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ORIGINAL ARTICLE

Effect of mirror therapy on brain re-organization, functional motor skills and quality of life in spastic hemiplegic cerebral palsy

Spastik hemiplejik serebral palside ayna terapisi uygulamasının beyin reorganizasyonu, fonksiyonel motor beceriler ve yaşam kalitesi üzerindeki etkisi

Duygu KORKEM YORULMAZ[1], Mintaze KEREM GÜNEL[2], Arzu Ceylan HAS SILEMEK[3], Kader KARLI OĞUZ[4]

Abstract

Purpose: Spastic hemiplegic cerebral palsy is a complex disability with sensory-motor problems characterized by functional movement and posture disorders and negatively effects daily living activities. The aim of this study was to investigate the effects of mirror therapy for upper extremity and hand functions on brain re-organization, functional motor development, daily living activity level, and quality of life in children with spastic hemiplegic cerebral palsy.

Methods: This self-control study employed a sample of nine children aged from 4 to 18. The children were evaluated before and after eight weeks of routine physiotherapy and were included in mirror therapy sessions of 30 minutes each for three days a week by the same physiotherapist. The evaluation measured activation intensity, upper extremity activation intensity, upper extremity skill levels, goal achievement states, functional independent states, brain re-organization states, and quality of life levels.

Results: No statistically significant difference was detected regarding the evaluation parameters before and after the first eight-week follow-up period (p>0.05). However, a statistically significant improvement was found in upper extremity skill states, functional independence levels, brain re-organization states, and quality of life levels in the second 8-week study period in which mirror therapy was added to physiotherapy (p<0.05).

Conclusion: This study contributes to the limited literature on the determination of treatment effectiveness by employing functional magnetic resonance imaging *(fMRI)* in the mirror therapy on children with spastic hemiplegic cerebral palsy.

Keywords: Cerebral palsy, Motor skills, Functional status, Quality of life.

Öz

Amaç: *Spastik hemiplejik serebral palsi, duyusal-motor sorunlar, fonksiyonel hareket ve postür bozuklukları ile karakterize, günlük yaşam aktivitelerini olumsuz etkileyen kompleks bir nöro-gelişimsel bozukluktur. Bu çalışmanın amacı, üst ekstremite ve el fonksiyonlarına yönelik ayna terapisinin beyin yeniden örgütlenmesi, fonksiyonel motor gelişim, günlük yaşam aktiviteleri ve yaşam kalitesi üzerindeki etkilerini incelemekti.*

Yöntem: *Bu özdenetimli çalışma, yaşları 4 ile 18 arasında değişen dokuz çocuktan oluştu. Çocuklar, sekiz haftalık rutin fizyoterapi öncesi ve sonrası değerlendirildi, ardından aynı fizyoterapist tarafından haftada üç gün, 30'ar dakikalık ayna terapisi seanslarını içeren bir müdahale programına alındı. Değerlendirmelerde aktivasyon şiddeti, üst ekstremite aktivasyon yoğunluğu, üst ekstremite beceri düzeyleri, hedef gerçekleştirme durumu, fonksiyonel bağımsızlık düzeyi, beyin yeniden örgütlenme durumu ve yaşam kalitesi ölçüldü.*

Bulgular: *İlk sekiz haftalık takip döneminde, değerlendirme parametreleri açısından istatistiksel olarak anlamlı bir değişiklik saptanmadı (p>0,05). Ancak, ayna terapisinin fizyoterapi programına eklendiği ikinci sekiz haftalık dönemde üst ekstremite becerilerinde, fonksiyonel bağımsızlık düzeylerinde, beyin yeniden örgütlenme bulgularında ve yaşam kalitesinde istatistiksel olarak anlamlı iyileşme görüldü (p<0,05).*

Sonuç: *Bu çalışma, spastik hemiplejik serebral palsili çocuklarda ayna terapisinin etkinliğinin belirlenmesinde fonksiyonel manyetik rezonans görüntüleme (fMRI) kullanımına ilişkin sınırlı literatüre katkı sağlamaktadır.*

Anahtar Kelimeler: *Serebral palsi, Motor beceriler, Fonksiyonel durum, Yaşam kalitesi.*

1: Health Science University, Faculty of Gulhane Physiotherapy and Rehabilitation, Department of Pediatric Rehabilitation, Ankara, Türkiye.
2: Hacettepe University, Faculty of Physiotherapy and Rehabilitation, Ankara, Türkiye.
3: Universitätsklinikum Hamburg-Eppendorf, Germany
4: Hacettepe University, Faculty of Medicine, Department of Radiology, Ankara, Türkiye.
Corresponding Author: Duygu Korkem Yorulmaz: duygukorkem@yahoo.com
ORCID IDs (order of authors): 0000-0003-1264-5415; 0000-0003-4942-5272; 0000-0003-4609-0956; 0000-0002-3385-4665
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INTRODUCTION

