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

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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 (Δ muscle activity, Δ LF/HF, and Δ pupil 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 Δ LF/HF and Δ pupil 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
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 (Irisorder 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. 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.

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). The HF component reflects parasympathetic nervous activity, while the LF/HF ratio indicates a dominance of sympathetic over parasympathetic nervous activity. 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. 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.

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. 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.

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

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Data are expressed as mean ± standard deviation

SBP, systolic blood pressure; DBP, diastolic blood pressure; SpO2, 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
Figure 4. Relationships between $\Delta$ LF/HF and $\Delta$ muscle activity (A), and $\Delta$ LF/HF and $\Delta$ MAS (B)
LF, low-frequency component; HF, high-frequency component; MAS, modified Ashworth scale

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

Figure 6. Relationships between $\Delta$ pupil size and $\Delta$ muscle activity (A), and $\Delta$ pupil size and $\Delta$ 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 Δ LF/HF and Δ muscle activity, and Δ LF/HF and Δ MAS are shown in Figures 4A and B, respectively. A positive correlation between Δ LF/HF and Δ muscle activity was determined (r = 0.65, P = 0.001). However, we did not observe a significant correlation between Δ LF/HF and Δ MAS.

Figures 5A and B show the relationships between Δ HF and Δ muscle activity, and Δ HF and Δ MAS, respectively. No significant correlations for either relationship were observed.

Figures 6A and B show the relationships between Δ pupil size and Δ muscle activity, and Δ pupil size and Δ MAS, respectively. A positive correlation between Δ pupil size and Δ muscle activity was observed (r = 0.61, P = 0.003), while no significant correlation between Δ pupil size and Δ MAS 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, and that transdermal electric stimulations with a 1/f fluctuation reduce pain in patients with lower back pain. Healthy adults also experience a comfortable feeling while rocking on a chair with a 1/f fluctuation. When a sense of 1/f fluctuation is transmitted to the peripheral nervous system, it is considered to modulate autonomic nervous activity by promoting a feeling of comfort.

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. 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.

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References

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