Original Contribution

Kitasato Med J 2013; 43: 67-73

Hippotherapy to improve hypertonia caused by an autonomic imbalance in children with spastic cerebral palsy

Misako Yokoyama,[1,2] Takeshi Kaname,[3] Minoru Tabata,[1] Kazuki Hotta,[1] Ryosuke Shimizu,[1] Kentaro Kamiya,[1] Daisuke Kamekawa,[1] Michitaka Kato,[1] Ayako Akiyama,[1] Mitsuaki Ohta,[3] Takashi Masuda[1,2]

[1] Department of Angiology and Cardiology, Graduate School of Medical Sciences, Kitasato University
[2] Department of Rehabilitation, School of Allied Health Sciences, Kitasato University
[3] Laboratory of Effective Animals for Human Health, Azabu University School of Veterinary Medicine

Objective: Hippotherapy (i.e., equine-assisted therapy, horseback riding) has been reported to have beneficial effects on children with spastic cerebral palsy (CP). The purpose of this study was to determine the effects of a single session of hippotherapy on hypertonia caused by the autonomic imbalance in children with spastic CP.
Methods: Twenty-two children with spastic CP underwent hippotherapy for 15 minutes. Vertical movement acceleration during hippotherapy was analyzed to detect a 1/f fluctuation. Pupil size, gastrocnemius muscle activity, and modified Ashworth scale (MAS) scores were determined before and after hippotherapy. The high-frequency (HF) and low-frequency (LF) components were analyzed to determine heart rate variability using R-R intervals obtained from a Holter electrocardiogram. The change in muscle activity, LF/HF, and pupil size before and after hippotherapy were calculated (Δmuscle activity, ΔLF/HF, and Δpupil size).
Results: A 1/f fluctuation was observed during hippotherapy in 17 of 22 children evaluated. The LF/HF, pupil size, muscle activity, and MAS score significantly decreased after hippotherapy ($P = 0.04$, $P = 0.03$, $P = 0.04$, $P < 0.001$, respectively), while the HF value increased ($P = 0.04$). Furthermore, muscle activity correlated positively with both ΔLF/HF and Δpupil size ($r = 0.65$, $P = 0.001$; $r = 0.61$, $P = 0.003$, respectively).
Conclusions: The 1/f fluctuation induced by hippotherapy lead to improved autonomic imbalance and reduced muscle tone in children with spastic CP.

Key words: hippotherapy, autonomic nervous activity, spastic cerebral palsy, 1/f fluctuation, hypertonia

Abbreviations: CP, cerebral palsy; GMFCS, gross motor functional classification scale; HRV, heart rate variability; HF, high frequency; LF, low frequency; MAS, modified Ashworth scale

Introduction

Hippotherapy (i.e., equine-assisted therapy, horseback riding) is an exercise therapy known to improve mind and body functions in horseback riders by giving them pleasant feelings. As an underlying mechanism, it has been proposed that rhythmical movements associated with horseback riding promote relaxation and reduce elevated muscle tone.[1,2]

Spastic cerebral palsy (CP) results in a pathological condition whereby muscle tone is enhanced, thereby causing hypertonia. Previous reports showed that hippotherapy reduced hip joint adductor muscle tone in children with spastic CP.[3,4] Moreover, hippotherapy was shown to improve muscle tone in patients with leg hypertonia due to multiple sclerosis.[5] Lechner et al. reported that hippotherapy reduced hip joint adductor muscle tone in patients with lower limb spasticity caused by spinal cord injury.[6] Furthermore, researchers have also demonstrated that horseback riding significantly

Received 20 November 2012, accepted 21 December 2012
Correspondence to: Takashi Masuda, Department of Rehabilitation, School of Allied Health Sciences, Kitasato University
1-15-1 Kitasato, Minami-ku, Sagamihara, Kanagawa 252-0373, Japan
E-mail: tak9999@med.kitasato-u.ac.jp

improves spasticity, while providing a feeling of happiness in patients with spinal cord injury.[7]

In regard to the relaxation effect provided by hippotherapy, parasympathetic nervous activity assessed by heart rate variability (HRV) analysis has been shown to increase significantly after a 30-minute horseback riding session in healthy adults.[8] However, the effect of hippotherapy on the autonomic nervous activity of children with spastic CP has not been sufficiently investigated. In addition, few studies have shown that changes in autonomic nervous activity induced by hippotherapy affect muscle tone in children with CP.