Spastic hemiparetic cerebral palsy (SHCP) results from brain damage during fetal and infant development, leading to motor pathway degeneration, primarily affecting the premotor (PM, BA6) and primary motor (M1, BA4) areas, involved in somatosensory control and bimanual coordination.[1] SHCP presents with complex sensory-motor issues and declined upper extremity function, particularly in distal sections.[2] Functional imaging studies demonstrate increased stimulability of the ipsilateral primary motor area (BA4) when observing extremity illusions during unilateral movement.[3] Interhemispheric disinhibition occurs after bilateral movements.[4]

Bilateral movements stimulate the affected hemisphere's primary motor area during the acute recovery phase after brain injury,[5,6,7] impacting daily living activities and bimanual coordination in children with SHCP.[8] Mirror therapy (MT) is a recent approach aiming to improve the functionality of the affected extremity and brain re-organization.[5,9-11]

MT activates the mirror neuron system using mirror visual feedback to stimulate the motor cortex.[12-15] Visual, motor order, and proprioceptive capacity play crucial roles in activating mirror neurons.[5,6,16] MT enhances awareness and spatial perception in children, reducing learned non-use following motor imagery.[4,11]

Previous studies have shown that MT can improve functional outcomes in SHCP, increasing hand strength and function.[17] It effectively enhances muscle activity, motor speed, and functionality in daily living activities.[18,19] Considering the limitations in evidence-based studies and the lack of research on MT's effect on brain re-organization in children with SHCP, this study aims to investigate the combined effect of MT and routine therapy on brain re-organization, upper extremity function, daily living activities, and quality of life.

METHODS

Participants

This study included randomly selected children with SHCP from the Department of Pediatric Physiotherapy, Faculty of Physiotherapy and Rehabilitation, Hacettepe University. Ethical approval (No: 99950669/3A) was obtained from University Health Sciences Research Ethics Committee. The minimum number of subjects required for the study was eight, based on an alpha error rate of 0.05 and a beta of 0.20, together with 80% power. Assuming the loss of 25% of individuals during the training period, we specified the number of subjects as 10. The clinical trial number was NCT03612128. Parents or their carers gave informed consent for participation. Children aged 4 to 18 years, without visual function disorders other than refractive errors, and their families agreed to participate. Exclusion criteria included upper extremity fractures, recent muscle-tendon and bone surgery, exposure to spasticity-inhibiting drugs in the last six months, dental braces, epileptic seizures, or platinum in the upper extremity. Fourteen children were assessed, but only nine completed the treatment program (Figure 1).

Study design

The study was a self-control study to ensure similarity between experimental and control groups, enhancing intervention effectiveness in SHCP (Figure 2). A single group of children participated in two eight-week periods. The first period was the control group without MT while the second period included MT alongside routine physiotherapy. Routine physiotherapy comprised various exercises for the upper extremity. Initial assessments were made before the first period, and routine physiotherapy was conducted twice a week. Second assessments were performed after the first period, and then MT was added to routine sessions. MT was applied for 30 minutes three days per week during the second period, following the literature.[19,20]

Treatment protocol

A single physiotherapist conducted all implementations. During MT, each child sat upright with both feet on the floor, supported by a chair with back support, and arms on the table. A mirror divided the body into two parts, reflecting the healthy extremities while concealing the affected ones. Each child with SHPC was given exercises for fine motor activities such as opposition, picking up and throwing objects into a box, and rolling soft objects for MT. Prior to the MT intervention, all participants received routine physiotherapy based on neurodevelopmental principles. The program included stretching, strengthening, bilateral upper extremity activities, task-oriented functional motor training, and activities of daily living practice. These sessions were conducted twice weekly by the same physiotherapist to ensure consistency.

Clinical assessment

Brain Re-organization

Its non-invasive nature has made functional magnetic resonance imaging (fMRI) the most commonly used method for mapping the neural activities of the human brain. We used fMRI to evaluate the brain re-organization in this study (Figure 3). A neuroradiologist performed fMRI assessments.

