient. The distance between them can also be adjusted. Two cups straightening the knees that were originally installed in the device have been removed so that the patient is able to lift the leg and bend the knee. In case the patient has little or no control over the extensor muscles of the leg, the cups may be replaced with a rubber band so that the legs return to the straightened position.

The measurement of the applied force is done by load cells mounted in the frame. Each of the highlighted surfaces on the left in Figure 1 is capable of sensing the force acting perpendicularly to the surface. Load cells used in the pillows (Figure 1a and Figure 1b) are beam type load cells NA27-005. Their measurement range is wide enough so that a person weighing 90 kg and with a height between 155 and 185 cm may lean on any pillow and the reading will be adequate to the leaning force. In order to measure the body weight distribution between right and left leg, load cells YZC-161 are used (Figure 2, left). Their advantage is that they have very low profile (12mm) while being able to measure and withstand significant loads (up to 40 kg each).

Both left and right standing platform is equipped with a vertical barrier on the inside edge of the platform (Figure 2, right). This is due to the fact that the patient with whom we were working had problems with putting his feet back on the platform after raising them. A 10 cm barrier between his feet is enough to manage this problem.

The device is designed targeting both private customers and medical centres that focus on the therapy of CP patients. With all that in mind the design allows the device to be lightweight and easy to move in a house or at a gym, so that it can be placed in a convenient place. The weight and size of the device allows carrying it around with minimal effort.

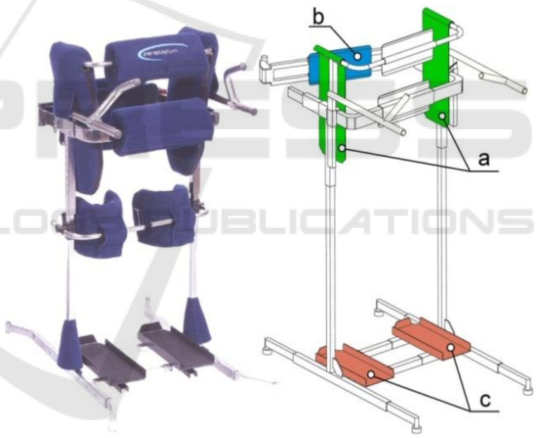

Figure 1: Static stander in a basic version (left), sensing surfaces after mounting sensors (right); a) green - two side pillows surfaces; b) blue - rear pillow surface; c) red - sensors under the feet.

Figure 2: Four YZC-161 load cells bundled to measure weight of the patient (left); standing platforms mounted on the top of the load cells (right).

Shifting body weight from one leg to another implies shifting the position of the hips to the sides as well. For this reason the distance between each of the side pillows and the patient's hips remains approximately 3 cm. This distance was chosen after trial tests. We noticed it was still enough for the patient to feel comfortable and safe, knowing that he can lean on the side pillow, while it was enough for him to shift the body weight as well. Lack of constant pressure between the patient's body and the side pillows of the stander requires more physical strength from the patient, therefore it has to be adjusted specifically for the patient.

The complete device, prepared for tests is presented in Figure 3 with LED (Light Emitting Diode) display mounted in front of the patient. Since no one is in the device only two LEDs indicating null weight applied to the right and left standing platforms are illuminated. In this setup, the two holding bars in front of the patient are present but during later tests they were removed.

Figure 3: A photograph of the JStep platform with LED display mounted in front of the modified stander.

2.2 Sensory System and Data Acquisition Module

Each load cell mounted in the pillows is a separate measuring cell. Load cells mounted under the standing platforms are placed in bundles of four and create two groups of Wheatstone half-bridges configuration on each of the two platforms. This gives possibility to measure body weight distribution between left and right leg.

