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Effects of robotic rehabilitation on walking and balance in pediatric patients with hemiparetic cerebral palsy

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ABSTRACT

Background: The most prominent characteristics of hemiparetic cerebral palsy (hCP) children are structural and functional asymmetries. These children have low walking speeds, endurance and poor balance. The robotic walking devices repeat and experience symmetrical stepping at the corresponding speed and angles of the lower extremities.

Research Question 1: Are robotic walking devices effective in the development of walking in hCP children who can walk?

Research Question 2: How does the aerobic exercise experience with assisted and symmetrical movement affect the walking and local muscle, peripheral oxygenation of children with hCP?

Methods: This prospective, controlled study included 24 children with hCP. All children attended to a standard physiotherapy rehabilitation (PTR) program (three days a week for 12 weeks); those in the study group (n = 12) also attended to an Robotic Gait Training (RGT) program three times a week. Evaluations performed before treatment, after treatment, and at the 3rd month after treatment included assessment of balance, functionality walking and measurements for oxygenation of vastus lateralis muscle and peripheral oxygenation.Results: The evaluations were similar for both groups before treatment. After treatment, walking speed, endurance and peripheral O2 saturation were increased and balance abilities and functional performances improved in the RGT group as compared with the pre-treatment evaluations; these improvements in balance and functional performance were generally preserved after 3 months of treatment. An increase in 6-min walking distance and a partial increase in gross motor functions and functional muscle strength were observed in the control group; however, these abilities were not preserved after the treatment.

Significance: RGT can provide a faster and higher effect on the development of functional muscle strength, balance, walking speed and endurance than the standard PTR program. It improves functional walking performance. RGT can be used for aerobic exercise training in children with walking hCP.

1. Introduction

Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of CP are often accompanied by disturbances of sensation, perception, cognition, communication and behaviour, by epilepsy, and by secondary musculoskeletal problems [1]. Hemiparetic CP (hCP) characterized by motor and/or sensory damage of unilateral limbs is the most prevalent type of spastic CP [1]. Motor asymmetry is the initial clinical symptom of hCP and subsequent problems arise from structural and functional asymmetry [2]. In children with hCP, gait patterns deviates from normal and their walking speed and balance and their competence in advance functional skills are poor [3]. Performance loss in skills due to impairment in flexibility and fluency of movement is observed even in CP individuals with the highest functionality [4]. All these conditions negatively affect emotional satisfaction and self-confidence [5].

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Elimination of factors negatively affecting individual's independence and participation in life is among the most critical goals of rehabilitation. For these purposes, using robotic systems is increasingly becoming more popular. Robotic systems are used to enhance residual capacity and develop standing, balance, and locomotion and as a part of rehabilitation since they facilitate cortical reorganization through intensive, controlled, repetitive, task/goal-oriented training and motor learning [6].

This study aimed to investigate the effects of robotic gait training (RGT) on functional walking, balance, and muscle and peripheral oxygenation of children with hemiparetic cerebral palsy (hCP).

2. Method

This study was performed in January-October 2016 in the Physiotherapy and Rehabilitation Department of Hacettepe University Faculty of Health Sciences. The Clinical Research Ethics Board of Hacettepe University and the Ethics Committee of Turkish Medicine and Medical Devices Agency (Decision no: 2016/06-34, KA-16045) approved the study. Parents of children gave written informed consent to the research and to publication of the results.

2.1. Participants

The study enrolled 24 children (aged 5–12 years) with congenital spastic hCP who were regularly attending a standard physiotherapy rehabilitation (PTR) program. Children with Gross Motor Function Classification System (GMFCS) Level I (those walking without restriction and having limitations in advanced gross motor skills) or Level II (those walking without an assistance device and having limitations while walking outside and in crowd) [7], children with no visual or hearing impairment, and children without mental retardation at a level hindering communication were included. Exclusion criteria included having lower limb fracture or muscle-tendon/bone surgery in the last six months, exposure to any pharmacological agent likely to inhibit spasticity in the last six months, cardiac or respiratory problems, and lower limb contracture that might hinder robotic walking device use.

2.2. Study design

In this prospective, controlled study, 12 patients agreed to participate in the robotic gait training (RGT) in addition to the standard PTR program (study group) three times a week. The RGT was performed three times a week with each session being 30 min. Patients who did not agree to participate in the RGT formed the control group. Randomization could not be performed as the study group included the children whose families were able to allocate time for RGT. However, attention was paid for the patient distribution to be similar between the groups regarding demographic and clinical characteristics. The treatments were performed in both groups for 12 weeks.