Imaging

The 3T magnetic resonance imaging scanner (Magnetom, Trio TIM system, Siemens, Germany) with a 32-channel head coil was used for imaging before and after control and study periods. Imaging protocol included a multi-section single-shot T2* echo-planar imaging sequence (TR/TE: 2000/35 msec) with 28 sections, 3.4x3.4x3.4 mm voxel size, 220x220 FOV, and 64x64 matrix size. fMRI-BOLD procedure lasted 610 seconds with five repetitions, each cycle comprising 20 seconds of right-hand movement, 20 seconds of left-hand movement, 20 seconds of bimanual movement, and 20 seconds of rest. 3D T1-weighted high-resolution images were also obtained (TR/TE: 1900/3.4 msec; FA: 90; FOV: 256 mm; matrix: 224x256; distance factor: 50%).

fMRI Analysis

fMRI data were analyzed using Brain Voyager QX 1.2 (Brain Innovation, Netherlands). Image preprocessing involved eliminating low-frequency shifts, 3D motion detection, and correction, and spatial antialiasing (6 mm FWHM). The General Linear Model (GLM) determined voxel correlations between BOLD signal and predictor. Six motion parameters from fMRI pretreatment (X, Y, Z translation and rotation) were used as covariates in GLM. Images were reconciled with an anatomical dataset, and Talairach transformation was performed by manual detection of AC-PC point for normalization. Correlation estimation used $p<0.05$ threshold (family-wise errors) with minimum cluster threshold of 10 mm and $t>3.1$. Regions of interest (ROI) were created with bilateral Brodmann areas 4 and 6, extracting mean t-stat value for each ROI.

Functional Motor Capacity

Functional motor capacity of cerebral palsy was measured by using the Gross Motor Function Classification System (GMFCS). GMFCS is a 5-level system used for classifying motor activation intensity in children with cerebral palsy. Level I and Level II indicate that ambulation can be performed in society or at home without any restriction. In contrast, children at level V do not have independent mobility (Cronbach's alpha 0.99).[21,22]

Manual Skills

The Upper Extremity Bimanual Ability Classification System (MACS) classified subjects' manual abilities into five levels. Level I indicates easy object handling, while Level V reflects limited activity performance (Cronbach's alpha 0.99). The Quality of Upper Extremity Skills Test (QUEST) evaluated upper extremity skills in children with spastic cerebral palsy aged 18 months to 18 years. QUEST comprises 7 sections, assessing various aspects of hand function (Cronbach's alpha 0.98).[23]

Goal Achievement

The Goal Achievement Scale (GAS) evaluates children's success in achieving targets. Scores range from -2 (poor) to +2 (above expected). GAS measures individualized progress and is reliable for assessing treatment effects.[24] In our study, three goals were set for each child based on importance and difficulty. Achievement was assessed using GAS (Cronbach's alpha 0.83).

Functional Independence

The Functional Independence Measure for Children (WeeFIM) is a pediatric scale with 18 items in 6 areas: self-care (6), sphincter control (2), transfers (3), locomotion (2), communication (2), and social status (3). Scores range from 1 (entirely dependent) to 7 (full independence), considering assistance, timing, and device use (Cronbach's alpha 0.95).[25]

The Evaluation of Health-Related Quality of Life

The Child Health Questionnaire–Parent Form 50 (CHQ-PF50), a 50-item parent-reported measure, was used to assess the health-related quality of life (HRQoL) of the participants. CHQ-PF50 has been prepared for children aged 5–18 years. It has 12 subscales. Each subscale is scored between 0 and 100, and high scores express a better quality of life and well-being (Cronbach's alpha 0.96).[26]

Statistical analysis

SPSS 22.0 analyzed data. Cronbach's alpha estimated internal consistency. Descriptive stats used mean and standard deviation for quantitative data (X±SD), and number/percentage for qualitative. Kolmogorov-Smirnov tested normal distribution. Friedman test assessed time change significance. Wilcoxon test with Bonferroni correction ($p<0.017$) conducted post-hoc comparisons. Variance analysis examined changes in normally distributed body activation and upper extremity quality. Cohen's d measured effect sizes (0.2: small, 0.5: moderate, 0.8: large). The significance level was set up as 0.05. Greenhouse-Geisser corrected non-sphericity assumption.

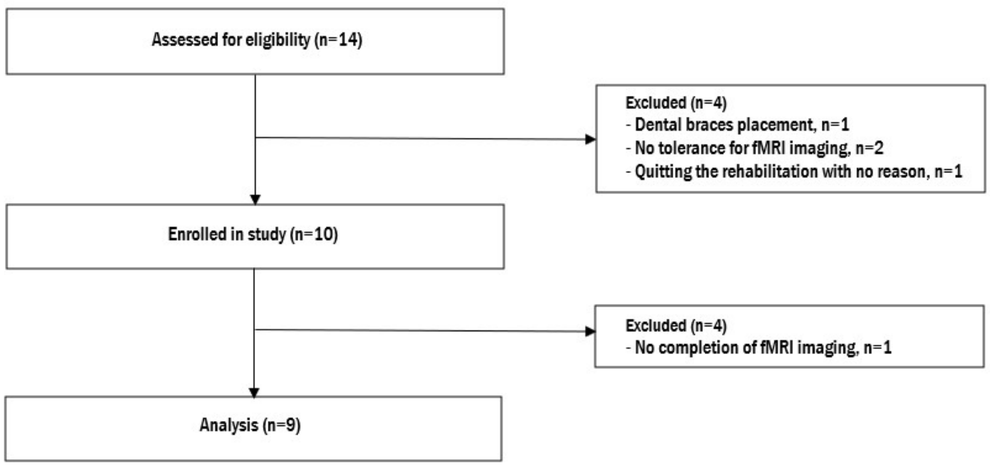

Figure 1. The flow diagram of the individuals included in the study.

