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EVALUATION OF THE HIPPOTHERAPY BENEFITS FOR DOWN SYNDROME PARTICIPANTS USING GOETHE GAIT LAB MOTION TESTING SYSTEM

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AbstractHippotherapy is a treatment approach that harnesses the motion of horses to produce practical outcomes in individuals with Down syndrome (DS), who experience motor and neurophysiological alterations impacting their musculoskeletal system. In this study the impact of hippotherapy on the development of children with Down syndrome who have mobility impairments is modelled and investigated. The gait test characterises motor coordination and monitors changes. Our results show that hippotherapy helps children with Down syndrome.

Keywords: Hippotherapy, Down Syndrome, Hip Deformities, Postural Asymmetry, Motor Coordination, Rehabilitation Therapy, Developmental Disorders, Inclusive Health Care, Quality of Life, Mobility Enhancement, Neurorehabilitation, Good Health and Well-Being, Reducing Inequalities, Sustainable Communities.

AMS Mathematics Subject Classification: 92C30, 92C35, 92C50, 92C55, 92C80, 92B05, 62P10.

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1 Introduction

Down syndrome stands as one of the most prevalent congenital disabilities, which affects approximately one in 600 children due to a chromosomal defect. Humans typically possess 23 pairs of chromosomes, totalling 46, with equal contributions from maternal and paternal sources. However, in individuals with Down syndrome, chromosome 21 is triplicated in every cell, a condition known as trisomy, which happens from flawed cell division processes. While translocation, where chromosome 21 attaches to another pair, or mosaic Down syndrome, where trisomy appears in only some cells, are rarer occurrences, they further illustrate the complexity of this disorder [1–3]. Evidence suggests that Down's syndrome has persisted throughout history, with representations found in early artistic depictions, yet it wasn't until 1866 that Dr. Langdon Down formally recognized and described the associated intellectual disability. Despite advancements in understanding, the likelihood of Down's syndrome increases with parental age, although the average age of parents of newborns with Down's syndrome remains consistent with the general population, underscoring the condition's enduring prevalence. It's essential to distinguish Down syndrome as a condition rather than a disease, as it stems from chromosomal aberrations that lead to distinct biochemical imbalances in the body, influencing various bodily functions [4]. While drug treatments aim to address these imbalances, many lack robust statistical support, which highlights an ongoing challenge in managing this condition. Moreover, individuals with Down syndrome face a heightened risk of various comorbidities, which necessitate comprehensive screening and treatment approaches to address associated health issues effectively [1].

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The cognitive development of children with Down syndrome progresses slowly, accompanied by abnormal body proportions, weak muscles, loose joints, short stature, and abbreviated limbs. Their movement is notably sluggish, influenced by various factors. Firstly, asymmetrical body development, primarily attributed to hip deformities, affects their posture and mobility. Additionally, fine motor skills like writing and gross motor movements such as walking are hindered due to impaired motor coordination. Obesity, a common concern documented through various body mass indices (BMI), further exacerbates their physical challenges [2]. Moreover, characteristic muscle hypotonia contributes to their overall muscle weakness. In Down syndrome, differences in the development of right and left side movement are widespread, largely influenced by hip deformities and lax joints. Surgical intervention is often the most effective solution, as physiotherapy struggles to maintain their mobility, necessitating multiple surgeries as they continue to grow.

Facial features in individuals with Down syndrome typically include a small nose, a flat bridge, slanted eyes, tiny ears, and a distinctive blush. Moreover, they commonly exhibit traits such as honesty, sensitivity, warmth, and strong social skills. They express deep affection towards their loved ones and lack the capacity for deceit or manipulation. The disorder is characterized by abnormal intellectual abilities and lax joints within the musculoskeletal system. Despite the looseness of their joints, their range of movement is often limited. While their intellectual potential was previously underestimated, we now recognize their ability to learn steadily. Many individuals with Down syndrome can acquire reading and writing skills, primarily driven by love and motivation. Their intellectual challenges are offset by simple reasoning, emotional understanding, and a penchant for music, dance, and humour. Historically, untreated illnesses and unaddressed heart conditions led to a lower average lifespan for individuals with Down syndrome. However, advancements in healthcare have resulted in many living well into their 70s, with only a slightly reduced average age. Nonetheless, they often face mild to moderate intellectual disability, as indicated by IQ assessments. Given these challenges, specialized education and effective therapies are crucial for supporting individuals with Down syndrome and easing the burden on healthcare professionals [4–7].