The signal flow diagram is presented in Figure 4. The entire device is powered only through USB 2.0 5V, therefore the signal from load cells has to be amplified with low voltage analogue amplifiers TL084. A central unit ATmega328 controller is equipped with a built-in analogue-digital converter with a resolution of 10-bit, and six channels. In order to light up adequate number of LED on a display in front of the patient, shift registers are used. Fast switch ing between illuminated LEDs gives the possibility to control nine independent LEDs with one output from the ATmega unit. Collected data includes amount of time spent in order to execute an exercise as well as amount of force applied to the device by the patient. All together is transmitted through UART via USB to a personal computer with a 10 Hz frequency.

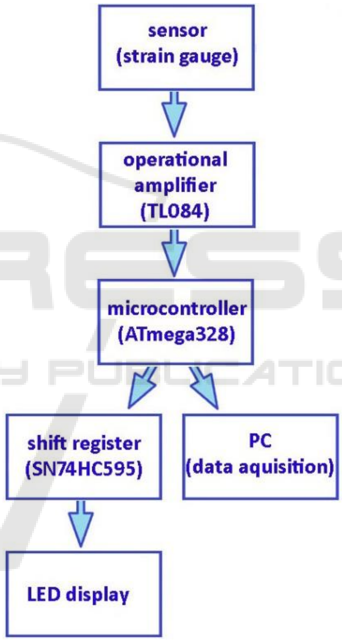

Figure 4: A diagram of information flow of the force applied to the device.

2.3 LED Display and Control Panel

Significant difficulties in reading and understanding complex information by patients with vestibular system damage within Cerebral Palsy in cerebellum (Ojoga and Marinescu, 2013) implies that the information about the forces applied to the device has to be shown in a simple and informative way. A numerical display with values changing in respect to the force applied to the device was tested, but the patient could not understand the readouts during the exercises, thus there was no biofeedback. Any results from these tests are inconclusive.

Authors decided, that a solution to this problem would be a LED display (shown in Figure 5) composed of five bars, each representing one sensing surface (presented earlier in the Figure 1 on the right). Applying force to a sensing surface results in lighting up a correlated LED bar. The more force is applied, the more LEDs in the bar are illuminated. Force applied to the side and rear pillows is shown in green bars on the sides and at the bottom of the display. Body weight distribution between left and right leg is shown as two yellow-red tapering bars. When the force is equally distributed all yellow LEDs are illuminated. As soon as the weight is transferred to one of the sides, more LEDs on this side is illuminated, whereas the bar showing readings from the opposite side is diminishing.

Such a display setting allows to understand the body weight distribution at a glimpse of an eye, which allows to see the reactions between the patient and the device. Moreover it is very easy to set a goal for an exercise and the patient clearly sees if he is succeeding or not. This lets the patient put more attention to execute the task rather than focusing on reading the information from the display.

The simplicity of the display is achieved at the expense of readings resolution. As it is mentioned by a number of authors (Matyja, 2012)(Matyja and Domagalska, 1998)(Batra et al., 2011) the asymmetry of movements and reflexes is crucial in the examination of motor skills. For that reason a system that visualizes movement asymmetry rather than precise forces applied to the device by the patient gives better feedback information and is more informative. Independent to what is shown to the patient on the display, raw data is sent directly to the PC (Personal Computer) for further analysis.

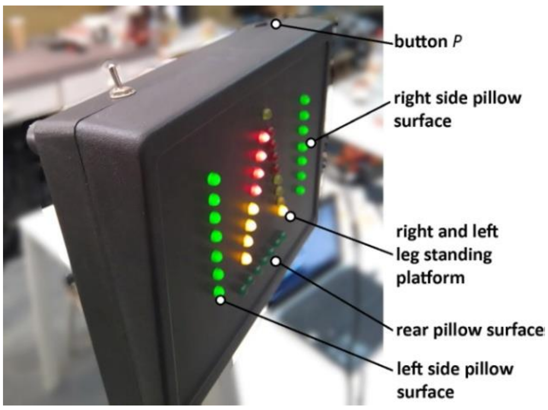

Figure 5: LED display mounted in front of the patient with LED bars and button "P" indicated.

