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Leap Motion Controller–based training for upper extremity rehabilitation in children and adolescents with physical disabilities: A randomized controlled trial

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ABSTRACT

Study Design: Randomized controlled trial.
Introduction: Juvenile idiopathic arthritis (JIA), cerebral palsy (CP), and brachial plexus birth injury (BPBI) are the most common disorders that cause upper extremity impairments in children and adolescents. Leap Motion Controller–based training (LMCBT) is a novel therapeutic method for upper extremity rehabilitation.
Purpose of the Study: The aim of the present study was to investigate the potential efficacy of an 8-week LMCBT program set as an upper extremity rehabilitation program by comparing conventional rehabilitation program in children and adolescents with physical disabilities such as JIA, CP, and BPBI.
Methods: A randomized control trial which included children and adolescents of different disabilities (JIA, CP, BPBI) were grouped according to their diagnosis. All patients were randomized into 2 groups namely LMCBT (group I) and conventional treatment (group II) for the treatment (3 days/8 weeks). Duruoz Hand Index and Jebson Taylor Hand Function Test were used as primary outcomes. Secondary outcomes included the nine-hole peg test, Childhood Health Assessment Questionnaire, and assessments of grip and pinch strength using a dynamometer.
Results: One hundred three patients were included in the study, and 92 of them completed the treatment. After treatment, significant differences were found in Childhood Health Assessment Questionnaire, Duruoz Hand Index, Jebson Taylor Hand Function Test, nine-hole peg test, and grip and pinch strength scores in almost all groups (effect size [ES] = 0.10 to −0.77 for group I and 0.09 to −0.70 for group II in CP; ES = 0.31 to 2.65 for the group I and 0.12 to 1.66 for group II in JIA; and ES = 0 to −0.44 for group I and 0.08 to −0.62 for group II in BPBI) ($P < .05$). Comparisons between LMCBT and conventional treatment groups showed similar results in all parameters in all disease groups ($P > .05$).
Conclusions: This study has quantitatively shown that LMCBT should be used as an effective alternative treatment option in children and adolescents with physical disabilities.
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Introduction

Juvenile idiopathic arthritis (JIA), cerebral palsy (CP), and brachial plexus birth injury (BPBI) are the most common disorders that cause upper extremity impairments in children and adolescents.[1-3] Depending on the underlying pathologies, the common problems of these disorders are the limitations of activities of daily living (ADLs) due to impairments of upper extremity functions such as decreased joint movement, muscle weakness, and muscle imbalance.[2,4,5] ADLs such as feeding, personal care, and dressing that use upper extremity are commonly limited to children and adolescents. Rehabilitation is mostly used to address these

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problems, and upper extremity rehabilitation is a long-term, demanding and difficult process to improve fine motor skills in children with chronic diseases affecting upper extremity.[6]

The typical management of children and adolescents with physical disabilities includes a conventional physiotherapy program consisting of stretching, strengthening, positioning, splinting, casting, and facilitation of movement.[7] Therefore, the current paradigm of upper extremity rehabilitation strategies to promote motor recovery is focused on high-intensity, repetitive and task-specific practice.[8] The use of technology in rehabilitation is well suited to fulfill these rehabilitation principles as they can be used to provide controlled, repeatable, intensive, interactive, and motivating rehabilitation with feedback.[9] The use of digital technology has been gaining momentum in addressing the aforementioned rehabilitation problems among medical professionals. Therefore, an upcoming therapeutic method is video game–based training (VGBT) along with virtual reality (VR). VGBT integrates playing to children's ADLs, and motivated children start using the experiences acquired while playing games in their daily lives.[10] So, active video games are a potential task-orientated intervention that could positively influence movement outcomes through increased opportunities to practice motor skills.[11-13] Also, increased compliance by children with physical therapy using VR has been reported.[14]

VR may assist children in acquiring new motor skills, sustaining the benefits from exercise, and enable children to use their hands for more functional skills.[7] Several recent studies have confirmed that VGBT may enhance motor skill performance in children and adolescents with chronic diseases such as CP, cystic fibrosis, burn scars, and JIA.[15-20] Compared with the classical exercises, VGBT with motion sensor interactions has been applied to various disease groups and has been reported in studies where children were able to perform the desired activities easily and repetitively. By providing feedback and performance information, it improves children's upper extremity functions due to their motivation and willingness to exercise.

Popular most commonly used devices such as Microsoft Kinect and Nintendo Wii-Fit could be used in VGBT.[21] However, these devices fail to detect fine hand and finger movements, which is needed to train dexterity.[22] A novel commercially available device called Leap Motion Controller (LMC) is a low-cost and low-complexity optoelectronic system, which can track hand and finger movements with declared submillimeter accuracy.[23] Because of its low cost, its reduced dimensions compared with other devices, especially its easiness to use, the absence of markers, and the captivating aspects of its technology, the number of its potential applications is wide and includes video game–based application also in pediatric rehabilitation.