It's important to note that therapy design can target two key areas: intellectual and psychological development, and movement and motor coordination enhancement. These areas are closely interconnected as children require physical, intellectual, and emotional growth to integrate successfully into society. Various psychological techniques can foster emotional, intellectual, and social development. For instance, children can learn writing, reading, and arithmetic through visual aids such as pictures and diagrams. Additionally, specialized methods can teach children social norms and interactions. Improving movement entails primarily addressing asymmetry and muscle atrophy while promoting proper muscle function and coordinated movement. Physiotherapy plays a crucial role in addressing muscle hypotonia, developing normal muscle tone, and strengthening the weaker side of the child [8]. In severe cases, surgery may be necessary to correct hip deformities, with the appropriate osteotomy chosen by the doctor based on the specific pathology [2]. Subsequently, post-operative rehabilitation physiotherapy is conducted, tailored to the type of hip replacement. However, this approach can be physically and psychologically demanding for the child. Furthermore, individuals with Down's syndrome often have other medical conditions, such as drug allergies and cardiovascular problems, which increase the risks associated with surgery.

Our exploration of existing research reveals that initial studies on children with Down syndrome were carried out in Japan, followed by similar investigations involving adults in the United States [1–5]. These studies involved training children in aerobic exercises, monitoring their heart rate and oxygen uptake, and assessing their respiratory rate post-exercise. The

findings suggested that the exercises were quite intense, prompting a recommendation for brisk walking as a less taxing alternative [6]. Nevertheless, recent research has demonstrated that movement therapy, particularly aerobics, can enhance both muscle function and mental abilities. While numerous studies have analyzed movement patterns in individuals with Down syndrome, most of them compared these patterns with those of healthy individuals of similar age, rather than assessing the effectiveness of specific exercise therapies. Meanwhile, reports from a local auxiliary school indicate significant enhancements in movement coordination among pupils undergoing hippotherapy, corroborating our own observations. Therefore, it is worthwhile to investigate how hippotherapy, also known as horse riding therapy, influences movement development [7]. To address this, we initiated a study in Budapest, drawing on international experiences. After conducting a preliminary medical examination, we randomly selected children with Down syndrome, both participating and not participating in hippotherapy, from a specific school. We measured their motor coordination before and after therapy initiation [8]. We opted to evaluate walking as it is a common daily activity for everyone, thus ensuring that the test did not place undue psychological or physical stress on the children. This consideration is crucial for ethical reasons [9]. We hypothesised that if children's locomotor coordination is altered by riding, it will profoundly affect their walking. As a form of locomotion, walking requires the coordinated action of many muscle groups i.e., practically the whole body, which requires both the proper development of the musculoskeletal system and the precise regulation of muscle function (e.g. the proper functioning of flexor and extensor reflexes) [10–12]. Nor should it be overlooked that the sense of position and location also plays a vital role in the movement. It means that correct signals from receptors in the sacculi, utriculi and ampullae of the auditory and vestibular organs are required, and the correct transmission of information from the VIIIth nerve and, ultimately, the correct integrating role of the cerebrum. Many components, therefore, influence movement control [13, 26–28].

2 Materials and Methods

In this study 30 participants with Down syndrome aged 10–13 years are included under the schoolвЂ™s doctor supervision and approval. 15 riding and 15 non-riding participants i.e., control group, were randomly selected. The control group received physiotherapy sessions set up by the conductor, so our study compared the two therapies. Four sets of measurements were taken as follows: 1. before starting the therapy, 2. after one month of therapy, 3. after a three-month break before therapy, 4. after one month of therapy. Before the start of therapy and one month later, gait analysis assessed changes in motor coordination. We chose to study gait because it is a movement that is part of every person's daily life, so the study does not impose a particular burden on the children.

The movement therapy of the control group was prepared and carried out by the conductor with the children three times a week for one hour. During the hippotherapy, the children rode a particular western-style horse for 15 minutes once a week. We used western style riding for hippotherapy. The reason is that when riding injured children, and therefore during hippotherapy, special attention must be paid to the rider's safety. It requires increased attention and tolerance from the trainer and absolute obedience from the horse to the trainer. In addition, the equipment used in western style riding is much more suitable for riding a person with mobility difficulties than that used in English riding because it offers more excellent safety for children.