2.4 Sensor Calibration

The spasticity of some muscle groups in CP can cause the inability to equalise the pressure of left and right leg on the base. It does not, however conclude for the inability of maintaining stability. The device allows calibrating the pressure range for sensing surfaces, so that it is tailored to the patient and their abilities.

The microcontroller used in the control system enables adjustment of the device performance to the patients of various weight and independently of how much force they apply to the device when leaning on the side or rear pillows. This feature has been achieved by implementing a sensor calibration.

The calibration is based on measuring maximum force applicable by the patient to the specific sensing surface and scaling the range of the readings accordingly. The result is, that the first LED and all LEDs up to the last one of a selected bar on the display are illuminated when minimum and maximum force is applied respectively.

Each time the device is switched on, an average reading during first three seconds is considered a null force reading for each sensor. During that time the patient cannot be in the device. The system enters the operational mode after three seconds and the patient may enter the device.

At this point the patient is asked to apply as much force to this sensing surface as he is capable. The system picks maximum value read during that time and sets it as the maximum value readable for this sensor. This information is mapped to eight levels, so that the LED bar can be lit properly. Afterwards the system goes back to operational mode and in order to calibrate another sensor, this procedure has to be repeated. The presented procedure does not influence readouts sent to PC via USB. The calibration refers only to the LED display resolution and range of signals.

3 CASE REPORT

The device has been designed and built in close cooperation with a patient and his family. The patient was given the device to test it for the duration of six weeks. During this time he was asked to work with the assignments and complete each of them every day. The two assignments are discussed in the 3.2 Subsection. He was also asked to carry out the calibration procedure for null weight and maximum weight for all the sensors each day before he did the assignments.

3.1 Subject

The patient is a 16 y.o. boy with Cerebral Palsy in the cerebellum diagnosed when he was 20 months old. Based on MRI tests his palsy affected multiple areas of his brain: extrapyramidal nerves in his brain stem, cranial nerves, the diencephalon and the pyramidal nerve system of cortex. More precise examination is presented in a case study (Koczyk, 2015) which discusses EEG, MNRI and BAEP tests results. The patient is classified with GMFCS in between level IV and level V. His motor abilities allow him to sit and keep the torso upright while sitting. He is also capable of keeping his head upright and execute reaching tasks although dysmetria, tremor and dyssynergia are evident. He has strong astigmatism and difficulties in controlling the eyes movements when tired.

The patient moves around his home on all fours. This is the only way he can translocate from one place to another in a safe environment on his own. Outside his home he is able to move in his wheelchair but only with an assistance. He is unable to stand still without any support but he can hold on to furniture and rise as well as stand holding on to it. Making steps is challenging for the patient even when he is using external support. An assistant is necessary to walk him around the house but then the patient leans on the assistant giving him full control over the equilibrium.

Due to the spasticity of his legs' rear muscles e.g. plantar flexion is present permanently. Hence, the patient struggles to maintain an upright standing position because he has to flex the knees, keep his weight on the toes and rotate his hips backwards achieving anterior pelvic tilt. The result of such a posture is that the patient does not bring his hips in contact with the front pillow of a stander.

3.2 Testing Procedure and Exercises Scenarios

The device was located in a room, where the patient could easily enter the stander. In case the patient requires assistance, the assistant helps him walking into the device, locking the rear clasp and turning on the device. The patient performs twice two exercise scenarios each day, what results in approximately 30 minutes of standing in the device daily. In case the patient is sick or unable to perform his duty that day he is asked to complete his task the other day additionally to the scheduled exercises for that day.
Exercise scenarios:
1. Illuminate specific number of LEDs related to the body weight distribution – goal is to shift the weight in order to reach a given number of LEDs randomly chosen from two tapering LED bars as discussed in Subsection 2.3. In order to complete the exercise the given LED has to be kept illuminated for five consecutive seconds. The patient has 120 seconds to succeed. Otherwise the system automatically ends this round of an exercise. The exercise consists of two rounds.
2.Illuminate specific number of LEDs related to the body weight distribution while refraining from illuminating the LEDs related to the side or rear pillows – the patient has to execute the same algorithm as in the first exercise but this time leaning on the device results in lighting up the green bars on the LED display while the LED bars related to the standing platform are switched off. The patient is obliged then to diminish the pressure on the side pillows and find the correct weight distribution again

During the exercises the patient was asked not to grasp the stander with his hands. To facilitate that, he was given two cylindrical objects to hold.

