Analysis of Heart Rate Variability in Young Male Adults with Depression and Anxiety during Warm-water Footbath

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Abstract

Background: Heart rate variability (HRV) modulates both the sympathetic nervous system and the parasympathetic nervous system (PNS) of the autonomic nervous system. Mood disorder is one of the contributing factors to influence HRV. The warm-water footbath as a relaxing way is used to enhance the PNS. In this study, we intended to explore the association between HRV and a footbath in the mood disorder group. **Methods:** We recruited 14 young male study participants to receive a 30-minute warm-water footbath three times a week. Furthermore, we monitored the heart rates electrocardiographically before, during, and after the intervention. **Results:** This study showed that the footbath not only significantly enhanced standard deviation of NN (SDNN) intervals, high-frequency (HF) power, and low-frequency (LF) power during the first five minutes footbath ($p < 0.01$) but also increased all the parameters in five minutes after finishing the footbath. SDNN intervals, HF power, and LF power remained significantly upward in the next five minutes ($p < 0.05$). **Conclusion:** In line with previous studies, this study showed that a footbath elevated the PNS-related HRV parameters. We suggest that a warm-water footbath improves the PNS modulation possibly through baroreflex. In addition, those with cardiac conditions and depression should be particularly attentive to their condition during and following a footbath.

Key words: autonomic nervous system, electrocardiogram, the standard deviation of NN intervals, baroreflex
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Introduction

Heart rate (HR) is well known to modulate the autonomic nervous system (ANS) [1]. The ANS has both the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS), to influence the involuntary physical process [2]. In a non-invasive approach, both qualitative and quantitative influences can be assessed by analyzing heart rate variability (HRV), which refers to the fluctuations in the time intervals between consecutive heartbeats [3].

Since the first report of arrhythmia in infants analyzed through electronic equipment [4], scientists have adopted the Fourier's transform to analyze the interval from the onset of one R wave to the onset of the next one, also called the RR interval in the electrocardiogram (ECG) [5]. The frequency domain of the HRV correlates with the SNS and PNS [6]. The decrease or elevation of the PNS and SNS fluctuates with healthy variation, physically and psychologically, including age, sleep, ischemic heart disease, depression, anxiety, schizophrenia, and so on [6].

HRV provides us with a way to know how those diseases take effect through the ANS. Meanwhile, HRV is not only affected by diseases but also by the stress of daily life [7]. Stress is defined as any intrinsic or extrinsic stimulus, to evoke a biological response [7], which either impacts the cardiovascular system through stimulating the SNS and suppressing the PNS. Many methods already exist to reduce stress, such as diaphragmatic breathing, meditation, and exercise, which all positively contribute to ANS. As one of these means, the footbath has been used for relaxation worldwide by soaking

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one's feet above the ankles in a warm-water pool, especially in the Taiwanese and Japanese culture [8]. Past studies showed that a warm-water footbath and bathtub intervention can decrease ANS activity along with enhancing the PNS [9, 10]. In our previous report [11], we also confirmed that a 15-min footbath can decrease RR interval of the ECG, that the effect even lasts for at least 5 min after finishing the footbath, and that the footbath can improve the severity of depression and anxiety when combined with the antidepressant treatment in a small group of young adults.

But little is known between HRV and the footbath in the group of young males with depression. In this study, we intended to duplicate the findings [11] through analyzing the frequency domain of ECG, to explore the changes of ANS during a warm-water footbath in 14 young male study participants.

Methods

Study participants

This study protocol was reviewed by the institutional review board at the Tri-Service General Hospital, National Defense Medical Center in Taipei, Taiwan (TSGHIRB No. 2-103-05-098 and date of approval September 16, 2014), with the need to obtain informed consent from the study participants.

In view of the HRV dependent on age [12], we recruited 14 male young adult patients of 22–25 years of age. They had a diagnosis of mild depression (*International Statistical Classification of Diseases and Related Health Problems, 10th Revision*: F32.0, F32.8, F32.9) during their admission at the Tri-Service General Hospital, Beitou Branch, from 2015 to 2016.

Apart from depression, all study participants were free from chronic medical conditions such as type 2 diabetes mellitus, hypertension, stroke, coronary artery disease, heart failure, chronic obstructive pulmonary disease, and severe arrhythmia to reduce the confounding effect by the comorbidities or disease status. Besides, the participators were prohibited from the use of drinking alcohol and cigarette smoking during the previous 2 weeks and from caffeine consumption for at least 24 h. They also avoided exercising and binge eating for at least 8 h to avoid the possible influences on the HRV indicators. Furthermore, they would have their usual meal on the day of the study to ensure the standardization of the ECG record and analysis. All patients were examined for their skin integrity of their feet in the beginning, and any presence of wounds or infectious symptoms on their feet was excluded from the study.

