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ORIGINAL

Effect of Auditory Stimulus using White Nosie on Dynamic Balance in Patients with Chronic Stroke during Walking

Hee Sung Lim[1], Jiseon Ryu[1,2], Sihyun Ryu[1,3]

[1]Motion Innovation Centre, Korea National Sport University, Seoul, South Korea
[2]Department of Health and Exercise Science, College of Lifetime Sport of Korea National Sport University, Seoul, South Korea
[3]Department of Taekwondo, College of Lifetime Sport of Korea National Sport University, Seoul, South Korea

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Corresponding Author
Sihyun Ryu
Department of Taekwondo,
College of Lifetime Sport of
Korea National Sport University,
1239, Yangjae, Songpa-gu, Seoul,
05541, South Korea
Tel : +82-2-410-6927
Fax : +82-2-410-6927
Email : hope222ysh@knsu.ac.kr

Objective: This study aimed to investigate the effect of white noise on dynamic balance in patients with stroke during walking.

Method: Nineteen patients with chronic stroke (age: 61.2±9.8 years, height: 164.4±7.4 cm, weight: 61.1±9.4 kg, paretic side (R/L): 11/8, duration: 11.6±4.9 years) were included as study participants. Auditory stimulus used white noise, and all participants listened for 40 minutes mixing six types of natural sounds with random sounds. The dynamic balancing ability was evaluated while all participants walked before and after listening to white noise. The variables were the center of pressure (CoP), the center of mass (CoM), CoP-CoM inclined angle.

Results: There is a significant increase in the antero-posterior (A-P) CoP range, A-P inclination angle, and gait speed on the paretic and non-paretic sides following white noise intervention ($p<.05$).

Conclusion: Our findings confirmed the positive effect of using white noise as auditory stimulus through a more objective and quantitative assessment using CoP-CoM inclination angle as an evaluation indicator for assessing dynamic balance in patients with chronic stroke. The A-P and M-L inclination angle can be employed as a useful indicator for evaluating other exercise programs and intervention methods for functional enhancement of patients with chronic stroke in terms of their effects on dynamic balance and effectiveness.

Keywords: Auditory stimulus, White noise, Dynamic balance, Stroke, Walking

INTRODUCTION

Stroke is a condition in which the abnormal blood supply in the brain due to lack of blood flow (ischemic) or bleeding (hemorrhagic) results in brain damage and functional deterioration that cause physical and cognitive impairments (Peurala, Könönen, Pitkänen, Sivenius & Tarkka, 2007). Post-stroke physical disabilities accompany hemiplegia that induces imbalance between the paretic and non-paretic sides, which increases postural sway and asymmetry during weight bearing and shifting. Patients with hemiplegic stroke have difficulty bearing weight on the paretic side, and the resulting changes in muscle tone on the paretic and non-paretic sides affect balance abilities (Sheean, 2002; Sheean & McGuire, 2009). Impaired balance after stroke disrupts independent daily living and reduces activities daily of living that lead to loss of functional mobility and eventually to falls (Batchelor, Mackintosh, Said & Hill, 2012). Patients with stroke who developed hemiplegia or paralysis in one side have loss of balance and reduced mobility; thus, appropriate rehabilitation exercise is required for recovery. Such post-stroke rehabilitation programs are primarily focused on enhancing balance and mobility, which are highly critical factors of functional performance during an independent activity. To maximize the effects of proper rehabilitation in patients with stroke, stimulating neural plasticity is of great importance. Neural plasticity is the brain's reorganizing and reshaping of its neural networks to complement the lesion based on information transmitted by sensory afferents. This requires that the patient not only passively performs given exercises but also voluntarily exercises with motivation and updates performance using various sensory stimulus (Shepherd, 2001).

The goal of rehabilitation is to improve impaired function, which requires that the patient's potential is fully realized through training at the level of impairment (Michaelsen, Dannenbaum & Levin, 2006). Augmented stimulus, which helps maximize patient potential, effectively improves movement performance and thus complements conventional therapy. Stimulus is effective in improving the method of task performance or goal achievement, as well as independence of performance by allowing the patient to practice on his or her own and attain satisfaction for achieving the intended movement (Robertson et al., 2009; Schmidt & Wrisberg, 2004).

