Auditory feedback alters postural control and functional ability in patients with chronic stroke

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Research

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Abstract

Background: This study aimed to investigate the effect of white noise on dynamic balance in patients with stroke and the pre- and post-intervention changes in dynamic balance during walking by analyzing the anterior-posterior (A-P) and medial-lateral (M-L) center of pressure (CoP) range and velocity, center of mass (CoM), and A-P/M-L inclination angle using CoM-CoP and to establish the basis for using auditory feedback as an effective means of exercise intervention by bringing changes in dynamic balance abilities of patients with chronic stroke and retain the necessary abilities for maintaining independent and functional daily living.

Methods: 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 feedback used white noise, and all participants listened for 20 minutes mixing six types of natural sounds with random sounds. The dynamic balancing ability was evaluated during the walking, and 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 A-P CoP range, A-P inclination angle, and gait speed on the paretic and non-paretic sides following white noise intervention ($p < .05$). In addition, the changes in CoP velocity on the paretic and non-paretic sides increased in both the A-P and M-L directions but not significantly.

Conclusion: Our findings confirmed the positive effect of using white noise as auditory feedback 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.

Contributions To The Literature

- Auditory feedback using white noise appears to more effectively improve in walking and dynamic balance abilities of hemiplegic stroke patients.
- Significant improvements in walking were immediately observed after auditory feedback using white noise.
- A-P and M-L inclination angle is useful assessment for dynamic.
- The objective assessment of walking and balance abilities with CoP and CoM variables is more useful to decide for improvement after all intervention in stroke patients.
- In the future, we need to investigate training effect with white noise comparing with other intervention in chronic stroke patients.

Background

The central nervous system (CNS) plays an important role in maintaining postural control of the human body by integrating visual, auditory, and vestibular inputs from the outside world and proprioceptive input; damage to which leads to loss of balance. It has been reported that balance depends on the intricate interactions between the neural and musculoskeletal systems, and damage to not just the CNS but any neural system including the somatosensory system brings about musculoskeletal changes that affect postural control.¹

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 mental impairments.² 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.^{3,4} 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.⁵

Patients with stroke who developed hemiplegia or paralysis in one side display loss of balance and reduced mobility; thus, appropriate (movement) 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 feedback.⁶

The purpose of rehabilitation is to enhance the impaired function, which requires that the patient's potential is fully realized through training tailored to the severity of impairment.⁷ Augmented feedback, which helps maximize patient potential, effectively improves movement performance and thus complements conventional therapy. Feedback is effective in enhancing the method of task performance or goal achievement,⁸ as well as independence of performance by allowing the patient to practice on his or her own and attain satisfaction when the intended movement is achieved.⁹

Recent studies showed that the sensory component plays a crucial factor in balance and walking improvement in patients with stroke; thus, new intervention methods involving exteroceptive stimuli are being developed.¹⁰ Inside the human body, sensory stimuli including visual, olfactory, proprioceptive, and auditory stimuli can greatly influence balance control through interactions with the cerebrum. 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.^{11,12} A relevant

previous study reported that of the various feedback employed in stroke rehabilitation, auditory feedback and visual feedback have been proven effective.¹³

Auditory feedback has been utilized to enhance task performance of the subject, which can improve postural stability during independent standing and thus effectively reduce fall rate in the elderly.¹⁴ There are various types of auditory feedback, such as rhythmic metronome cues and music, and white noise has been introduced as a means.¹⁵ 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.¹⁶ White noise is a series of noise with continuous and uniformly distributed frequency across the range of 20–20,000 Hz.¹⁵ Among various research employing white noise, Söderlund¹⁷ and Söderlund et al¹⁸ reported that presenting white noise in place of music during task performance facilitated cognitive performance, whereas Thaut¹¹ asserted that rhythmic auditory stimulation, such as white noise, induces motor synchronization and coordinates the cortical 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.^{19,20} 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.^{21,22,23} 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.²⁰ We should thus investigate the effects of white noise in patients with chronic stroke who develop CNS damage and monitor the changes in dynamic balance after the white noise intervention.