Because the LMC is smaller in size and does not have a marker, it provides reduced fear in the child and makes the movement easier and more efficient. The simplicity of LMC could facilitate patients' approach to technology, increasing their feeling of immersion into the virtual environment, their imagination, and the interaction with the virtual environment (being immersion, imagination, and interaction known as the 3 I's of VR). Several studies[24-27] focused on hand motor recovery using only the LMC and a virtual environment are found. A small sample-feasibility study demonstrated that VGBT using LMC is a useable rehabilitation tool to train dexterity in the early rehabilitation phase of stroke inpatients.[28] In only one study, Gieser et al[28] reported that they presented a prototype of a game-like simulation of matching static hand gestures to increase motor control of the hand in patients with CP. Also, in another experimental study, De Oliveira et al[29] reported that they developed playful therapeutic games with LMC quite feasible for rehabilitation of patients with CP. Therefore, in the literature, no comparative randomized study of rehabilitation using LMC was found especially in the rehabilitation of children with chronic illnesses, especially JIA and BPBI.

Furthermore, the aim of the present study was to evaluate the efficacy of 8-week Leap Motion Controller–based training (LMCBT) program set as an upper extremity rehabilitation program comparing conventional rehabilitation program in children and adolescents with physical disabilities. We hypothesized that VGBT using the LMC would be more effective than conventional treatment to train hand functions in children and adolescents with physical disabilities as a therapy.

Methods

Participants

All patients referred for rehabilitation to the outpatient clinic of Istanbul University-Cerrahpasa, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation were recruited between April 2016 and July 2017 to participate in this study. All participants signed informed consent forms. The participants were volunteers who were examined by the pediatric physician who participated in the present study. Approval for this study was obtained from the ethical committee (the Research Ethics Committee of Istanbul University-Cerrahpasa) (no.: 108400987-275), and the study was conducted in accordance with the Declaration of Helsinki. Inclusion criteria consisted of a diagnosis of JIA, CP, or BPBI; being aged between 5 to 17 years; having at least one affected distal joint in upper extremity (wrist and/or finger joints); having upper extremity spasticity (0), (1), (1+) according to the Modified Ashworth Scale for children with CP; and also being able to read and write in the Turkish language. All patients were diagnosed 6 months before the study. Patients were excluded from the study if they had another chronic disease; if another treatment such as Botulinum Toxin injection, intra-articular injection, surgery, or hand rehabilitation has been applied in the last 1 year; if they had a history of mental deficit or psychological problem; or if there was no acceptance for participation in the study by their families. Also, eligible patients for inclusion who could not come to the clinic due to various reasons were excluded from the study. The demographic data of the participants are presented in Table 1.

Study design

This study was conducted as a randomized parallel group trial. All patients attending our clinic during the study duration were assessed, and those who were suitable for inclusion accepted to participate in the study. Patients' characteristics (sex, age, dominant and affected side) data were collected by the physiotherapists. The randomization was performed by using the Microsoft Excel "RAND (USA)" function. All measurements were performed before and 8 weeks after. The selector (OK) was aware of the randomization scheme but did not perform any assessments. The assessor (ET) was blind to the groups to which the participants had been allocated and conducted standard procedures in all groups and assessed all participants. The physiotherapists (DT and NA) were blind to the assessments but were aware of the nature of this intervention and the physical findings of disease and treated the participants.

A participant flow diagram is presented in Supplemental Figure 1. Patients in group I (CP, $n = 15$; JIA, $n = 18$; and BPBI, $n = 9$) completed the 8-week LMCBT program, and patients in group II (CP, $n = 15$; JIA, $n = 25$; and BPBI, $n = 10$) completed an 8-week conventional rehabilitation program.

Outcome measures

In the present study, the patients were assessed with the Duruoz Hand Index (DHI) and Jebson Taylor Hand Function Test (JTHFT) as

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Table 1
Demographic and clinical features of the patients

Demographic and clinical features	CP			JIA			BPBI		
	Group I $n = 15$	Group II $n = 15$	P	Group I $n = 18$	Group II $n = 25$	P	Group I $n = 9$	Group II $n = 10$	P
Sex, n (%)			1.00[a]			.701[a]			1.00[a]
F	7 (46.70)	6 (40)		14 (77.80)	21 (84)		5 (55.60)	6 (60)	
M	8 (53.30)	9 (60)		4 (22.20)	4 (16)		4 (44.40)	4 (40)	
Age (y), mean (SD)	10.93 (4.09)	11.06 (3.23)	1.00[b]	12.22 (3.29)	13.16 (3.35)	.940[b]	8.22 (2.58)	8.30 (2.21)	1.00[b]
BMI (kg/m^2), mean (SD)	20.82 (4.05)	21.37 (6.07)	.999[b]	16.72 (3.00)	18.41 (3.77)	.744[b]	15.82 (2.71)	16.85 (2.74)	.993[b]
Dominant side, n (%)			.014[a]			.293[a]			1.00[a]
Right	7 (46.70)	14 (93.30)		15 (83.3)	24 (96)		1 (11.1)	1 (10)	
Left	8 (53.30)	1 (6.7)		3 (16.7)	1 (4)		8 (88.90)	9 (90)	
Affected side, n (%)			.050[a]			1.00[a]			1.00[a]
Right	8 (53.30)	2 (13.30)		15 (83.30)	20 (80)		8 (88.90)	9 (90)	
Left	7 (46.70)	13 (86.70)		3 (16.70)	5 (20)		1 (11.10)	1 (10)	
Type of CP, n (%)			1.000[a]	-	-	-	-	-	-
Spastic	12 (80)	11 (73.3)							
Dyskinetic	3 (20)	4 (26.7)							
Number of involvement joint, mean (SD)	-	-	-	9.28 (3.08)	6.84 (5.11)	.059	-	-	-
Type of Narakas, n (%)	-	-	-	-	-	-			.148[a]
C5-C6							3 (33.3)	3 (30)	
C5-C7							4 (44.4)	4 (40)	
C5-T1							2 (22.2)	3 (30)	

