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Original Article

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Effects of Underwater Gait Training Using Auditory Stimulation with Progressive Rhythm on Lower Extremity Muscle Strength, Balance, and Gait Abilities in Stroke Patients

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Purpose: The purpose of this study was to examine changes in muscle strength, balance and gait abilities in stroke patients through underwater gait training with progressive rhythm auditory stimulation and to identify effective aquatic rehabilitation methods.
Methods: A total of thirty-seven subjects diagnosed with stroke were randomly divided into three groups. Progressive rhythm auditory stimulation underwater gait training group (PUG) (n = 15), comfortable velocity underwater gait training (CUG) (n = 11) and control group (n = 11). Subjects received underwater gait training for 30 minutes, three times a week for 6 weeks. All subjects were assessed with Medical Research Council (MRC), Berg Balance Scale (BBS), Timed Up and Go test (TUG), 10 Meter Walking Test (10MWT) and Fugl-Myer Assessment (FMA) pre-and post-intervention.
Results: All participants indicated significant improvements in all measured outcomes across all participants following the intervention ($p < 0.05$). The PUG showed significant differences in all evaluation parameters when compared to the CUG ($p < 0.05$). Additionally, the PUG demonstrated significant improvements in all assessment areas compared to the control group ($p < 0.05$). Similarly, the CUG showed significant improvements in all assessment parameters compared to the control group ($p < 0.05$).
Conclusion: These results suggest that Progressive rhythm auditory stimulation underwater gait training is effective in improving balance and gait abilities and suggests an effective strategy of aquatic rehabilitation.

Keywords: Balance, Gait, Stroke, Muscular strength, Rehabilitation

INTRODUCTION

Stroke patients experience difficulties in postural control due to muscle weakness and sensory loss, which in turn impair their walking ability and hinder independent daily living activities.[1] Among these, muscle weakness is a primary factor contributing to reduced balance and gait function, making it one of the most common issues in stroke patients. This weakness is associated with a decline in the proportion of type II muscle fibers and a significant reduction in neural transmission speed, leading to delayed muscle contraction. In particular, the weakening of key postural muscles such as the tibialis anterior, gastrocnemius, quadriceps, and hamstrings significantly increases the risk of falls.[2]

Balance refers to the ability to maintain bodily stability despite various external and environmental factors. Stroke patients, due to hemiparesis, often exhibit impaired balance control caused by asymmetric weight shifting and muscle weakness. To facilitate balance recovery, various interventions such as virtual reality training, aquatic therapy, and Biofeedback have been extensively studied.[3]

Biofeedback plays a crucial role in stroke rehabilitation by providing additional sensory information to compensate for deficiencies in intrinsic feedback mechanisms, including somatosensory, visual, and auditory. This allows patients to correct movement errors effectively.[4] Among these interventions, auditory stimulation-based training utilizes sound cues to influence motor control, synchronize movement perception areas, and enhance activation in various brain regions.[5] Schauer and Mauritz[6] demonstrated that gait training with auditory stimulation improved gait speed, stride length,

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and symmetry in stroke patients. Subsequently, Roerdink et al.[7] reported that gait training with rhythmic auditory cues enhanced joint range of motion and flexibility, thereby improving spatiotemporal gait characteristics. However, during these high-level task-oriented and dynamic training sessions, patients are at an increased risk of falling.

The aquatic environment helps mitigate fall-related concerns, allowing patients to engage in exercise with greater confidence and motivation.[8] Beyond psychological benefits, aquatic therapy also reduces joint stress through buoyancy, enabling stroke patients to perform high-level movements and functional activities with less effort compared to land-based training. This, in turn, promotes a more symmetrical gait pattern.[9] Matsumoto et al.[10] conducted an aquatic gait training program for stroke patients and found that muscle relaxation led to increased muscle activation, ultimately improving gait performance. Similarly, Park and Chung[11] demonstrated that underwater treadmill training significantly enhanced balance and gait function in stroke patients. These findings highlight aquatic exercise as a highly effective and safe rehabilitation approach for improving balance and walking ability in stroke patients.