Study evaluations performed before the treatment, after the treatment (at the end of 12 weeks), and at the third month after the treatment (for assessing the persistence of treatment efficacy) included clinical evaluations to assess balance, walking, and functional performance level and near-infrared spectroscopy (NIRS) measurements to assess oxygenation of vastus lateralis (VL) muscle bilaterally, heart rate (HR), and peripheral oxygenation. At the end of 12 weeks of treatment, two children in the control group withdrew the study (one due to botulinum toxin-A administration into his/her lower extremity muscles and the other due to moving to another city). Thus, evaluations performed at the post-treatment third month were performed in 22 children.

2.3. Intervention program

The PTR program included active functional strengthening exercises for antigravity muscles of the lower extremities, stretching exercises for flexor muscles of the knee and hip, plantar flexors, and adductor muscles, terminal squat, stair climbing-descending exercises, functional reaching, balance training using a balance board, and standing on a single leg.

For RGT, *the Innowalk Pro* (Made for Movement, Norway), medium-size (for children between 100 cm and 140 cm in height) and large-size devices (for children > 140 cm in height), was used [8]. RGT was also performed as an aerobic exercise. Specific target HR interval was determined as 55–75% of the maximum HR. During aerobic exercises, a low-intense 5-min warm-up and cooling program was performed at 30–40% of the maximum HR; brisk walking was performed for 20 min with increasing speed at 55–75% of the maximum HR. Gait training comprised a 30-min active walking training. Polar FT7 HR monitor watch (Polar Electrro Oy, Kempele, Finland) and a sensor strap, which was placed onto the chest at the cardiac level, were used for monitoring target HR during walking.

2.4. Evaluation methods

Data on age, gender, height, body weight, age at onset of walking, and involved side were recorded.

Gross Motor Function Measurement (GMFM) measures the changes in motor performances of children with CP aged 5–16 years [9]. We used GMFM-88 including the following dimensions: A: lying and rolling, B: sitting, C: crawling and kneeling, D: standing, and E: walking, running and jumping [10].

Functional muscle strength was assessed using lateral step-up test, sit-to-stand test, and half kneeling standing test, which were performed within a closed kinetic loop. Number of repeated movements of the paretic (P) and non-paretic (NP) extremities in 30 s were recorded [11,12].

Static balance was evaluated by standing on one leg test and dynamic balance was evaluated by the Pediatric Berg Balance Scale (PBS) [13,14]. Duration of standing on one leg was recorded separately for P and NP extremities.

Ten-meter walk test (10mWT) was used to assess walking speed. Children were asked to walk a 10-m distance for three times at their selected velocity and at the fastest speed that he/she could walk. The arithmetic mean of times measured for the intermediate six meters was calculated [15].

The six-minute walk west (6MWT) was used to evaluate walking speed and capacity [15,16]. Children were asked to walk a 20-m distance for six minutes without stopping and running and by not providing any directive regarding walking speed.

Independence and functionality of children during functional locomotor activities was assessed by the Gillette Functional Assessment Questionnaire Walking Scale (FAQ-WL) [17]. The same parent (mother or father) accepted to participate in the study answered the questionnaire.

NIRS enables investigation of physiological responses occurring in the oxygenation of muscles during exercise and resting [18–21]. This study evaluated the VL muscle, the most appropriate muscle showing regional muscle oxygenation (rSO2) during dynamic exercises.

Physiological changes at rest, during exercise, and due to changes in workload were evaluated using SenSmart™ Model X-100 Universal Oximetry System [20,22]. Changes in blood volume and rSO_2 were recorded from the proximal VL muscles in each extremity and SpO_2 and HR were recorded simultaneously from the index finger on the NP side. Changes in rSO_2 SpO_2, and HR values were evaluated during five-min resting periods both before and after exercising and during 30-min exercising performed with *Innowalk Pro*. The mean value of five-min measurements performed between 13^{th} and 18^{th} minutes of the 30-min exercising was calculated as the maximum exercise performance and the changes in these measurements according to the initial resting value (ΔrsO_2, ΔSpO_2, and ΔHR) were also calculated. Fractional oxygen

Fig. 1. Near-infrared spectroscopy evaluation during robotic gait training.

consumption was calculated using the following formula: $fO_2 = (SpO_2 - rSO_2)/SpO_2$). This change between the repeated measurements was evaluated. NIRS evaluation during robotic gait training is demonstrated in Fig. 1.