F = female; M = male; BMI = body mass index; JIA = juvenile idiopathic arthritis; CP = cerebral palsy; BPBI = brachial plexus birth injury; SD = standard deviation.
[a] Chi-squared test.
[b] Independent *t*-test.

primary outcomes. Also, Nine-Hole Peg Test (9HPT), Childhood Health Assessment Questionnaire (CHAQ), and assessments of grip and pinch strengths with a dynamometer were used as secondary outcomes.

Primary outcomes

DHI is a self-reported questionnaire developed to assess hand ability in the kitchen, during dressing, while performing personal hygiene, in office tasks, and other general items. DHI is derived from 18 validated questions to assess functional disability and handicap of the hand. Each answer is scored on a scale of 0 (no difficulty) to 5 (impossible to do), with a maximum score of 90. A higher score indicated worse disability or handicap.[30] The questions of DHI were answered by the parent.

JTHFT was created to provide quantitative measurements of standardized tasks to assess broad aspects of hand function commonly performed in everyday activities. Seven subsets of the test represent a broad spectrum of hand function, which includes writing, turning over 3 × 5 inch cards (to simulate page turning), picking up small common objects, simulated feeding, stacking checkers, picking up large light objects, and picking up large heavy objects.[31]

Secondary outcomes

CHAQ is a reliable and valid tool for the assessment of functional ability in patients with JIA, and also, CHAQ is used for various pediatric diseases.[32] In 8 activities (dressing/grooming, arising, eating, walking, hygiene, reach, grip, and activities), a number of questions were answered and scored on a scale of 0 to 3, where 0 = able to do with no difficulty, 1 = able to do with some difficulty, 2 = able to do with much difficulty, and 3 = unable to do. Total score identified the CHAQ score (range, 0-3). The CHAQ also provided an assessment of discomfort using a 100-mm visual analog scale (VAS) for the evaluation of pain and a 100-mm VAS for the evaluation of overall well-being. A score of 0 indicated “no pain” and 100 indicated “extreme pain” for VAS pain, and a score of 0 indicated “very well” and 100 “very bad” for VAS overall well-being. A higher score indicated more problems in both pain and overall well-being. The questions of CHAQ were answered by the parent.

Nine-Hole Peg Test is a timed test in which 9 pegs are inserted and removed from 9 holes in the pegboard with each hand. Nine-Hole Peg Test has the potential to be a quick and easy-to-administer tool for screening fine motor problems in children.[33]

Grip strength was measured using a standard adjustable handle Jamar Plus + Hand Dynamometer (Irvington, NY) in the sitting position with the shoulder adducted and neutrally rotated and the elbow flexed at 90°.[34] Three trials for both grip strengths were performed following standardized procedures and were averaged to obtain a final score in pounds.[35]

Pinch strengths (tip, key, and palmar pinch) were measured by using a hydraulic pinch gauge (Irvington, NY) in the sitting position with the shoulder adducted and neutrally rotated and the elbow flexed at 90°. Pinch positions were defined using the American Society for Hand Therapists guideline. Each pinch strength test was performed thrice with a 30-second interval between tests, and the mean value was recorded.[36]

Intervention

The rehabilitation program for both groups was conducted as 1-hour sessions 3 times a week for 8 weeks. The 2 different rehabilitation programs were set up as LMCBT program (group I) and conventional rehabilitation program (group II).

LMCBT program

Our team developed 2 rehabilitative games using LMC under a research and development project. The aim of the developed games was to improve the joint range of motion, muscle strength, coordination, and fine motor functions of the hand and wrist in patients. Two games called as “Fizyosoft CatchAPet” and “Fizyosoft Leapball” were developed using LMC with funding support (supported by The Scientific And Technological Research Council Of Turkey form under 3001-Starting Research and Development Projects Funding Program Project number: 215S191). The games were academically developed for rehabilitation and were used for LMCBT program.

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"Leapball" was designed to focus on the development of grasping and individuating motor skills of hand; the improvement of the dexterity and coordination of the digits; the improvement of the ability to flex and extend the hand, the increase in the joint range of motion of the wrist and digits; the improvement of the movement speed, muscle strength, and motor control. In "Leapball" game, the aim is to grasp a virtual ball with all the fingers and to throw the ball into the bucket of the same color. The size of the ball can be reduced to provide progression to the ball. Figure 1 presents a participant who is trained in activities of grasping and releasing in Leapball game.

In the "CatchAPet" game, it is aimed to touch the rabbits coming out of the holes with repetitive wrist flexion/extension movements. The rabbits come out randomly from the holes. The individual sees the avatar of his/her hand on the screen and touches the rabbits coming out of the hole consecutively by doing wrist flexion/extension. The faster you touch the rabbits, the more points you earn. Figure 2 presents a participant who is trained in wrist flexion/extension for CatchAPet game.

The training protocol involves 4 stages:

Stage 1: The physiotherapists introduced the games and LMC sensor and informed the child about how the games were played.