However, due to reduced physical and social activity, stroke patients often experience overall declines in physical function, necessitating higher-intensity exercise interventions. Kim and Kang[12] reported that progressive task-oriented training improved both physical endurance, such as walking endurance, and the ability to perform daily activities. Additionally, Seo and Yang[13] increased training intensity by adjusting gait speed, leading to improvements in physical function. In a study by Lee et al.[14], when auditory stimulation was used for gait training at a 10% increased speed, the number of steps per minute increased and the symmetry of walking improved accordingly. In addition, Wada et al.[15] reported that fast-speed walking training increases the number of steps per minute to maintain the appropriate speed. In this way, there have been studies that have sought to change the speed of intervention as a way to increase the intensity of exercise, and have utilized gradual auditory stimulation as a method for this.

Despite these results, research on aquatic gait training using progressive auditory stimulation is still limited. Previous studies have used progressive or tempo-changing auditory stimulation to increase training intensity in over-ground gait training, but its application to aquatic gait training has not yet been studied. Therefore, this study aimed to investigate the effects of underwater gait training using progressive auditory stimulation on lower extremity muscle strength, balance ability, and walking function in stroke patients, and to compare it with general underwater gait training to ultimately suggest an effective treatment strategy for aquatic rehabilitation.

METHODS

1. Subjects

This study was conducted on a total of 50 patients diagnosed with stroke who were admitted to the rehabilitation center at Chungnam National University Hospital. Before initiating the study, sufficient explanations regarding the training were provided, and voluntary consent was obtained from all participants. To minimize errors in study results due to natural recovery, only patients who had experienced a stroke at least six months prior to the study were included.

Participants were randomly assigned into three groups using the random selection method of the SPSS ver. 25.0 program (IBM Co., Armonk, NY, USA). The inclusion criteria for participants were as follows: sufficient cognitive ability to understand the intervention methods and assessments (a minimum MMSE score of 24) and the physical ability to walk at least 10 meters independently. The exclusion criteria included patients who had not been diagnosed with a stroke, as well as those with open injuries such as fractures or those in neurologically or medically unstable conditions. The general characteristics of the participants are presented in Table 1. Of the 55 subjects, 5 dropped out before the start of training due to personal reasons and hospital schedules. During the study, 13 out of 50 participants dropped out due to personal reasons such as discharge or deterioration in condition. Therefore, 37 subjects ultimately participated in and completed the study (PUG = 15, CUG = 11, Control group = 11). The recruitment process, study procedures, and design are detailed in Figure 1. This study was approved by the Institutional Review Board (IRB) of Sahmyook University (Approval No. 2-1040781-AB-N-01-2016112HR).

1) PUG (Progressive Rhythmic Auditory Stimulation Underwater Gait Training Group)

Progressive rhythmic auditory stimulation underwater gait training refers to underwater gait training performed using a metronome with

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Table 1. Clinical characteristics of participants (n=37)

	PUG (n=15)	CUG (n=11)	Control (n=11)	F	p
Age (year)	55.7±5.4	56.5±4.4	57.1±5.9	0.258	0.725
Height (cm)	166.4±6.8	165.3±5.4	165.3±7.8	0.430	0.645
Weight (kg)	68.5±5.3	69.6±9.1	70.3±8.9	0.637	0.750
Onset (months)	8.3±1.2	8.0±2.7	8.5±4.8	0.192	0.820
MMSE-K (score)	28.3±1.1	28.2±1.7	28.3±1.0	0.876	0.685
Gender					
Male	8	6	7		
Female	7	5	4	0.812	0.162
Hemiplegic side					
Left	8	6	5		
Right	7	5	6	0.746	0.224
Mechanism					
Haemorrhage	5	7	6		
Ischaemia	10	4	5	0.232	0.114

PUG: Progressive rhythmic auditory stimulation underwater gait training Group, CUG: Comfortable speed underwater gait training Group, MMSE-K: Mini-Mental State Examination Korean. Mean±standard deviation.