The basic requirements for horse breeding are as follows. (1) Absolute obedience to the trainer, the horse must respond immediately to the slightest signal from the trainer. (2)

Courage, i.e. the horse should not be frightened by the noise of its environment nor react unpredictably in unexpected situations. (3) A low saddle so that the horse can be saddled well and the saddle does not cause damage to the horse's body, even if the rider sits incorrectly. A wide, rounded rump and solid hind legs are necessary to ensure robustness, i.e. the horse can change gait at any time at the trainer's or rider's command or signal. (4) It is essential that the horse moves steadily in all gaits and maintains its balance at changes of pace, even if the rider is sitting incorrectly.

In this study the Goethe Gait Lab (GGL) motion testing system is used. The walk was recorded from four views (front, back, left and right) using four video cameras. The data was then processed using the GGL video analysis system available at the Department of Biomechanics of the Hungarian University of Physical Education. The Dempster model was used to identify body segments. We take accurate anthropometric measurements to determine the centre points of the segments. Our method allowed us to follow the movement of the body's points of interest in three dimensions and analyse the extent of the changes. Calibration and

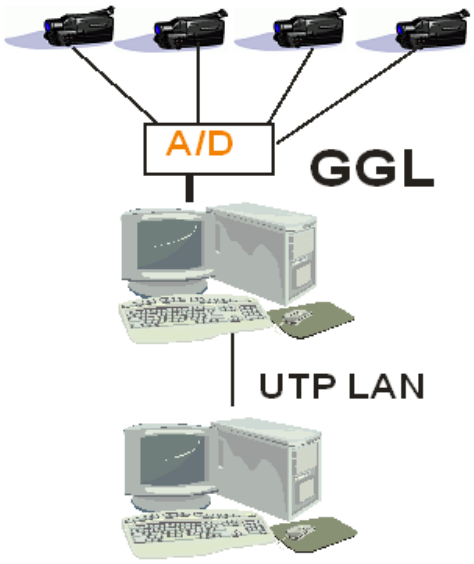

Figure 1: GGL video analysis system.

positioning of the cameras before recordings is essential. The calibration system needed to be simplified due to the location of the test, so an 8-point calibration brick body is helpful for our tests. Once we have fixed the location of the calibration body, the brick body can be removed, as we do not change the measurement position afterwards, so its presence does not disturb the children's movements. The coordinates of the eight control points declare in the figure. The coordinate of 1 point is not 0 in all three directions because we had to shift the position of the grid points relative to a virtual origin to display the result correctly. For example, the coordinates should never be negative. The eight points can thus define three directions of space. The simplification of the control point system was necessary because of the need for more space: the school had only a gym where we could do the measurements. Before that, trial measurements checked the accuracy of the measurement system. The two thick black marks represent the 200 cm distance within which we selected the step cycle to be processed.

It is necessary to mark points of emphasis on the body to track its movement of the body.

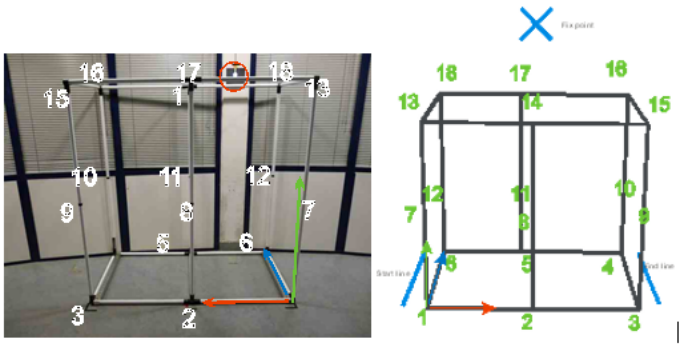

Figure 2: Calibration system.

Therefore, we create a body model. In the processing, a modified Dempster's body model is used, which consists of 18 notable points and the sections connecting them. The location of the 19th point (centre of mass) was calculated. We take each subject anthropometric data into account. Globally, the height and weight were taken into account, and locally, the location of the centre of mass of the corresponding body segments was determined from our measured data, thus modifying the model.