For the sake of completing the second exercise a feasible threshold of force applied to the pillows has to be set, otherwise a person with stability deficits will not be able to finalize this task. After some trial tests the threshold value was set as 40% of the maximum force applicable to the pillows for this particular patient. This is in line with a very important aspect of the gamification, which is the win-lose ratio. In order to keep the patient actively involved in the game, hence in the rehabilitation process, a game designer has to maintain the game challenging for the patient but at the same time plausible to succeed.

All the tests and exercises were performed in a room temperature varying between 21°C and 30°C. To achieve results independent from the temperature variations, load cells readouts were verified in respect to the temperature changes. This was done thanks to the sensors' null calibration feature, which is essentially the readout of a non-loaded sensor. This data was collected from each day the device was used and stacked with room temperature changes in order to avoid any temperature influence onto the results.

3.3 Results and Discussion

During six week time period the patient performed the first exercise scenario 154 times and the second exercise scenario 113 times. It took him 23 days to complete all these exercises which was the result of patient's frequent respiratory infections. It was notable that after each break (the longest was five days in a row) he struggled with achieving a correct body weight distribution.

All the results gathered include: date and time; current number of exercise (1 or 2); current round number (1 or 2); current LED number illuminated as a target for this exercise, which together with the round number refers to the requested body weight distribution (1 through 8); amount of time spent on completing the exercise (in milliseconds); amount of time spent with a correct body weight distribution (in milliseconds); and for the second exercise, the amount of time the patient applied force to the pillows higher than the threshold (in milliseconds).

Data acquired during tests is divided based on the side to which the patient had to transfer the body weight as well as the amount of body weight applied to the particular side. There are four weight levels: 63% or less, $63-75\%$, $75-88\%$ and $88-100\%$ of body weight transferred to a particular leg. Such a division is done in order to identify if the patient has a problem with acquiring a specific body weight distribution.

The first quality criteria for both of the exercises is T_a which is the amount of time necessary for the patient to achieve and maintain the desired body weight distribution for five consecutive seconds. The exemplary results showing T_a gathered for exercise 1, when the task was to keep the body weight evenly distributed between left and right leg with maximum 63% of the weight on one leg in a timespan of 42 days is shown in Figure 7, top. A trend function: y=-1.15+68 with coefficient of determination R^2=0.15 is embedded into the plot.

For both legs and all four body weight distribution levels, the trend function during the six weeks training time resulted in a negative slope constant which is presented in Table 1 as a linear trend function of subsequent plots. Additionally, the percentage of decrease of time necessary to complete the exercise ΔT_a for both legs combined based on a trend function is also included. A significant decrease of time necessary to succeed in this task as the training proceeded can clearly be noticed. The activity which took approximately 70 seconds, after 6 weeks of training was more often achieved in only 20 seconds. Also, at first glance, an improvement in case of $63-75\%$ level is least impressive, but in this case T_a was the lowest out of all four load cases which is further shown in Table 2. This shows, that for tasks which are generally easier for the patient, the improvement is less notable.