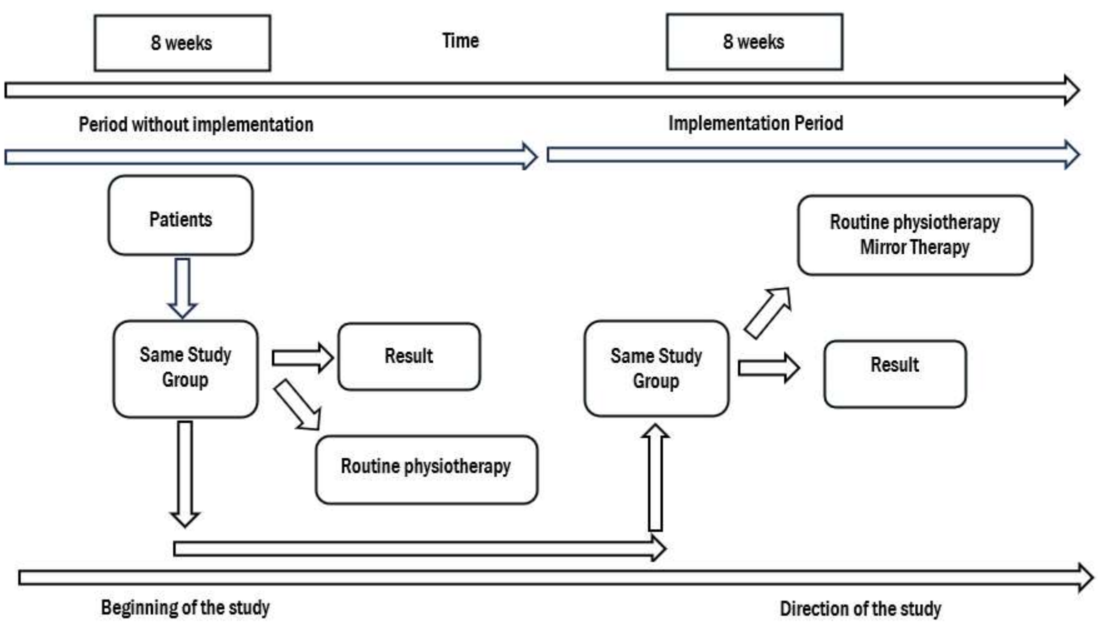

Figure 2. Study design.

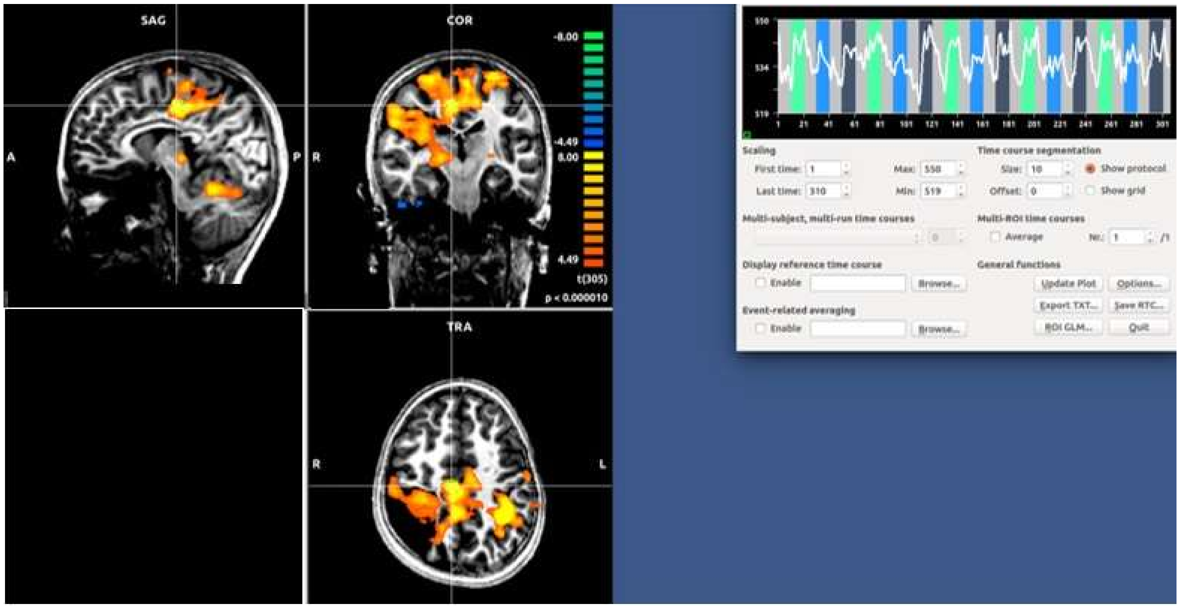

Figure 3. fMRI sample showing increased hemisphere activation with movements of both hands compared to rest at 2 months follow up. Time course segmentation was extracted from highly activated nodes in the BA4.