Study procedures

Every participant wore uniform in shorts and a short-sleeved T-shirt without a coat or jacket. During the period of the study, their medication included 12 subjects of selective serotonin receptor inhibitors (5 – fluoxetine, 4 – escitalopram, 2 – sertraline, and 1 – paroxetine), one subject of norepinephrine–dopamine reuptake inhibitors (bupropion), and 1 subject of noradrenergic and specific serotonergic antidepressant (mirtazapine). We adjusted the dosages of antidepressants for reaching defined daily dosages, and all patients were in a clinically stable condition. There were no other medications prescribed in these subjects, particularly in the usage of beta-blockers, calcium channel blockers, and angiotensin-converting enzyme inhibitors. We explained in detail to let all the participants fully comprehend the study's purpose, process, risks, possible benefits, and alternative treatment. Signed informed consent from the participants was obtained, and they were free to withdraw from the study at any time. Through the whole process, the participants were guided to sit on while breathing naturally and their anonymity was preserved.

The whole study was done in an air-conditioned room set at 26°C and a fixed daily relative humidity. ECG was recorded throughout the footbath. We requested participants to sit on a chair and measured their ECG at 3:00 p.m. on the test day, following a 10-minute rest with natural, spontaneous breathing to ensure they reached their resting heart rate. Then, they soaked their feet to a depth just above the ankles into an automatically thermostatic barrel with 40°C warm water for 30 min. The ECG recording lasted from 5 min before the footbath to 10 min after they took their feet out of the barrel. Every participant received three repeated ECG tests to accumulate a relatively comparable follow-up intensity and adjusted for covariates.

Physiological monitoring

Heart rate

HR was the targeted and the physiology signal was monitored 5 min before, during, and 10 min after the footbath. After a 10-min rest in a quiet, air-conditioned room, a telemetrically transmitted lead I of ECG with 288-s signal sequence was recorded.

Heart rate variability interpreted from electrocardiogram

The raw ECG signals were amplified by a gain of the number of times the power of 1000 and band-pass filtered in a range of 0.68–16 Hz. After that, the signals were then recorded with an eight-bit analog-to-digital converter at a sampling rate of 256 Hz. The digitized ECG signals were analyzed online and simultaneously stored in removable hard disks for offline verification. The raw data were gathered and analyzed every 5 min which gave every HRV parameter.

All the signal acquisition, data storage, and processing were done through a general purpose personal computer. We identified each QRS complex and rejected the ventricular premature complex, or noise, according to its likelihood in a standard QRS template using our computer algorithm. Next, we resampled the stationary RR interval values and interpolated at a rate of 7.11 Hz to produce continuity in the time domain.

The mean RR interval, measured in milliseconds (ms), is the time-domain parameter. We excluded the study participants who did not have a mainly regular sinus rhythm, or those who had sustained atrial arrhythmias, such as atrial fibrillation or ectopic complexes. The standard deviation of NN (SDNN) intervals, another time-domain parameter, indicates the extent of fluctuation or changes in the duration between successive heartbeats. A higher value of SDNN typically suggests greater variability in HR, which is often associated with better cardiovascular health and functioning of the ANS [13].

Among the parameters of HRV, high frequency (HF) represents the PNS activity by respiratory input, whereas low frequency (LF) is regarded as a marker of the SNS [14]. LF also contributes to both the PNS and SNS activities by feedback regulation of the baroreceptor [15, 16]. In other words, the PNS predominates by the LF value when relaxing or taking a deep breath. The very LF was not taken into consideration by a reason of the low validity in the short-term measurements [3]. In brief, HF activity in HRV analysis is often associated with the PNS, whereas LF activity is thought to possibly relate to the SNS. But the interpretation of LF activity's relation to the SNS is debated and may involve contributions from both sympathetic and parasympathetic influences.

Statistical analysis

We first did the descriptive analyses of the demographic data of participants, such as age, RR interval, SDNN, HF, and LF. In addition, due to the small sample size, we compared the parameters using nonparametric analysis to know the change of the HRV parameters during the footbath with the baseline set at 5 min before footbathing. All the analyses were through an application of the Statistical Package for the Social Sciences software version 25 for Windows (SPSS Inc., Chicago, Illinois, USA).