Stage 2: The child was given the opportunity to try games, and the critical points were highlighted for the correct play of the game (eg, the distance from the hand to the sensor).

Stage 3: It was ensured the game was played correctly by prevention of compensatory movements during play with the guidance of physiotherapists.

Stage 4: The game was launched from the appropriate level according to the individual needs of the child. The game progresses by changing the speed, repetition of trial, and number and size of ball/hole.

Conventional rehabilitation program

The aim of the conventional rehabilitation program was to facilitate arm's use in functional leisure and self-care tasks. Emphasis was placed on the re-education of muscles using a sensorimotor approach to control motor output. Subjects needed to show the ability to independently perform basic mass functional movements before progressing to more isolated advanced functional patterns. The tasks included such as grasp and release activities to improve the ability to flex and extend the hand and increase the joint range of motion of the wrist and digits. Progression within each movement was facilitated by increasing the number of repetitions, the weight of the item being handled, height at which tasks were done, and so on. To achieve these goals, a variety of exercise materials (velcro cylinders, skill cubes, exercise bands, therapeutic putties, objects with different shapes) were used that varied for each disease group in the rehabilitation program.

Fig. 1. Fizyosoft Leapball.

Fig. 2. Fizyosoft CatchAPet.

Statistical analysis

The statistical package "Statistical Package for Social Sciences" (version 21; SPSS Inc, Chicago, IL) was used for data analysis. The level of significance was set at 0.05 (2-tailed). Normality of baseline data was verified using the Shapiro-Wilks test ($P > .05$). Therefore, parametric testing was applied to both the groups. Descriptive statistics were reported as mean ± standard deviation. Between-group differences in demographic and baseline variables were tested using a chi-square test for categorical variables and an independent *t*-test for continuous variables. The independent *t*-test was used to compare the score changes between the groups after the treatment. The paired *t*-test was used to examine within-group changes from baseline to 8 weeks. Also, the effect size was calculated using Cohen's d formula.[37]

Results

One hundred nine subjects were enrolled in the study. Two patients were excluded because of the transportation problem, and 4 eligible patients refused to participate in the treatment. Eleven subject's data were not included in the analysis as they did not complete their rehabilitation program because of personal and transportation problems. So, 92 people completed an 8-week rehabilitation program in their groups. A participant flow diagram is presented in Figure 1. The demographic data in each group are presented in Table 1. The groups were similar in terms of demographic and clinical data except for the dominant side in the CP groups ($P > .05$).

The effects of LMCBT and CT on patients with CP

Table 2 shows the results of all outcome scores for LMCBT and CT in patients with CP before and after treatment. The changes after treatment in all outcome measures were statistically significant for the group I and group II ($P < .05$). After the treatment, all results of the differences were similar for both the groups ($P > .05$). Cohen's d indicated on outcomes scores ranged from 0.10 to −0.77 for the group I and 0.09 to −0.70 for group II. Effect sizes were medium for significantly improved results of all outcomes except for 9HPT and hand grip in group I. However, the results of all outcomes had an effect size as low to moderate in group II.

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Table 2
Pretreatment and posttreatment outcomes scores and differences between the rehabilitation groups in patients with CP

CP	LMCBT, $n = 15$					CT, $n = 15$					p2
	BT	AT	Difference of AT-BT	[a]Effect size	p1	BT	AT	Difference of AT-BT	[a]Effect size	p1	
	Mean (SD)	Mean (SD)	Mean (SD)			Mean (SD)	Mean (SD)	Mean (SD)			
DHI	42 (14.05)	32.80 (13.25)	9.20 (6.02)	0.67	0.0001	36.06 (14.31)	29.60 (12.25)	6.46 (2.82)	0.48	0.0001	0.127
JTHFT (sn)	180 (84.31)	129.12 (60.16)	50.88 (34.42)	0.69	0.0001	236.88 (296.18)	181.12 (204.47)	55.76 (105.33)	0.21	0.060	0.866
CHAQ total	1.70 (0.56)	1.36 (0.53)	0.32 (0.21)	0.62	0.0001	2.31 (0.67)	1.86 (0.68)	0.43 (0.15)	0.66	0.0001	0.112
CHAQ well-being	47.66 (18.21)	38.46 (18.45)	9.20 (4.17)	0.50	0.0001	43.80 (12.59)	35.40 (11.13)	8.40 (3.41)	0.70	0.0001	0.571
9HPT (sn)	80.26 (63.63)	74.18 (57.42)	6.08 (10.46)	0.10	0.041	92.40 (131.65)	80.78 (114.57)	11.62 (17.90)	0.09	0.025	0.312
Hand grip (lb)	7.88 (4.18)	9.96 (5.35)	2.08 (1.92)	−0.43	0.001	8.72 (5.76)	11.40 (6.73)	2.69 (2.77)	−0.42	0.002	0.489
Tip grip (lb)	1.30 (0.78)	1.70 (0.78)	0.46 (0.34)	−0.51	0.002	1.72 (0.95)	2.08 (1.04)	0.47 (0.31)	−0.36	0.005	0.913
Lateral grip (lb)	2.65 (1.54)	3.66 (2.10)	1.01 (0.96)	−0.54	0.001	2.73 (1.18)	3.55 (1.53)	0.82 (0.53)	−0.60	0.0001	0.502
Triple grip (lb)	1.63 (1.09)	2.34 (1.55)	0.70 (0.66)	−0.77	0.001	2.21 (1.10)	2.67 (1.29)	0.46 (0.41)	−0.38	0.001	0.235

