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Monitoring the Autonomic Nervous Activity as the Objective Evaluation of Music Therapy for Severely and Multiply Disabled Children

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Severely and multiply disabled children (SMDC) are frequently affected in more than one area of development, resulting in multiple disabilities. The aim of the study was to evaluate the efficacy of music therapy in SMDC using monitoring changes in the autonomic nervous system, by the frequency domain analysis of heart rate variability. We studied six patients with SMDC (3 patients with cerebral palsy, 1 patient with posttraumatic syndrome after head injury, 1 patient with herpes encephalitis sequelae, and 1 patient with Lennox-Gastaut syndrome characterized by frequent seizures, developmental delay and psychological and behavioral problems), aged 18-26 (mean 22.5 ± 3.5). By frequency domain method using electrocardiography, we measured the high frequency (HF; with a frequency ranging from 0.15 to 0.4 Hz), which represents parasympathetic activity, the low frequency/high frequency ratio, which represents sympathetic activity between the sympathetic and parasympathetic activities, and heart rate. A music therapist performed therapy to all patients through the piano playing for 50 min. We monitored each study participant for 150 min before therapy, 50 min during therapy, and 10 min after therapy. Interestingly, four of 6 patients showed significantly lower HF components during music therapy than before therapy, suggesting that these four patients might react to music therapy through the suppression of parasympathetic nervous activities. Thus, music therapy can suppress parasympathetic nervous activities in some patients with SMDC. The monitoring changes in the autonomic nervous activities could be a powerful tool for the objective evaluation of music therapy in patients with SMDC.

Keywords: cerebral palsy; disabled children; heart rate variability; high frequency; music therapy
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Severely and multiply disabled children (SMDC), who have severe to profound cognitive impairments or intellectual disabilities, are frequently affected in more than one area of development, resulting in multiple disabilities. SMDC frequently experience epilepsy, secondary musculoskeletal problems, and disturbances of sensation, perception, cognition, communication, and behavior (Rosenbaum et al. 2007). The most common medical diagnosis was cerebral palsy.

Music therapy has been used since ancient times to improve patients' well-being (McCaffrey et al. 2002). Music therapy offers SMDC the opportunity to experience success in their own activities and to express themselves at their individual development levels (Layman et al. 2002; Rainey et al. 2003). Yu et al. (2009) observed that music therapy intervention significantly reduced blood pressure and heart rate levels in patients with cerebral palsy. However, objective evaluation of the effects of music therapy in SMDC has not been established.

The autonomic nervous system has been evaluated

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using the frequency domain analysis of heart rate variability (HRV) (Akselrod et al. 1981; Pomeranz et al. 1985; European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996). HRV is caused by beat-to-beat fluctuations of the R-R interval on the electrocardiogram (ECG). The analysis of HRV is a form of measuring autonomic balance, which is principally controlled by the sympathetic and parasympathetic nervous systems (Akselrod et al. 1981). Although frequency domain analysis of HRV is a simple and noninvasive tool that can be used to investigate autonomic nervous system activity in SMDC (Yang et al. 2002), the effectiveness of music therapy in patients with SMDC has not been estimated.

In this study, we evaluated the efficacy of music therapy in patients with SMDC by monitoring changes in the autonomic nervous system by frequency domain analysis of HRV.

Materials and Methods

Study Participants

We conducted a cross-sectional design of six patients with SMDC (three men and three women) aged 18-26 years. They were patients at a residential, day treatment and educational institution for SMDC located in Nagasaki, Japan. Demographic data, including age, sex, diagnosis, and a history of cardiac disease were collected from each patient. Five women volunteers were included in the study as a control. None of them had a history of developmental delay, neurologic deficit, or cardiac disease. Before the study, ethical approvals were obtained from the ethical committees of Nagasaki University and Nagasaki National Hospital. Informed consent was obtained from parents of all patients and volunteers.

Collecting data and frequency domain analysis of heart rate variability

In this study, we used a small monitoring device a bi-axial accelerometer (ACM), thermometer, ECG, central processing unit (CPU), memory IC and lithium cell battery. ECG data were recorded and stored in the device, connected to a personal computer, and analyzed using software that we also developed.

HRV was analyzed by frequency domain methods (European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996). The frequency domain components were obtained from two main components: a low-frequency (LF) component representing sympathetic and parasympathetic influence, with a frequency ranging from 0.04 to 0.15 Hz, and a high-frequency (HF) component of parasympathetic origin, with frequency ranging from 0.15 to 0.4 Hz. The measurement of LF and HF components was made in power component (milliseconds squared). The controlled and balanced behavior between the sympathetic and parasympathetic system may be defined as the LF/HF ratio (LF/HF). In this study, we analyzed HF, LF/HF, and heart rate (HR) in each study participant.