2.5. Statistical analysis

The Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA; v.15) was used. Numerical variables were expressed as mean (standard deviation); categorical variables were expressed as number. Normality was tested using Kolmogorov-Smirnov analysis. Two group comparisons were performed by Mann–Whitney *U* test. Pre- and post-treatment data were compared using Wilcoxon signed-rank test. Pre-treatment, post-treatment, and post-treatment 3rd month data were compared using the Friedman test; Wilcoxon signed-rank test was used for paired comparisons. Statistical significance was set at $p < 0.05$.

3. Results

No significant difference was determined between the study and control groups regarding general characteristics (Table 1). There were three children with right-sided hCP and nine children with left-sided hCP in both groups. In each group, there were 10 children with GMFCS Level I and two children with GMFCS Level II. There were six girls and six boys in each group.

Table 1
General characteristics of the children in the study and control groups.

Characteristics	Study Group Mean (SD)	Control Group Mean (SD)	p^*
Age, year:month	8:9	9:6	0.501
Weight, kg	28.50 (11.21)	29.17 (7.17)	0.386
Height, cm	130.58 (17.51)	136.00 (12.92)	0.340
Body mass index, kg/m^2	16.14 (2.32)	15.72 (2.59)	0.603
Age at onset of walking, months	20.42 (9.07)	16.42 (7.05)	0.219

SD, standard deviation.
* Mann–Whitney *U* test.

Pre-treatment comparisons revealed no significant differences between the groups regarding walking speed and endurance, balance, functional performance values, and parameters indicating physiological changes at rest and during activity.

An increase was observed in the muscle oxygenation after the treatment in both P and NP extremities of the children, with no significant difference (Table 2). This increase was determined in nine children in the study group and in five children in the control group. This improvement was maintained at the post-treatment 3rd month in five children in the study group and three children in the control group. SpO_2 was increased after the treatment in the study group.

Intra-group comparisons of the pre-treatment, post-treatment, and post-treatment third month rSO_2 values of the VL muscle revealed no significant difference in either group.

In the study group, comparison of the outcomes before and after the treatment (Table 3) revealed a decrease in the 10-m walk time at the child's selected velocity but an increase in the distance determined by the 6 MWT. In the control group, the distance determined by the 6MWT was increased. While an increase was observed in the time of standing on the P extremity and in the PBS score in the study group, no difference was observed in the control group.

A significant difference was determined in the scores of GMFM-88, GMFM-D, and GMFM-E in the study group and in the score of GMFM-88 and GMFM-D in the control group. All functional muscle strength parameters were increased in the study group. In the control group, all functional muscle strength parameters, except for standing from half kneeling on the P extremity, were increased.

In the study group, the improvements in the post-treatment values were maintained at the post-treatment third month for the following parameters (Table 3): PBS, GMFM-88, and GMFM-D, and sit-to-stand test. The improvements in the following parameters continued increasingly at the post-treatment third month: standing on the P leg and lateral step-up by the P and NP extremities. In the control group, only the improvements obtained after the treatment in the 10-m walk time at child's selected velocity and the number of lateral step on the NP leg were maintained.

4. Discussion

Results revealed improved balance, walking speed, and functionality with the RGT in addition to the PTR in children with hCP.

Prefrontal synchronization could be enhanced with fast walking and walking speed improves performance [22]. Modulation of walking speed and steps with active walking training requires higher attention and cortical activity compared with passive training [23,24]. RGT was performed as an aerobic exercise with active participation of children but without challenging conditions. The children participated in RGT were observed to have a decreased 10-m walking time at child's selected velocity and to feel more comfortable at higher velocity. This suggested that children's perception of speed changed by the child-active high repetition walking training at a speed higher than children felt comfortable, which was attributed to the effect of high repetition training on sensation-perception-motor integration. Earlier studies have demonstrated that walking parameters of hemiparetic children can be changed depending on the rate of sensorial stimulants [25].

The distance measured by 6MWT was increased in both groups according to the pre-treatment values. The improvement in the study group (mean, 66 m increase) was three times higher than that in the control group (mean, 22 m increase). These increases can be accepted as a significant gaining by considering that improvement of performance in children with CP is achieved slowly and hardly.