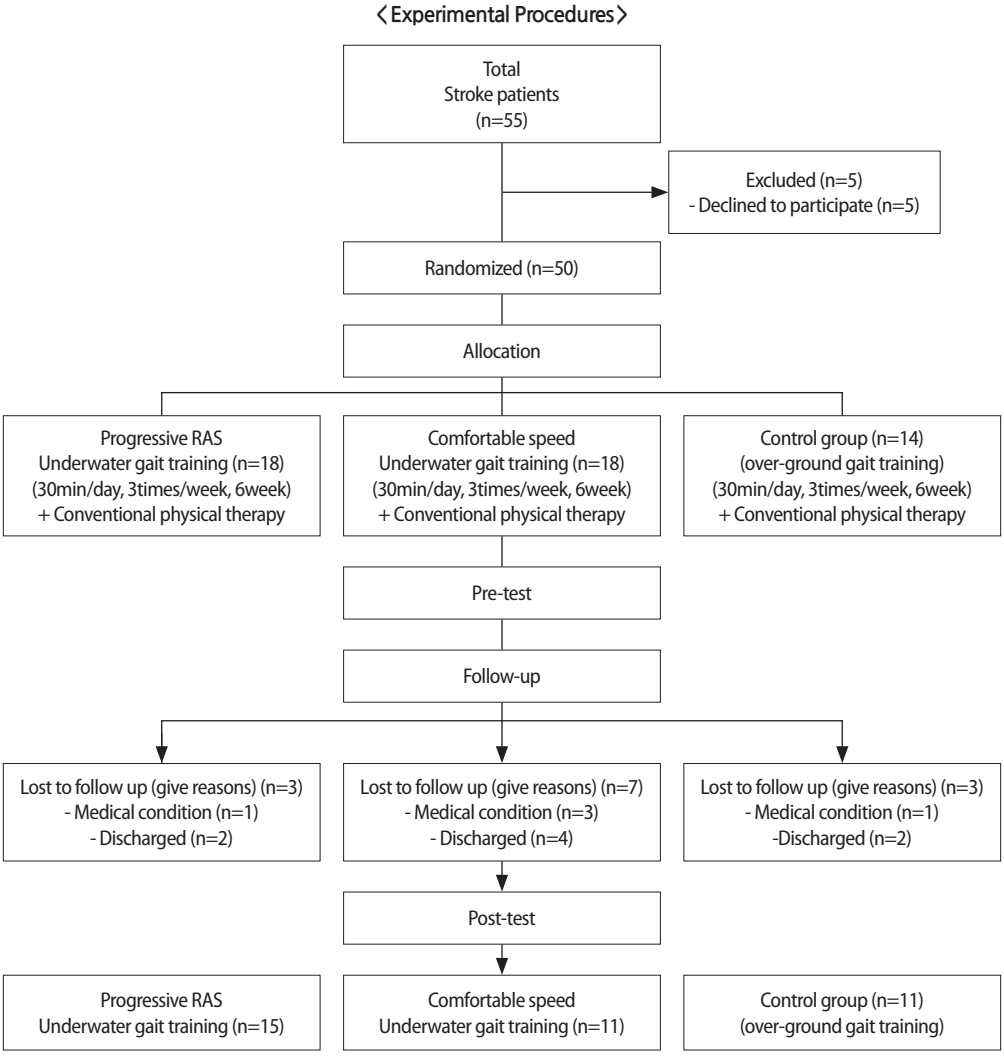


Figure 1. Enrollment of stroke patients

gradually increasing tempo adjustments. The initial tempo was set to match each participant's comfortable walking speed, and the tempo was progressively increased by 10% at two 10-minute intervals during the training session. The training was conducted in the aquatic therapy room at Chungnam National University Hospital (12×8m). Participants performed gait training at a water depth reaching chest level (xiphoid process, T12 level), with the water temperature maintained at a constant 30–32°C. To prevent colds and secondary illnesses, the external temperature of the facility was maintained at 25–26°C.

To enhance the reliability of the training and assessment process, evaluations were conducted before the training began. The therapist responsible for the assessment was different from the therapist conducting the training to minimize bias in the study results. The training was conducted for 30 minutes per session, three times a week, for six weeks. Additionally, all participants received conventional physical therapy daily for six weeks. For participant safety, a licensed physical therapist with over three years of clinical experience, along with a research assistant, provided assistance during the training sessions.

2) CUG (Comfortable Speed Underwater Gait Training Group)

Participants in this group performed general underwater gait training at their self-selected comfortable walking speed. The training duration and frequency were identical to those in the PUG group, consisting of 30-minute sessions, three times a week, for six weeks.

3) Control group

The control group performed land-based gait training at the same frequency and duration as the experimental groups. Additionally, they received conventional physical therapy for 30 minutes, five times a week, over a six-week period, similar to the experimental groups. To prevent falls during land-based gait training, a physical therapist with over three years of clinical experience supervised the sessions.

2. Experimental methods

1) Measurement

(1) Lower limb muscle strength

Lower limb muscle strength was assessed using the Medical Research Council (MRC) scale (ICC = 0.95), a widely used clinical tool for evaluating muscle strength. The assessment included six movement categories, each scored for a total of 30 points: hip flexion, hip extension, knee flexion, knee extension, ankle dorsiflexion, and ankle plantarflexion.