lb = pound; CHAQ = Childhood Health Assessment Questionnaire; JTHFT = Jebsen Taylor Hand Function Test; 9HPT = Nine-Hole Peg Test; DHI = Duruoz Hand Index; LMCBT = Leap Motion Controller–based training; CT = conventional treatment; BT = before treatment; AT = after treatment; SD = standard deviation.
p1: Intragroup comparison (comparison of BT and AT scores with Paired Sample t Test), p2: Intergroup comparison (comparisons of differences of AT-BT scores with the Independent t Test).
[a] Effect size was calculated using the Cohen's d formula.

The effects of LMCBT and CT in patients with JIA

Table 3 shows the results of all outcome scores for LMCBT and CT in patients with JIA before and after treatment. The changes after treatment in all outcome measures except for JTHFT scores were statistically significant for the group I and group II ($P < .05$). There was a statistically significant difference only in DHI scores between the groups after the treatment in favor of group I ($P < .05$). Cohen's d indicated on outcomes scores ranged from −0.31 to 2.65 for the group I and from 0.12 to 1.66 for group II. Effect sizes were very large for significantly improved outcomes of CHAQ total, CHAQ pain, CHAQ well-being, and DHI measurements in both the groups. While effect sizes were low to large for significantly improved outcomes of results of the hand grip and pinch grips, JTHFT, and 9HPT in group I, the effect size was low to moderate in group II.

The effects of LMCBT and CT in patients with BPBI

The results of all outcome scores for LMCBT and CT in patients with BPBI before and after treatment were shown in Table 4. The changes after treatment in all outcome measures except for CHAQ well-being were statistically significant for the group I ($P < .05$). However, the changes after treatment in all outcome measures except for lateral pinch grip and CHAQ well-being were statistically significant in group II ($P < .05$). Cohen's d indicated on outcomes scores ranged from 0 to −0.44 for the group I and from 0.08 to −0.62 for group II. Effect sizes were very small for significantly improved all outcomes in group I. However, only results of triple grip had an effect size of moderate, and others were small in group II.

Discussion

The aim of the present study was to evaluate the efficacy of 8-week LMCBT program set as an upper extremity rehabilitation program comparing the conventional rehabilitation program in children and adolescents with physical disabilities. Although we hypothesized that VGBT using the LMC would be more effective than conventional treatment, we have proved that the therapeutic use of LMC-supported games provide similar results with conventional training in terms of improving hand functions. So, LMCBT is an effective alternative treatment option in patients with physical disabilities.

Video game–based training

The therapeutic reasons for using technology in rehabilitation include the option of repeating exercises with success and

Table 3
Pretreatment and posttreatment outcomes scores and differences between the rehabilitation groups in the patients with JIA

JIA	LMCBT $n = 18$					CT $n = 25$					p2
	BT	AT	Δ	[a]Effect size	p1	BT	AT	Δ	[a]Effect size	p1	
	Mean (SD)	Mean (SD)	Mean (SD)			Mean (SD)	Mean (SD)	Mean (SD)			
DHI	21.27 (11.34)	0 (0)	21.27 (11.34)	2.65	**0.0001**	12.56 (10.66)	0 (0)	12.56 (10.66)	1.66	**0.0001**	**0.015**
JTHFT (sn)	37.37 (6.72)	39.38 (5.92)	2 (4.40)	−0.31	0.070	43.33 (9.21)	42.08 (9.21)	1.14 (4.99)	0.12	0.265	0.551
CHAQ total	1.37 (0.67)	0.30 (0.30)	1.05 (0.47)	2.06	**0.0001**	0.98 (0.63)	0.20 (0.34)	0.77 (0.47)	1.54	**0.0001**	0.064
CHAQ pain	31.94 (30.49)	6.94 (11.77)	25 (23.70)	1.08	**0.0001**	43.60 (28.52)	9.20 (17.54)	34.40 (24.03)	1.45	**0.0001**	0.210
CHAQ well-being	55.27 (55.27)	21.94 (15.44)	33.33 (14.65)	0.82	**0.0001**	57 (26.41)	29.28 (18.69)	27.72 (18.49)	1.21	**0.0001**	0.274
9HPT (sn)	19.25 (2.57)	18.01 (3.44)	1.23 (2.11)	−0.40	**0.023**	21.04 (5.11)	19.31 (4.08)	1.72 (2.55)	0.37	**0.002**	0.497
Hand grip (lb)	12.72 (8.47)	20.79 (10.24)	8.08 (4.81)	−0.85	**0.0001**	16.11 (10.87)	23.99 (13.56)	7.87 (5.60)	−0.64	**0.0001**	0.895
Tip grip (lb)	1.64 (1.64)	3.46 (2.21)	1.86 (1.74)	−0.93	**0.001**	7.39 (3.07)	8.58 (3.17)	1.33 (1.65)	−0.38	**0.002**	0.322
Lateral grip (lb)	6.13 (3.10)	8.03 (3.70)	1.90 (1.97)	−0.55	**0.001**	3.21 (3.14)	5.63 (3.47)	2.42 (1.56)	−0.73	**0.0001**	0.361
Triple grip (lb)	3.13 (2.50)	5.83 (3.13)	1.23 (2.11)	−0.95	**0.0001**	5.18 (2.86)	7.13 (3.15)	1.95 (1.54)	−0.64	**0.0001**	0.178