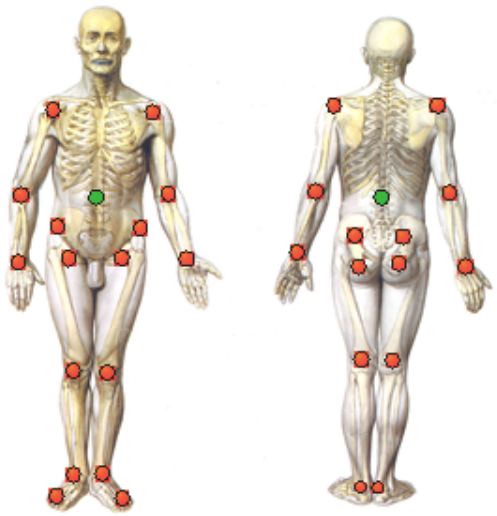

Figure 3: The modified body model.

Inclusion criterion: Down's syndrome and age 10–13 years. Riding and non-riding children were randomly selected from children with Down's syndrome in the particular school. The school doctor recommended that all children participate in hippotherapy. There were 15 children in each group, and the non-riding children received physiotherapy. The latter group—as a control group—received physiotherapy sessions set up by the conductor, so our study compared the two therapies. The movement therapy of the control group was prepared and carried out by the conductor with the children three times a week for one hour. It requires increased attention and tolerance from the trainer and absolute obedience from the horse to the trainer. The basic requirements for breeds created in horse breeding are as above. It is

essential that the horse moves steadily in all gaits and maintains its balance at changes of pace, even if the rider is sitting incorrectly.

3 Results

3.1 Assessment of the measurement

We compared the movement coordination data of riding and non-riding children to analyse our results. We could only process data from 13–13 children in the two groups because 2–2 did not participate in the second study due to illness. We will first highlight one child from each group, analyse their movements in detail, and then present the main results of the two groups. Observing the progressive movements of the riding child, we can see the following.

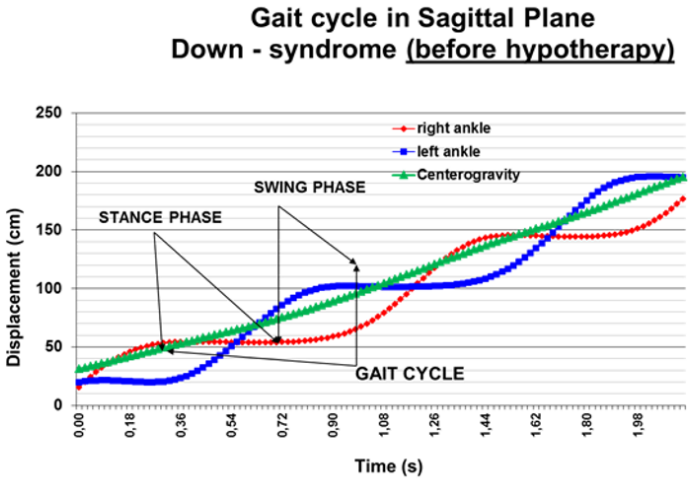

Figure 4: The riding child's gait before therapy.

We plotted as a function of time the displacement in the direction of progression (x-axis) of the right and left foot. The first figure shows that the two legs did not subject to the same load. The subject took shorter steps with the right foot, and the foot was on the ground for longer (the straight sections of the curves are longer). The areas enclosed by the two curves are unequal due to asymmetric loading. The vertical lines mark the sections where both feet are on the ground (double support). The asymmetry is also clearly visible in these cases. So in the case of the child, the right leg is weaker.

The second figure shows this difference between the two sides due to riding, or the subject has covered more distance simultaneously. The duration of double supports and the areas covered by the curves are almost identical. The following results were obtained by observing the progression of the non-riding child.

We also plotted the displacement in the direction of progression for the right and left foot as a function of time. The areas enclosed by the two curves are not equal due to asymmetric loading. Here, the vertical lines indicate the sections where both feet are on the ground (double support). The asymmetry is also clearly visible in these cases. In the non-riding child, no improvement is observed in the post-treatment step pattern.