(2) Balance and gait ability assessment

Balance was assessed using the Berg Balance Scale (BBS) (ICC = 0.99) and the Timed Up and Go (TUG) test (ICC = 0.99), both widely used in clinical settings to evaluate mobility and task performance across different difficulty levels. These assessments provide insight into mobility and serve as strong predictors of gait recovery. The TUG test was performed three times, and the average value was recorded. Gait ability was assessed using the 10-Meter Walk Test (10MWT) (ICC = 0.91), one of the most commonly used clinical tools that require minimal equipment and expertise. The test was conducted three times, and the average value was recorded. Additionally, the 6-Minute Walk Test (6MWT) (ICC = 0.95) was conducted to measure the walking distance covered within six minutes, widely used to assess endurance in patients with cardiopulmonary or neurological impairments. The 6MWT was performed three times, and the average value was recorded. To ensure the accuracy of balance and gait assessments, evaluations were conducted by an experienced clinician with more than three years of clinical practice, accompanied by an assistant.

2) Data analysis

All statistical analyses were performed using SPSS ver. 25.0 (IBM Co., Armonk, NY, USA). Descriptive statistics were used to analyze general characteristics of the participants, including age, height, weight, and duration since stroke onset. A paired t-test was conducted to compare within-group differences before and after the intervention. After the six-week intervention, one-way ANOVA was performed to determine statistically significant differences in balance and gait ability among the three groups. Duncan's post-hoc test was used for multiple comparisons. Statistical significance was set at $p < 0.05$.

RESULTS

1. General characteristics of participants

A total of 37 stroke patients ultimately participated in the training in this study. The gender of the subjects participating in the study was 7 females and 8 males in the PUG (n = 15), 5 females and 6 males in the CUG (n = 11), and 4 females and 7 males in the control group (n = 11). The mean age of the subjects was evenly distributed: 55.7 years in the PUG, 56.5 years in the CUG, and 57.1 years in the control group. In ad-

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Table 2. Changes in outcome measures of the participants in this study (n=37)

	PUG (n=15)			CUG (n=11)			Control (n=11)			F	p
	Pre-test	Post-test	Difference (post-pre)	Pre-test	Post-test	Difference (post-pre)	Pre-test	Post-test	Difference (post-pre)		
MRC (score)	14.53±0.91	20.60±1.18	6.06±1.16*†	14.36±1.12	18.81±1.72	4.45±1.03*	14.45±0.93	17.81±0.60	3.36±0.67	23.887	<0.001*
BBS (score)	38.53±2.55	49.06±3.01	10.53±2.77*†	39.27±2.57	47.27±1.61	8.00±2.19*	39.27±2.24	44.54±1.80	5.27±1.84	15.786	<0.001*
TUG (sec)	29.33±2.58	17.26±2.86	-12.06±1.75*†	30.54±2.69	21.27±2.57	-9.27±4.31*	29.81±3.28	24.00±2.68	-5.81±1.88	15.921	<0.001*
10MWT (sec)	29.13±1.72	18.86±2.19	-10.26±1.90*†	28.36±2.80	21.09±2.58	-7.27±1.34*	28.81±3.06	25.18±2.85	-3.63±0.92	61.130	<0.001*
6MWT (m)	255.80±15.06	301.73±13.80	45.93±9.12*†	258.63±19.64	291.09±19.98	32.45±7.14*	252.90±15.00	274.18±16.35	21.27±5.08	34.557	<0.001*

PUG: Progressive rhythmic auditory stimulation underwater gait training Group, CUG: Comfortable speed underwater gait training Group, MRC: Medical Research Council, BBS: Berg Balance Scale, TUG: Timed Up and Go, 10MWT: 10Meter Walking Test, 6MWT: 6 Minute Walking Test. †: Significant difference ($p<0.05$) between PUG and CUG, *: Significant difference ($p<0.05$) between PUG and Control, CUG and Control. Mean±standard deviation. *$p<0.05$.

dition, the mean height and weight of each group were 164.4cm and 68.5kg in the PUG, 165.3cm and 69.6kg in the CUG, and 165.3cm and 70.3kg in the control group. In addition, the MMSE-K scores of each group were 28.3±1.1, 28.2±1.7, and 28.3±1.0, respectively. The average duration of onset of the subjects was 8.3 months, 8.0 months, and 8.5 months, respectively, and the subjects consisted of stroke patients with a duration of 6 months or longer. The general characteristics and medical characteristics of all subjects who participated in the study are detailed in Table 1 and were normally distributed.