lb = pound; CHAQ = Childhood Health Assessment Questionnaire; JTHFT = Jebsen Taylor Hand Function Test; 9HPT = Nine-Hole Peg Test; DHI = Duruoz Hand Index; LMCBT = Leap Motion Controller–based training; CT = conventional treatment; BT = before treatment; AT = after treatment; SD = standard deviation.
p1: Intragroup comparison (comparison of BT and AT scores with Paired Sample *t* Test), p2: Intergroup comparison (comparisons of differences of AT-BT scores with the Independent *t* Test).
Bold *P* values are statistically significant ($P < .05$).
[a] Effect size was calculated using the Cohen's d formula.

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Table 4
Pretreatment and posttreatment outcomes scores and differences between the rehabilitation groups in the patients with BPBI

BPBI	LMCBT, $n = 9$					CT, $n = 10$					p2
	BT	At	Δ	[a]Effect size	p1	BT	At	Δ	[a]Effect size	p1	
	Mean (SD)	Mean (SD)	Mean (SD)			Mean (SD)	Mean (SD)	Mean (SD)			
DHI	35.80 (16.50)	30.90 (14.53)	4.90 (4.30)	0.31	**0.006**	34.90 (15.35)	30.10 (14.09)	4.80 (2.48)	0.32	**0.0001**	0.950
JTHFT (sn)	91.51 (62.19)	72.48 (40.86)	19.02 (22.64)	0.36	**0.036**	117.23 (82.09)	104.52 (75.70)	12.71 (7.91)	0.16	**0.001**	0.446
CHAQ total	1.22 (0.55)	1.22 (0.55)	0	0	1	1.20 (0.73)	1.20 (0.73)	0	0	1	1
CHAQ well-being	42.22 (19.22)	40.55 (16.47)	1.11 (3.33)	0.09	0.195	38 (21.62)	36 (18.97)	1.50 (3.37)	0.09	0.104	0.804
9HPT (sn)	47.94 (48.29)	42.82 (45.56)	5.12 (5.45)	0.10	**0.023**	48.90 (48.88)	44.94 (44.89)	3.96 (1.02)	0.08	**0.014**	0.611
Hand grip (lb)	5.70 (3.71)	6.84 (4.31)	1.13 (0.97)	−0.28	**0.007**	5.74 (4.42)	6.57 (4.82)	0.82 (0.61)	−0.17	**0.002**	0.422
Tip grip (lb)	0.91 (0.55)	1.18 (0.67)	0.27 (0.31)	−0.44	**0.031**	1.13 (0.96)	1.58 (1.19)	0.45 (0.34)	−0.41	**0.003**	0.274
Lateral grip (lb)	1.80 (0.89)	2.08 (0.89)	0.28 (0.32)	−0.31	**0.030**	2.21 (1.16)	2.41 (1.16)	0.20 (0.29)	−0.17	0.060	0.546
Triple grip (lb)	1.67 (1.06)	2.11 (1.09)	0.43 (0.36)	−0.40	**0.008**	1.25 (0.94)	1.83 (0.93)	0.58 (0.26)	−0.62	**0.0001**	0.340

lb = pound; CHAQ = Childhood Health Assessment Questionnaire; JTHFT = Jebsen Taylor Hand Function Test; 9HPT = Nine-Hole Peg Test; DHI = Duruoz Hand Index; LMCBT = Leap Motion Controller–based training; CT = conventional treatment; BT = before treatment; AT = after treatment; SD = standard deviation.
p1: Intragroup comparison (comparison of BT and AT scores with Paired Sample *t* test), p2: Intergroup comparison (comparisons of differences of AT-BT scores with the Independent *t* test).
Bold *P* values are statistically significant ($P < .05$).
[a] Effect size was calculated using the Cohen's d formula.

feedback, the ability to use motivating exercises, and the fact that feedback and success improve motor learning.[37] Interest in the use of VGBT is constantly increasing, and the activities performed with video-based games for upper extremity rehabilitation are considered superior in terms of their density, frequent repetitiveness, high motivation, and innovation for physiotherapists to make treatment entertaining. Levac et al[25] reported that the therapists identified fun and motivation as positive attributes aligning with their goal of motivating the child to participate in therapy with VGBT. Motivation may be a key "active ingredient" or reason why a treatment is expected to be effective of VR interventions.

At the same time, video-based games integrate playing to children's ADLs and motivated children to start using the experiences acquired while playing games in their daily lives.[10] Several recent studies have confirmed that VGBT may enhance motor skill performance in children and adolescents with chronic diseases such as CP, cystic fibrosis, and JIA and in children with burns.[15-20] Compared with classical exercises, VGBT with motion sensor interactions applied in various disease groups has been reported in studies to help children perform the desired activities more easily and repetitively by providing feedback and performance information and improve children's upper extremity functions due to their motivation and willingness to do exercise. We suggested that the children focused on the fun of games rather than their perception of being treated because video-based games are interactive, providing visual and verbal feedback, and stimulating and increase motivation and incentive of achievement according to our experience in the present study.

