Evaluation of the Effectiveness of Warm Footbaths on Heart Rate Variability in Patients with Profound Multiple Disabilities

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Background: Patients with profound multiple disabilities (PMD) are defined as individuals with profound cognitive disabilities (IQ < 35) and neuromotor dysfunction. Additionally, PMD patients often have sensory impairment and clinical manifestations. These conditions may result in severe developmental disability, functional and behavioral deficits, and a lack of language-based communication. Warm footbaths are implemented for patients with PMD. But the objective evaluation of warm footbaths has not been established. The aim of this study was to investigate the effectiveness of warm footbaths through the monitoring of autonomic nervous activity using heart rate variability (HRV) in patients with PMD. **Methods:** Eight patients with PMD (five patients with cerebral palsy, one with Aicardi's syndrome, one with post-traumatic syndrome after a head injury, and one with Lennox-Gastaut syndrome) and one healthy adult male volunteer had a warm footbath for 20 minutes. We used electrocardiography to measure the high frequency components (HF; with frequency ranging from 0.15 to 0.4 Hz), which represent HRV due to parasympathetic activity. Analysis of variance was used to compare the level of HF pretreatment, during warm footbath, and post-treatment in each study participant. **Results:** Six of the eight patients, including three patients with clinically severe behavioral and emotional disturbance, showed significantly lower log HF during the warm footbath than pretreatment. Seven of the eight patients showed lower log HF in the first period phase (soak lower legs and feet in 40ºC water) of the warm footbath.**Discussion:** Our results showed that warm footbaths in patients with PMD suppressed parasympathetic nervous activity and stimulated their tactile senses and emotional inputs when soaking their feet in warm water.

[Orita M, Hayashida N, Shinkawa T, Urata H, Kudo T, Katayama S, Togo M, Hiramatsu K, Takamura N. **Evaluation of the Effectiveness of Warm Footbaths on Heart Rate Variability in Patients with Profound Multiple Disabilities.** *Life Sci J* 2014;11(1):88-92]. (ISSN:1097-8135). http://www.lifesciencesite.com. 12

Keywords: Autonomic nervous activity, heart rate variability, high frequency components, patients with profound multiple disabilities, warm footbath

1. Introduction

Profound multiple disabilities (PMD) are defined as individuals with profound cognitive disabilities (IQ < 35) and neuromotor dysfunction. They also often have sensory impairment and clinical manifestations, such as seizures, respiratory problems, and feeding problems (Hamamoto et al. 2003, Iiyama et al. 2008). These conditions may result in severe developmental disability, functional and behavioral deficits, and a lack of language-based communication (Bax et al. 2005, Rosembaum 2007, Maes et al. 2007). Consequently, they are totally dependent on the support of others for all aspects of their daily needs.

Warm footbaths are frequently administered in nursing practice to improve subject's wellbeing (Saeki et al. 2007, Liao et al. 2008, Yamamoto and Nagata 2011). Warm footbaths are perceived as being a suitable method for inducing comfort and relaxation. Saeki et al. investigated the effect of footbaths on the autonomic nerve activity and immune function of healthy young females and reported that a footbath set at 42ºC for 10 minutes induced an increase in parasympathetic activity and a decrease in sympathetic activity, suggesting that footbaths promote a relaxed state. Moreover, they induced increases in subjects' white blood cell counts and natural killer cells, indicating an improved immune status (Saeki et al. 2007). In addition to their physiological effects, footbaths brought about comfortable, restful sleep (Sung and Tochihara 2000).

Warm footbaths also have frequently been provided in nursing practice to patients with PMD in order to improve their wellbeing. Although this is considered to be effective for the improvement of relaxation, immune status and sleep and the enhancement of quality of life, an objective evaluation of warm footbaths provided to patients with PMD has not been undertaken. These patients are unable to communicate with others on their own. Continued objective and non-invasive evaluation of warm footbaths as part of day-to–day care is required.

Autonomic nervous activity has been evaluated 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). Frequency domain analysis of HRV is a simple and noninvasive tool that can be used to investigate autonomic nervous system activity in patients with PMD (Yang et al. 1997, Yang et al. 2002). Heart rate variability is measured by the beat-to-beat fluctuations of the R-R intervals on an electrocardiogram (ECG). The analysis of HRV measures autonomic balance, which is principally controlled by the sympathetic and parasympathetic nervous systems (Akselrod et al. 1981).

In this study, we investigated the effectiveness of warm footbaths through the monitoring of autonomic nervous activity using HRV analysis in patients with PMD.