Robotic approaches provide people with walking by simple repetitions [26]. Walking with lower effort enhances continuity and automatization of walking in children having walking skills [26–28]. The children experienced walking at higher speeds with lower efforts and their active participation. This substantial increase in the endurance of

Table 2
Comparison of the physiological changes at rest before exercise, during exercise, and at rest following exercise in the groups before and after treatment.

NIRS measurements	Study Group Pre-T Mean (SD)	Study Group Post-T Mean (SD)	p^*	Control group Pre-T Mean (SD)	Control group Post-T Mean (SD)	p^*
At initial rest						
P VL	85.36 (4.11)	86.23 (2.92)	0.530	83.66 (4.25)	84.18 (4.24)	0.838
NP VL	85.75 (4.17)	86.08 (3.23)	0.695	83.89 (2.95)	84.75 (3.97)	0.195
P/NP VL	0.39 (1.27)	0.15 (1.55)	0.346	0.23 (2.62)	0.58 (1.42)	0.838
During exercise						
P VL	82.03 (5.37)	84.13 (2.39)	0.060	80.24 (7.56)	81.50 (5.60)	0.530
NP VL	83.61 (3.86)	84.71 (3.16)	0.241	81.22 (4.47)	82.90 (4.21)	0.182
P/NP VL	1.59 (2.69)	0.58 (2.06)	0.224	0.98 (3.74)	1.40 (2.71)	0.789
At final rest						
P VL	83.22 (5.36)	84.97 (2.20)	0.170	81.98 (5.99)	83.08 (5.90)	0.583
NP VL	84.90 (4.01)	86.15 (3.12)	0.347	83.45 (3.73)	84.47 (3.91)	0.367
P/NP VL	1.69 (2.47)	1.18 (1.55)	0.695	1.47 (3.34)	1.39 (2.78)	0.789
SpO_2	97.27 (2.17)	99.00 (3.60)	**0.045**	96.98 (2.08)	96.83 (2.64)	0.476
HR, beats/min	104.45 (11.09)	106.92 (11.99)	0.480	83.66 (4.25)	105.33 (6.67)	0.477

NIRS, near infrared spectroscopy; **Pre-T**, pre-treatment; **Post-T**, post-treatment; **P**, paretic; **NP**, non-paretic; **VL**, vastus lateralis, **SpO_2**, peripheral oxygen saturation; **HR**, heart rate; **SD**, standard deviation.
Bold values signifies $p < 0.05$.
* Wilcoxon signed-rank test.

Table 3
Intra-group comparisons of the test results evaluating the functional performance of children before the treatment, after the treatment and at the post-treatment third month.