Results

Table 1 includes information of 14 young male participants and their demographic details along with HRV parameters measured at three different stages: pretest, during the test, and posttest. The average age of ± standard deviation of study participants was 23.6 ± 0.914 years. At the pretest stage, the average RR interval ± SD was 813 ± 110 ms. SDNN was 52.0 ms squared with a variance of 22.3. The natural logarithm ± SD of LF was 6.27 ± 0.948 units, and that of HF was 5.39 ± 0.983 units. The average RR interval ± SD during the test was 794 ± 91.0 ms.

This change of PR before and during the test was significant ($p < 0.01$). SDNN during the test was 49.6 ± 12.9 ms^2. The average LF ± SD during the test was 6.24 ± 0.711 units. The average HF ± SD during the test was 5.41 ± 0.848 units.

At the posttest stage, the average RR interval ± SD was 798 ± 92.7 ms. The change during and posttest was not significant. The average SDNN ± SD in posttest was measured at 57.1 ± 19.6 ms^2, indicating a significant change ($p < 0.05$) from during to posttest. The average LF ± SD in posttest was 6.56 ± 0.800, showing a significant increase ($p < 0.01$). The average HF ± SD in posttest was measured at 5.53 ± 0.848, showing no significant increase. These results display the changes in HRV parameters among the young male participants across different stages of testing, indicating notable variations during and after the test compared to the pretest values.

We tracked each HRV parameter every 5 min and compared it with the baseline to detail the effect of the footbath (Figure 1).

Table 1. The demographic data and heart rate variability parameters of male study participants (n = 14)

Factors	Value (mean ± SD)
Age	23.6 ± 0.914
Before the footbath	
RR (ms)	813 ± 110
SDNN (ms^2)	52.0 ± 22.3
LF ln (ms^2)	6.27 ± 0.948
HF ln (ms^2)	5.39 ± 0.983
During the footbath	
RR (ms)	794 ± 91.0**
SDNN (ms^2)	49.6 ± 12.9
LF ln (ms^2)	6.24 ± 0.711
HF ln (ms^2)	5.41 ± 0.848
After the footbath	
RR (ms)	798 ± 92.7
SDNN (ms^2)	57.1 ± 19.6*
LF ln (ms^2)	6.56 ± 0.800**
HF ln (ms^2)	5.53 ± 0.848

* $p < 0.05$, ** $p < 0.01$ using nonparametric analysis comparing the HRV parameters with baseline (5 min before the footbath)

HF, high frequency; LF, low frequency; SD, standard deviation; SDNN, standard deviation of NN interval; HRV, heart rate variability

RR interval versus time

At the beginning of the footbath, no pronounced change was observed in RR interval. RR interval depicted a continuously significant decline from 15 to 30 min after the beginning. At the end of the footbath, the RR interval returned to reach its baseline.

Standard deviation of NN versus time

At the onset of the footbath, the SDNN presented a significant peak ($p < 0.001$) followed by a sharp decline below the basic level, maintaining a minor oscillation around this level until the conclusion of the footbath. Afterward, the SDNN climbed up remarkably in the 10-min follow-up ($p < 0.05$).

High frequency versus time

The HF emerged with significant growth ($p < 0.001$) after starting the footbath and went down to basis with minimal fluctuation all along the footbath. The HF rose again in the 10-min follow-up ($p < 0.05$).

Low frequency versus time

Similar to the HF pattern, the LF showed a significant surge ($p < 0.01$) at the initial stage of the footbath and then dropped with minor fluctuations around its baseline until the end of the footbath. Subsequently, there was a significant increase in LF during the 10-min follow-up ($p < 0.01$).

Taken together, the footbath significantly enhanced the SDNN, HF, and LF during the first 5-min footbath and then returned to being insignificant when compared with its basic level through the footbath. On the contrary, RR interval was relatively stable at the beginning and then declined from 15 to 30 min during footbath. After the finishing of the footbath,