2. Outcomes of the study

1) Muscle strength

According to the research results, all subjects who participated in the training showed significant differences in the lower limb muscle strength evaluation (MRC) after the intervention ($p<0.05$). In particular, PUG showed a significant improvement of 6.06±1.16 points from 14.53±0.91 to 20.60±1.18 ($p<0.05$). This showed a significant difference compared to the CUG and control groups, which showed changes of 4.45±1.03 and 3.36±0.67 points, respectively, indicating the result of muscle strength improvement ($p<0.05$) (Table 2).

2) Balance abiity

All subjects who participated in the study showed a significant difference in the BBS after the intervention ($p<0.05$). In particular, the PUG showed a significant improvement of 10.53±2.77 points, from 38.53±2.55 to 49.06±3.01 ($p<0.05$). This was a significant difference compared to the CUG and control groups, which showed changes of 8.00±2.19 and 5.27±1.84 points, respectively, and showed the result of improvement ($p<0.05$) (Table 2). The TUG also showed the same result as the BBS, with the PUG showing a change of -12.06±1.75 seconds, from 29.33±2.58 to 17.26±2.86 ($p<0.05$). This also showed a significant difference in the group comparison with the CUG and control groups, which showed changes of -9.27±4.31 and -5.81±1.88, respectively ($p>0.05$) (Table 2).

3) Gait ability

All subjects who participated in the study showed a significant difference in the 10MWT after the intervention ($p<0.05$). In particular, the PUG showed a significant improvement of -10.26±1.90 seconds, from 29.13±1.72 to 18.86±2.19 ($p<0.05$). This was a significant difference compared to the CUG and control groups, which showed changes of -7.27±1.34 and 3.63±0.92 seconds, respectively, and showed the result of improvement ($p<0.05$) (Table 2). The 6MWT also showed the same result as the 10MWT, with the PUG showing a change of 45.93±9.12 m, from 255.80±15.06 to 301.73±13.80 ($p<0.05$). This also showed a significant difference in the group comparison with the CUG and control groups, which showed changes of 32.45±7.14 and 21.27±5.08, respectively ($p>0.05$) (Table 2).

DISCUSSION

Stroke patients commonly exhibit impaired lower limb strength, asymmetrical weight shifting, and discoordination between upper and lower limb movements, all of which contribute to balance deficits. These deficits significantly reduce gait speed and lead to asymmetrical gait patterns.[8] To address these challenges, the present study investigated the effects of underwater gait training combined with progressive rhythmic auditory stimulation on lower limb strength, balance, and gait performance in stroke patients, with the aim of proposing an effective aquatic rehabilitation strategy.

This study incorporated the benefits of the aquatic environment along with the therapeutic advantages of auditory stimulation. Both

the PUG and CUG participated in underwater gait training, and the findings demonstrated significant improvements in lower limb strength, balance, and gait performance following the intervention. Notably, lower limb strength improved by 6.06 ± 1.16 in the PUG and 4.45 ± 1.03 in the CUG, compared to 3.36 ± 0.67 in the control group, indicating a statistically significant advantage for the experimental groups. These results support the notion that underwater gait training is highly effective in enhancing lower limb strength in stroke patients, compared to conventional over-ground gait training. Aquatic exercise provides physiological and physical benefits that cannot be obtained on land due to water's unique properties, such as buoyancy, hydrostatic pressure, and viscosity. Buoyancy and viscosity serve as both supportive and resistive forces, making them highly effective in improving muscle strength. Additionally, the aquatic environment offers stroke patients more time to react when experiencing a loss of balance, reducing the risk of falls and injuries. These environmental factors instill confidence and psychological stability, ultimately enhancing motor outcomes and reducing muscle tone.[13,16] Matsumoto et al.[17] reported that underwater gait training decreased muscle tone and increased muscle activation in stroke patients. Similarly, Barela et al.[18] found that underwater gait training activated the tensor fasciae latae, vastus lateralis, and biceps femoris, contributing to muscle strengthening. These improvements in muscle strength enhance lower limb stability, facilitate rhythmic and energy-efficient movements, and promote symmetrical weight shifting, leading to better balance and gait performance.[11,16]

In this study, both experimental groups demonstrated significant improvements in balance, as assessed by the BBS and TUG. Additionally, intergroup comparisons revealed significant differences, further confirming that underwater gait training enhances balance ability by improving lower limb strength. Stroke patients typically experience postural instability, with postural sway in standing positions being twice as great as in healthy individuals, leading to reduced stability limits and compromised balance. These impairments negatively affect gait performance. Buoyancy, a key property of water, mitigates fall risk and enhances movement efficiency, allowing patients to perform complex functional activities with less exertion.[10] Park and Chung[9] reported that underwater gait training improved both lower limb strength and balance ability. Furthermore, Yang and Choi[19] demonstrated that treadmill-based underwater gait training facilitated symmetrical weight shifting and improved balance, ultimately leading to gait recovery in stroke patients.