It was recently reported that heart rate rhythms contain a 1/f fluctuation, which provides beneficial effects to the body.[9] A 1/f fluctuation is the fluctuation in which the power spectral density obtained from the analysis of motion or sound is inversely proportional to the frequency (i.e., when fluctuation is categorized according to the power of frequency). Studies have shown that people feel comfortable when fluctuations by external stimuli follow a 1/f fluctuation pattern.[10-12] Although the rhythmical motion of horseback riding has been proposed to contain a 1/f fluctuation, this hypothesis has not been scientifically tested.

In the present study, we hypothesized that the vertical motion acceleration of horseback riding contained a 1/f fluctuation capable of providing a pleasant stimulation in children with spastic CP. We also hypothesized that this 1/f fluctuation resulted in changes in their autonomic nervous activity, thereby improving hypertonia. To test these hypotheses, we investigated the effect of a single session of hippotherapy on autonomic nervous activity and hypertonia in children with spastic CP.

Patients and Methods

Patients

The present study adhered to the tenets of the Declaration of Helsinki and received approval from the Internal Review Board of the School of Allied Health Sciences, Kitasato University.

Children who were diagnosed with spastic CP by a pediatrician according to the Surveillance of Cerebral Palsy in Europe classification tree of cerebral palsy subtypes[13] and the recommendations of Sanger et al.,[14] and who were classified as level IV or V according to the Gross Motor Functional Classification Scale (GMFCS) were recruited for this study. Children with a prior history of selective dorsal rhizotomy, uncontrolled tonic-clonic seizures, known allergies to horses, or those who received botulinum toxin A injections were excluded from the study. A total of 22 children (10 boys and 12 girls) participated in the present study. The mean age, height, and weight were 7.7 ± 2.2 years (range, 5－12 years), 113.8 ± 11.6 cm (range, 100.0－135.0 cm), and 17.6 ± 3.3 kg (range, 14.0－22.9 kg), respectively. The study protocol was thoroughly explained to the children and the parents, and written informed consent was obtained. Age, sex, height, weight, and the GMFCS were obtained from the children's medical records or by interviewing their parents.

Hippotherapy

The study was carried out at the riding ground of Azabu University School of Veterinary Medicine. A 15-year-old crossbred horse (height, 1.56 m; weight, 530 kg) was used for the hippotherapy sessions. The horse was fitted with a saddle, pad, and surcingle to provide a safe ride. In addition, a physical therapist experienced in hippotherapy, for more than 5 years, rode with each child for support while a handler led the horse at a steady pace of 50 m/minute along a 50-m circular track. The total horseback riding time was 15 minutes (7.5 minutes clockwise and 7.5 minutes counterclockwise).

Children were instructed to rest for 10 minutes on an adaptive chair suited for their bodies prior to hippotherapy (baseline). A Holter electrocardiogram (ECG) (120-FM, Fukuda Denshi, Tokyo) and triaxial accelerometer (MA-3-20AC, MicroStone, Nagano) were fitted onto the chest and waist to record R-R intervals and vertical movement acceleration, respectively. Muscle activity corresponding to both the right and left gastrocnemii was measured using surface electromyography (PH-2501/8EMG isolator, DKH, Tokyo), and hypertonia was assessed using a modified Ashworth scale (MAS).[15] Pupil size of both the right and left eyes was measured using a pupillometer (Iriscorder Dual C10641, Hamamatsu Photonics, Shizuoka). Furthermore, systolic and diastolic blood pressure and pulse rate were measured using an automatic manometer (HEM-080IC, Omron, Kyoto), and percutaneous oxygen saturation was determined with a finger pulse oximeter (Onyx 9500, NONIN, MN, USA) every 5 minutes during hippotherapy. Measurements taken at baseline were determined again immediately after hippotherapy.

