Accepted Article

J Musculoskelet Neuronal Interact 2024

Journal of Musculoskeletal
and Neuronal Interactions
JMNI

Original Article

Effect of Upper Limb Repetitive Facilitative Exercise on Gait of Stroke Patients based on Artificial Intelligence and Computer Vision Evaluation

Caiping Song[1], Lingcong Wang[1], Jianhui Ding[2], Cui Xu[1], Hang Yang[1], Yajun Mao[1]

[1]Department of Rehabilitation, the First Affiliated Hospital of Zhejiang Chinese Medical University (Zhejiang Provincial Hospital of Traditional Chinese Medicine), Hangzhou, Zhejiang, China;
[2]Beijing Fushu Health Technology Co., LTD, Beijing, China

Abstract

Objective: This study aims to assess how enhancing upper limb function on the affected side of stroke influences the gait of the lower limb. **Methods**: Forty eligible stroke patients were randomly assigned to either a control group or a treatment group, with 20 patients in each group. Both groups underwent dynamic evaluation using artificial intelligence and computer vision before treatment. This evaluation focused on analyzing the range of motion of the shoulder and elbow during the gait cycle, as well as various gait parameters (such as step length, step speed, and percentage of stance phase) on the affected side. Following evaluation, the control group received routine rehabilitation treatment. **Results**: The results indicated that there was no significant difference between the two groups before treatment. However, following treatment, there was a notable improvement in the motion of the shoulder and elbow joints on the affected side among patients in the treatment group ($p<0.05$), whereas the control group showed only slight improvement, which was not statistically significant ($p>0.05$). **Conclusion**: The improvement in upper limb function on the affected side also appears to positively influence gait recovery. However, it's important to note that the observation period was relatively short. Further studies are needed to confirm whether this effect is sustained over the long term.

Keywords: Artificial Intelligence, Computer Vision, Gait, Repetitive Facilitative Exercise, Stroke

Introduction

Stroke refers to a group of disorders characterized by damage to brain tissue resulting from the sudden rupture of blood vessels in the brain or the obstruction of blood flow to the brain due to blocked blood vessels. While advancements in stroke prevention and treatment have led to a reduction in morbidity and mortality rates, many patients still experience various dysfunctions such as impaired movement, cognition, speech, and sensation due to the location and severity of brain injury[1]. Among these dysfunctions, motor impairment often presents as hemiplegic gait.

The underlying cause of hemiplegic gait is the damage to upper motor neurons following a stroke. This damage leads to inhibition of the cerebral cortex, the higher center responsible for regulating body motor function, while depressing reflexes at the spinal cord level. Consequently, primitive reflexes and overall limb movement patterns are released, disrupting normal movement conduction and resulting in abnormal physical activity[2]. In the lower limbs, this manifests as hemiplegic gait.

Additionally, following hemiplegia, patients' center of gravity tends to shift towards the affected side, increasing the load-bearing on that side. However, muscle weakness, asymmetrical muscular tone, sensory loss, and perceptual deficits on the paralyzed side decrease the load-bearing capacity of the affected side, exacerbating the abnormal hemiplegic gait pattern[3-5]. Consequently, patients experience

---

The authors have no conflict of interest.

Corresponding author: Yajun Mao, Department of Rehabilitation, the First Affiliated Hospital of Zhejiang Chinese Medical University (Zhejiang Provincial Hospital of Traditional Chinese Medicine), Wuchang Street, Hangzhou, Zhejiang, 310001, China
E-mail: tougaochenggong@163.com

Edited by: G. Lyritis
Accepted 92 April 2024

balance and coordination disorders and are at an increased risk of falls[6].

As research on gait after stroke progresses, the focus of gait recovery has expanded beyond the central nervous system to include the influence of upper limb function. Walking, a fundamental activity in daily life, is a complex process that requires coordination between the upper and lower limbs on both sides of the body, facilitated by the trunk. During walking, the swinging motion of the upper limbs in opposition to the lower limbs helps prevent compensatory movements of the pelvis and maintains body balance. Arm swings during walking are crucial for reducing energy expenditure[7], enhancing gait stability and balance[8], and facilitating leg swing and acceleration[9-11].