Intervention strategies utilizing auditory stimulation have also proven highly effective in restoring balance and gait function in stroke patients. Roerdink et al.[7] found that gait training with auditory stimulation improved joint range of motion, flexibility, and spatiotemporal gait characteristics. Similarly, Park et al.[20] indicated that rhythmic auditory stimulation during gait training significantly enhanced stride length and gait speed. Consistent with these previous findings, this study showed that PUG exhibited significant improvements across all measured variables after the intervention. Intergroup comparisons also revealed significant differences across various outcome measures, suggesting that underwater gait training incorporating auditory stimulation was therapeutically superior to over-ground gait training. Thaut et al.[21] reported that gait training with auditory stimulation effectively improved gait symmetry and speed in stroke patients. Additionally, Ford et al.[22] suggested that rhythmic auditory cues enhance coordination between the upper and lower limbs, increase pelvic and thoracic rotation, and facilitate gait recovery in stroke patients. Auditory stimuli provide clear and simple signals that enhance patient focus, synchronizing motor and perceptual areas of the brain to promote stable gait patterns.[4] Furthermore, external auditory cues improve movement concentration and motivation, contributing significantly to muscle strength and balance enhancement.[3] Enhanced motor efficiency through auditory stimulation positively affects not only lower limb strength but also gait speed and endurance, crucial indicators of physical recovery.[23]

However, stroke patients often experience reduced overall physical activity and social participation, leading to declines in physical function and aerobic capacity. To counteract these effects, previous studies have suggested the implementation of progressive-intensity task-oriented training to promote physical recovery.[12] Yang et al.[24] demonstrated that progressive-intensity task-oriented training significantly improved lower limb strength and motor function in stroke patients. Similarly, Kim and Kang[12] reported that progressive-intensity leg strengthening exercises not only improved balance ability but also enhanced activities of daily living. Gait speed, a key indicator of physical recovery and functional mobility, is known to increase with improved energy efficiency, contributing to a more normalized gait pattern and better muscle performance.[22,25] Hesse et al.[26] noted that fast-paced treadmill training enhances the

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activation of antigravity muscles, improving locomotor efficiency. Later, Lee[27] reported that progressive-speed treadmill training enhanced gait symmetry in stroke patients. These findings collectively suggest that progressive-intensity interventions are highly effective in improving muscle strength and physical function in stroke patients. Based on these results, this study utilized high-intensity intervention by applying progressive rhythmic auditory stimulation to underwater walking training. The PUG exhibited significantly greater improvements in gait speed and endurance compared to the CUG, demonstrating the aerobic benefits of progressive-intensity modulation. These results indicate that the PUG's superior performance in gait speed and endurance was likely due to enhanced lower limb strength, particularly in the ankle and hip joints. Furthermore, progressive rhythmic auditory stimulation maintained participants' attention and concentration at high levels, increasing exercise efficiency and positively influencing gait endurance.[24] Seo and Yang[13] reported that high-intensity gait training with speed modulation improved cardiopulmonary function and endurance. Additionally, Kim and Kang[12] demonstrated that progressive-intensity interventions significantly enhanced gait endurance, confirming the effectiveness of high-intensity training in improving endurance. Accordingly, the results of this study align with previous findings, suggesting that progressive rhythmic auditory stimulation enhances training intensity, thereby improving exercise efficiency and endurance.

In conclusion, this study demonstrated that underwater gait training incorporating progressive rhythmic auditory stimulation is a highly effective intervention for improving lower limb strength, balance, and gait ability in stroke patients. Additionally, compared to conventional underwater gait training, this approach offers a more effective rehabilitation strategy. However, limitations such as participant dropouts due to sudden health condition down or discharge, as well as short hospitalization periods, may have influenced the study outcomes. Future research should aim to minimize participant variability by ensuring an adequate sample size for more robust findings.

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