2. Material and Methods

Subjects

We conducted a cross-sectional design of eight patients with PMD (four men and four women, aged 17–28 years). They were patients at a residential daycare treatment and educational institution for patients with PMD located in Nagasaki, Japan. Socio-demographic data, including age, sex, diagnosis, and history of cardiac disease, are shown in Table 1. Five patients (patients 2, 3, 4, 5 and 8) had cerebral palsy, one (patient 1) had posttraumatic syndrome after head injury, one (patient 6) had Lennox-Gastaut syndrome and one (patient 7) had Aicardi's syndrome. Clinically, patients 1–3 could express their feelings through facial expressions and body movements, i.e., non-verbal expression. Patients 4–8 were permanently bedridden and showed severe behavioral and emotional disturbances.

One male volunteer (aged 21 years) was included in the study as a healthy control. He had no history of developmental delay, neurological deficit, or cardiovascular disease.

Prior to the study, informed consent was obtained from the parents of all patients as well as the healthy control volunteer. Approval was obtained from the ethical committee of Nagasaki University before the study commenced.

Table 1. Characteristics of study participants.

No.	Sex	Age	Diagnosis
1	M	28	Posttraumatic syndrome after head injury
2	M	17	Cerebral palsy
3	F	25	Cerebral palsy
4	M	21	Cerebral palsy
5	M	27	Cerebral palsy
6	F	24	Lennox-Gastaut syndrome
7	F	23	Aicardi's syndrome
8	F	19	Cerebral palsy
C	M	21	Healthy control

Abbreviations: C =healthy control; M = male; F = female

Warm foot bath procedures

Before the warm footbath, the study participants rested in a recumbent position for 30 minutes, i.e., the pretreatment period. Warm footbaths were then performed for 20 minutes. In the post-treatment period, the study participants again rested in a recumbent position for 30 minutes.

The warm footbath was performed in the sitting position on a reclining chair. During the footbath, the lower legs and feet were initially soaked for 7 minutes in 40ºC water (the first phase). The feet were then rubbed for 6 minutes with a foamy body shampoo using cotton gloves (the second phase). Finally, 40ºC water was poured over the lower legs and feet for 6 minutes, and the feet were wiped with a towel for 1 minute (the third phase). In total, each warm footbath lasted 20 minutes.

All warm footbaths were given by a single care worker. The warm footbaths were performed under stable room conditions during the day, i.e., temperature: 28ºC; humidity: 50%.

Data collection of HRV

We used a small monitoring device, i.e., a bi-axial accelerometer (ACM), thermometer, electrocardiograph (ECG), central processing unit (CPU), memory chip, and lithium cell battery (M-BIT, R.I.E., Tokyo, Japan). Each study participant wore the monitoring device on their chest, and data was measured for 80 minutes, consisted of the pretreatment period (30 min), warm footbaths period (20 min), the post-treatment period (30 min). Electrocardiogram data was recorded and stored in the device every minute and later connected to a personal computer at which time it was analyzed using software to calculate the HRV.

Frequency domain analysis

The participants' HRVs were analyzed using frequency domain methods (European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). The two main frequency domain components were: a low-frequency (LF) component of sympathetic and parasympathetic origin, with frequencies ranging from 0.04 to 0.15 Hz; and a high-frequency (HF) component of parasympathetic origin, with frequencies ranging from 0.15 to 0.40 Hz. The measurements of the LF and HF components were in power components, i.e., ms^2. In this study, because LF components are distributed in a skewed manner for patients with PMD, we measured the HF components—which represent parasympathetic nervous activity—in each study participant.

Statistical analysis

The results were expressed as mean ± standard deviation (SD). Because the HF components were distributed in a skewed manner, a logarithmic transformation was performed. Analysis of variance was used in this study. Log HF components were calculated as an average value per minute. We continued the measurements by accumulating an average of one measurement per minute. We obtained the average value of 80 measurements for each subject during the warm footbaths using Log HF components. Analysis of variance was performed for each individual before, during, and after the warm footbaths. 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).