At the second measurement, the average speed of the child's progress increased, with more trips made in the same amount of time. However, at the second measurement, the

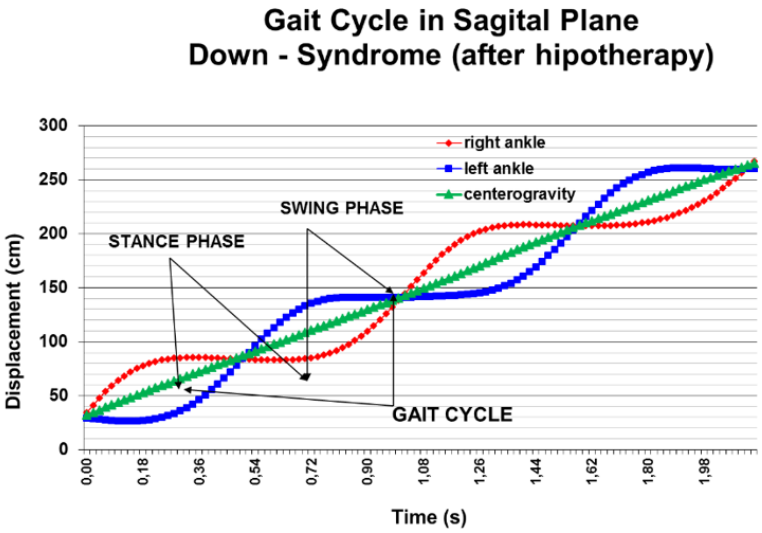

Figure 5: Step diagram of the riding child after therapy.

double support time increased significantly. It contradicts how the child can progress faster if the double support takes longer, during which the gait slows down. It can explain that the child's balance has deteriorated and therefore needs to be corrected by conscious motor control (standing longer at a given position). However, the swing phase of the stride has accelerated, and the result of the two processes has allowed faster movement overall. The following important parameter is the directional speed of the centre of gravity.

In the case of the riding child, the measured data shows that the speed of the centre of gravity doubled after the treatment, demonstrating that coordination has improved, as the better balance is essential for faster progress (the speed of progress in a healthy person is 110–130 cm/sec). However, it is worth noting that the upward slope of the curve decreased after the treatment. It means that less muscular work is required to achieve the higher speed, so the better balance explains the increase in speed. Examining the same for the non-riding child, we concluded the following.

In the case of the non-riding child, the speed of the centre of gravity's progress did not improve; the balance is therefore not correct.

We had to make several considerations in comparing the riding and non-riding groups. When analysing the children's motor coordination, we looked for a parameter that would describe the changes well: improvement and deterioration are associated with increases and decreases in the parameter. At the same time, it provides information on the degree of hip deformity and asymmetry of the two sides and information on the functioning of balance, i.e. motor coordination. We considered the value of the stride length to be such an important parameter (a longer stride length implies a faster progress speed, better balance and better movement coordination).

Since the asymmetry of the two sides characterises children, the stride length from the ground grip of the foot to the following ground grip of the same foot (e.g. the stride length of the right foot from the ground grip of the right foot to the following ground grip of the right foot) was measured in centimetres using the points of the body model. Based on both recordings (before the start of therapy and one month later), we measured stride length for both riding and non-riding children, calculated the mean, standard deviation and variance of the data obtained and then used a double T-test to check for significant differences between

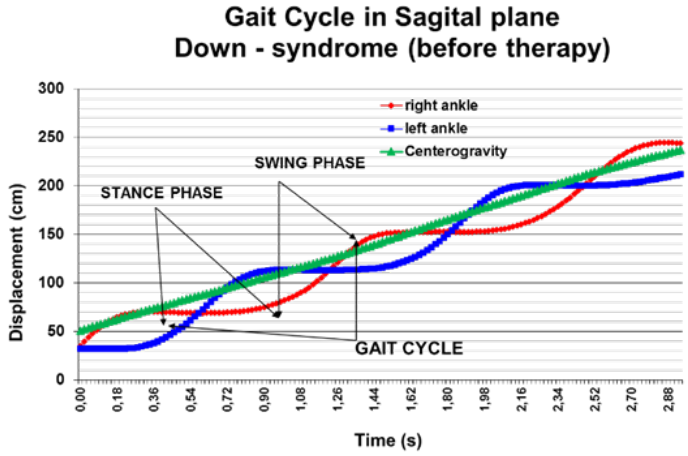

Figure 6: The non-riding child's gait pattern before therapy.