Corriveau et al^{24,25} reported that the center of pressure (CoP)–center of mass (CoM) variable is a reliable measure 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.²⁶

Dynamic balance is quantified and evaluated by the scalar distance between CoM and CoP²⁷ 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.²⁸ Therefore, tracking CoM motion within CoP can be useful for assessing dynamic balance 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 before 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

Patients

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. The physical characteristics of the participants are shown in Table 1.

Experimental procedure and data collection

We conducted the experiment to measure and assess the variables of dynamic balance in the study participants after hearing white noise.

We used white noise for auditory feedback, which was presented for 20 minutes to the participant who was comfortably seated in a quiet place and wearing optic glasses that blocked vision to amplify the auditory effect within a short window. White noise used in this study was generated using the MC square X7 (GEOMC) equipped with 6 programs and 6 natural sounds that could be randomly mixed depending on the user's taste and used simultaneously. For the purposes of this study, we used a mix of 1 program and 6 natural sounds (Figure 1). This program functions to regulate attention and biasing using pulsed sounds as external stimuli, which is thought to activate the reticular formation in the midbrain that induces blockage of alpha waves, while the thalamic tract acts to globally broadcast alpha. Beta waves induced during all states of conscious activity disrupt alpha waves, induced during relaxation and mediation (mental stability) with closed eyes, and theta waves, induced during states of creativity and learning.²⁹

In this study, participants performed walking before and after hearing white noise to measure their dynamic balance abilities and CoP, CoM, and gait speed during walking. To measure the kinematic variable during walking, we used a force platform (AMTI, BP1200, USA) and measured the CoP, which is a classical variable used for balance testing.³⁰ Participants were allowed to walk at preferred speed. We set the sampling rate to 1000 Hz and collected data using the Qualisys track manager (QTM, Qualisys, Sweden) software. The force platform was synced with and triggered by the QTM program by interconnecting the A/D boards using internal trigger cables. To record movements during walking, we used 8 infrared cameras (Oqus 300, Qualisys, Sweden) with a sampling rate of 100 Hz. The human body was estimated to be a rigid body of 14 segments (right/left feet, lower limbs, quadriceps, hands, upper limbs, biceps, head, and trunk) and a total of 46 reflection markers were attached. For each participant, we built the 3D coordinates of the walking space through Non-Linear Transformation (NLT) and recorded gait motion using a total of 8 infrared cameras. We simultaneously sampled the locations of the ground

reaction force (GRF) using the force platform with the sampling rate of 1000 Hz. The CoMs for calculating the anterior-posterior (A-P) and medial-lateral (M-L) inclination angles in dynamic balance assessment were recorded using the 8 infrared cameras.

Data processing

We conducted kinematic and kinetic analyses on the collected data for derivation of variables using the Visual 3D software (C-motion, USA) and Matlab 2014a software (The Mathworks, USA).

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 were processed using the Visual 3D software (C-motion, USA) (Matlab R2014b (The Mathwork, USA)).

The GRFs for kinetic variable derivation 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 upward perpendicular, respectively. To remove noise-driven errors, we low-pass filtered the data using a second-order Butterworth filter with a cutoff frequency corresponding to the 99% integral of the power spectrum density (PSD). After the GRF values had been derived, we normalized data across participants by dividing the number of frames per gait phase by the phase duration and showing the value in percentage.

Analysis variables

In this study, we measured the kinetic variable of CoP range and velocity, A-P/M-L inclination angles, and gait speed to test the effects of white noise on dynamic balance.

CoP range and velocity

Using the CoP derived from the GRF data obtained using the force platform, 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.³¹

$$\text{Anterior – posterior (A – L)CoP : } \text{CoPx} = -\text{My}/\text{Fz}$$

$$\text{Medial – lateral (M – L) CoP : } \text{CoPy} = \text{Mz}/\text{Fz}$$

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.^{32,31} 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.³⁰

$$xCM = \sum_{i=1}^n r_i x_i \quad yCM = \sum_{i=1}^n r_i y_i \quad zCM = \sum_{i=1}^n r_i z_i$$

$x_i, y_i, z_i = CM \text{ of the } i_{th} \text{ segment}$

$n = \text{number of segments}$

$r_i = \text{Ratio of the } i_{th} \text{ segment as a percent of total body mass}$

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 tan2 equation (Figure 2).