To better understand the relationship between shoulder and elbow swing amplitudes, walking function, and balance coordination, and to inform the rehabilitation of upper limb motor function during stroke rehabilitation, the author conducted relevant experiments. Currently, most evaluations are conducted with patients at rest. However, in clinical practice, many patients exhibit kinematic abnormalities during movement, which can negatively impact gait, balance, dynamic upper limb function[12], and activities of daily living.

Video-based pose estimation is an emerging technology that holds significant promise for enhancing clinical gait analysis. It enables quantitative movement analysis at low costs in terms of money, time, and effort[13]. Convolutional neural networks (CNNs) have proven highly successful in video-based gait recognition[14,15]. CNNs excel at working with images due to their strong spatial dependencies and translation invariance. Similarly, time series data can exhibit locally correlated points that remain invariant with time shifts. OpenPose, a human posture estimation model based on CNNs, can detect and estimate human key points and pose information in real-time from images or videos. This technology has various applications, including gait recognition.

A recent study by KD Ng et al. analyzed walking videos of 31 older adults with dementia using tracked pose information. Gait features were extracted from video recordings, and their association with clinical mobility assessment scores was examined. A significant association was found between the extracted gait features and clinical mobility assessments, providing concurrent and predictive validation of this approach[16].

Building on the natural coupling of upper limb and lower limb kinematics during human walking[17], we used Visual Tools based on AI to evaluate shoulder and elbow joint range of motion on both affected and healthy sides. We then implemented targeted repetitive facilitative exercises to improve the swinging ability of the upper limb on the affected side, aiming to enhance patients' walking and balance abilities while reducing the risk of falling.

Materials and Methods

General Data

Forty stroke patients (male: 26 and female: 14), aged between 25 and 70 years, who underwent rehabilitation treatment at our hospital from December 2020 to January 2022, were selected.

The inclusion criteria were: (1) Age between 25 and 70 years old; (2) First confirmed stroke by MRI or CT; (3) Medical history of 2-6 months; (4) The Brunnstrom assessment of the affected lower limb was ≥ grade III, and the patient could walk independently for 10 meters. Exclusion criteria were: (1) Diseases that affected normal walking and shoulder or elbow joint activity before onset (such as neurological disorders, musculoskeletal disorders, severe osteoarthritis, severe cardiovascular diseases, etc.); (2) Patients with severe cognitive impairment who could not cooperate.

The demographic details of the patients are provided in Table 1. These patients had their first stroke confirmed by MRI or CT scans, and the duration since the stroke ranged from 2 to 6 months. They exhibited stable vital signs, no cognitive dysfunction, and demonstrated active cooperation with evaluation and treatment procedures. Additionally, they were capable of independently walking 10 meters. None of the patients had pre-existing conditions that would impair their ability to walk normally, such as neurological disorders, musculoskeletal diseases, severe osteoarthritis, or severe cardiovascular diseases.

Interventional Methods

This clinical study was a randomized, controlled trial involving 40 stroke patients who met the inclusion and exclusion criteria. They were randomly allocated into either the control group or the treatment group, with 20 patients in each group.

The control group received routine exercise therapy and occupational treatment. Exercise therapy comprised active and passive joint training, muscle strength training, double or single lower limb standing balance training, and gait training (including assisted and independent walking). Occupational therapy focused on activities of daily living, such as dressing and feeding. In addition to routine therapy, the treatment group underwent targeted upper limb nerve communication technology training to enhance shoulder and elbow flexion and extension range. This training was conducted twice daily for 20 minutes, 5 days a week, over a period of 2 weeks. Prior to training, the range of motion (ROM) and angles of the shoulder and elbow joints on the affected and healthy sides were compared between the two groups.