Vertical movement acceleration during horseback riding was recorded using a triaxial accelerometer set at a sampling frequency of 200 Hz. The sampling of vertical movement acceleration was started 7 minutes after the start of hippotherapy, and the first 4,096 samples were analyzed using fast Fourier transform to evaluate fluctuation. Maximum frequency was defined as 100 Hz of the Nyquist frequency based on the sampling theorem, while minimum frequency was defined as 0.05 Hz of the fundamental frequency.[16] Scatter charts for both logarithmic graphs were generated with the vertical axis representing the power spectrum density and the horizontal axis representing the frequency of vertical movement acceleration. The slope of the regression line was then calculated from the scatter chart using linear regression analysis. If the slope was shown to be between -1.2 and -0.8, the vertical movement acceleration during horseback riding was determined to contain a 1/f fluctuation.[17]

Autonomic nervous activity was determined from HRV obtained from R-R intervals using a Holter ECG. R-R intervals were analyzed by the maximal entropy method (MemCalc, Suwa Trust, Tokyo) to obtain the frequency domain power spectra for low (0.04−0.15 Hz) and high (0.15−0.40 Hz) frequency components (LF and HF, respectively).[18] The HF component reflects parasympathetic nervous activity, while the LF/HF ratio indicates a dominance of sympathetic over parasympathetic nervous activity.[18] Mean HF and LF/HF values measured during a 5-minute period before and after hippotherapy were used for statistical analysis. Pupil size was measured before and after hippotherapy, and the mean value of left and right diameters was calculated.[19] If pupil size decreased or increased after hippotherapy, parasympathetic or sympathetic nervous activity was determined to be dominant, respectively.

Hypertonia

Resting muscle action potential corresponding to right and left gastrocnemii was measured for 1 minute in a sitting position using surface electromyography before and after hippotherapy at a sampling frequency of 1,000 Hz. The muscle action potential amplitude was then converted using a root-mean-square algorithm, and the mean value of right and left amplitudes was used as an analytical determinant of muscle activity.[20]

The MAS is a scale rating system with 6 scores (i.e., 0, 1, 1+, 2, 3, and 4) used to assess the spasticity of the gastrocnemius muscle.[15] In the present study, a MAS score of 1+ was converted to a variable of 1.5, and the mean MAS score corresponding to the right and left gastrocnemii was used as an analytical determinant before and after hippotherapy.[21]

Statistical analysis

The LF/HF, HF, pupil size, muscle activity, and MAS score measured before hippotherapy were defined as baseline values and compared to those measured after hippotherapy using a paired *t*-test. The changes in those values were expressed as ΔLF/HF, ΔHF, Δpupil size, Δmuscle activity, and ΔMAS, which were calculated using the formula: *rate of change (%) = (value after hippotherapy − baseline value)/baseline value × 100*.

The relationships between Δmuscle activity or ΔMAS and ΔLF/HF, ΔHF, and Δpupil size were evaluated using Pearson's correlation coefficient. Unless otherwise stated, data were expressed as mean ± standard deviation (SD). A P value of <0.05 was determined to be statistically significant. All analyses were performed using the SPSS version 11.0J for Windows (SPSS, Japan).

Results

Table 1 shows changes in cardiovascular parameters during hippotherapy. No significant changes in blood pressure, pulse rate, or percutaneous oxygen saturation were determined during hippotherapy.

Figure 1 shows the fluctuations caused by hippotherapy from three representative cases. The linear regression slopes ranged between -1.2 and -0.8 in 17 of 22 children, indicating that a 1/f fluctuation resulted from hippotherapy.

Figure 2 shows the changes in LF/HF, HF, and pupil size before and after hippotherapy. We observed that LF/HF decreased, while HF increased significantly after hippotherapy compared to the baseline values (P = 0.03 and P = 0.04, respectively). Pupil size also decreased

Table 1. Changes in cardiovascular responses during hippotherapy

	Before	5 min	10 min	15 min	After
SBP (mmHg)	111 ± 15	106 ± 9	105 ± 10	104 ± 16	104 ± 17
DBP (mmHg)	65 ± 7	64 ± 5	65 ± 6	64 ± 7	62 ± 5
Pulse rate (beats/min)	107 ± 6	98 ± 17	97 ± 19	102 ± 17	93 ± 22
SpO_2 (%)	98 ± 1	97 ± 3	97 ± 2	96 ± 3	98 ± 1