Video game–based training with LMC

A commercially available device, the LMC, is a low-cost, low-complexity, optoelectronic system framed within semi-immersive VR that is capable of tracking hand movements.[38] Vanbellingen et al[26] explained that 4 reasons why the LMC is useable. First, LMC is a small, lightweight, USB-powered device which can be plugged in to every computer. Second, the installation of the integrated software is user-friendly. Third, no expert technician is needed as there is no need to attach markers of the device to the hands, making the tool beneficial in its use compared with other VR upper limb tools such as virtual gloves or exoskeletons. Fourth, the fact that the LMC system is relatively cheap and easy to purchase may be easily integrated into the home setting, and also, they consider this high feasibility of VGBT with LMC.[26] In addition to all these features, the LMC has been superior for the rehabilitation of fine and gross manual dexterity, enhanced by a virtual environment that stimulates the patient.

Several studies reported that VGBT was deemed to be more enjoyable than, and preferable to, the conventional therapy because VGBT with LMC using interactive VR games can provide task-oriented practice, as well as visual and auditory feedback regarding performance and gain, which further motivates and engages players to increase the rehabilitation intensity.[39] A greater amount of practice promotes better outcomes in the event of impairments. Therefore, the effect of VGBT with LMC should be associated with the principle of high-intensity, repetitive and task-orientated training.[27] The results of the present study indicate that LMCBT improves hand functions and also promotes hand and pinch strengths in patients with CP, JIA, and BPBI. Furthermore, it has been reported that no patient experienced intervention-related adverse events during VGBT with LMC.[22] Thankfully, we did not observe any side effects.

After the treatment, we found improvements by LMC-based games in the objective and subjective functional outcomes (in JHFT and 9HPT, CHAQ and DHI) in 3 different diseases. We believe that these improvements are relevant to the training with LMC games being intensive, highly repetitive, and task-specific similar to conventional training. Although spasticity limits speed-dependent activities in patients with CP and JHFT evaluates the duration of various functional activities in daily life, we found statistically significant results for JHFT scores in CP by using LMC games. So, we suppose that these games contribute to motor control in patients with CP.

We also found quite significant improvements in grip and pinch strengths in both the training groups. In fact, there is no resistance of real-world objects involved in the LMC training. So, although this is somewhat unexpected, it may be due to the multiple repetitive uses of the hand during play, and the game progression is associated with an increase in speed and number of objects. Similar to this study, 2 studies reported that VGBT with LMC achieved improvements on the grip and pinch forces in patients with stroke.[22,26] In the present study, the decrease in grip strength, which is commonly seen in the 3 disease groups, is caused by different reasons. However, the LMCBT program achieved significant improvement in the grip strengths in the 3 groups similar to the results of the conventional treatment. So, we predict that the LMC games we developed could be used for strengthening in many other diseases.

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Video game–based training vs conventional rehabilitation program

It is suggested that VGBT with LMC was deemed to be more enjoyable than, and preferable to, the conventional therapy, because VGBT with LMC using interactive VR games can provide task-oriented practice, as well as visual and auditory feedback regarding performance and gain, which further motivates and engages players to increase the rehabilitation intensity.[39] Also, Wang et al[27] claimed that VGBT with LMC not only facilitates the motor function recovery of paretic upper limbs but also promotes neural reorganization, as evidenced by the functional magnetic resonance imaging scan.

In the present study, we have achieved significant improvement in upper extremity functions in all LMCBT and conventional rehabilitation groups. However, when we compared the groups to understand which treatment is more effective, the largest effect sizes were found in the outcomes of JIA treatment groups. On the other hand, almost all changes of the outcomes after treatment were more effective in LMCBT than conventional treatment in patients with JIA. If to point the baseline results of the 2 treatment groups, although the baseline results of the LMCBT group are worse in almost all scores than the conventional treatment group, improvements of the upper extremity functions were more excellent in the LMCBT group than in the conventional treatment group in patients with JIA. When we compared the CP groups to understand which treatment is more effective, effect sizes were found to be moderate in almost all outcomes of the LMCBT group, but the effect size was smaller in almost all results of conventional treatment group. So, these results confirmed that LMCBT is quantitatively effective for improving upper extremity functions in patients with JIA and CP.

Otherwise, we found significant improvements after the treatment in BPBI, but we obtained low effect sizes in almost all results in both treatment groups of BPBI. The fact that we did not achieve remarkable improvements by both treatment groups in BPBI may be related to limited motor capacity due to nerve damage because of the nature of BPBI. So, neuromuscular limits related to the disease may be inadequate in providing benefit from the treatments.

Although the baseline scores of JTHFT and 9HPT in which we evaluated the activity performance were very poor in CP and BPBI, we found quite significant changes after treatment in the results of 2 tests especially in LMCBT groups, even if effect sizes were small. Conversely, the fact that we could not obtain a significant change in these scores after treatment in patients with JIA could be explained by the fact that pretreatment scores in patients with JIA were better than those of the patients in other groups, due to not having motor disabilities. Finally, we have obtained significant improvements for these 2 tests in patients with CP and BPBI. Because baseline performance of the activities was poor in patients with CP and BPBI, the games with LMC used in the present study encouraged the children to be fast depending on the motivation to succeed during the games.