Recent studies showed that the sensory factor plays an important part in balance and walking improvement in patients with stroke; thus, new intervention methods using sensory stimulation from outside are being developed (Michel & Mateer, 2006). In the human body, sensory stimuli including visual, olfactory, proprioceptive, and auditory stimuli can greatly influence balance control through interactions with the brain. Auditory stimuli, in particular, behave differentially than the visual or olfactory stimuli, as it has been reported that repetitive auditory stimulation bypasses the cortical cognitive processes to be transmitted to the reticular formation in the brainstem and influences body movement via spinal motor neurons (Thaut, 2005; Thaut & Abiru, 2010). A relevant previous study reported that of the various stimulus employed in stroke rehabilitation, auditory stimulus and visual stimulus have been proven effective (van Vliet & Wulf, 2006).

Auditory stimulus has been used to improve task performance of the subject, which can improve postural stability during independent standing and thus effectively reduce fall rate in the elderly (Mirelman et al., 2011). There are various types of auditory stimulus, such as rhythmic metronome cues and music, and white noise has been introduced as a means (Carter, Dillon, Seymour, Seeto & Van Dun, 2013). Noise is characterized by time-varying, irregular intensity and frequency, and it has been shown years ago that irregular, intermittent noise is the direct cause of decline in task performance and is more deteriorating than continuous noise (Eschenbrenner, 1971). White noise is a series of noise with continuous and uniformly distributed frequency across the range of 20~20,000 Hz (Carter et al., 2013). Among various research employing white noise, Söderlund (2007) and Söderlund, Sikström & Smart (2007) reported that presenting white noise in place of music during task performance facilitated cognitive performance, whereas Thaut (2005) showed that rhythmic auditory stimulation, such as white noise, induces muscle synchronization and coordinates the cerebral cortex motor areas and motor output, so that the muscles move in a more organized and sequential manner to generate an efficient gait pattern. In addition, white noise is known to stimulate the somatosensory of healthy adults to reduce postural sway and activate the senses to provide the necessary motivation (Ross, Will, McGann & Balasubramaniam, 2016; Ross & Balasubramaniam, 2015). Recent studies have shown that white noise enhances balance control and thus prevent falls in patients with postural instability due to visual, vestibular, or somatosensory deficits, with greater enhancement effects in individuals with peripheral sensory deficits (Dozza, Horak & Chiari, 2007; Hegeman, Honegger, Kupper & Allum, 2005; Palm, Strobel, Achatz, von Luebken & Friemert, 2009). Therefore, determining the intervention effect of white noise in patients with loss of balance due to CNS damage is important, as chronic stroke is needed for and may provide insight into dynamic balance research (Ross & Balasubramaniam, 2015). We should thus investigate the effects of white noise in patients with chronic stroke who develop CNS damage and examine the effect of dynamic balance after the white noise intervention.

Corriveau, Hébert, Prince & Raîche (2000, 2001) reported that the center of pressure (CoP)-center of mass (CoM) variable is a reliable measurement for assessing postural stability in subjects with postural disabilities due to stroke or diabetic neuropathy and in the elderly. In addition, the CoP-CoM variable provided accurate measurement for assessing postural stability assessment in elderly patients with stroke (Corriveau et al., 2001). Dynamic balance is quantified and evaluated by the scalar distance between CoM and CoP and recently, the CoM-CoP inclination angle, determined by the instantaneous orientation of the line connecting CoP and CoM with respect to the vertical line passing through CoP, has been proposed as a method of quantifying dynamic stability during walking (MacKinnon & Winter, 1993; Lee & Chou, 2006). Therefore, tracking CoM motion within CoP can be useful for assessing dynamic balance

Table 1. General characteristics of the subjects

Subjects	Age (years)	Height (cm)	Weight (kg)	Paretic side (R/L)	Duration (years)	Hemorrhage /infarction
n=19	61.2±9.8	164.4±7.4	61.1±9.4	11/8	11.6±4.9	3/16

Values are expressed mean ± standard deviation, R/L: right/left

control. To assess dynamic balance during walking, as opposed to standing balance, in patients with stroke, application of these variables is required to quantify the CoM-CoP inclination angle and specially to track the changes pre and after the intervention.

The present study thus aimed to establish the CoM-CoP inclination angle as an evaluation indicator of the dynamic gait stability by using the angle to monitor the effects of white noise on dynamic stability.