Data are expressed as mean ± standard deviation

SBP, systolic blood pressure; DBP, diastolic blood pressure; SpO_2, percutaneous oxygen saturation

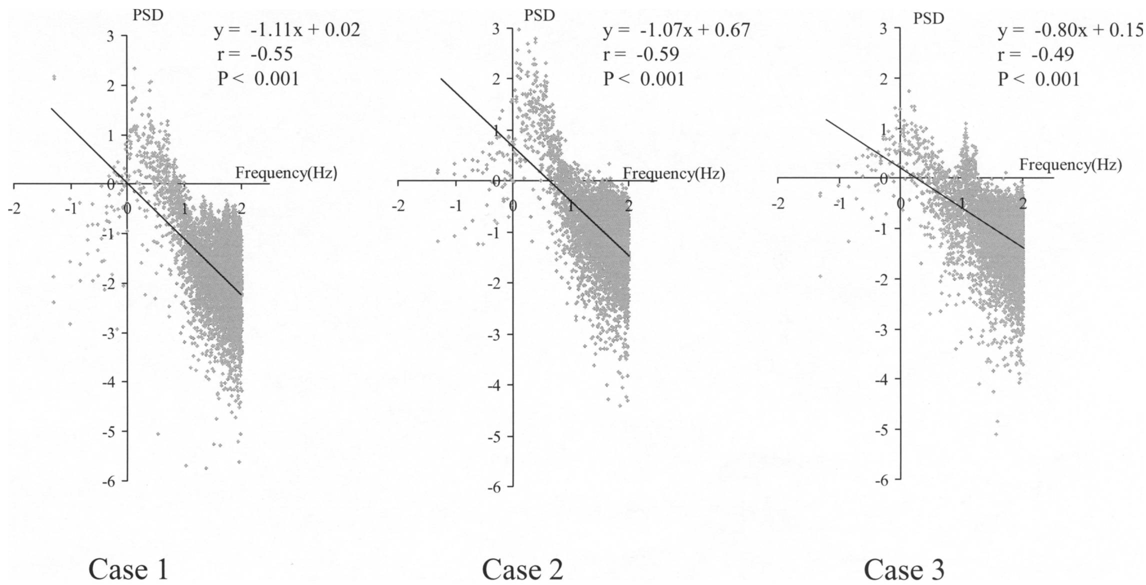


Figure 1. Relationship between frequency and power spectral density in fast Fourier transform analysis of vertical movement acceleration in three representative cases
The linear regression slopes were -1.11, -1.07, and -0.80 in cases 1, 2, and 3, respectively.
PSD, power spectral density

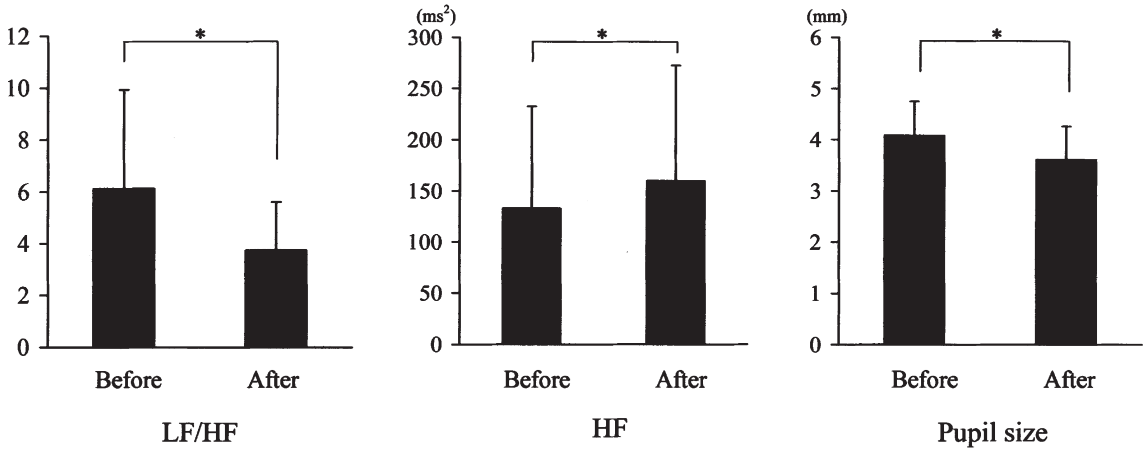


Figure 2. LF/HF, HF, and pupil size before and after hippotherapy
Data are expressed as mean ± standard deviation.
*P < 0.05, before vs. after hippotherapy LF, low-frequency component; HF, high-frequency component