Music therapy and estimates of frequency domain of heart rate variability

All study patients wore the monitoring device during their stay in the institution for 5 hours. Although we monitored for five women volunteers, the intervention of music therapy was not performed for them. A music therapist performed therapy through the piano playing for 50 min.

Before therapy, the study patients spent their daily lives for 150 min (watch TV, eat for lunch, sleep, fully relax). During therapy, music therapist sang songs to patients who were sitting or supine positions, and played musical instruments, such as piano, guitar, keyboard and rhythm instruments, in order to encourage their active participation in the therapy. Three nurses assisted patients during therapy. We monitored each study participant for 150 min before therapy, 50 min during therapy, and 10 min after therapy. After therapy, they were at rest for 10 min and sampling periods was ended. Music therapy was performed under stable room conditions (temperature, 28°C; humidity, 60%).

HRV was analyzed by frequency domain methods. The frequency domain components were obtained from two main components: a low-frequency (LF) component of sympathetic and parasympathetic origin, with frequency ranging from 0.04 to 0.15 Hz, and a high-frequency (HF) component of parasympathetic origin, with frequency ranging from 0.15 to 0.40 Hz. The measurements of LF and HF components were made in power component (milliseconds squared). The controlled and balanced behavior between the sympathetic and parasympathetic system was defined as the LF/HF ratio (LF/HF). In this study, we measured HF, LF/HF, and heart rate (HR) in each study participant in every one minutes.

Statistical analysis

Results are expressed as mean ± standard deviation (S.D.) or median (25th to 75th quartile). Differences between patients and controls were evaluated using the Mann-Whitney's *U* test. Using HRV components, such as HF, LF/HF and HR values, which were recorded in every minute, analysis of variance was used to compare, before (150 min), during (30 min) and after music therapy (10 min) in each study participant. Probability values less than 0.05 were considered statistically significant. All statistical analyses were performed using SPSS software, v.18.0 for Windows (SPSS Japan, Tokyo, Japan).

Results

Characteristics of study participants are shown in Table 1. There was no hearing disturbance in all patients. Three patients had cerebral palsy, one had posttraumatic syndrome after head injury, one had herpes encephalitis sequelae, and one had Lennox-Gastaut syndrome, characterized by frequent seizures, developmental delay and psychological and behavioral problems. There was no significant difference in age between patients and controls. Clinically, Patients 1 and 2 had spent their time in a sitting position, had been relatively react to the music therapy. On the other hand, Patients 3, 4, 5 and 6 had been bedridden all day due to severe behavioral and emotional disturbances.

Before music therapy, HF components were significantly lower in patients than in controls ($p = 0.03$, Table 2) and HR was significantly higher in patients than in controls ($p = 0.03$). On the other hand, LF/HF did not differ significantly between groups ($p = 0.9$). These results suggest that the HF component, rather than LF/HF, is useful for the evaluation of music therapy in patients with SMDC.

Table 3 showed the heart rate variability with music

Table 1. Characteristics of study participants.

Case	Sex	Age	Diagnosis	Position
1	M	26	Posttraumatic syndrome after head injury	Sitting
2	F	24	Cerebral palsy	Sitting
3	M	20	Cerebral palsy	Supine
4	M	23	Herpes encephalitis sequelae	Supine
5	F	18	Cerebral palsy	Supine
6	F	23	Lennox-Gastaut syndrome	Supine

Table 2. HRV in SMDC (before music therapy) and controls. Music therapy was not performed for controls.

	SMDC (n = 6)	Control (n = 5)	P value
Age	22.5 ± 3.2	22.4 ± 2.0	0.93
HF	389.6 ± 240.7	1,807.5 ± 662.3	0.03
LF/HF	2.5 ± 0.7	2.6 ± 0.5	0.93
HR	98.7 ± 4.7	82.8 ± 3.0	0.03

Values are mean ± standard deviation (s.d.) or standard error (s.e.).
Abbreviations: SMDC; severely and multiply disabled children, HF; high frequency, LF/HF; low frequency/high frequency ratio, HR; heart rate.

Table 3. Heart rate variability with music therapy intervention in SMDC.