Gait speed

For gait speed, we analyzed the stance and swing phase data during walking from heel-contact to toe-off on the paretic and non-paretic sides.

Statistical analysis

To identify the pre-post white noise changes in the variables of dynamic balance – CoP range and velocity, CoM, A-P/M-L inclination angle, and gait speed – we conducted a paired samples t-test using a significance level of $\alpha=.05$.

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 longitudinal CoM range showed no post-noise change in the M-L, but in the A-P and longitudinal directions, the CoM range significantly increased by 13.3% and 11.1%, respectively ($p<.05$) (Figures 3, 4, 5, 6, 7, 8). 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 ($p<.05$) (Figure 9, 10). The A-P inclination angle between heel-contact and toe-off increased, but not significantly. Gait speed significantly increased by 11.3% relative to pre-noise ($p<.05$) (Figure 11). 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

longitudinal CoM range showed no post-noise change in the M-L, but in the A-P and longitudinal directions, the CoM range significantly increased by 11.4% and 14.2%, respectively ($p < .05$) (Figures 5 and 6). The M-L inclination angle increased after white noise but not significantly, whereas the A-P inclination angle significantly increased by 10.6% ($p < .05$) (Figure 9). 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 affirming the effectiveness of continuous white noise and auditory feedback^{33,19,20} reported a post-feedback decrease in CoP range and improvement in balance, which contradicts our findings. However, the studies evaluated the effects of auditory feedback 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 feedback-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.³¹ In particular, this result is consistent with the finding by Thaut¹¹ that rhythmic auditory stimulation, such as white noise, induces motor synchronization and coordinates cortical motor areas and the actual motor output, so that the muscles move 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,²⁸ and gait training in the elderly increased the posterior inclination angle of the initial swing.³⁴ The present study demonstrated an increase in the A-P inclination angle between 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^{35,36} suggested that individuals with greater imbalance and lowered confidence in balance tend to restrict their activities, 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.^{37,38,39,40,41,42} 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.²⁸ 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.

List Of Abbreviations

A-P: anterior-posterior, M-L: medial-lateral, S-I: superior-inferior, CoP: center of pressure, CoM: center of mass, CNS: central nervous system, GRF: ground reaction force

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of H University located in Seoul (20180801-057).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

HSL and SR drafted the manuscript. HSL, JSR and SR participated in the conception of the research project. HSL recruited the participants. HSL performed the experimental procedure. HSL and SR calculated the variables. HSL and SR performed the statistical analysis. HSL, JSR and SR interpreted the data. All authors provided critical feedback, reviewed, edited and approved the final version of the manuscript.

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Tables

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

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

Variables	Pre-white noise	Post-white noise	<i>t</i>	<i>p</i>
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

* Statistically significant at the level of $p < .05$

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 before and after receiving auditory white noise

Variables	Pre-white noise	Post-white noise	<i>t</i>	<i>p</i>
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 (s)	0.52±0.17	0.59±0.17	-4.638	.000*

Note: values are expressed as mean±standard deviation

*Statistically significant at the level of $p < .05$

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

Figures

Figure 1

MC Square X7

Figure 2

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

Figure 3

Descriptive information of center of pressure (CoP) range between pre-post white noise

Figure 4

Descriptive information of center of pressure (CoP) velocity between pre-post white noise

Figure 5

Descriptive information of center of mass (CoM) range between pre-post white noise

Figure 6

Descriptive information of center of mass (CoM) velocity between pre-post white noise

Figure 7

Patterns of (top) medial-lateral CoP position and (bottom) anterior-posterior CoP position between pre-post white noise.

Figure 8

Patterns of (top) medial-lateral CoM position, (middle) anterior-posterior CoM position, and (bottom) superior-inferior CoM position between pre-post white noise.

Figure 9

Descriptive information of inclination angle between pre-post white noise

Figure 10

Patterns of (top) medial-lateral inclination angle and (bottom) anterior-posterior inclination angle between pre-post white noise.

Figure 11

Descriptive information of gait speed between pre-post white noise