Table 2. Changes in log HF during pretreatment, warm footbath, and post-treatment. Values are mean ± standard deviation (SD).Abbreviations: C = healthy control; HF = high frequency, *$p < 0.01$ vs. lower than pretreatment; † $p < 0.01$ vs. higher than pretreatment; †† $p < 0.01$ vs. higher than footbath

No.	Pretreatment	Footbath	Post-treatment
1	2.76 ± 0.30	2.41 ± 0.11*	2.57 ± 0.20††
2	2.74 ± 0.32	2.50 ± 0.27*	2.52 ± 0.29
3	2.45 ± 0.20	2.06 ± 0.25*	2.06 ± 0.26
4	2.45 ± 0.28	2.26 ± 0.25*	2.72 ± 0.21††
5	1.68 ± 0.33	1.34 ± 0.14*	1.49 ± 0.21
6	1.83 ± 0.29	1.46 ± 0.31*	1.73 ± 0.39††
7	1.27 ± 0.42	1.27 ± 0.28	1.69 ± 0.35††
8	2.18 ± 0.15	2.06 ± 0.19	2.03 ± 0.25
C	3.00 ± 0.12	3.28 ± 0.30†	3.23 ± 0.19

3. Results

The healthy control male showed a significantly higher log HF during the footbath than pretreatment (Table 2). On the other hand, six of the eight PMD patients showed significantly lower log HFs during their footbaths than pretreatment.

Clinically, patients 1–3 reacted to the footbaths in that their log HFs were significantly suppressed during their footbaths. Interestingly, the log HF's of the patients 4–6 who had severe behavioral and emotional disturbances clinically were also suppressed during the footbaths, in the same way as patients 1–3. Patients 1, 4, 6, and 7 showed significantly higher log HFs post-treatment than during their footbaths.

Table 3 shows the change of log HFs pretreatment, during the warm footbaths (including the three phases), and post-treatment. The healthy control male showed a significantly higher log HF in the second phase of the warm footbath compared with the pretreatment. On the other hand, patients 1–7 showed lower log HFs in the first phase of the warm footbaths, and patients 1, 3, and 5 showed significantly lower log HFs in first phase of the footbaths compared with the pretreatment.

No.	Pre-treatment	Footbath (20 min)			Post-treatmen
	(30 min)	1st phase (7min)	2nd phase (6 min)	3rd phase (7 min)	(30 min)
1	2.76 ± 0.30	2.30 ± 0.11*	2.45 ± 0.03	2.48 ± 0.09***	2.57 ± 0.20****
2	2.74 ± 0.32	2.50 ± 0.23	2.35 ± 0.35**	2.62 ± 0.19	2.52 ± 0.29****
3	2.45 ± 0.20	2.10 ± 0.25*	2.11 ± 0.19**	1.97 ± 0.31***	2.06 ± 0.26****
4	2.45 ± 0.28	2.31 ± 0.16	2.27 ± 0.11	2.21 ± 0.14	2.72 ± 0.21††††
5	1.68 ± 0.33	1.18 ± 0.11*	1.44 ± 0.13	1.42 ± 0.15	1.49 ± 0.21****
6	1.83 ± 0.29	1.46 ± 0.31	1.66 ± 0.28	1.27 ± 0.27	1.73 ± 0.39
7	1.27 ± 0.42	1.08 ± 0.16	1.41 ± 0.31	1.33 ± 0.27	1.69 ± 0.35††††
8	2.18 ± 0.15	2.18 ± 0.13	2.13 ± 0.18	1.87 ± 0.10***	2.03 ± 0.25****
C	3.00 ± 0.12	3.12 ± 0.33	3.45 ± 0.09††	3.31 ± 0.32†††	3.23 ± 0.19††††

Table 3. Changes in log HF during Pretreatment, Warm Footbath (including Three Phases), and Post-Treatment. Values are mean ± standard deviation (SD).Abbreviations: C = control; HF = high frequency. 1st phase: Soak lower legs and feet in 40ºC water for 7 minutes. 2nd phase: Rub feet using foamy body shampoo and cotton gloves for 6 minutes. 3rd phase: Pour 40ºC water over lower legs

and feet for 6 minutes and wipe feet with a towel for 1 minute.

* $p < 0.01$ vs. lower than pretreatment; ** $p < 0.01$ vs. lower than pretreatment; *** $p < 0.01$ vs. lower than pretreatment; **** $p < 0.01$ vs. lower than the pretreatment; †† $p < 0.01$ vs. higher than pretreatment; ††† $p < 0.01$ vs. higher than pretreatment; †††† $p < 0.01$ vs. higher than pretreatment.