Shoulder Flexion: Rubbing

Starting Position: The patient was in a supine position. The therapist slightly held the distal forearm with one hand

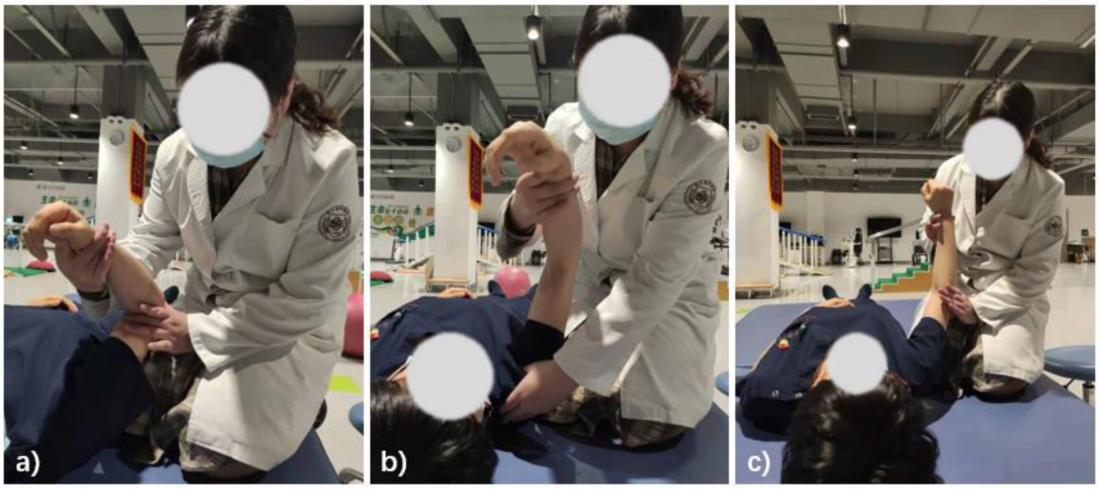

Figure 1. Upper limb repetitive facilitative exercise.

(the lower hand), maintaining shoulder flexion in external rotation, while the other hand (the upper hand) supported the shoulder.

Operational Procedures: The therapist elevated the shoulder joint while rapidly rubbing the deltoid muscle with the thumb of the upper hand. This action helped prevent impingement of the acromion. The lower hand maintained external rotation of the shoulder joint and encouraged the patient to actively initiate shoulder joint flexion, providing verbal cues such as "lift your arm." The procedure was repeated 50-100 times.

Shoulder Flexion: Tapping

Starting Position: The patient was placed in a supine position. The therapist gently held the distal forearm of the patient with one hand (the lower hand) and maintained shoulder joint flexion at 60 degrees external rotation. The thumb of the other hand (the upper hand) was placed on the upper arm, while the middle and ring fingers were positioned on the humeral head at the lower edge of the acromion.

Operational Procedures: The therapist rapidly tapped the anterior deltoid (the humeral head at the lower rim of the acromion) with the middle and ring fingers of the upper hand, while lightly resisting movement with the thumb. The lower hand maintained external rotation of the shoulder joint and encouraged the patient to actively initiate shoulder joint flexion, using verbal commands such as "lift your arm." After each tap, the therapist quickly returned to the starting position to utilize the stretch reflex and enhance muscle excitability. The procedure was repeated 50-100 times.

Elbow Flexion

Starting Position: The patient was in a supine position. The therapist gently held the distal forearm of the patient with the palm of the upper hand's fingers, keeping the elbow extended, forearm pronated, and palm facing outward. The lower hand positioned the middle finger in front of the patient's elbow (over the biceps tendon), while keeping the shoulder flexed 90 degrees forward.

Operational Procedures: The therapist applied pressure with the lower hand's finger to stimulate the biceps tendon, while the upper hand guided the patient's forearm into supination to promote elbow flexion. Subsequently, the therapist quickly applied pressure to the forearm and stimulated the triceps tendon by pressing with the thumb to extend the elbow back to the starting position. The procedures were repeated 50-100 times, as shown in Figure 1.