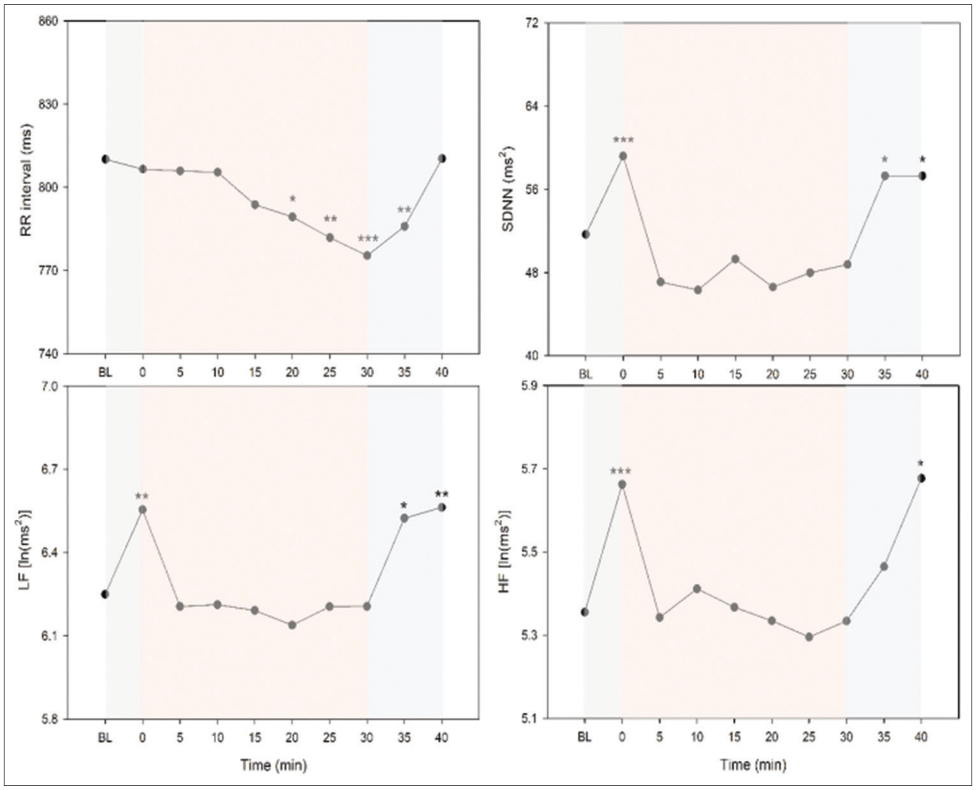

Figure 1. Footbath - related parameters of heart rate variability (including 5- min before, during, and 10- min after the footbath) $*p < 0.05$, $**p < 0.01$, $***p < 0.001$, significantly different using nonparametric analysis comparing the HRV parameters with baseline (5- min before the footbath).

the RR interval, SDNN, HF, and LF grew in the first 5 min. Nevertheless, the SDNN ($p < 0.05$) and LF ($p < 0.01$) remained significantly elevated in the subsequent 5 min compared to the baseline, while the RR interval climbed back to the baseline level.

Discussion

This study included a small number of participants ($n = 14$) and being only male. Consequently, regarding gender differences, no further analysis or adjustments were made. HRV time-domain measurements steadily decline with normal aging, primarily due to a significant decrease in nocturnal parasympathetic activity observed across each decade [17]. Since the participants in our study were all within the 22–25 years' age range, the same age bracket, we did not do any age-based analytical adjustments or corrections. We previously reported that the footbath improves depression and anxiety in the same group through analyzing the Beck Depression Inventory (BDI) and Beck Anxiety Inventory (BAI) scores, which are self-report assessment tools designed to measure the severity of depression and anxiety symptoms, respectively [11]. The data of the BAI and BDI were already discussed in that article [11]. In this article, we further explored the possible underlying HRV changes before, during, and after the footbath.

First, the increase in SDNN, HF, and LF during the initial 5 min of the footbath was observed, presumably attributed to heightened parasympathetic activity. The main contributor to SDNN variability is the parasympathetically mediated respiratory sinus arrhythmia, particularly in short-term resting recordings involving slow, paced breathing [18]. In a previous Japanese study, immersing in shoulder-deep warm water while seated can increase in body temperature, resulting in a subsequent thermoregulatory vasodilation, mediated by parasympathetic stimulation [9, 19]. Therefore, the baroreflex connects HR, blood pressure, and vascular tone [20]; vascular dilation concurrently accompanies changes in blood pressure, initiating the baroreflex, which is reflected by LF during resting conditions [18]. The underlining mechanism of the warm-water bath and PNS has been proven that it kindles the pituitary gland to release the beta-endorphin hormones which provoke the PNS [21, 22]. Despite variations in water pressure during whole-body immersion, our study focused on the use of footbaths. We observed significant decreases in RR interval ($p < 0.01$) during the footbath, as well as in SDNN ($p < 0.05$) and LF ($p < 0.01$) after the footbath, when compared to pre-test data (Table 1).

Past study demonstrated that the warm-water footbath can alleviate fatigue in those receiving the chemotherapy [8]. The LF was surged during the initial phase of the footbath (Table 1) also as a consequence of induced relaxation. Subsequently, this change returned to the baseline when individuals adapted to the new external thermal conditions. Throughout the footbath process, no notable fluctuations were observed in the HRV parameters except for the RR interval (Table 1). A consistent and significant decline in the RR interval was noted between the 15th and 30th min of the footbath (Figure 1). This change aligns with that found in a previous research, indicating that immersing in 40°C water elevates core body temperature after a hot bath lasting more than 10 min [23]. Specifically, the warm-water temperature gradually increased the body's core temperature, leading to an elevated HR through reducing the RR interval, as observed in our study as well.