RESULTS

Sociodemographic characteristics

Nine children with SHCP completed the study (mean age: 12.3±2.4 years, disease symptom onset: 6±2.8 months, diagnosis age: 7.9±4.0 months). Table 1 shows sociodemographic and descriptive characteristics. Bimanual hand skills and GMFCS levels showed no significant difference between control and study periods (p>0.05) (Table 1).

Primary outcomes

Brain Re-organization

At the beginning and end of the control period, brain re-organization in BA4 and BA6 areas showed no statistically significant difference (p>0.05). However, after the study period, significant differences were found in the affected hemisphere's BA6 area during affected extremity and in the affected and unaffected hemisphere BA4 and affected hemisphere BA6 areas with bilateral extremity movement after the study period (p<0.05).

When a comparative evaluation of brain re-organization at the beginning and end of the study period was performed, a statistically

Table 1. Socio-demographic and descriptive characteristics, Gross Motor Functional Classification System (GMFCS), and Manual Ability Classification System (MACS) scores of individuals (n=9).

	X±SD
Age of child (year)	12.3±2.4
Age of onset of disease symptoms (months)	6.0±2.8
Time of diagnosis by the doctor (months)	7.9±4.0
Physiotherapy period (years)	8.9±3.1
	n (%)
Gender	
Male	2 (22
Female	7 (78)
Classification	
Right Hemiplegia	4 (44)
Left Hemiplegia	5 (56)
	Median (Min-Max)
GMFCS	
1st assessment	2 (1-2)
2nd assessment	2 (1-2)
3rd assessment	2 (1-2)
MACS	
1st assessment	3 (1-3)
2nd assessment	3 (1-3)
3rd assessment	3 (1-3)

Min-Max: minimum – maximum. GMFCS: Gross Motor Function Classification System. MACS: Manual Ability Classification System.

significant difference was found in the affected hemisphere BA6 area with the movement of the affected extremity and in the unaffected hemisphere BA6 area with bilateral extremity movement ($p<0.05$) (Table 2).

Effect sizes for BA4 activation in the non-affected hemisphere with bilateral limb movement were medium (2nd and 3rd assessments: d=0.79) and large (1st and 3rd assessments: d=0.9). Effect sizes for BA6 activation in the affected hemisphere with bilateral limb movement were medium (1st and 2nd assessments: d=0.65) and large (2nd & 3rd assessments: d=0.93, 1st and 3rd assessments: d=1.63). Other variables had small effect sizes.

Upper Extremity Manual Skills

No statistically significant difference was found in the QUEST sub-sections between evaluations at the beginning and end of the control period ($p>0.05$).

However, disassociated movements, grip, weight carrying, and protective extension sub-sections showed a significant difference ($p<0.05$) (Table 2). Effect sizes for disassociated movements were medium (2nd and 3rd assessments d= 0.54, 1st and 3rd assessments d= 0.59). Other variables had small effect sizes.

Secondary outcomes

Functionality in Daily Living Activities

No difference at control period's start and end, but a significant difference in motor score and total score of self-care sub-section in the functional independence measurement at study period's start and end ($p<0.05$). All variables had small effect sizes.

The State of Achieving the Identified Goals

No significant difference in achieving identified goals between control period evaluations ($p>0.05$). However, a significant difference in goal 1 at study period's start and end ($p<0.05$) (Table 3). GAS' effect sizes were medium (2nd & 3rd assessments d=0.52, 1st & 3rd assessments d=0.52).

Health-Related Quality of Life

No significant difference in life quality levels between control period evaluations ($p>0.05$). However, HRQoL showed significant differences in Physical Function (PF), Role/Social-Physical Behavior (REB), Self-Esteem (SE), Parent Effect/Time (PT), and

Table 2. Evaluation of brain re-organization (fMRI) and quality of upper extremity skills test (QUEST).