Evaluation

Data collection

As shown in Figure 2, for the video recordings, two cameras (DJI, China, 1080P resolution, 30 frames per second) were used. One was placed in front of the 5-meter-long and 1-meter-wide line where the participant turned (front-view) and the other in the side of the line (side-view). Two reference marks were placed at known locations on the floor for calibration of the video cameras. Wearing tight clothes, the patient walked back and forth 3 times on the 5-meter-long walkway in a relaxed state, resting for 5 minutes at intervals after each walk.

Data processing

The posture extraction network took the videos as input and produced 18 accurate positions of body parts, including

Figure 2. 5-meter-long and 1-meter-wide walkside.

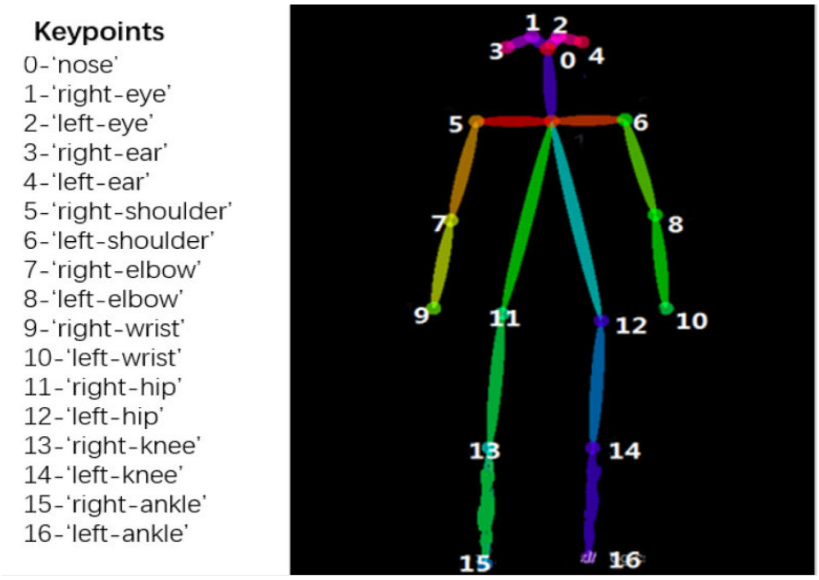

Figure 3. Human body skeleton data.

the nose, neck, eyes, ears, shoulders, elbows, wrists, hips, knees, and ankles (Figure 3), for each person in every frame as output in real-time. The location information was then imported into the computing unit to calculate gait parameters. Specifically, the swing amplitudes of the shoulder and elbow joints, along with characteristic data such as step length, step width, and step speed in the affected lower limb gait, were extracted.

Evaluation of ROM at shoulder and elbow

Before and after treatment, Visual Tools based on AI were used to calculate and compare the range of motion

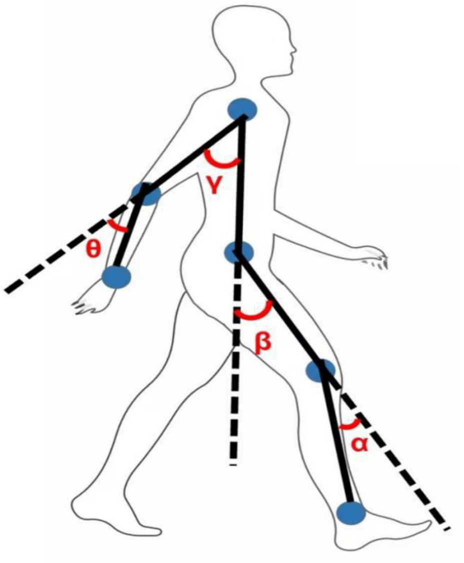

Figure 4. Angle of joints.