Tests	Study Group Pre-T	Study Group Post-T	Study Group Post-T third month	p^*	Control Group Pre-T	Control Group Post-T	Control Group Post-T third month	p^*
10 m walking at selected velocity, s	5.80 (0.56)^a	5.11 (0.92)^b	5.36 (0.96)^{a,b}	**0.017**	5.18 (1.13)^a	4.86 (0.67)^a	5.90 (0.90)^b	**0.050****
10 m walking at fast velocity, s	3.84 (0.71)^{a,b}	3.41 (0.37)^a	3.66 (0.51)^b	**0.039**	3.85 (0.65)^a	3.78 (0.59)^a	3.94 (0.45)^a	0.104
Six-min walking, m	409.58 (49.1)^a	475.17 (47.7)^b	438.17 (47.3)^a	**0.002**	437.0 (55.0)^{a,c}	459.17 (53.75)^b	443.43 (43.91)^{b,c}	0.066
Standing on the P leg, s	4.38 (3.84)^a	9.90 (14.81)^b	31.80 (74.91)^b	**0.046****	5.80 (5.81)^a	13.87 (19.46)^a	8.09 (7.02)^a	0.180
Standing on the NP leg, s	42.95 (76.17)^a	58.81 (69.96)^a	61.54 (74.37)^a	0.076	74.74 (117.2)^a	105.11 (173.6)^a	112.77 (196.0)^a	0.867
Berg balance score	50.08 (2.43)^a	52.08 (2.68)^b	52.00 (3.08)^b	**0.000****	50.25 (2.93)a	51.00 (3.30)^a	51.71 (3.82)^a	0.066
GMFM-88	253.00 (8.81)^a	256.17 (8.23)^b	256.17 (8.24)^b	**0.000****	253.67 (7.70)^{a,c}	255.25 (7.94)^b	254.25 (9.00)^{b,c}	0.163
GMFM-D	36.08 (2.27)^a	36.92 (1.73)^b	36.92 (1.88)^b	**0.003****	36.75 (2.22)^{a,c}	37.42 (1.98)^b	37.63 (2.00)^{b,c}	0.115
GMFM-E	64.00 (6.90)^a	66.25 (6.78)^b	65.50 (6.69)^b	**0.000**	64.08 (6.43)^a	64.92 (6.72)^a	63.87 (7.92)^a	0.305
P lateral step	19.50 (4.28)^a	23.00 (4.13)^{a,c}	24.83 (5.80)^{b,c}	**0.005****	20.08 (3.68)^{a,c}	22.83 (4.51)^b	21.71 (4.92)^{b,c}	0.317
NP lateral step	19.67 (4.40)^a	24.25 (4.73)^b	26.33 (5.76)^b	**0.002****	21.08 (3.45)^a	24.75 (3.86)^b	22.29 (3.95)^b	**0.015****
Sit-to-stand	15.08 (3.09)^a	18.50 (2.24)^b	17.17 (2.37)^c	**0.000****	15.50 (3.66)^a	16.92 (3.94)^b	14.71 (2.75)^b	0.141
Standing from half kneeling on the P leg	14.00 (4.73)^a	18.92 (5.58)^b	16.17 (3.46)^a	**0.001**	15.50 (3.43)^a	16.42 (4.91)^a	15.14 (2.91)^a	0.738
Standing from half kneeling on the NP leg	15.92 (2.39)^{a,c}	20.50 (5.90)^b	18.83 (4.17)^{b,c}	**0.017**	18.33 (3.60)^{a,c}	19.17 (5.56)^b	17.00 (5.16)^{b,c}	0.764
FAQ-WL	91 (7.14)^{a,c}	93.92 (8.96)^b	93.00 (10.11)^{b,c}	**0.025**	92 (9.27)^a	94.00 (8.36)^a	92.71 (8.88)^a	0.091
ΔrSO_2 for P leg	4.89^a	2.63^a	2.14^a	0.280	3.04^a	3.07^a	3.05^a	0.314
ΔrSO_2 for NP leg	2.98^a	1.47^a	1.44^a	0.636	3.18^a	2.07^a	2.09^a	0.231

Data are presented as mean (standard deviation) or median, where appropriate. **Pre-T**, pre-treatment; **Post-T**, post-treatment; **P**, paretic; **NP**, non-paretic; **GMFM**, Gross Motor Function Measurement; **FAQ-WL**; Functional Assessment Questionnaire Walking Scale; **rSO2**, regional oxygenation of the muscle; **SD**, standard deviation.
a, b, and c stands for indicating significant difference between the means defined by different letters in the same line ($p < 0.05$).
ΔrsO_2 = rSO_2 at rest − rSO_2 at maximum exercise.
Bold values signifies $p < 0.05$.
* Friedman test.
** Indicates preserved or continuing improvement.

children could be attributed to the automated skills and their increased continuity due to repetition of simple motor movements [27,28].

Children with hCP could not bear enough weight on their affected leg and transfer their gravity center towards to the unaffected side [11,24,29]. Vertical stiffness increases as the connective tissue and muscle contraction cannot modulate the movement. This is particularly higher in standing position and at low walking speed. At high walking speed, however, asymmetry decreases and outcomes become similar to those of healthy children [29]. Children with CP can perform more functional walking at high walking speed as connective tissue can be stretched more easily [29]. In study group, improvement in balance after the treatment indicated the positive effects of RGT. It is thought that more weight can be transferred to the P extremity during robotic walking due to decreased connective tissue and vertical stiffness depending on the walking speed. In our study, during robotic walking, the children with hCP experienced a walking pattern similar to that of healthy children and sequential weight-shift during walking. These effects were thought to result in increased weight-bearing time in both extremities of the children in the study group.

The improvements provided by RGT in all functional parameters in the study group were higher than in the control group. The 30-minute walking training with *Innowalk Pro* is also an aerobic exercise and endurance training. Endurance training substantially contributes to the improvement of functional capacity and motor performance by enhancing strength [30]. Accordingly, a difference was observed in all parameters related to functional strength and endurance in the study group as compared with the pre-treatment period.