METHODS

1. Subjects

Nineteen patients with stroke who had been diagnosed with poststroke hemiplegia at least 1 year ago were recruited from the welfare institute for the disabled in Gyeonggi Province. The patients who agreed to participate after receiving a detailed explanation about the experimental procedure were recruited. The inclusion criteria were individuals who could perform unassisted independent walking for at least 10 m and who were able to understand the therapist's directions and scored 24 or above in the Mini Mental State Examination-Korean (MMSE-K). Participants with visual or hearing problems, vertigo or vestibular dysfunction, and orthopedic or cardiorespiratory problems were excluded from the study. All participants gave informed consent after detailed orientation of the study purpose and important matters prior to the experiment. This study was approved by the Institutional Review Board of H University located in Seoul (20180801-057). The general characteristics of the participants are shown in Table 1.

2. Experimental procedure

This experiment was conducted to measure and evaluate the factors of dynamic balance after listening to white noise of each participant. In this study, white noise was used as an auditory stimulus, and white noise was worn in a quiet space for 40 minutes with the headset to listening while sitting comfortably in a chair and wearing glasses that blocked the vision to add an auditory effect. The white noise used in this study was the MC square X7 (GEOMC Co., Ltd) product, which can be by mixing 6 programs and 6 kinds of natural sounds. In this study, 1 program and 6 types natural sounds were used by mixing. For the purposes of this study, we used a mix of 1 program and 6 natural sounds (Figure 1). The feature of this program is the function of controlling attention and concentration in tasks to be performed by acting to diffuse alpha waves extensively in the thalamic tract using pulsed sound as an external stimulus. It has been reported that the beta waves from all conscious activities interfere with alpha waves from relaxation, meditation (mental stability) and closed eyes, and theta waves from a state of creative learning (Tracy, Ahmed, Khan & Sperling, 2007). Therefore, the white noise used in this study was used to block beta waves and diffuse alpha and theta waves, which have a positive effect on the thalamus.

In this study, each subject walked before and after listening to white noise to measure dynamic ability, and measured CoP, CoM, and gait speed during walking with headset. All subjects had sufficient time to adapt to exclude the leading effect on the laboratory and equipment. All subjects performed gait at a preferred speed, and calibration were set through the NLT (Non-Linear Transformation) method. For modeling the body into 14 segments (left and right foot, lower leg, thigh, hand,

Figure 1. MC Square X7.

forearm, upper arm, head and trunk), 36 markers and 4 clusters were attached to the human body. To measure the kinetical variable during walking, we used a force platform (AMTI, BP-1200, USA) and measured the CoP, which is a representative variable used for balance testing (Hamill & Ryu, 2003), and the sampling rate was set to 1,000 Hz. 8 infrared cameras (Oqus 300, Qualisys, Sweden) were used to record the 3 D coordination data of gait, and the sampling rate was set to 100 Hz. Equipment for data collection was controlled by Qualisys track manager (QTM, Qualisys, Sweden) software.

3. Data processing

For the collected data, Visual 3D (C-motion, USA) and Matlab 2014a software (The Mathworks, USA) were used for kinematic and kinetic data processing and variable calculation. To explore the kinematic variables, we set the space coordinates using the NLT method and defined the exact area by extracting the 3D coordinates of the reflection markers attached to the human body. Space coordinates data were processed using the Visual 3D software (C-motion, USA) (Matlab R2014b (The Mathwork, USA). The ground reaction force used for the calculation of the kinetic variable were stored in the QTM as 8-channel analog voltage values, which are then converted and outputted as a total of 3 digital values (Fx, Fy, Fz, Units: N). The positive values of Fx, Fy, and Fz were defined as the left, anterior, and vertical upward, respectively. To remove noise-driven errors, Butterworth second order low pass filtering was performed, and the cutoff frequency was filtered to a frequency corresponding to the power spectrum density (PSD) of the signal being 99% cumulative. We analyzed the stance and swing phase data during walking from heel-contact to toe-off on the paretic and non-paretic sides.

4. Analysis variables

1) CoP range & velocity

Using the CoP derived from the ground reaction force obtained using the force plate, we calculated the M-L and A-P CoP range and CoP velocity as a function of time. CoP range was described as the difference between the maximum and minimum values and CoP velocity as the mean of instantaneous velocities (Ryu, 2010).

$$\mathrm{A-P\ CoP} = -\mathrm{My}/\mathrm{Fz}$$

$$\mathrm{M-L\ CoP} = \mathrm{Mx}/\mathrm{Fz}$$

where A-P indicates antero-posterior, M-L indicates medio-lateral, Mx & My indicate the moment of x & y axis provided by force plate, and Fz indicates the vertical ground reaction force.