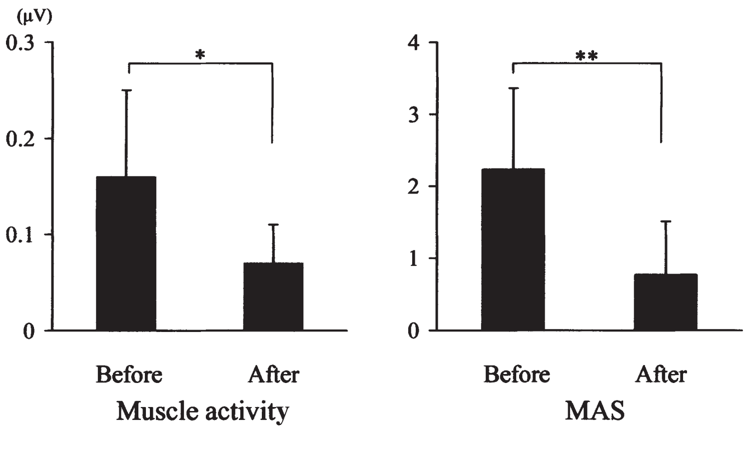
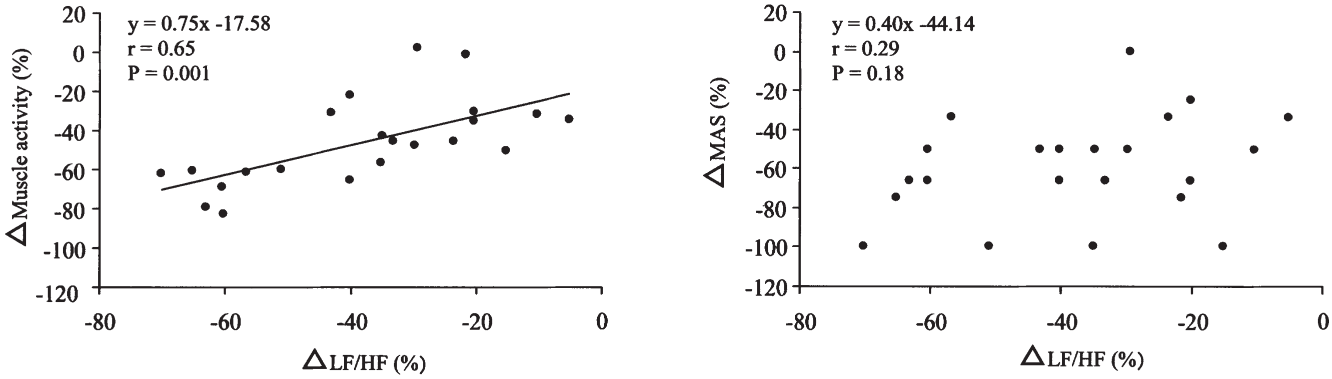
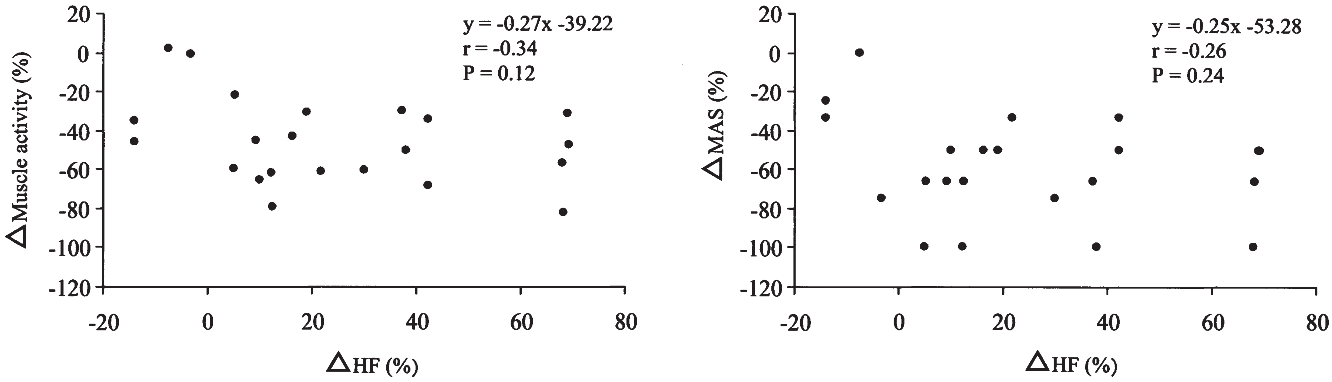