The second quality criteria for both of the exercises is T_s which is the amount of time during which the desired body weight distribution was achieved but not necessarily maintained for consecutive five seconds. The T_s in its nominal value does not include that the overall time of completing the task may change reducing possibility to achieve higher T_s values. Hence, T_s is further considered a percentage value of a T_a time, where:

$$T_{s\%} = \frac{T_s}{T_a} \cdot 100\% \qquad (1)$$

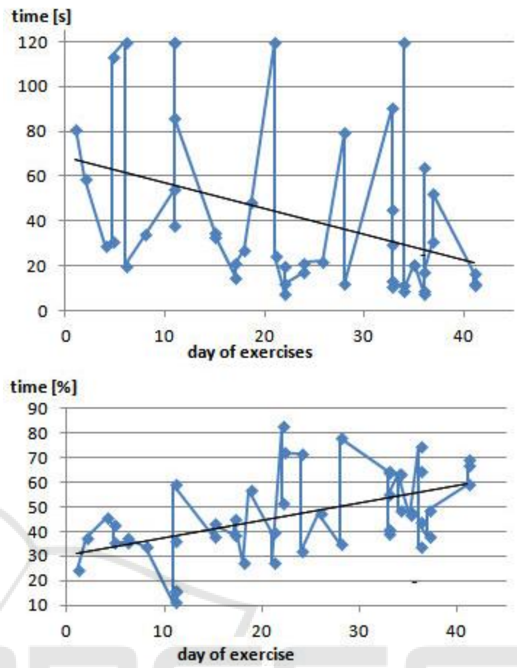

Figure 6: On the top - time necessary to complete the task in exercise 1 - T_a; on the bottom - percentage of time necessary to complete the exercise during which patient achieved desired body weight distribution but not necessarily maintained it for consecutive 5 seconds - $T_{s\%}$. Data presented for case where the patient's weight had to be distributed evenly with up to 63% of weight on one leg.

Table 1: Linear trend function *y=ax+b* of T_a and $T_{s\%}$ in function of days (t) the exercises were performed for subsequent body weight distribution levels. LL stands for the left leg, RL stands for the right leg, and TO stands for both legs combined. Additionally, ΔT_a is a percentage decrease of time necessary to complete the exercise for both legs combined based on a trend function T_a (TO).

	100-88% of weight on one leg	88-75% of weight on one leg	75-63% of weight on one leg	up to 63% of weight on one leg
T_a (LL)	-0.37t+31	-2.09t+81	-0.44t+44	-0.99t+51
T_a (RL)	-1.89t+129	-2.0t+89	-0.1t+35	-1.2t+79
T_a (TO)	-2.15t+113	-2.0t+87	-0.27t+39	-1.15t+68
$T_{s\%}$ (LL)	-1.91t+105	0.91t+25	0.06t+48	0.74t+33
$T_{s\%}$ (RL)	0.66t+8.95	1.3t+24	0.17t+49	0.68t+27
$T_{s\%}$ (TO)	0.52t+23	1.14t+25	0.1t+49	0.71t+30
ΔT_a [%]	78	85	28	68

An exemplary result for $T_{s\%}$ is presented in Figure 7, bottom, where data was gathered for the first exercise with body weight evenly distributed between left and right leg with maximum 63% of the body weight on one leg in a timespan of 42 days. Here the trend function y=0.71+30 with coefficient of determination R^2=0.26 is embedded into the plot. Calculated trend functions of $T_{s\%}$ for each leg separately as well as for both legs combined and for all of the four body weight distribution levels are presented in Table 1.

In most cases $T_{s\%}$ rises as the patient progresses with the training with an exception for 88 – 100% of body weight transferred to the left leg. This could be explained by a very low T_a values for this load case (fastest was 11 seconds and slowest was 25 seconds). Having in mind, that for 5 seconds patient has to maintain the correct balance anyway, achieving better results becomes very challenging. Another aspect is that $T_{s\%}$ is inversely proportional to the T_a values. This implies that decreasing T_a readouts with consecutive training days (what evidently occur) will always result in $T_{s\%}$ getting higher. Therefore, even though $T_{s\%}$ shows improvement over time, changes of nominal time spent on standing with proper body weight distribution in most cases were found not to have an apparent trend nor change significantly.

The combined results of T_a from six-weeks training period are calculated in order to achieve an overall view of patient's abilities. Mean time value T_a is presented in Figure 8 and Table 2 for each body weight distribution level separately what provides information about posture dissymmetry.