Improvement was observed in GMFM-D in both groups. However, improvement in GMFM-E was observed only in the study group. Considering that walking speed enhances performance and that children achieve flexibility with high-speed movements, increased performance in our study could be associated with increased walking speed [22]. Moreover, the gained experiences concerning production, transfer, and utilization of power during robotic walking might also have an impact on gross motor skills.

Functional muscle strength evaluations of the lower extremities revealed significant improvements in all parameters, except for lateral step-up by the P extremity, in the study group. The half kneeling standing test demonstrated an improvement in weight-bearing and thereby in stabilizing skills of the P extremity, as was also observed in balance evaluations [12]. For standing from half kneeling, the extremity on the ground needs to have a good stabilization and a power for weight-bearing and forward weight shift. Accordingly, while an increase was observed in these skills for the P and NP extremities in the study group, no difference was determined in the control group compared with the pre-treatment period.

In study group, functional walking skills in daily living showed difference according to the post-treatment period; however, no difference was determined in the control group. This indicated the effects of changes in speed and functional performance on walking in daily living in the study group.

No difference was observed in the oxygenation of VL muscles of the P and NP extremities at initial rest, during exercise, and at final rest before the treatment. After the treatment, although not significant, an increase was determined in the muscle oxygenation of both P and NP extremities according to baseline. The difference between the extremities was much lower after the treatment and changed in favor of P extremity at the post-treatment third month. The significant improvement in the peripheral oxygenation after the treatment in the study group confirmed the aerobic effects of RGT [30]. Accordingly, we could say that, overall, oxygen consuming ability was improved using RGT, which provided symmetric training.

In study group, the remarkable post-treatment improvement in speed and endurance determined by the 6MWT was not preserved at the post-treatment third month. This could be attributed to the fact that cardiorespiratory gains with aerobic exercises are lost and return to baseline values 3 weeks after completion of training [30]. The duration of standing on the P leg increasingly continued and post-treatment improvement in balance was preserved at the post-treatment third month. Likewise, improvement in the motor functions determined by GMFM was preserved. The functional muscle strength tests revealed that post-treatment improvement was either continued or preserved. According to the FAQ-WL, post-treatment improvement was preserved also at the post-treatment third month. These improvements could be associated rather with the improvement in the P extremity regarding its control of standing. The improvement gained over the treatment period continued or preserved via improving the weight-bearing duration and capacity of the P extremity, increasing the balance and functional performance, and continuing to use functional skills in daily living.

The improvements in the control group regarding strength and speed are significantly lower than those in the study group. The post-treatment improvement in the outcome of lateral step-up test by the NP extremity was also maintained at the post-treatment third month. Moreover, an increase was observed in the 10-m walking time at child's selected velocity at the post-treatment third month. Accordingly, the effects of PTR program on the functional walking performance were slower in the children able to walk.

The high level of independence in our patients was a limitation in exposing pre-treatment extremity differences and in demonstrating post-treatment physiological improvement. Studies on children having higher differences in strengths of extremities or studies evaluating walking by three-dimensional analysis would yield clearer results for discussing improvement of walking. Moreover, using quality assessment scales to compare effects of RGT and PTR program on walking may yield different outcomes. Most of the children at GMFCS I level had spasticity in the knee flexor and extensor muscles in the range 0–1 according to Modified Ashworth Scale, and it was known that children with GMFCS II having the higher spasticity level than GMFCS level I. However, spasticity was not evaluated before and after treatment because of clinical tests were used to examine changes in functionality in the study. The fact that the effect of RGT on spasticity cannot determined objectively is the second limitation of the study.

Conclusively, in hCP, walking impairment is associated rather with loss of strength in the lower extremities; however, walking can be improved with strengthening and balance exercises. Improvement of walking speed has critical effects in enhancing functionality and participation in daily life. Including aerobic exercises to the PTR program of hCP children is an approach not to be ignored in enhancing children's functional performance. Robotic rehabilitation alone should not be considered a therapeutic method but should be considered a supportive tool.

Conflict interest

Authors have no conflicts of interest to disclose.

Author's contribution

Meltem Yazıcı, contributed to every step of study planning, robotic rehabilitation applications, data collection, and data analysis; she had complete access to the study data that support the publication.