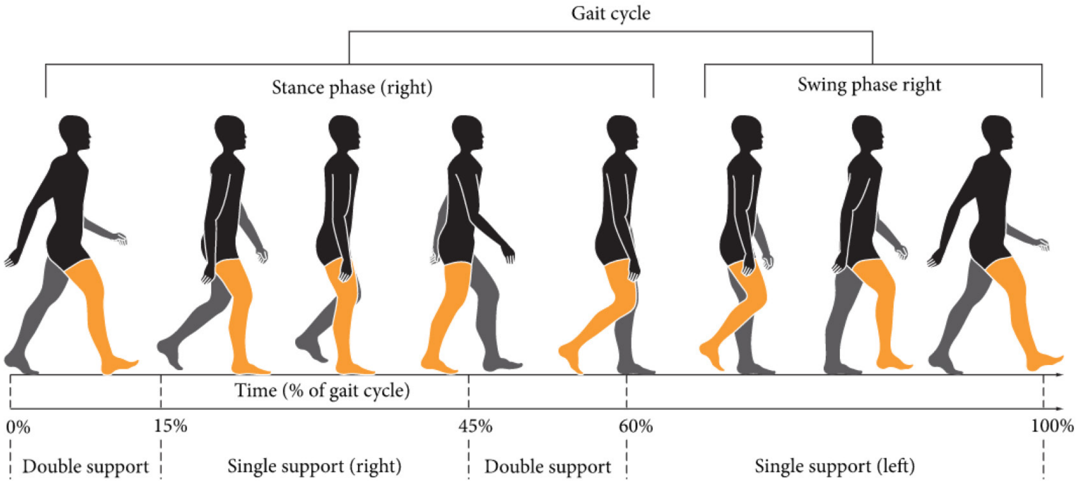

Figure 5. Gait cycle diagram.

of the shoulder and elbow joints during the swing phase of walking on the affected side and the healthy side of stroke patients. Joint angle measurements are shown in Figure 4.

Gait analysis

Step length, step speed, and percentage of support phase on the affected side during the walking process are illustrated in Figure 5.

Statistical Analysis

Data analysis was performed using SPSS 20.0 software. As shown in Table 2, measurement data were expressed as mean ± standard deviation (X ± S). Paired t-tests were used for intra-group comparisons, and two-independent sample t-tests were used for inter-group comparisons. The χ^2 rank sum test was used for comparisons between grade data groups. A p-value <0.05 was considered statistically significant.

Table 1. Baseline demographics in hemiplegic patients for the treatment group and control group.

Group	Age (years) 25-70	Sex (case)		Hemiplegia side (case)		Height (m)	Duration since stroke (day)
		Male	Female	Right Side	Left Side		
Treatment Group	54.65±7.92	12	8	6	14	1.66±5.40	85.80±11.7
Control Group	55.80±7.55	14	6	4	16	1.67±6.77	82.40±13.4
T values	-0.493	/		/		-0.671	0.853
χ^2 values	/	0.440		0.533		/	/
p values	0.627	0.507		0.463		0.506	0.399

Table 2. Upper limb kinematic variables.

Group	Shoulder ROM		Elbow ROM	
	Before treatment	After treatment	Before treatment	After treatment
Treatment Group	11.56±3.10	13.35±2.92	10.96±3.00	13.95±2.39
Control Group	11.33±2.70	11.37±2.72	10.37±1.97	11.99±1.91
T values	0.247	2.571	1.625	2.649
P values	0.80	0.014	0.112	0.012

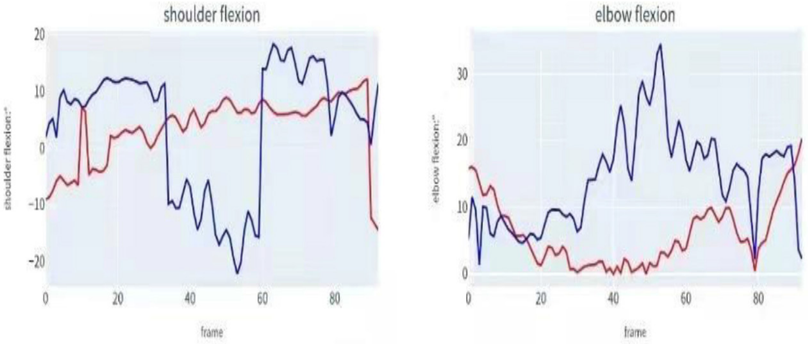

Figure 6. ROM of shoulder and elbow joints during a gait cycle (—affected side —healthy side).