	No	Music therapy		
		before	during	after
HF	1	273.9 (182.0-397.1)	135.1 (96.5-175.6)*	188.6 (126.6-240.3)
	2	351.5 (206.8-602.3)	194.6 (162.5-326.8)*	353.3 (255.7-468.4)
	3	330.3 (233.6-449.0)	141.4 (109.5-200.4)*	144.4 (101.4-260.7)
	4	662.1 (311.2-1841.3)	240.1 (175.8-358.2)*	547.9 (311.7-829.8)
	5	82.4 (61.8-118.6)	96.4 (72.7-113.0)	276.0 (100.9-416.0)**
	6	66.8 (44.5-94.5)	56.5 (34.6-104.5)	96.5 (75.5-159.0)
LF/HF	1	4.5 (3.3-5.7)	5.1 (3.2-6.6)	7.5 (5.1-8.5)
	2	2.5 (1.7-3.9)	2.7 (1.6-4.0)	3.1 (2.3-3.8)
	3	2.6 (1.6-4.2)	2.7 (1.6-5.0)	0.9 (0.7-2.9)
	4	5.1 (3.8-7.4)	4.9 (3.4-6.7)	4.6 (2.8-6.8)
	5	2.7 (1.8-4.1)	3.1 (2.1-4.2)	3.9 (2.7-6.7)
	6	3.2 (2.0-5.0)	2.5 (0.9-6.1)	4.2 (2.8-5.0)
HR	1	91.8 ± 4.8	106.9 ± 4.9*	105.2 ± 4.2
	2	94.7 ± 6.8	97.9 ± 4.6	96.3 ± 2.9
	3	91.1 ± 7.3	99.4 ± 4.8*	102.6 ± 6.1
	4	87.0 ± 14.4	95.0 ± 9.5*	88.1 ± 9.6
	5	91.0 ± 5.7	91.6 ± 3.7	82.4 ± 8.5**
	6	95.3 ± 4.9	94.4 ± 4.0	95.5 ± 2.3

Values are means ± s.d. or median (25th to 75th). Abbreviations are shown in Table 2.
*$p < 0.01$ vs. before music therapy, **$p < 0.01$ vs. during music therapy.

therapy intervention in SMDC. Patients 1, 2, 3, and 4 showed significantly lower HF components during music therapy than before therapy. Clinically, Patients 1 and 2 relatively reacted to the music therapy and HF components were actually suppressed during music therapy (Fig. 1). Interestingly, Patients 3 and 4 had severe behavioral and emotional disturbances, but their HF components were also suppressed during music therapy same as Patients 1 and 2. On the other hand, Patients 5 and 6 had severe behavioral and emotional disturbances clinically and HF components

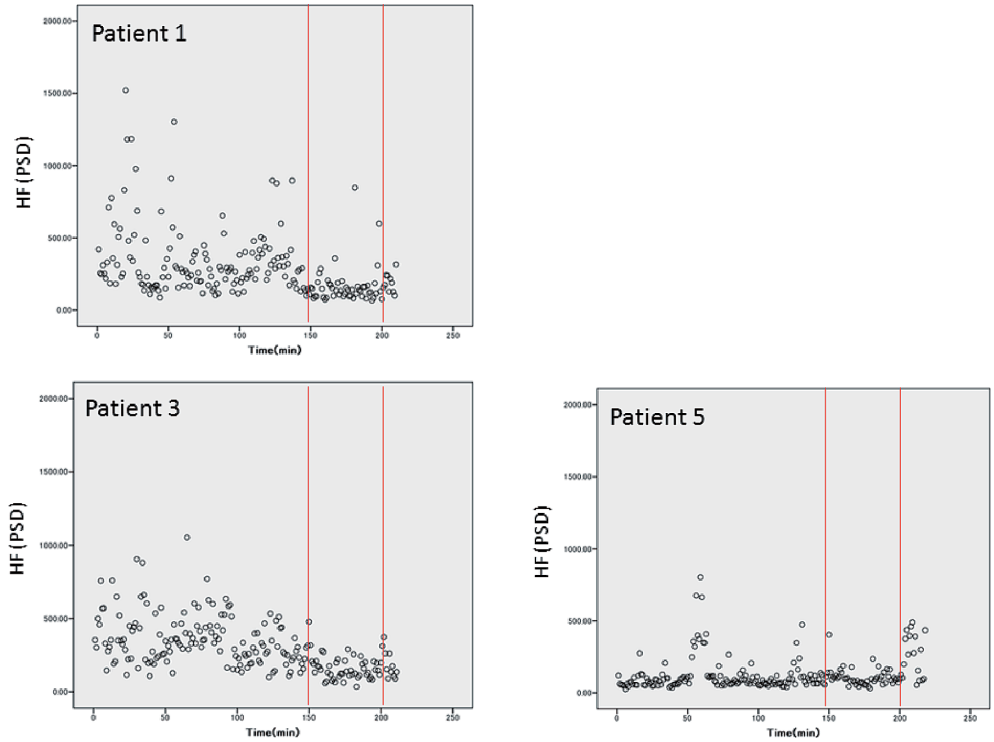

Fig. 1. Changes in HF during music therapy in Patients 1, 3 and 5. Music therapy was performed from 150 to 200 min (between two lines). Each plot represents recorded HF values at every minute. There are 200 plots between 1 and 200 minutes.