2) CoM

Using the anthropometric model as reference, we calculated the location of segmental CoM based on the proximal and distal markers of each segment and derived the CoM using the coordinates of the markers (Winter, 2009; Cha, Kim, Choi, Kim & Son, 2018). We derived the locations of all segmental CoMs and then calculated the weighted sum of all body segments to obtain the whole-body CoM position data (Hamill & Ryu, 2003).

3) A-P and M-L inclination angles

We performed a 3D motion analysis to calculate the inclination angles. We analyzed the stance and swing phase data during walking from heel-contact to toe-off on the paretic and non-paretic sides. For each side, the A-P inclination angle in the sagittal plane and the M-L inclination angle in the frontal plane were defined as the angle between the vector connecting the CoM and CoP and the vertical axis. The position vectors of CoM and CoP were calculated using the inverse tangent equation (Figure 2).

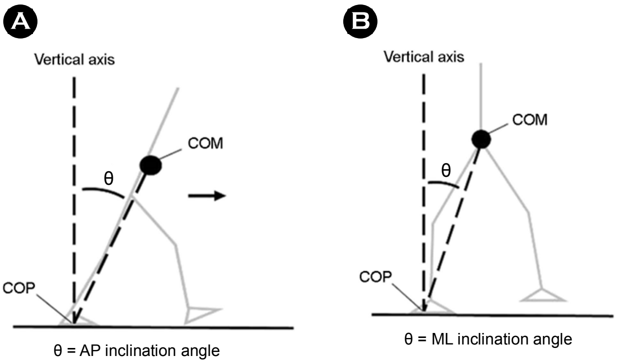

Figure 2. Center of mass (CoM)-center of pressure (CoP) inclination angles in the (A) sagittal and (B) frontal planes

4) Gait speed

The gait speed was presented by measuring the time of the section where the subject was walking, and dividing the distance by the time.

5. Statistical analysis

For statistical analysis, SPSS 24.0 (IBM, USA) was used, and to identify the pre-post white noise changes in the variables of dynamic balance, we used the paired *t*-test. Statistical significance level was set to α = .05.

RESULTS

Analysis of the pre-post white noise changes in the variables of dynamic balance on the paretic and non-paretic sides in patients with chronic stroke yielded the following results. For the paretic side, we analyzed and compared the pre-post white noise values of A-P/M-L CoP range and velocity, CoM range, A-P/M-L inclination angle, and gait speed and found that the A-P/M-L CoP range did not significantly change. A-P/M-L CoP velocity also did not show any statistically significant change, but the velocity did increase after white noise (Table 2). A-P/M-L and S-I CoM range showed no post-noise change in the M-L, but in the A-P and S-I directions, the CoM range significantly increased by 13.3% and 11.1%, respectively (p<.05). The M-L inclination angle decreased after white noise but not significantly, while the A-P inclination angle significantly increased by 10% relative to pre-noise (p<.05). The A-P inclination angle between heel-contact and toe-off increased, but not significantly. Gait speed significantly increased by 11.3% relative to

Table 2. Change in CoP, CoM, inclination angle, and gait speed in the paretic side during walking pre and post receiving auditory white noise

Variables	Pre-white noise	Post-white noise	*t*	*p*
M-L COP range (mm)	72.61±70.95	91.82±45.00	-1.701	.106
A-P COP range (mm)	123.19±35.45	135.24±34.37	-1.635	.119
M-L COP velocity (mm/s)	381.23±307.70	430.60±231.51	-1.221	.238
A-P COP velocity (mm/s)	374.19±281.80	521.22±371.83	-1.949	.067
M-L COM range (mm)	34.42±16.17	34.62±12.81	-0.065	.949
A-P COM range (mm)	340.34±125.87	392.65±144.82	-3.692	.002*
S-I COM range (mm)	26.24±8.86	29.50±9.83	-3.056	.007*
M-L COM velocity (mm/s)	84.83±55.23	84.37±45.77	.051	.960
A-P COM velocity (mm/s)	541.24±260.06	683.46±347.34	-2.055	.053
S-I COM velocity (mm/s)	245.11±284.34	307.91±316.92	-1.033	.314
M-L inclination angular range (deg)	12.49±3.32	12.44±3.38	0.085	.933
M-L inclination angle at HC (deg)	14.55±3.26	13.51±3.34	1.567	.134
M-L inclination angle at TO (deg)	15.31±3.15	15.72±5.73	-0.354	.728
A-P inclination angular range (deg)	8.19±2.50	9.10±2.94	-2.205	.041*
A-P inclination angle at HC (deg)	12.02±4.74	13.39±5.97	-1.882	.076
A-P inclination angle at TO (deg)	12.08±5.68	14.96±8.48	-2.111	.052
Gait speed (m/s)	0.52±0.17	0.59±0.17	-2.773	.013*

