The Stress-Decreasing Effects of Urban Green Environments based on Intraindividual and Interindividual Variations in Heart Rate

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Abstract: In recent years, the stress-decreasing effects of “forest-bathing” have been garnering attention, and experimental research has been actively conducted by measuring physiological responses, such as heart rate. The present study focused on green environments in urban areas. We measured the stress-decreasing effects of resting and walking in urban green environments using a watch that monitors heart rate. First, it was confirmed that there were large variations and individual differences in each measurement of interbeat intervals (R–R interval: RRI) while resting. The heartbeat index “RRI-lowering rate while walking” was then defined taking into account such intraindividual and interindividual variations. On comparing both environments, we found that nine out of 12 participants showed greater RRI values in the green environment than in the non-green environment.

Keywords: Heart Rate, Green Environmental, Stress Assessment, Individual Differences, Condition of Examinee

1. INTRODUCTION

Modern society is considered to be a “society of stress,” in which there is an increasing awareness and need for individuals to obtain peace of mind and relaxation from nature. It has been reported that the accumulation of unpleasant stimulation in urban life causes a state of stress, which disturbs in vivo hemostasis and leads to many diseases in the long term. Forest-bathing has recently been garnering attention as a means of decreasing such physiological stress.

For examination of the stress-decreasing effects of vegetation, Miyazaki et al. (2010) conducted a series of studies in which the relaxation effect of forest therapy was examined on the basis of vital reaction data measured in urban areas and forests. Increasing evidence has also accumulated on the physiological effects of vegetation in natural environments, such as the rehabilitative effect of forest-bathing by Takeda and Kondo (2009), the stress-decreasing effect of walking in forests and botanical gardens by Mitsui (2008), heart rate variations after walking in forests by Suzuki (2008), and improved bodily immune function from forest-bathing by Li (2010).

On the other hand, greenways and green spaces in urban areas (hereafter referred to as urban green environments) are expected to decrease urban heat islands, improve townscapes, and alleviate stress as “local forests” and, in this respect, several experimental studies have been conducted to date. On the basis of brain wave and heart rate measurements, Kuroko and Fujii (2002) found that stress caused by noise exposure was relieved more in spaces with vegetation than in unnatural spaces. Furthermore, on the basis of walking heart rate measurement data, Matsuba et al. (2010) found that increase in heart rate with the same load was restrained when walking in the Shinjuku Imperial Gardens compared to walking near the train station, suggesting that walking in green environments in urban areas has a relaxing effect.

Although various in vivo observations, such as those mentioned above, have been attempted, there is currently no established measurement method or evaluation index. Among vital reactions, heart rate is readily affected by various external factors; however, heart rate measurement has advantages in that devices to measure heart rate are simple and inexpensive, enable on-site and real-time measurements, and allow easy statistical analysis. In terms of international standards related to human engineering, biological signals include heart rate variations, and we believe that heart rate measurement will become common practice in future.

For stress assessment by heart rate, the following indicators are proposed and adopted. Kajima et al. (2009) have confirmed the time-series variation of RRI (RR-Interval), find the difference from the value at rest, and propose the total stress value (TSV) at the target time from the total value. Ishida et al. (2012) found the distribution area of Lorentz plot of RRI and show that it is valid for stress measurement when riding in a railroad. Uchimura et al. (2012) measure the amount of stress from the ratio of HF and LF obtained from the spectrum of RRI. However, there is a problem that the above indicator is limited to application to only a specific subject. This is because the indicators don't take into consideration personal conditions and individual differences.

As shown in Figure 1, heart rate is affected by various factors. Therefore, measurement conditions and data-processing procedures need to be devised to extract only target influential factors (stressors) and measure associated stress intensity. For example, to examine the relationship between stress and the presence or absence of greenery, as in the present study, area-specific influences other than greenery, such as humidity, noise, and slope, clearly need to be controlled and standardized. As fitting a measurement device to the body can cause stress, small and simple devices need to be made available. It is also preferable to take measurements and perform analyses while taking intraindividual changes in heart rate (intraindividual variations), and interindividual differences (interindividual variations) into consideration, according to psychological and physical conditions.