Limitations

Although the results are encouraging, some limitations of our study should be noted. First, we did not perform power analysis because the participants included to the present study were patients who attended our clinic. So, the sample size is too small for an in-depth analysis, and therefore, any future work should be planned with larger patient groups according to power analysis. Second, the long-term effects of LMCBT were not evaluated in this study. Third, we think that VGBT can increase the motivation of the patients, but we did not evaluate the motivation of patients which could influence the adherence to the treatment.

Conclusion

The present study has quantitatively shown that the video-based games with LMC can be designed as an effective treatment. LMCBT is a feasible and alternative training for children and adolescents with physical disabilities. Also, this randomized controlled trial has proven that 8-week VGBT with LMC was more effective in patients with JIA and CP than in patients with BPBI. In addition, no adverse effects of LMCBT were observed. Fizyosoft Games with LMC are the newest video game option for rehabilitation that may be suitable as an intervention for functional recovery in other patients with chronic diseases. Future research should investigate the effects of using these LMC games, which we developed, for rehabilitation in patients with various diseases.

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JHT Read for Credit
Quiz: # 676

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1. The study design was
   a. prospective cohort
   b. qualitative
   c. case series
   d. RCTs

2. The acronym LMCBT is short for
   a. Learning More Clinical-based training
   b. Live Motivational Concept-based training
   c. Leap Motion Controller-based training
   d. Louisville Medicine Center-based training

3. The primary outcome measure(s) was(were) the
   a. JTHFT and DHI
   b. DASH
   c. modified Weeks test
   d. Sollerman and Mayo Clinic Index

4. LMCBT utilizes
   a. a high-cost, high-complexity visiodynamic system
   b. a low-cost, low-complexity optoelectronic system
   c. an EMG biofeedback system
   d. a surface electrode audioelectronic system

5. The system takes advantage of the pediatric populations' preference for playing video games rather than participating in traditional clinical sessions
   a. not true
   b. true

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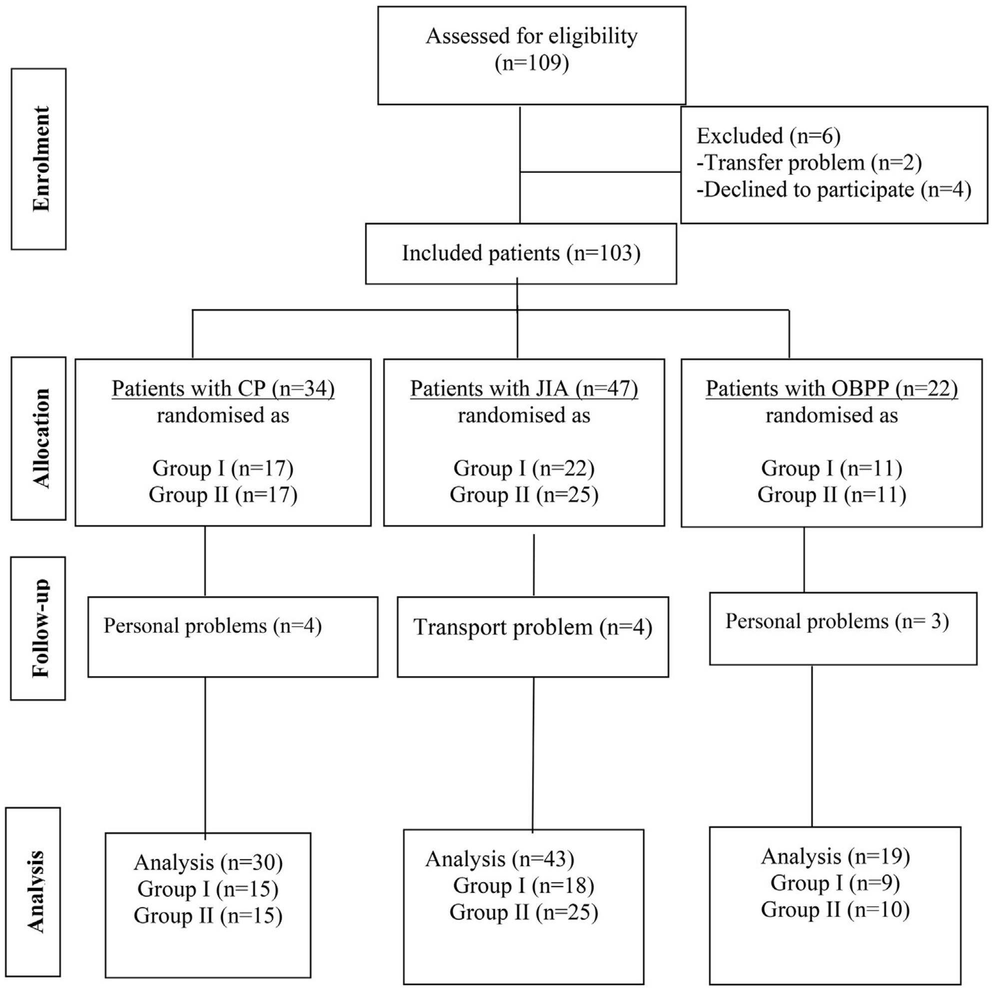
Appendix



Supplementary Fig. 1. Progress of study participants.

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