Results

General data

Statistical analysis was conducted on sex, age, duration of disease, height of hemiplegia, and upper and lower limb measurements in both the control and treatment groups. The obtained p-values, all greater than 0.05, indicate no significant difference between the two groups (Table 1).

Evaluation of shoulder and elbow range of motion (ROM)

In this study, we calculated the range of motion (ROM) of the shoulder and elbow between the affected and healthy sides (Figure 6).

There was no significant difference in the range of motion (ROM) between the control group and the treatment group before treatment ($p > 0.05$). However, while the improvement in ROM was not statistically significant in the control group ($p > 0.05$), it was significantly greater in the treatment group ($p < 0.05$).

Gait analysis

Before treatment, there were no significant differences in step length, step speed, and percentage of support phase between the control group and the treatment group

Table 3. Gait parameters of hemiplegic patients.

Group	Step length (cm)		Velocity (cm/s)		Percentage of supporting phase (%)	
	Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment
Treatment Group	18.37±2.51	24.73±2.07	18.77±7.55	26.53±7.37	67.48±3.67	60.76±4.24
Control Group	19.28±1.62	20.30±1.70	18.97±7.01	20.22±7.04	66.88±3.70	65.12±3.88
T values	-1.36	7.402	-0.059	2.762	0.515	-3.39
P values	0.182	0.000	0.953	0.009	0.610	0.002

($p > 0.05$). After treatment, step length, percentage of support phase, and step speed in the control group showed improvement but did not exhibit significant differences ($p > 0.05$). In contrast, step length and percentage of support phase in the treatment group showed significant differences before and after treatment ($p < 0.05$).

Discussion

Stroke, characterized by central nervous system injury, is associated with a high disability, mortality, recurrence rate, and economic burden, making it the primary cause of death and disability in adults[18]. One of the most significant motor dysfunctions affecting stroke patients is abnormal gait[19]. Although many stroke patients regain their ability to walk, they often exhibit impaired gait quality, leading to reduced balance and an increased risk of falls, which significantly impacts their daily life and social functioning[20]. Various factors influence the walking function of stroke survivors, including trunk movement, lower limb function, sensory function, and cognitive function, all of which are increasingly recognized by clinical therapists for evaluation and treatment. However, even when patients experience significant recovery in cognition, sensation, and lower limb function, their walking function and stability remain greatly affected. This may be attributed to the overlooked interaction between upper limb activity and walking stability. People often have a cognitive misunderstanding of the walking process: while gait activity relies on the lower limbs to support the trunk and provide forward propulsion, the role of the upper limbs may appear secondary, focused on tasks such as carrying items or placing hands in pockets. However, in natural walking, the swing of the arms is an integral part of the process, synchronizing with the stride of the lower limbs and maintaining consistent frequency[21]. For example, during running, as the frequency of steps increases, so does the frequency of arm swings. Inappropriate arm swing during walking can lead to excessive compensatory movements of the trunk, thereby affecting core stability, which is crucial for maintaining balance and stability during walking[22]. Additionally, trunk stability and control are essential for the normal function of the upper limbs and hands[23], with both aspects mutually reinforcing each other. Despite the occurrence of upper limb-related reactions during gait training for stroke patients, the impact of these responses on gait function is often overlooked in clinical practice[24].

Data from the initial evaluation in this study reveal significant differences in the walking process of stroke patients. The range of motion (ROM) of the upper limb on the affected side was smaller than that of the shoulder and elbow joints on the healthy side, resulting in asymmetric swing, shortened step length, increased percentage of support phase, and slowed step speed, all of which significantly impacted the patients' walking ability. Following one month of targeted treatment on the affected side in the treatment group, there was a marked improvement in the patients' gait function ($p < 0.05$), aligning with the objectives of our study. This improvement in the upper limb function on the affected side, characterized by an increase in ROM, brings the swinging motion closer to that of the healthy side, resulting in a more pronounced enhancement of lower limb function and gait. Stephenson et al.[10] observed that stroke subjects exhibited increased bursts of activity in the semitendinosus and quadriceps muscles, with greatest soleus activation during early stance when performing unsupported arm movements. They also found that tibialis anterior muscle activation was highest during walking with unsupported arm movements. Thus, stroke patients' gait approaches normalcy when their upper limbs can swing freely during walking. Additionally, Smith[25,26] reported beneficial effects of botulinum toxin in reducing spasticity and improving passive range of motion in the hemiplegic upper limb. Some patients noted improved walking ability following botulinum toxin injections, attributed to enhanced walking symmetry, particularly in cases where severe flexor spasticity at the elbow shifted their center of gravity towards the contralateral side.