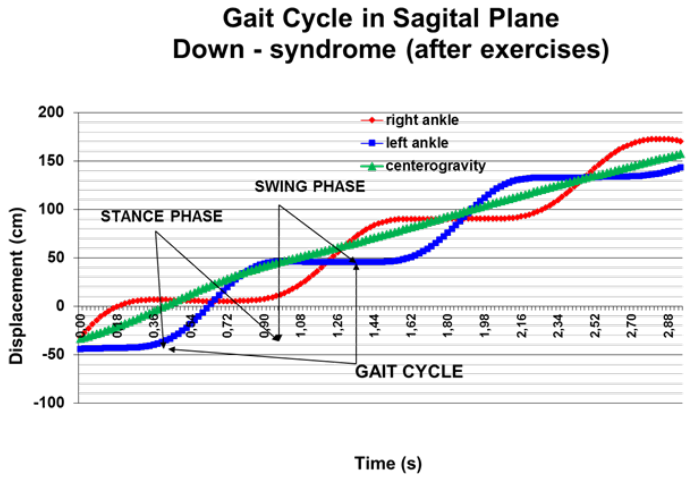

Figure 7: Step pattern of the non-riding child after therapy.

our data ($p < 0.05$). It was done for both the right and left sides. The data obtained led to the following result. For the riding children, there was a significant increase on both the right and left side, indicating better motor coordination and a decrease in hip deformity.

The means, standard deviations and variances for the difference values may seem very large. However, it is essential to note that a very high percentage of children achieved a stride length of around 13 cm at the first measurement, while stride lengths of 50 cm are not uncommon in the second.

In the children in the non-riding group, on the other hand, there is a significant decrease in the step length of the right leg (double T-test) but not of the left leg. It is because the two sides of the children are not equally affected by gymnastics. However, there is a decrease on both sides compared to the original condition. Here again, the statistical values are relatively large due to the sample's heterogeneity and the magnitude of the change.

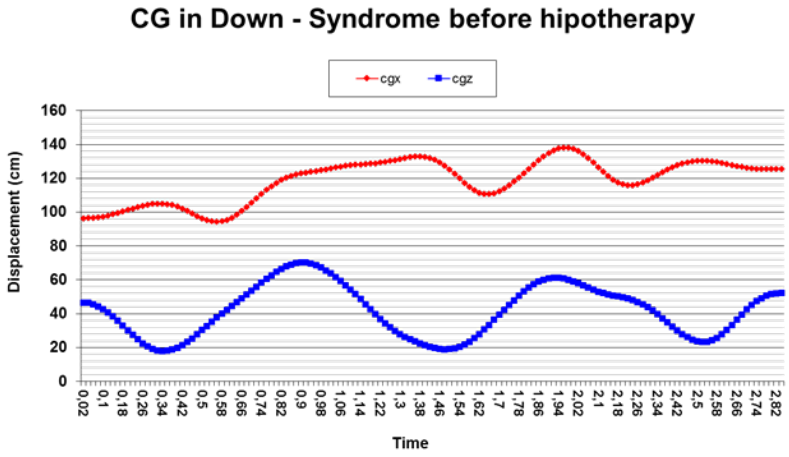

Figure 8: Centre of mass movement of the riding child before therapy.

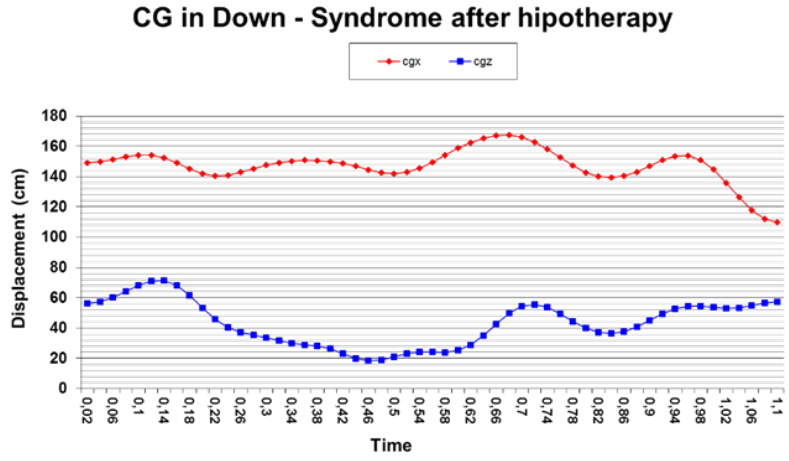

Figure 9: Movement of the centre of gravity of the riding child after therapy.