Second, all measurements including SDNN, HF, and LF continuously rose when compared with the baseline in the following 10 min after the footbath, with the exception of the RR interval (Table 1), which returned to its baseline level. The possible explanation is the sudden temperature change of both feet from 40°C in the footbath to 26°C in the conditioned room temperature. Upon exposure to the relatively colder air, the blood circulation in the extremities of the feet responded rapidly by vasoconstriction which was mediated sympathetically to lower the perfusion to the peripheries. Gradually, the skin temperature of the feet approaches the ambient environmental temperature [24]. Nonetheless, the PNS remains activated even after the footbath in view of the sustained long-lasting relaxing and releasing effect. We speculate that the temperature of the footbath may have different influences on the time course of the SNS versus PNS. All the HRV measurements are enhanced after finishing the footbath with the higher increments of the parasympathetic-related variables than the sympathetic-related ones, because PNS hold a relatively dominant status that added to a greater dynamic range of activity [25, 26]. We further suggest that PNS becomes more flexible and easily excited after a footbath. But previous studies from Japan and India [10, 27] showed that the parasympathetic withdrawal is observed alone with the sympathovagal balance toward the SNS regardless of whether head-out immersion or arm and footbath. This finding is not compatible with that in our study. The bath level up to chest height possibly induces the pressure of the water on the body, potentially increasing the stroke volume of heart and cardiac output, similar to the activity of SNS. The viewpoint has been supported by the finding of a population-based prospective study in Japan with a total of 30,076 participants aged 40–59 years [28].

Third, patients with major depressive disorder or anxiety disorder reflectively reduce HF than the healthy controls in the previous meta-analysis [29]. But an interesting finding of our study showed that the warm-water footbath elevated the HF in the group of young males with depression (Figure 1), suggesting that a warm-water footbath may have the potential ability to improve the PNS and might be associated with the baroreflex.

Finally, an increased HR causes greater stress on the heart. Our study showed that heart rhythms began to shorten interval and regularly accelerate after a 15-min footbath. Individuals with depression with preexisting heart conditions should take caution during foot baths, avoiding durations exceeding 15 min. Ten minutes after the footbath, there was a gradual return to normal heart rhythm as indicated by RR intervals. Nevertheless, the notable rise in SDNN suggests considerable HRV during this timeframe. Individuals with depression with cardiac arrhythmias need to be cautious during this postfootbath phase.

Study limitations

Our greatest strength is that this is the first study to discuss the association of the footbath and HRV in a group of young males with depression. We not only monitored the whole process of the footbath but also kept track of the period before and after the footbath. But this study has a limited generalizability to other populations, because this study has six limitations:

- We only included younger, exclusively male, and an entirely Taiwanese population. Given the gender impact on HRV, the design of our study was focused on a male group, and it would have been better to arrange a comparison between women and men [30]
- The time of the day in our study was designated at 3:00 p.m., not a 24-h monitoring. The time of the day can subject to the influences on HRV of the circadian rhythms
- The relatively small sample size can cause additional uncertainties to the estimations of our study
- We did not have any control group in this pre–post study
- Each participant attended our study no more than 2 weeks with a short-term footbath exposure and lack of follow-up
- The sensitivity of each participant to externally thermal stimulus is different.

All the aforementioned items may produce some additional bias to our study. Further investigations are still needed to determine the most representative indicators of the temperature variability and HRV parameters, also evaluating their associations with a more robust study design and a larger sample size.

Study summary

In this study, we explored the possible underlying HRV changes before, during, and after the warm-water footbaths which revealed significant elevation of PNS-related HRV parameters, consistent with the whole-body immersion bath. Moreover, HRV measurements significantly improved following the completion of the footbath, showing greater increases in parasympathetic-related variables. Warm-water footbaths may possess the potential to enhance the parasympathetic nervous system and could be linked to baroreflex function, as indicated by the results of our study. We also remind that individuals with both heart conditions and depression should consider to limit their footbath duration to no more than 15 min. In addition, those with cardiac arrhythmias and depression should be particularly careful and pay attention to their condition following a footbath.

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Data Availability Statement

Original study data used in this study can be shared if contact with the corresponding author is made.

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None declared.

Conflicts of Interest

The authors declare no conflicts of interest in writing this report.

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