4. Discussions

Warm footbaths were originally designed as a means to promote relaxation (Saeki et al. 2007). Despite the fact that a number of studies have reported the relaxing effects of footbaths, the effectiveness of the warm footbath in causing changes in HRV in patients with PMD has not been investigated. We therefore undertook to investigate the latter and found that, in our study, six of the eight patients with PMD showed significantly lower log HF during the footbath than the pretreatment whereas the healthy control male showed significantly higher log HF during the footbath compared with the pretreatment. These results suggest that the warm footbath may have activated the parasympathetic nervous system in the healthy male, whereas in most patients with PMD, the warm footbath suppressed parasympathetic nervous activity.

Yamamoto et al. examined the acute effects of a wrapped warm footbath on the autonomic nervous activity of healthy young volunteers and reported that their HF components increased during the footbath, suggesting that sympathetic activity is suppressed by a footbath (Yamamoto et al. 2008). However, several other studies have indicated footbath-induced stress. Xu and Uebara instructed healthy adult female subjects to take a 42ºC footbath in the sitting position for 30 minutes and reported a significant decrease in HF components alongside a significant increase in the LF/HF ratio (Xu and Uebaba 2003). These different effects could perhaps be explained by the divergent study methodologies, and the reduction in parasympathetic nervous activity in the patients with PMD might not only be due to the effects of the warm footbath itself but also the effects of tactile stimulation from soaking in warm water, massage, and washing.

On the other hand, we showed that two of the eight patients with PMD showed no significant changes in log HF components either during the footbath or pretreatment. These two patients (7 and 8) had been bedridden all day and showed severe behavioral and emotional disturbances. These results suggest that the efficacy of a warm footbath depends to a certain extent on the severity of each individual. Yang et al. and Park et al. evaluated the autonomic nervous activity in patients with cerebral palsy using an HRV analysis and reported disuse of the autonomic function (Yang et al. 1997, Yang et al. 2002, Park et al. 2002). Furthermore, Hamamoto et al. investigated autonomic nervous function over 24-hour period using power spectral analysis of HRV in healthy adolescents and individuals with severe motor and intellectual disabilities (SMID). Their study showed that the LF/HF circadian rhythm disappeared in patients with SMID (Hamamoto et al. 2003). These findings indicate that the autonomic nervous function is undeveloped in patients with PMD, and the balance of activity between the sympathetic and parasympathetic nervous systems is disturbed during a long-term bed-ridden state.

Interestingly, although patients 4–6 had severe behavioral and emotional disturbances clinically, their log HF levels were suppressed during their footbaths, the same as patients 1–3, who reacted to the warm footbath clinically. This suggests that patients 4–6 might react to a warm footbath despite the fact that we were not able to observe their reactions clinically. Kwak suggested that individual characteristics play an important role in gait training for ambulation in patients with cerebral palsy (Kwak 2007). Our current results suggested that an evaluation of the effects of warm footbaths in patients with PMD should be made not only through clinical observation but also by objective monitoring, and frequency domain analysis of HRV may be a powerful tool for such objective evaluation.

In this study, we observed a higher log HF in the healthy control during the warm footbath when his feet were rubbed by the care worker. On the other hand, most patients with PMD showed a lower log HF only when their lower legs and feet were soaked in hot water—before their feet were rubbed—compared with pretreatment. These results suggest that, in patients with PMD, the warm footbath phase in which their lower legs and feet are soaked in hot water attracts their attention and generates stimulation rather than inducing relaxation. A warm footbath may stimulate the tactile senses of patients with PMD through soaking their feet in warm water and consequently stimulating their emotional inputs.

Our study had several limitations. First, the study was conducted with a relatively small sample. Continuous sample collection is definitely needed in order to extend the study. In addition, this study examined only one healthy volunteer. Extension of the study will require an increased number of healthy volunteers. Second, the sampling times need to be extended, particularly after the warm footbath treatment. Since frequency domain analysis of HRV is a simple and noninvasive tool that can be used to investigate the sympathetic and parasympathetic components of autonomic function, further studies are needed to evaluate the effects of a warm footbath by monitoring the changes in HRV in patients with PMD.

In conclusion, we were able to demonstrate that, in patients with PMD, warm footbaths suppressed parasympathetic nervous activity but may have stimulated the patients' tactile senses during the phase in which their feet were soaked in warm water and consequently stimulated their emotional inputs. Moreover, we demonstrated that frequency domain analysis of HRV could be a powerful tool for the objective evaluation of warm footbaths in patients with PMD. Future studies are needed to further develop objective strategies for the evaluation of the effectiveness of warm footbaths in patients with PMD.

Acknowledgements:

We thank all of the patients as well as the healthy volunteer for their participation in this study. We also thank to Ms Rina Matsumoto and Ms Honami Okubo for their technical support.

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12/31/2013