4 Discussion

Therapy effectively corrects the difference between Down syndrome's right and left sides, and the double support time becomes symmetrical. Significantly, the vertical displacement of the foot is improved, and the child's foot is closer to the ground, so he/she walks on tiptoe less than before. The speed of progress reaches a healthy level, and the muscles work more efficiently. Riding makes the spine and hips move closer to normal, the muscles become more flexible than before, and the asymmetry of the two sides reduces. The stiffness of the hip, which is compensated by the high amplitude movement of the shoulder, is eliminated, and the shoulders and hips movement are in the same phase, proving that the spine and trunk are now able to rotate. Knee flexion/extension increases, showing that the knee is more flexible than before. When evaluating the results, it should not be forgotten that getting children to cooperate with Down's syndrome is not easy. Furthermore, if they are unaware of what is happening around them, they can panic more quickly than healthy children, making it more difficult for the doctors and nurses who are trying to help. Equine therapy as a therapy tries

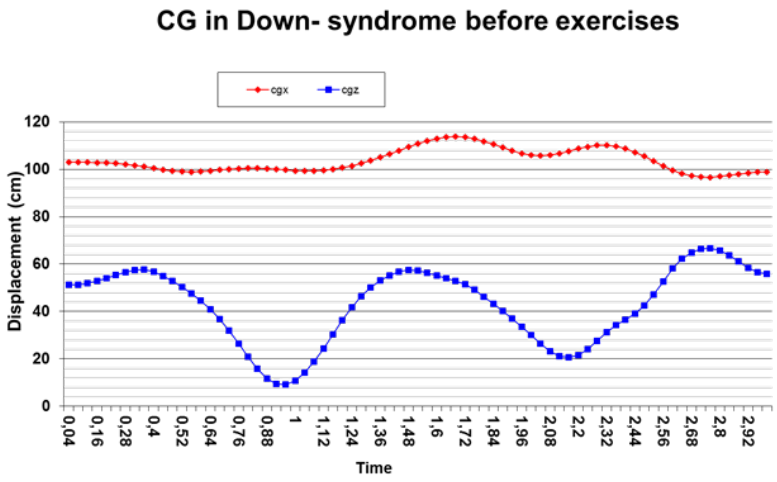

Figure 10: Centre of mass movement of the non-riding child before therapy.

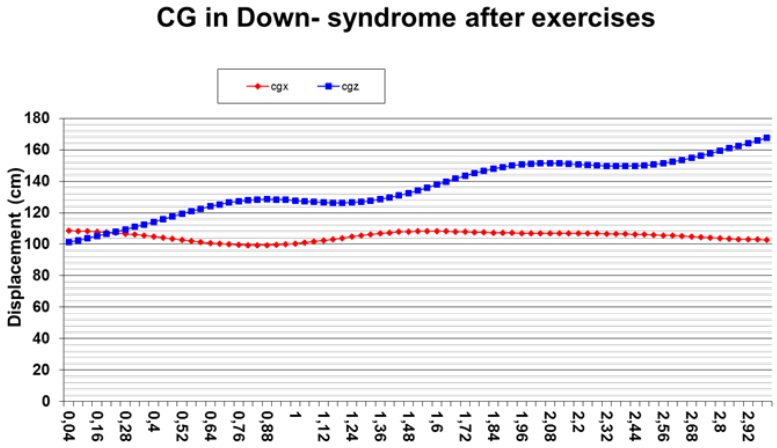

Figure 11: Centre of mass movement of the non-riding child after therapy.

to help with this, as does the measurement process.

Observations and measurements of movement in children with Down's syndrome were first carried out in Japan [2]. The children were trained in aerobics, and researchers measured heart rate, oxygen uptake and respiration rate after each exercise. Their measurements showed strenuous exercise, so they recommended brisk walking instead. Later, a study on adults in the United States of America showed that exercise therapy (aerobics) improves not only muscle function but also mental ability [1]. In contrast, a unique form of physiotherapy is helpful in a children's institution in Hungary. Hippotherapy, special riding exercises, were carried out with children in several school groups instead of physiotherapy sessions organised by the conductors [14]. The pupils at the school thus received hippotherapy, and their motor coordination improved significantly, according to their teachers. International experience confirms the positive effects of horse riding, with good results in the United States for amputee soldiers. Moreover, later, in several countries, such as Germany and the former Soviet Union, disabled people with physical and mental handicaps were ridden [15–20]. However, no scientific reports of their work were available in medical databases. The difference between the right