It is notable, that tasks involving shifting body weight to the right leg are much more difficult for the patient. Also, the more weight is to be transferred to the right leg, the more difficult the task becomes.

Standard deviations of up to SD=22 for the body weight shifted mainly onto the left leg and up to SD=43 for the body weight shifted mainly onto the right leg are the result of frequent failures in body weight distribution task in 120 seconds time limit. For the task of transferring body weight onto the left leg patient did not succeeded only twice (for 87 times the task was assigned) whereas in the case of transferring body weight onto the right leg it happened 11 times throughout all 67 times the task was assigned. Observation of the patient while he was in training though revealed that most of the times he did not succeeded happened when he was distracted by a nearby discussion or was anxious to do something else in the time he was exercising. It is disputable therefore if a drop-out ratio should be considered as an important parameter for this study.

Restriction inflicted in the second exercise by the presence of side and rear pillows significantly extended the time necessary for the patient to achieve and maintain the desired body weight distribution for

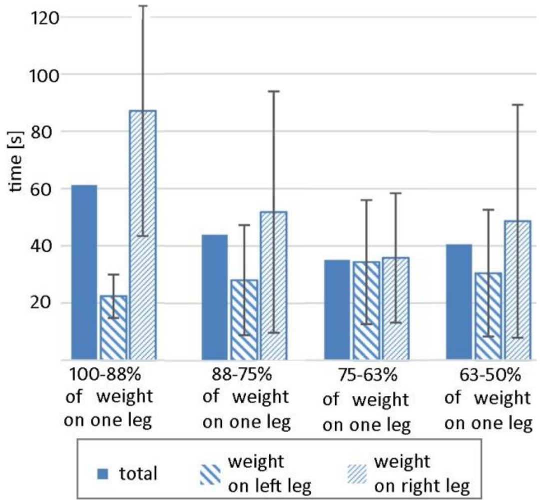

Figure 7: Mean time value $\overline{T_a}$ necessary to complete the task in exercise 1 - data divided for four levels of body weight distribution and presented for each leg separately as well as for both legs combined (total).

Table 2: Data referring time value $\overline{T_a}$ necessary to complete the task in exercise 1 presented for both legs in total as well as for the left and right leg separately in all four body weight distribution cases. LL stands for the left leg and RL stands for the right leg.

Percentage of weight on one leg:	100-88%	88-75%	75-63%	63-50%
$\overline{T_a}$ total [s]	61	44	35	41
$\overline{T_a}$ (LL) [s]	87	52	36	49
$\overline{T_a}$ (RL) [s]	22	28	34	30

five consecutive seconds (T_a). Mean time value $\overline{T_a}$ is presented in Figure 9 as well as in the Table 3. Here the differences in shifting body weight over left or right leg are not so obvious and improvement in $\overline{T_a}$ is only notable in respect to amount of body weight shifted to the side. This suggests, that it was more difficult for the patient to stand without leaning on the pillows than it was to shift the body weight to a correct position.

The task of transferring the body weight properly to the left and right leg in the second exercise was assigned 57 and 56 times respectively. In case of the left leg the patient did not manage to achieve success in the 120 seconds time limit six times and for the right leg it was eight times. This resulted in standard deviations of $\overline{T_a}$ up to SD=38 for the left leg and up to SD=54 for the right leg results. Again, the drop-out Case were mostly inflicted by external disturbances.

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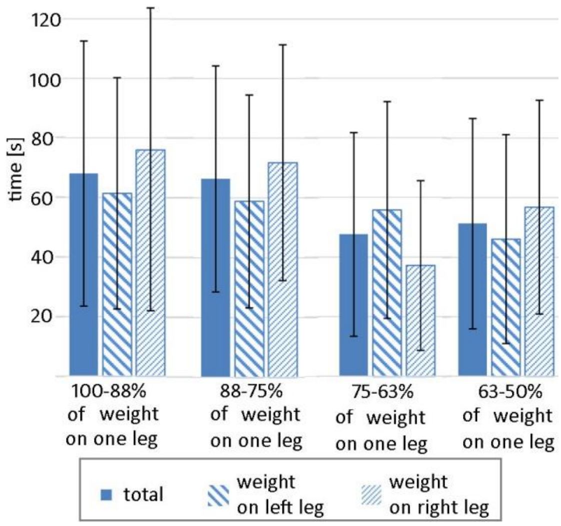

Figure 8: Mean time value $\overline{T_a}$ necessary to complete the task in exercise 2 - data divided for four levels of body weight distribution and presented for each leg separately as well as for both legs combined (total).