	1. week Median (IQR)	8. week Median (IQR)	16. week Median (IQR)	p	
Functional Magnetic Resonance Imaging (fMRI)					
BA4 ACT in AF-Hem w/ associated affected limb movement	2.3 (7.5)	5.4 (12.5)	6.6 (9.8)	1.00	
BA4 ACT in NAF-Hem w/ associated affected limb movement	5.1 (5.87)	2.8 (7.9)	2.9 (6.2)	0.79	
BA6 ACT in AF-Hem w/ associated affected limb movement	0.0 (0.0)	0.0 (3.9)	5.8 (5.6)	<0.001	a,b
BA6 ACT in NAF-Hem w/ associated affected limb movement	0.0 (0.0)	0.0 (4.3)	2.7 (6.1)	0.07	
BA4 ACT in AF-Hem w/ associated non-affected limb movement	2.5 (5.5)	2.7 (6.5)	0.0 (5.3)	0.94	
BA4 ACT in NAF-Hem w/ associated non-affected limb movement	5.9 (7.4)	6.2 (8.2)	8.6 (3.6)	0.19	
BA6 ACT in AF-Hem w/ associated non-affected limb movement	0.0 (0.0)	0.0 (5.0)	0.0 (0.0)	0.17	
BA6 ACT in NAF-Hem w/ associated non-affected limb movement	0.0 (0.0)	0.0 (6.1)	5.7 (7.0)	0.11	
BA4 ACT in AF-Hem w/ associated bilateral limb movement	5.2 (6.1)	5.5 (4.4)	7.2 (2.8)	0.03*	b
BA4 ACT in NAF-Hem w/ associated bilateral limb movement	6.2 (7.2)	7.5 (2.8)	8.0 (3.1)	0.03*	b
BA6 ACT in AF-Hem w/ associated bilateral limb movement	0.0 (0.0)	2.3(5.7)	5.6 (7.6)	0.01*	b
BA6 ACT in NAF-Hem w/ associated bilateral limb movement	0.0 (0.0)	2.6 (6.0)	6.2 (9.7)	0.08	
The Quality of Upper Extremity Skills Test (QUEST)					
Dissociated movement	73.4 (21.1)	73.4 (17.9)	76.6 (10.2)	0.01*	a,b
Grasp	55.5 (25.3)	55.5 (25.3)	60.0 (29.6)	<0.001	a,b
Weight bearing	82.0 (22.0)	82.0 (22.0)	84.0 (20.0)	<0.001	a,b
Protective extension	83.3 (26.4)	83.3 (26.4)	88.9 (23.6)	0.40	
Total Score	70.6 (23.7)	70.6 (22.9)	77.1 (20.3)	<0.001	a,b

*p<0.05. IQR; Inter Quantile Range. a: p<0.05, , 8-16. Week. b: p<0.05, , 1-16. Week. ACT: Activation. AF-Hem: Affected hemisphere. NAF-Hem: Non-affected hemisphere.

Table 3. Functional independence level (WeeFIM), achievement of defined goals (GAS) and health-related quality of life (CHQ_PF50).

	1. week Median (IQR)	8. week Median (IQR)	16. week Median (IQR)	p	
The Functional Independence Measure for Children (WeeFIM)					
Self-care	32.0 (8.5)	32.0 (8.50)	35.0 (7.5)	0.01*	a,b
Sphincter Control	14.0 (0.5)	14.0 (0.50)	14.0 (0.5)	1.00	
Transfers	21.0 (2.0)	21.0 (2.00)	21.0 (2.0)	1.00	
Locomotion	14.0 (0.5)	14.0 (0.50)	14.0 (0.5)	1.00	
Motor Subtotal Score	81.0 (10.5)	81.0 (10.5)	83.0 (10.0)	0.01*	a,b
Communication	14.0 (1.0)	14.0 (1.0)	14.0 (1.0)	1.00	
Social Cognition	19.0 (5.0)	19.0 (5.0)	19.0 (5.0)	1.00	
Cognitive Subtotal Score	33.0 (6.0)	33.0 (6.0)	33.0 (6.0)	1.00	
Total Score	110.0 (8.5)	110.0 (8.5)	113.50 (7.5)	0.01*	a,b
The Goal Achievement Scale (GAS)					
Goal 1	2.0 (1.0)	2.0 (1.0)	2.0 (0.5)	0.01*	a,b
Goal 2	2.0 (1.0)	2.0 (1.0)	2.0 (0.5)	0.50	
Goal 3	2.0 (1.5)	3.0 (1.0)	2.0 (1.0)	0.50	
The Child Health Questionnaire Parent Form (CHQ_PF50)					
Physical functioning (PF)	61.1 (36.9)	61.1 (50.8)	72.2 (36.1)	0.06	
Role/social-behavior (REB)	61.1 (64.5)	77.8 (61.1)	100.0 (65.6)	0.01*	
Role/social-physical (RP)	66.7 (48.1)	50.0 (55.6)	66.7 (33.3)	0.12	
Bodily pain (BP)	83.3 (33.9)	80.0 (30.0)	100.0 (20.0)	0.29	
Behavior (BE)	72.5 (42.1)	64.2 (27.1)	85.0 (31.7)	0.04*	a
Mental Health (MH)	80.0 (35.0)	80.0 (27.5)	80.0 (26.7)	0.29	
Self-esteem (SE)	65.0 (25.0)	70.0 (29.2)	75.0 (34.6)	<0.001	a,b
General health (GH)	35.0 (37.5)	39.2 (31.3)	43.3 (32.5)	0.19	
Parental impact/ emotional (PE)	33.3 (37.5)	26.7 (25.0)	41.7 (52.5)	0.07	
Parental impact/ time (PT)	66.7 (36.1)	55.6 (27.8)	77.8 (14.6)	<0.001	a,b
Family activities (FA)	77.8 (22.1)	75.0 (16.7)	83.3 (29.2)	0.09	
Family Harmony	60.0 (38.3)	70.8 (25.0)	85.0 (25.0)	0.15	
Physical Health Summary Score	35.2 (12.7)	33.9 (13.3)	40.2 (11.3)	<0.001	a,b
Psychosocial Health Summary Score	42.8 (14.1)	43.3 (13.1)	50.3 (15.4)	<0.001	a,b