Ayşe Livanelioğlu, PT, Prof. was the supervisor of the doctoral dissertation and contributed to the study planning, conduct of the study, and manuscript writing; she had complete access to the study data that support the publication.

Kıvılcım Gücüyener, Prof. and **Leman Tekin,** MD contributed to the applications and evaluations of Near Infrared Spectroscopy and manuscript writing on the subject; both authors had complete access to the study data that support the publication.

Erkan Sümer, MD, contributed to the study planning and conduct of the study; he had complete access to the study data that support the publication.

Yavuz Yakut, PT, Prof. contributed to the evaluation of walking and statistical analysis of data; he had complete access to the study data that support the publication.

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References

[1] P. Rosenbaum, N. Paneth, A. Leviton, M. Goldstein, M. Bax, D. Damiano, B. Dan, B. Jacobsson, A report: the definition and classification of cerebral palsy April 2006, Dev. Med. Child Neurol. 49 (2007) 8–14, https://doi.org/10.1111/j.1469-8749.2007.tb12610.x.

[2] J.M. Held, Recovery of function after brain damage: theoretical implications for therapeutic intervention, in: J.H. Carr, R.B. Shepard, J. Gordon, A.M. Gentile, J.M. Held (Eds.), Mov. Sci. Found. Phys. Ther. Rehabil. Aspen Publishers, 1987, pp. 155–177.

[3] F. Dobsan, M.E. Morris, R. Baker, R. Wolfe, H. Graham, Clinician agreement on gait pattern ratings in children with spastic hemiplegia, Dev. Med. Child Neurol. 48 (2006) 429–435.

[4] K. Adolph, S. Robinson, The road to walking: what learning to walk tells us about development, in: P. Zelazo (Ed.), Oxford Handbook of Developmental Psychology, Oxford University Press, New York, 2013, pp. 1–39.

[5] G.A. King, I.Z. Shultz, K. Steel, M. Gilpin, T. Cathers, Self-evaluation and self-concept of adolescents with physical disabilities, Am. J. Occup. Ther. 47 (1993)