Note: values are expressed as mean ± standard deviation
*Indicates statistically significant difference between pre-test and post-test
M-L: medial-lateral, A-P: anterior-posterior, S-I: superior-inferior, CoP: center of pressure, CoM: center of mass, HC: heel contact, TO: toe off

Table 3. Change in CoP, CoM, inclination angle, and gait speed in the non-paretic side during walking pre and post receiving auditory white noise

Variables	Pre-white noise	Post-white noise	*t*	*p*
M-L COP range (mm)	52.47±25.05	52.58±24.77	-0.031	.975
A-P COP range (mm)	150.60±37.90	150.82±34.13	-0.046	.964
M-L COP velocity (mm/s)	207.98±71.47	189.10±70.95	1.313	.206
A-P COP velocity (mm/s)	320.05±177.62	294.60±139.76	0.510	.616
M-L COM range (mm)	35.18±13.33	31.94±13.17	1.349	.194
A-P COM range (mm)	412.66±137.62	465.56±134.37	-4.662	.000*
S-I COM range (mm)	30.48±11.11	35.54±12.00	-3.256	.004*
M-L COM velocity (mm/s)	75.70±30.19	63.55±26.90	2.765	.012*
A-P COM velocity (mm/s)	584.19±255.92	595.54±233.56	-.229	.821
S-I COM velocity (mm/s)	176.32±206.26	139.27±141.24	1.033	.314
M-L inclination angular range (deg)	9.06±2.22	9.53±2.10	-1.255	.226
M-L inclination angle at HC (deg)	10.48±2.32	10.88±2.29	-0.831	.417
M-L inclination angle at TO (deg)	15.31±3.15	15.72±5.73	-0.662	.516
A-P inclination angular range (deg)	8.15±2.66	9.12±2.56	-3.747	.001*
A-P inclination angle at HC (deg)	13.85±6.27	15.68±7.87	-2.228	.039*
A-P inclination angle at TO (deg)	12.37±7.62	16.06±6.18	-5.602	.000*
Gait speed (m/s)	0.52±0.17	0.59±0.17	-4.638	.000*

Note: values are expressed as mean ± standard deviation
*Indicates statistically significant difference between pre-test and post-test
M-L: medial-lateral, A-P: anterior-posterior, S-I: superior-inferior, CoP: center of pressure, CoM: center of mass, HC: heel contact, TO: toe off

pre-noise ($p<.05$). For the non-paretic side, we analyzed and compared the pre-post white noise values of A-P/M-L CoP range and velocity, CoM range, A-P/M-L inclination angle, and gait speed and found no significant change in the A-P/M-L CoP range (Table 3). A-P/M-L CoP velocity also did not show any statistically significant change. A-P/M-L and S-I CoM range showed no post-noise change in the M-L, but in the A-P and S-I directions, the CoM range significantly increased by 11.4% and 14.2%, respectively ($p<.05$). The M-L inclination angle increased after white noise but not significantly, whereas the A-P inclination angle significantly increased by 10.6% ($p<.05$). The A-P inclination angle between heel-contact and toe-off also significantly increased ($p<.05$) (Table 3). Gait speed significantly increased by 11.9% relative to pre-noise ($p<.05$) (Table 3).

DISCUSSION

In the present study, we investigated the effects of white noise on the dynamic balance of patients with chronic stroke by monitoring the changes in A-P/M-L CoP range and velocity, CoM, A-P/M-L inclination angle, and gait speed during walking.