*p<0.05. IQR; Inter Quantile Range. a: p<0.05, , 8-16. Week. b: p<0.05, , 1-16. Week.

Parent Effect/ Emotional (PE) sub-sections of CHQ-PF50 and, Physical and Psychosocial Health Summary Scores at study period's start and end (p<0.05) (Table 3). Effect sizes were medium and large (REB 1st and 3rd assessments d=0.59; BE 2nd and 3rd assessments d=0.77; SE 2nd and 3rd assessments d=0.70, 1st and 3rd assessments d=0.86; PT 2nd and 3rd assessments d=1.08, 1st and 3rd assessments d=0.77; Physical Health Summary Score 2nd and 3rd assessments d=0.83, 1st and 3rd assessments d=0.59; Psychosocial Health Summary Score 2nd and 3rd assessments d=0.78, 1st and 3rd assessments d=0.84).

DISCUSSION

Authors observed an activation increase in the PM(BA6) area of the affected hemisphere with the movement of the hemiplegic arm and in the M1(BA4) area of the affected hemisphere as well as in the M1(BA4) and PM(BA6) areas of the unaffected hemisphere with bilateral arm movement when the brain re-organization evaluations were compared with fMRI in our study. The observation could indicate that the motor area of the hemisphere containing the lesion can be activated when the hemiplegic side is active, and the motor areas in both hemispheres can be activated with the use of both arms.

To the best of our knowledge, no study has explored fMRI for MT effectiveness in SHCP. Altschuler et al.[10] suggested that mirror illusion enhances PM(BA6) region by compensating for decreased proprioception in adult hemiplegic patients. Fukumura et al.[27] found increased activation in PM(BA6) and M1(BA4) with MT using transcranial magnetic stimulation. In this study showed activation in PM(BA6) and M1(BA4) in both hemispheres during MT.

Garry et al.[28] found increased PM(BA6) activation due to mirror neurons' increase using transcranial magnetic stimulation and MT in healthy subjects. Inverzinni et al.[29] showed MT activates patients' mirror neuron system, improving upper extremity mobility and functional independence. In this study, bilateral hand movements on fMRI revealed activation in motor regions of both hemispheres. PM(BA6) area activation in both hemispheres suggests involvement of mirror neurons in this development.

This study also showed increased activation in the affected hemisphere during hemiplegic hand movement, in contrast to the healthy hemisphere. Perry and Bentin[30] found stronger brain waves in the contralateral hemisphere after MT. Both hemispheres exhibited activation increase by MT, with the affected hemisphere showing stronger effects, consistent with our results. Previous studies have proven activation increase in specific neuronal regions of the lesioned hemisphere. Studies on mirror illusion related to poor motor function found decreased activation in control motor regions.[13,28,30]

In this study, MT improved disassociated movements, grasp, and weight-bearing in the upper extremity, aiding protective extension and supporting upper extremity skill development. Neuronal regeneration in M1(BA4) and PM(BA6) areas likely justifies these improvements.