132–140.
[6] I. Díaz, J.J. Gil, E. Sánchez, Lower-limb robotic rehabilitation: literature review and challenges, J. Robot. 2011 (2011) 1–11, https://doi.org/10.1155/2011/759764.
[7] R. Palisano, P. Rosenbaum, S. Walter, D. Russell, E. Wood, B. Galuppi, Development and reliability of a system to classify gross motor function in children with cerebral palsy, Dev. Med. Child Neurol. 39 (1997) 214–223, https://doi.org/10.1111/j.1469-8749.1997.tb07414.x/full.
[8] Made for Movement Innowalk Pro [Internet]. [cited 13 June 2018]. Avaliable from: http://madeformovement.com/products/innowalk-pro.
[9] The Practice Committee, American Physical Therapy Association (APTA), Section on Pediatrics List of Assessment Tools Used in Pediatric Physical Therapy [Internet], [cited 13 June 2018]. Available from: (2004) https://otpt13.wikispaces.com/file/view/AssessScreenTools_used + by + pedi + PT_r05.pdf.
[10] A. Lundkvist Josenby, G.-B. Jarnlo, C. Gummesson, E. Nordmark, Longitudinal construct validity of the GMFM-88 total score and goal total score and the GMFM-66 score in a 5-year follow-up study, Phys. Ther. 89 (2009) 342–350.
[11] G. Gray, Lower Extremity Functional Profile, Wynn Marketing, 1995, http://scholar.google.com/scholar?hl = en&btnG = Search&q = intitle:Lower + extremity + functional + profile#0.
[12] O. Verschuren, M. Ketelaar, T. Takken, M. Van Brussel, P.J.M. Helders, J.W. Gorter, Reliability of hand-held dynamometry and functional strength tests for the lower extremity in children with cerebral palsy, Disabil. Rehabil. 30 (2008) 1358–1366 http://www.ncbi.nlm.nih.gov/pubmed/18850351.
[13] M.R. Franjoine, J.S. Gunther, M.J. Taylor, Pediatric balance scale: a modified version of the berg balance scale for the school-aged child with mild to moderate motor impairment, Pediatr. Phys. Ther. 15 (2003) 114–128.
[14] T. Zumbrunn, B.A. MacWilliams, B.A. Johnson, Evaluation of a single leg stance balance test in children, Gait Posture 34 (2011) 174–177, https://doi.org/10.1016/j.gaitpost.2011.04.005.
[15] P. Thompson, T. Beath, J. Bell, G. Jacobson, T. Phair, N.M. Salbach, V.F. Wright, Test-retest reliability of the 10-metre fast walk test and 6-minute walk test in ambulatory school-aged children with cerebral palsy, Dev. Med. Child Neurol. 50 (2008) 370–376.
[16] C.A. Maher, M.T. Williams, T.S. Olds, The six-minute walk test for children with cerebral palsy, J. Rehabil. Res. 31 (2008) 185–188.
[17] G.E. Gorton, J.L. Stout, A.M. Bagley, K. Bevans, T.F. Novacheck, C.A. Tucker, Gillette functional assessment questionnaire 22-item skill set: factor and Rasch analyses, Dev. Med. Child Neurol. 53 (2011) 250–255.
[18] T. Hamaoka, K.K. McCully, M. Niwayama, B. Chance, The use of muscle near-infrared spectroscopy in sport, health and medical sciences: recent developments, Philos. Trans. R. Soc. A: Math. Phys. Eng. Sci. 369 (2011) 4591–4604.
[19] T. Hamaoka, K.K. McCully, V. Quaresima, K. Yamamoto, B. Chance, Near-infrared spectroscopy/imaging for monitoring muscle oxygenation and oxidative metabolism in healthy and diseased humans, J. Biomed. Opt. 12 (2007) 062105-1-062105-16.
[20] T. Nagasawa, Oxygen consumption in nonexercising muscle after exercise, Int. J. Sports Med. 29 (2008) 624–629.
[21] M.D. Kennedy, M.J. Haykowsky, C. a Boliek, B.T. a Esch, J.M. Scott, D.E.R. Warburton, Regional muscle oxygenation differences in vastus lateralis during different modes of incremental exercise, Dyn. Med. 5 (2006) 8 http://archive.biomedcentral.com/14765918/7/11/abstract%5Cnhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid = 1524724&tool = pmcentrez&rendertype = abstract%5Cnhttp://www.biomedcentral.com/1476-5918/5/8.
[22] T.C. Bulea, J. Kim, D.L. Damiano, C.J. Stanley, H.-S. Park, Prefrontal, posterior parietal and sensorimotor network activity underlying speed control during walking, Front. Hum. Neurosci. 9 (2015) 247, https://doi.org/10.3389/fnhum.2015.00247.
[23] E. Sellier, G. Surman, K. Himmelman, G. Andersen, A. Colver, I. Krägeloh-Mann, et al., Trends in prevalence of cerebral palsy in children born with a birthweight of 2500 g or over in Europe from 1980 to 1998, Eur. J. Epidemiol. 25 (2010) 635–642.
[24] M.E. Castle, T.A. Reyman, M. Schneider, Pathology of spastic muscle in cerebral palsy, Clin. Orthop. Relat. Res. 42 (1978) 223–232.
[25] H. Lim, Effect of the modulation of optic flow speed on gait parameters in children with hemiplegic cerebral palsy, J. Phys. Ther. Sci. 26 (2014) 145–148.
[26] L.M. Collins, Analysis of longitudinal data: the integration of theoretical model, temporal design, and statistical model, Annu. Rev. Physychol. 57 (2006) 505–528.
[27] J.W. Aldridge, K.C. Berridge, Basal ganglia neural coding of natural action sequences, Basal Ganglia VI (2003) 279–287, https://doi.org/10.1007/978-1-4615-0179-4.
[28] R. Poldrack, F. Sabb, K. Foerde, S. Tom, R. Asarnow, S. Bookheimer, B. Knowlton, The neural correlates of motor skill automaticity, J. Neurosci. 25 (2005) 5356–5364.
[29] S.T. Fonseca, K.G. Holt, L. Fetters, E. Saltzman, Dynamic resources used in ambulation by children with spastic hemiplegic cerebral palsy: relationship to kinematics, energetics, and asymmetries, Phys. Ther. 84 (2004) 344–354 discussion 355–358.
[30] S.K. Powers, E.T. Howley, Exercise Physiology: Theory and Application to Fitness and Performance, 5th edition, McGraw-Hill, Boston, Massachusetts, 2004.