In this study, non-contact Visual Tools based on AI were utilized to extract biological characteristics for evaluation. Currently, gait evaluation of stroke patients primarily focuses on lower limb assessment, while upper limb function evaluation relies mainly on scales. Visual Tools based on AI offer the advantage of conducting quantitative evaluation during walking, allowing for time-space fixed-point evaluation of the continuous process. This approach enhances the accuracy of evaluation and enables more targeted treatment interventions. Walking is a relatively symmetrical movement process, albeit with variations among individuals. Therefore, we compared the range of motion (ROM) of the shoulder and elbow between the affected and healthy sides. Subsequently, we designed personalized training programs to facilitate limb function recovery, aiming to align the ROM on the affected side more closely with that on the healthy side during the walking process. Moreover, Visual Tools based on AI evaluation offers the advantage of reducing interference from wearable devices, enabling patients to undergo evaluation in a more relaxed state and yielding more accurate detection data.

Conclusion

Visual Tools based on AI can dynamically evaluate the walking patterns of stroke patients and compare the affected side with the healthy side to identify disparities. This enables more precise treatment targeting the upper limb of the affected side, ultimately leading to better short-term treatment outcomes. Additionally, improvements in upper limb function on the affected side were associated with enhanced gait function in stroke patients. However, given the small sample size and short treatment duration in this study, further large-scale and long-term investigations are necessary to elucidate the impact of upper limb function improvement on gait in stroke patients.

Ethics approval

This study was approved by the Ethics Committee of the First Affiliated Hospital of Zhejiang Chinese Medicine University (Number:2022-K-300-01).

Funding

Funding support: 2023 Support Discipline-Rehabilitation Medicine Department (Zhejiang Provincial Hospital of Traditional Chinese Medicine Discipline High Quality Development Promotion Plan) (No. 2D02329).

Authors' contributions

CS designed the study and drafted the manuscript. LW, JD and CX were responsible for the collection and analysis of the experimental data. HY and YM revised the manuscript critically for important intellectual content. All authors read and approved the final version of the manuscript.