Table 3: Data referring time value $\overline{T_a}$ necessary to complete the task in exercise 2 presented for both legs in total as well as for the left and right leg separately in all four body weight distribution cases. LL stands for the left leg and RL stands for the right leg.

Percentage of weight on one leg:	100-88%	88-75%	75-63%	63-50%
$\overline{T_a}$ total [s]	68	66	48	51
$\overline{T_a}$ (LL) [s]	76	72	37	57
$\overline{T_a}$ (RL) [s]	61	59	56	46

The results in case of the second exercise are much more consistent and show very similar $\overline{T_a}$ values for all four cases where the weight had to be shifted onto the left leg. We noticed also very little improvement of T_a and $T_{s\%}$ parameters over the six-weeks training time in case of second exercise. This is probably due to a very high difficulty the patient had with the task of shifting the body weight while simultaneously caring not to lean on the device.

4 CONCLUSIONS

We have presented a new rehabilitation device for people with stability deficits. Discussed assisting device ameliorates keeping the equilibrium by training the body weight shifting in coronal plane while visualizing patient's current body weight distribution and forces inflicted onto the pillows keeping him in an upright standing position. The device is designed to be used by the people who may not necessarily be able to keep the upright standing position on their own but have muscle strength sufficient to maintain an upright position with use of a stander.

A set of exercises is proposed in order to train the stability with use of the device. They involve shifting patient's body weight so that it matches requested body weight distribution while avoiding leaning onto the side and rear pillows of the stander.

Forces inflicted onto the device are shown in form of LEDs being illuminated as the patient applies more force to the device or shifts the body weight. Such functionality gives physiotherapists real time information about body weight distribution while the patient is performing exercises in an erect position. Moreover it provides a wider knowledge about the compensation the patient may need in order to keep the upright standing position. It is also considered that the device may play a significant role in an evaluation process of patients' stability. Performing proposed exercises allows to estimate the capabilities of the patient.

For the patient, on the other hand, important aspect of using the device is that, with the instant biofeedback about the body weight distribution, the patient may adjust his position by himself. This can be done even if the person's reflexes are stunted or the nervous system doesn't work correctly.

Thanks to the presented calibration process the measurement system is versatile making the device suitable for work with patients of any weight or height.

The device was tested with an Ataxic Cerebral Palsy patient during a six-week time period. During this time the patient performed 267 times the exercises described. It means the patient spent approximately 30 hours in the device safely standing and performing exercises, what is already a great success. Detailed results given by the system were discussed with physiotherapists and several conclusions were drawn:

1. The patient tends to grasp the stander. This was notable mainly when the patient tried to produce dynamic movements with relatively high acceleration. Holding to a steady stander gave the patient more confidence in movements and requested tasks were performed faster. If the aim is to induce a correct muscle tonus while in erect position, then body dynamics should be drawn from body mobility and control rather than external support.
2. The randomness of body weight distribution requests should be introduced after repetitive movements requests. This is due to the fact, that the

integrity of reflexes of ataxic patients is not developed properly and they struggle to control their body. Giving them a task, to shift the body weight and ask to pay attention to leaning on the device is far too much for them at the beginning of the training.
3. Physiotherapists struggled with too much information from the system. It is considered for future works therefore to limit the possible body weight levels to: left, centre, and right, rather than eight separate levels.

In future works we would like to develop more sophisticated environment, where the patient is motivated to pursue best results based on gratification system embedded in a computer game.

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