were not suppressed during the therapy, indicating that music therapy did not trigger the dominant state of sympathetic nervous activities in these two patients.

There were no significant differences in LF/HF before and during music therapy in any patient. In addition, in all patients except for Patient 5, there were no significant differences in HF components and LF/HF during and after music therapy. These results suggest that music therapy did not change state of sympathetic nervous activities in the five patients.

Discussion

Frequency domain analysis of HRV is a simple and noninvasive tool that can be used to investigate sympathetic and parasympathetic contributions of autonomic function (European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996). Previous studies have evaluated autonomic function in patients with cerebral palsy using HRV analysis, but obtained results were inconsistent. Yang et al. (2002) investigated autonomic function for patients with cerebral palsy by power spectrum analysis and found that there were no significant differences in the LF component, HF component, and LF/HF ratios between patients with cerebral palsy and healthy controls. Park et al. (2002) investigated the function of the autonomic nervous system in children with spastic cerebral palsy and found that there were no significant differences in mean HR, the LF component, or the HF component, compared with normal controls. On the other hand, Ferreira et al. (2011) recently showed differences for the HF component, the LF component, and the LF/HF ratio between individuals with cerebral palsy and controls. In this study, we showed significant differences in the HF component and HR between patients and controls before music therapy. Several factors, such as timing and duration of data collection and inclusion criteria of study cases may cause inconsistent results in the evaluation of autonomic function for patients with cerebral palsy. On the other hand, except for Patient 5, none of the patients showed significant differences in LF/HF before and during music therapy, which suggests that the HF component, rather than LF/HF, is useful for the evaluation of music therapy in patients with SMDC.

Several studies have suggested that music has significant effects on heart rate, HRV, and blood pressure in most subjects (Bernatzky et al. 2004; Trappe et al. 2010). However, as far as we know, the effectiveness of music therapy in patients with SMDC using HRV analysis has not been assessed. In this study, we showed significantly lower HF components during music therapy than before therapy in patients with SMDC, which suggests that music therapy triggers the dominant state of sympathetic nervous activities. Previous studies have reported that relaxing music decreases the level of anxiety and reduces stress (Bringman et al. 2009; Nilsson et al. 2009). On the other hand, our results show that music therapy suppressed parasympathetic

nervous activities during music therapy in patients with SMDC. These different effects might be due to the different aim of music therapy between patients with SMDC and other patients, as the aim of the music therapy in patients with SMDC is to attract attention, rather than to induce relaxation.

We observed that HF components were significantly lower during music therapy than before therapy in Patients 1 and 2. Interestingly, both patients actively reacted to music therapy. On the other hand, there were no significant changes in HF components between during music therapy and before therapy in Patients 5 and 6. These patients had severe behavioral and emotional disorders, and did not react to the music therapy clinically. Kwak et al. (2007) suggested that individual characteristics play an important role in gait training for ambulation in patients with cerebral palsy. Our results suggest that the efficacy of music therapy depends to a certain extent on the severity of SMDC in each patient.

Interestingly, Patients 3 and 4 also had severe behavioral and emotional disorders and did not seem to react to music therapy clinically. Nevertheless, both patients showed significantly lower HF components during music therapy than before therapy. These results suggest that these patients might react to music therapy, although we may not clinically observe any reaction. These results suggest that frequency domain analysis of HRV may be a powerful tool for objective evaluation of music therapy in patients with SMDC.

Our study has several limitations. First, the study was conducted with a relatively small sample. Continuous sample collection is definitely needed to extend the study. Second, we need to extend sampling periods outside of an institution (ie, at home).

Conclusion

We showed that music therapy suppressed parasympathetic nervous activities and can trigger the dominant state of sympathetic nervous activities in patients with SMDC, and that the frequency domain analysis of HRV could be a powerful tool for the objective evaluation of music therapy in patients with SMDC. Further studies are needed to evaluate the effects of music therapy in patients with SMDC.

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Conflict of Interest

All authors have no conflict of interest in this study.

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