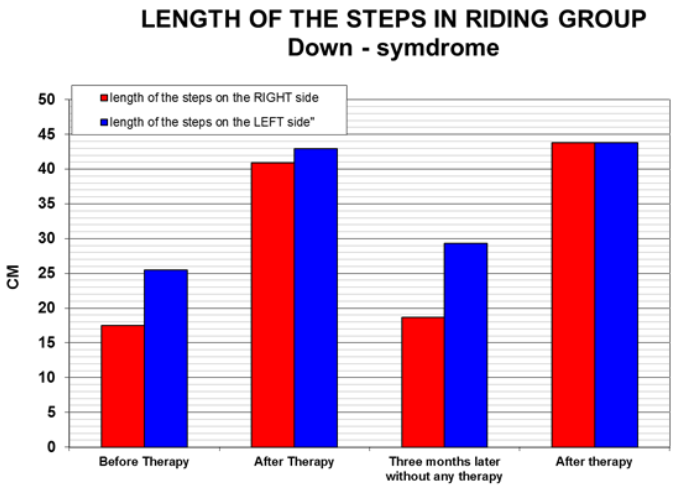

Figure 12: Change in stride length in the riding Down syndrome group.

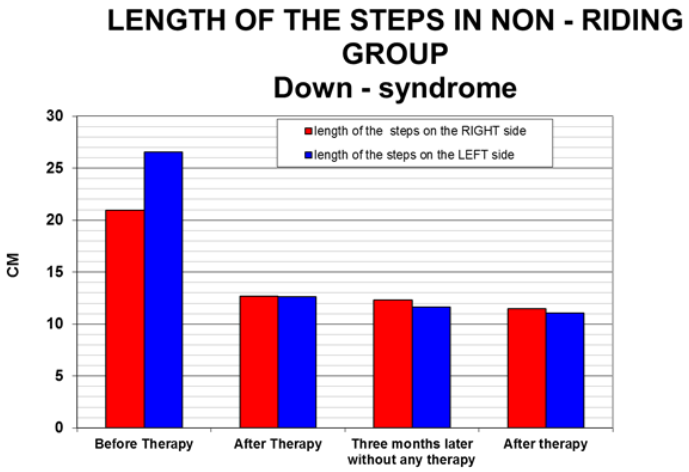

Figure 13: Change in stride length in the non-riding Down syndrome group.

and left sides characteristic of Down's syndrome can be effectively corrected with therapy, and the double support time becomes symmetrical. Notably, the vertical displacement of the foot is improved; the child's foot is closer to the ground and therefore walks less on tiptoe than before. The speed of progress reaches a healthy level, and the muscles work more efficiently. Riding makes the spine and hips move closer to normal, the muscles become more flexible than before, and the asymmetry of the two sides decreases [21–23]. The stiffness of the hip, which is compensated by the high amplitude movement of the shoulder, is eliminated, and the shoulder and hip move in phase, proving that the spine and trunk can now rotate. Knee flexion/extension increases, showing that the knee is more flexible than before. These findings are essential, considering surgical procedures cost much more than hippotherapy [24–26]. Our study also raised financial issues related to the therapy. Since several researchers have explained [3] that the asymmetry of the two sides (especially the hip deformity) in children with Down syndrome can only be resolved by surgery, which sometimes has to be performed several times, the question arose: how much does it cost? Neither for society nor children is it the same which procedures and methods are used to improve the situation of patients.

All medical interventions are very stressful for children (stressors) and slow the healing process by inhibiting the immune system. At the same time, it should not be forgotten that Down's syndromes are not easy to achieve children's cooperation. Moreover, if they are unaware of what is happening around them, they can panic more quickly than healthy children, making it more difficult for the doctors and nurses who are trying to help [27,28]. It is appropriate to develop a therapeutic procedure that does not cause psychological distress to children. In this way, they become cooperative and happy to do the task (which is often not a task but merely a game). It is in the interest of society and the children's families to use an effective and cheaper therapy to solve the problem.

5 Conclusions

Therapeutic interventions effectively address asymmetries in Down syndrome, improving symmetry in walking and foot positioning. Progress is evident in muscle efficiency and flexibility, with reduced tiptoe walking tendencies. Riding therapy enhances spinal and hip movement, reducing asymmetry and stiffness. Hippotherapy shows promise in enhancing motor coordination, with international experiences supporting its benefits. Considering the high cost of surgical interventions, alternative therapies like hippotherapy offer cost-effective solutions. However, challenges remain in children's cooperation during medical interventions, highlighting the need for psychologically non-distressing therapeutic approaches. Prioritizing such strategies benefits both individuals with Down syndrome and society.

Acknowledgement

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