Figure 3. Muscle activity and MAS score before and after hippotherapy
Data are expressed as mean ± standard deviation.
*P < 0.05 and **P < 0.01, before vs. after hippotherapy
MAS, modified Ashworth scale



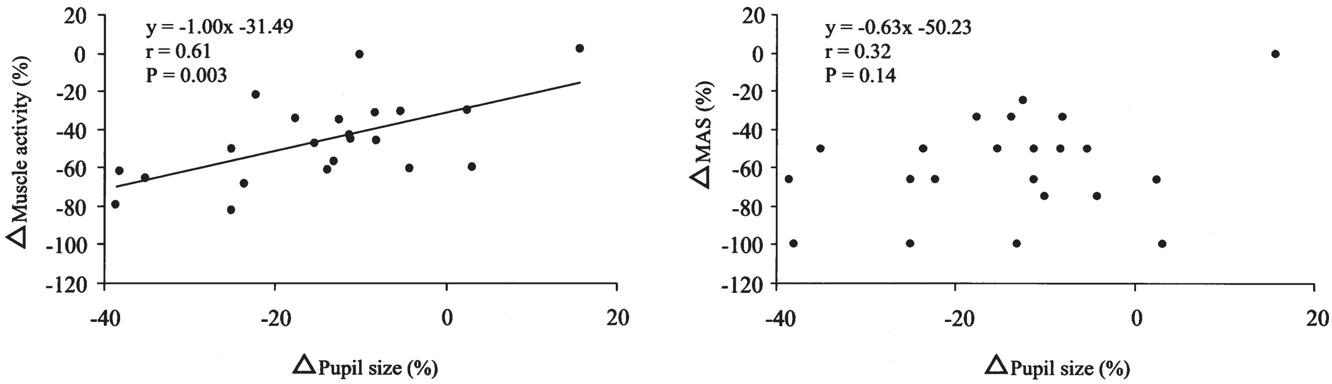
A B

Figure 4. Relationships between Δ LF/HF and Δ muscle activity (**A**), and Δ LF/HF and Δ MAS (**B**)
LF, low-frequency component; HF, high-frequency component; MAS, modified Ashworth scale



A B

Figure 5. Relationships between Δ HF and Δ muscle activity (**A**), and Δ HF and Δ MAS (**B**)
HF, high-frequency component; MAS, modified Ashworth scale



A B

Figure 6. Relationships between Δ pupil size and Δ muscle activity (**A**), and Δ pupil size and Δ MAS (**B**)
MAS, modified Ashworth scale

significantly after hippotherapy compared to the baseline value (P = 0.04).

Figure 3 shows the changes in muscle activity and MAS score before and after hippotherapy. The gastrocnemius muscle activity and MAS score decreased significantly after hippotherapy compared to the baseline values (P = 0.04 and P < 0.001, respectively).

The relationships between ΔLF/HF and Δmuscle activity, and ΔLF/HF and ΔMAS are shown in Figures 4A and B, respectively. A positive correlation between ΔLF/HF and Δmuscle activity was determined (r = 0.65, P = 0.001). However, we did not observe a significant correlation between ΔLF/HF and ΔMAS.

Figures 5A and B show the relationships between ΔHF and Δmuscle activity, and ΔHF and ΔMAS, respectively. No significant correlations for either relationship were observed.