References

1. Gao Y, Wang W. Research progress of cerebrovascular disease epidemiology. Chinese journal of neurology 2015;48(4):337-340.
2. Hu L, Zhao D. Research progress of Traditional Chinese and Western medicine in spastic hemiplegia after stroke. Chinese and Western medicine Journal of integrative cardio-cerebrovascular diseases 2016;14(7):729-733.
3. Ryerson S, Levit K. Functional Movement Reeducation: A Contemporary Model for Stroke Rehabilitation. Churchill Livingstone, London, 1997.
4. Seliktar R, Susak Z, Najenson T, Solzi P. Dynamic features of standing and their correlation with neurological disorders. Scand J Rehabil Med 1978;10(2):59-64.
5. Tasseel-Ponche S, Yelnik AP, Bonan IV. Strategies Motrices du Controle Postural Apres AVC Metappherique. Neurophysiologie Clinique 2015;45(4-5):327-333.
6. Shinde K, Ganvir S. Effectiveness of trunk propriocmood mus- chronic techniques after stroke: A meta-analysis. J Natl Med Allied Sci 2014; 3(3): 29-34.
7. Umberger BR. Effects of suppressing arm swing on kinematics, kinetics, and energetics of human walking. J Biomech 2008;41(11):2575-80.
8. Ortega JD, Fehlman LA, Farley CT. Effects of aging and arm swing on the metabolic cost of Stability in human walking. J Biomech 2008;41(16):3303-8.
9. Meyns P, Bruijn S, Duysens J. The how and why of arm swing during human walking. Gait Posture 2013;38(4): 555-62.
10. Stephenson JL, Lamontagne A, De Serres SJ. The coordination of upper and lower limb movements during gait in healthy and stroke individuals. Gait Posture 2009;29(1):11-6.
11. Romkes J, Bracht-Schweizer K. The effects of walking speed on upper body kinematics during gait in healthy subjects. Gait Posture 2017;54:304-10.
12. Davies BL, Kurz MJ. Children with cerebral palsy have greater stochastic features present in the variability of their gait kinematics. Res Dev Disabil 2013;34(11): 3648-53.
13. John K, Stenum J, Chiang CC, French MA, Kim C, Manor J, Statton MA, Cherry-Allen KM, Roemmich RT. Accuracy of Video-Based Gait Analysis Using Pose Estimation During Treadmill Walking Versus Overground Walking in Persons After Stroke. Phys Ther 2024;104(2):pzad121.
14. Wu Z, Huang Y, Wang L, Wang X, Tan T. A Comprehensive Study on Cross-View Gait Based Human Identification with Deep CNNs. IEEE Trans Pattern Anal Mach Intell 2017;39(2):209-226.
15. Shiraga K, Makihara Y, Muramatsu D, Echigo T, Yagi Y. GEINet: View-invariant gait recognition using a convolutional neural network. 2016 International Conference on Biometrics (ICB), Halmstad, Sweden 2016;1-8.
16. Ng KD, Mehdizadeh S, Iaboni A, Mansfield A, Flint A, Taati B. Measuring Gait Variables Using Computer Vision to Assess Mobility and Fall Risk in Older Adults With Dementia. IEEE J Transl Eng Health Med 2020; 8:2100609.
17. Yamamoto S, Iwata A, Yano Y, Ohmine T, Honma K, Senzaki K, Fujiwara M, Murakami T, Inoue J, Sano Y, Okagawa S, Otsuki Y, Wanaka H, Kataoka M, Iwata H. Preliminary study on the effects of movement velocity training of the upper limbs on gait ability in older adults: a nonrandomized controlled trial. Clin Interv Aging 2019;26(1):781-788.
18. Feigin V L, Krishnamurthi R V, Parmar P, et al. Update on

the global burden of ischemic and hemorrhagic stroke in. Neuroepidemiology 2015;45(3):161-176.

19. Wonsetler E C, Bowden MG. A systematic review of mechanisms of gait speed change post-stroke. Part 2: exercise capacity, muscle activation, kinetics, and kinematics. Top Stroke Rehabil 2017;24(5):394-403.
20. Hong S H, Jung S Y, Oh H K, et al. Effects of the Immobilization of the Upper Extremities on Spatiotemporal Gait Parameters during Walking in Stroke Patients: A Preliminary Study. Biomed Res Int 2020;36(2):1-7.
21. Ford MP, Wagenaar RC, Newell KM. Am constraint and walking in healthy adults. Gait Posture 2007;26(1):135-141.
22. Neuman M, Boiangiu C, Gillen G, et al. Posture affects upper extremity in adults. Percept Mot Skills 2007; 104(2):371-380.
23. Rosenblum S, Josman N. The relationship between postural control and fine manual dexterity. Phys Occup Ther Pediatr 2003;23(4):47-60.
24. Kahn MB, Clark RA, Williams G, Bower KJ, Banky M, Olver J, Mentiplay BF. The nature and extent of upper limb associated reactions during walking in people with acquired brain injury. J Neuroeng Rehabil 2019;16(1):160.
25. Smith SJ, Ellis E, White S, Moore AP. A double-blind placebo-controlled study of botulinum toxin in upper limb spason after stroke or Head Injury. Clin Rehabil 2000;14(1):5-13.
26. Bakheit AM, Sawyer J. Tahe Efrects of botulinum toxin treat - Gait Analysis of The Upper Limb for Gait. Disabil Rehabil 2002;24(10):519-522.