Following the white noise intervention, both the paretic and non-paretic sides demonstrated no statistically significant change in A-P/M-L CoP range and velocity and M-L inclination angle. Previous studies verifying the effect of white noise and auditory stimulus (Cha et al., 2018; Ross et al., 2016; Ross & Balasubramaniam, 2015) reported a post-stimulus decrease in CoP range and improvement in balance, it showed different results from our findings. However, the studies evaluated the effects of auditory stimulus during static posture; thus, their findings are not applicable to the scope of our study.

In this study, the paretic side A-P/M-L CoP range and velocity did not significantly change after the white noise intervention but it showed an increasing tendency. Rather than interpreting the finding in terms of paretic side balance, it is more appropriate to interpret it as a white noise stimulus-driven increase in the paretic side lower limb muscle activity, in line with the conclusions of previous studies reporting that the increase in CoP velocity is a result of the increase in lower limb muscle activity for maintaining postural stability (Ryu, 2010). In particular, this result is consistent with the finding by Thaut (2005) that continuous auditory stimulation, such as white noise, induces motor synchronization and coordinates cortical motor areas and the actual motor output, so that the muscles act in a more organized and sequential manner to generate an efficient gait pattern.

The A-P CoM range and A-P inclination angle significantly increased following the white noise intervention. This is consistent with the previous findings that anterior inclination angle tended to be greater in healthy elderly than in elderly with vestibular problems (Lee & Chou, 2006), and gait training in the elderly increased the posterior inclination angle of the initial swing (Yoon, Kim, Lee, Ryu & Kwon, 2007). The present study demonstrated an increase in the A-P inclination angle at the moment of heel-contact and toe-off, with a greater angle on the non-paretic side. A previous study on the relationship between balance during walking and falls suggested that individuals with greater imbalance and lowered confidence in balance tend to restrict their activities (Denkinger et al., 2010; Murphy, Williams & Gill, 2002), which can lead to a decline in physical functions and increased fall risk. Therefore, the increase in A-P inclination angle can be interpreted as the result of stable support provided by the lengthening of the stance phase and confident walking on the non-paretic side. Such finding may be interpreted as a result of unstable non-paretic balance but considering that the instability comes from increased speed during fast weight-shifts, white noise can be said to play a positive role in actual gait enhancement and confidence boost by inducing bold movements in patients with chronic stroke.

The gait speed significantly increased from 0.52±0.17 m/s to 0.59±0.17 m/s following white noise intervention. Gait velocity is the most important factor in gait assessment (Judge, Davis III & Õunpuu, 1996; Buchner et al., 1996; Kerrigan et al., 2000; Mills & Barrett, 2001; Brach, Berthold, Craik, VanSwearingen & Newman, 2001; Kressig et al., 2004). In particular, gait speed is a combination of multiple factors involved in walking, such as the step length and time, support rate, cadence, and angle of lower-extremity joint. In this study, it can be concluded that the increase in the paretic-side lower limb muscle activity predicted by the pre-post increase in CoP velocity, CoM, and inclination angle in turn increased the gait speed, whereas the aforementioned factors yielded bold gait.

Taken altogether, the findings predict that white noise increases the paretic-side lower limb muscle activity in patients with chronic stroke and consequently induced bold and faster gait. In particular, in gait analysis, the relationship between CoP and CoM is an important variable for assessing dynamic balance, but the simple calculation of horizontal distance can be affected by height (Lee & Chou, 2006). In the present study, we attempted to assess dynamic gait balance more accurately by deriving the anterior-posterior inclination angle, i.e., the angle formed by the line connecting CoP and CoM with the vertical angle passing through CoP when the feet are on the ground. Furthermore, while most studies of patients with stroke have assessed balance and stability during static state to analyze the intervention effects and factors, the present study explored the effects of white noise on dynamic gait balance in patients with chronic stroke and thus can be used as useful data for gait assessment in patients with other neurologic conditions.

CONCLUSION

The present study is significant in that it evaluated the intervention-specific changes in CoP range and velocity, CoM, gait speed, and A-P/M-L inclination angle and the effectiveness of continuous exercise in patients with chronic stroke using these indicators. The results of this study showed that A-P CoP range and velocity increased following white noise intervention and that white noise helps to enhance dynamic balance by inducing bold gait and thus increasing gait speed. Based on these findings, we conclude that measuring CoP range and velocity, CoM, and A-P/M-L inclination angle is useful for assessing dynamic balance abilities of patients with chronic stroke. In future research, these indices are expected to be used effectively for assessing dynamic balance in the exercise methods applied to patients with chronic stroke.

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