Figures 6A and B show the relationships between Δpupil size and Δmuscle activity, and Δpupil size and ΔMAS, respectively. A positive correlation between Δpupil size and Δmuscle activity was observed (r = 0.61, P = 0.003), while no significant correlation between Δpupil size and ΔMAS was observed.

Discussion

In the present study, we detected a 1/f fluctuation in 17 of 22 children through analysis of vertical movement acceleration during horseback riding. Accordingly, it was concluded that horseback riding does provide riders with a 1/f fluctuation. Previous reports have shown that a 1/f fluctuation promotes a comfortable feeling in people,[10-12] and that transdermal electric stimulations with a 1/f fluctuation reduce pain in patients with lower back pain.[22] Healthy adults also experience a comfortable feeling while rocking on a chair with a 1/f fluctuation.[11] When a sense of 1/f fluctuation is transmitted to the amygdaloid body and hypothalamus via the thalami, the fluctuation is known to suppress sympathetic nervous activity and enhance parasympathetic nervous activity by promoting a feeling of comfort in individuals.[23]

Our analysis of autonomic nervous activity showed decreased LF/HF and pupil size values, and increased HF value after hippotherapy. These results demonstrate that hippotherapy increases parasympathetic nervous activity and decreases sympathetic nervous activity, resulting in the improvement of autonomic imbalance. In previous studies investigating the autonomic nervous activity in children with CP, LF/HF was reported to be significantly higher compared to that obtained in healthy children.[24-26] This finding suggested that sympathetic nervous activity in children with spastic CP was also elevated compared to healthy children.

The level of muscle tone before and after hippotherapy was also evaluated in this study. Our results showed that both the gastrocnemius muscle activity and the MAS score decreased significantly after hippotherapy compared to the baseline values, suggesting that hippotherapy improves hypertonia in children with spastic CP. In regard to the relationship between autonomic nervous activity and muscle activity, the decrease in ΔLF/HF and/or Δpupil size, which reflects reduced sympathetic nervous activity, correlated positively with the decrease in muscle tone. Although HF increased significantly after hippotherapy, we found no significant correlations between ΔHF and Δmuscle activity or ΔHF and ΔMAS. These findings suggest that hippotherapy decreases sympathetic nervous activity directly, resulting in the improvement of hypertonia.

The results of the present study show that vertical movement acceleration with a 1/f fluctuation promotes a pleasant feeling in children with spastic CP, which results in a reduction of muscle tone by ameliorating autonomic imbalance. However, we did not examine the conduction process of 1/f fluctuation from the peripheral nervous system to the brain. Future studies should be focused at investigating the influence of 1/f fluctuation on the central nervous system. We did not examine the long-term effects of hippotherapy on hypertonia; therefore, longitudinal studies to assess the beneficial effects of hippotherapy are warranted.

These findings indicate that a single session of hippotherapy improves the imbalance in autonomic nervous activity, which results in reduced muscle tone in children with spastic CP. The 1/f fluctuation induced by hippotherapy is considered to modulate autonomic nervous activity in children by promoting a feeling of comfort.

Funding source: All phases of this study were supported by a grant from the Kitasato University School of Allied Health Sciences (Grant-in-Aid for Research Project, No. 2011-1041).
Financial disclosure: The authors have no financial relationships relevant to this article to disclose.
Conflict of interest: The authors have no conflicts of interest to disclose.