Bruchez et al.[31] studied 90 children with hemiparetic cerebral palsy, finding that MT improves upper extremity strength, function, and daily performance, especially grasp strength. Feltham et al.[32] measured MT's effect on muscle strength using EMG in children with SHCP, observing increased muscle activation, especially in the shoulder and elbow region. Michielsen et al.[33] studied 40 chronic adult hemiplegic patients, revealing increased upper extremity motor function development and neuronal re-organization, with a shift in hemispheric activation towards the affected hemisphere after MT. MT was found to have additional benefits beyond repetitive tasks and focused training, enhancing motor cortex excitability and somatosensory input. Summer et al.[34] reported that simultaneous movement of the hemiplegic and intact extremities during MT increased activation in the motor cortex, improving affected upper extremity motor functions. Steven and Stoykov[35] showed that MT positively affects affected extremity function by providing visual feedback, reinforcing our study's outcomes. Altschuler et al.[10] found that positive visual feedback during MT restructured decreased proprioceptive input in hemiplegic individuals. Kuys et al.[36] demonstrated MT's improvement of sensory disturbances, including mild touch sensation and proprioception, supporting our study's findings of increased weight bearing. Afferent messages transmitted to the spinal cord, along with joint mechanoreceptors' pressure sensation and proprioceptive knowledge restructuring, likely explain the development of weight-bearing in the upper extremities. In summary, various studies confirm the positive effects of MT on upper extremity skills and functions. The therapy's impact is attributed to enhanced motor cortex excitability and somatosensory input, providing valuable insights into its potential benefits for individuals with SHCP. Understanding the mechanisms underlying MT's effects may aid in refining its implementation and optimizing outcomes in clinical practice.

Various studies have explored the impact of MT on upper extremity skills, including grasp and disassociated movements.[19,37] Gygax et al.[17] investigated ten children with SHCP, observing increased grasp strength and functional arm movements with MT. Smorenburg[37] compared the effects of mirror visual feedback on impaired and less-impaired upper limbs, demonstrating that mirrors can offer appropriate visual feedback for intended and dissociated movements, grasp, and weight-bearing.

Dohle et al.[38] proved that MT increased corticospinal stimulability for motor function development in 25 hemiplegic adults, specifically affecting distal arm muscles. Proximal and distal motor functions were differently influenced by both hemispheres, with distal movements organized unilaterally and proximal movements primarily represented bihemispherically. Based on this, we believe MT stimulated lateralized motor areas, improving grasp in the distal parts of our study. The illusion of MT also activated both hemispheres, enhancing disassociated movements by increasing proximal extremity movements.

Altschuler et al.[10] found increased functionality associated with motor and sensory development. Park et al.[39] reported positive effects of MT on upper extremity function and daily living activities in 30 hemiplegic patients, enhancing independence, particularly in self-care. Yavuzer et al.[11] observed motor improvement and functional development in 20 hemiplegic patients after four weeks of MT, with improved self-care activities. Our study demonstrated that MT positively impacted upper extremity motor function, leading to better self-care activities, and increased functional independence levels.

In this study demonstrated that goal-oriented MT positively impacted self-care activities and increased functional independence levels. Similar findings were shown by Park et al.[39] where goal-oriented MT improved upper extremity function and self-care in hemiplegic patients. Eom-Ji et al.[40] also found positive effects of goal-oriented MT on upper extremity function and independence in daily activities for 20 hemiplegic patients. Increased daily living activities and motivation can lead to greater achievement, independence, and self-confidence, promoting positive behavioral development and encouraging individuals to fulfill their social and physical roles in life.

Previous studies were pilot studies without investigating brain re-organization with fMRI. Limited literature on MT in SHCP makes this study relevant.

Limitations

Although the number of individuals required was eight in the power analysis performed to detect the adequacy rate of the children, we believe that this number is inadequate for inter-group evaluations and should be increased for more detailed analysis in future studies.

The wide age range of the participants (4–18 years) represents a methodological limitation, as developmental differences across this span may influence neuroplasticity, motor learning capacity, and functional performance. Such heterogeneity may partially affect the interpretability and generalizability of the findings regarding the effects of MT on brain re-organization, functional motor skills, and quality of life. Future studies should include more age-homogeneous cohorts to strengthen the validity of the outcomes.

Out of the individuals included in the study, four had left hemisphere involvement and five had right hemisphere involvement. The fMRI imaging results for brain re-organization were not included in the group analysis based on etiological classification. We suggest evaluating the data according to hemisphere activation for more objective insights in future studies.

Long-term treatment evaluation is a limitation in our study. Future studies with follow-up time points can determine the continuity of MT effectiveness.

Conclusion

This study indicates that MT supports upper extremity motor recovery and functional independence in children with SHCP by enhancing activation in the M1(BA4) and PM(BA6) regions of both hemispheres, suggesting a positive influence on brain re-organization. Improvements in grasp, dissociated movements, and weight-bearing align with these neurophysiological changes and highlight the therapy's potential to augment motor cortex excitability through visual–somatosensory feedback. Despite the small sample size and lack of long-term follow-up, the findings contribute valuable evidence to pediatric neurorehabilitation literature and suggest that MT can serve as an effective, low-cost clinical adjunct to conventional treatment for improving upper extremity function in this population.

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