References

1. Freeman G. Hippotherapy: therapeutic horseback riding. *Clin Manage Phys Ther* 1984; 4: 20-5.

2. Munoz Lasa S, Ferriero G, Brigatti E, et al. Animal-assisted interventions in internal and rehabilitation medicine: a review of the recent literature. *Panminerva Med* 2011; 53: 129-36.
3. Benda W, McGibbon NH, Grant KL. Improvements in muscle symmetry in children with cerebral palsy after equine-assisted therapy (hippotherapy). *J Altern Complement Med* 2003; 9: 817-25.
4. Nancy HM, William B, Debbie SS, et al. Immediate and long-term effects of hippotherapy on symmetry of adductor muscle activity and functional ability in children with spastic cerebral palsy. *Arch Phys Med Rehabil* 2009; 90: 966-74.
5. Weber A. Hippotherapie bei multiple-sklerose-kranken. *Ther Reiten* 1994; 21: 16-9 (in German).
6. Lechner HE, Feldhaus S, Gudmundsen L, et al. The short-term effect of hippotherapy on spasticity in patients with spinal cord injury. *Spinal Cord* 2003; 41: 502-5.
7. Lechner HE, Kakebeeke TH, Hegemann D, et al. The effect of hippotherapy on spasticity and on mental well-being of persons with spinal cord injury. *Arch Phys Med Rehabil* 2007; 88: 1241-8.
8. Matsuura A, Nagai N, Funatsu A, et al. Comparison of the short-term effects of horse trekking and exercising with a riding simulator on autonomic nervous activity. *Anthrozoos* 2011; 24: 65-77.
9. Cyzarz D, Linhard M, Edelhauser F, et al. Unexpected course of nonlinear cardiac interbeat interval dynamics during childhood and adolescence. *PloS One* 2011; 6: e19400.
10. Voss RF, Clarke J. "1/*f* noise" in music: music from 1/*f* noise. *J Acoust Soc Am* 1978; 63: 258-63.
11. Kawashima T. Development of active rocking chair with changing swing according to heartbeat fluctuation. *JSME Int J* 2006; 49: 814-20.
12. Craig AD. How do you feel? Interoception: the sense of the physiological condition of the body. *Nat Rev Neurosci* 2002; 3: 655-66.
13. Cans C. Surveillance of cerebral palsy in Europe: a collaboration of cerebral palsy surveys and registers. Surveillance of Cerebral Palsy in Europe (SCPE). *Dev Med Child Neurol* 2000; 42: 816-24.
14. Sanger TD, Delgado MR, Gaebler-Spira D, et al. Classification and definition of disorders causing hypertonia in childhood. *Pediatrics* 2003; 111: e89-97.
15. Mutlu A, Livanelioglu A, Kerem MG, et al. Reliability of Ashworth and modified Ashworth scales in children with spastic cerebral palsy. *BMC Musculoskelet Disord* 2008; 44: 1-8.
16. John B, Paulo F, editors. *Modern sampling theory: mathematics and applications*. New York: Birkhauser Boston; 2001; 247-65.
17. Higuchi T. Relationship between the fractal dimension and the power law index for a time series: a numerical investigation. *Phsica D* 1990; 46: 254-64.
18. Huikuri HV, Niemela MJ, Ojala S, et al. Circadian rhythms of frequency domain measures of heart rate variability in healthy subjects and patients with coronary artery disease. Effects of arousal and upright posture. *Circulation* 1994; 90: 121-6.
19. Filipe JA, Falcao-Reis F, Castro-Correia J, et al. Assessment of autonomic function in high level athletes by pupillometry. *Auton Neurosci* 2003; 104: 66-72.
20. Abe D, Hotta N, Fukuoka Y, et al. Biomechanical analysis of gait and sit-to-stand patterns using a specially made knee supporter in healthy young and elderly individuals. *J Physiol Anthropol* 2010; 29: 65-70.
21. Wallen M, Ziviani J, Naylor O, et al. Modified constraint-induced therapy for children with hemiplegic cerebral palsy: a randomized trial. *Dev Med Child Neurol* 2011; 53: 1091-9.
22. Takakura K. Transcutaneous electrical nerve stimulation for relieving pain-physiological significance of the 1/f frequency fluctuation. *No Shinkei Gekka* 1982; 10: 349-57 (in Japanese).
23. Michelle HC. *Physical agents in rehabilitation: from research to practice*. 3rd ed. Amsterdam, The Netherlands: Saunders/Elsevier; 2009: 56-8.
24. Rose J, Haskell WL, Gamble JG. A comparison of oxygen pulse and respiratory exchange ratio in cerebral palsied and nondisabled children. *Arch Phys Med Rehabil* 1993; 74: 702-5.
25. Mita K, Akataki K, Itoh K, et al. Assessment of cardiovascular regulation in persons with severe multiple disabilities using heart rate variability. *Jpn J Rehabil Med* 1996; 33: 554-61 (in Japanese).
26. Park ES, Park CI, Cho SR, et al. Assessment of autonomic nervous system with analysis of heart rate variability in children with spastic cerebral palsy. *Yonsei Med J* 2002; 43: 65-72.