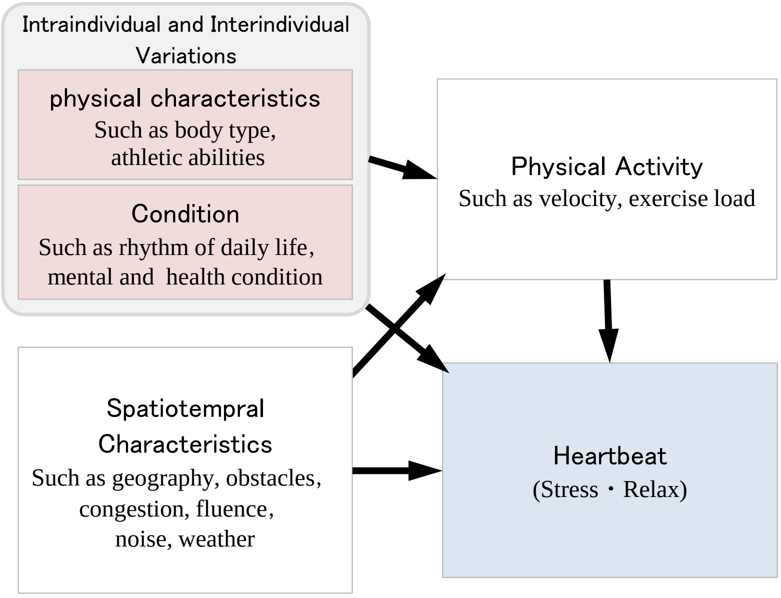


Figure 1. Factors influencing heartbeat

Given that most measurements and analyses in previous studies have not been conducted as described above, in the present study, we took measurements with a wrist watch-type wearable heart rate monitor and developed a stress evaluation index using heart rate data while taking intraindividual and interindividual variations into consideration. We also examined whether stress can be relieved more by walking in green environments than in non-green environments in the event of moving to urban areas. In the second chapter, we repeated the measurements while resting (rest experiment), and verified the extent of intraindividual variations in heart rate in the spatial environments used in the present study. In the third chapter, heart rate measurements were repeated for rest → walking (walking experiment), and the stress index, taking into account intraindividual variations, was examined. In the fourth chapter, measurements were taken for rest → walking in a large subject sample (multi-person experiment), and using the heart rate index while taking intraindividual and interindividual variations into consideration, the rate of stress relief due to walking in urban green environments and associated gender differences were examined.

2. Intraindividual Variations in Heart Rate while Resting (Rest Experiment)

2.1 Outline of the Rest Experiment

In this experiment, the greenway of Rikugi-en Garden in Bunkyo ward, Tokyo, and the area within Tokyo Dome City were selected as the green environment and non-green environment, respectively (Photo 1). Rikugi-en Garden is designated a special place of beauty under the Cultural Properties Protection Law, and is a traditional Japanese strolling garden that features a central pond and is rich in greenery with large trees, such as pines, maples, and Japanese elms, as well as shrubs and lawn grass. The park is known to be used by many people for exercise purposes, including walking. Tokyo Dome City is a large commercial facility adjacent to Tokyo Dome (Baseball Ground) located in Bunkyo ward, Tokyo as well as Rokugi-en. The walking space is covered with concrete, tiles, reinforcing bars, etc. as shown in Photo 1, and it is used for many purposes such as commuting and school attendance.

Green envrionment
(greenway of Rikugi-en Garden)

Non-green envrionment
(pedestrian space in Tokyo Dome City)

Photo 1. Experiment environment

In both environments, subjects sat restfully with their eyes closed for 5 min, eyes open for 5 min, and eyes closed for 5 min, and measurements were taken in task order for a total of 15 min, using the RS800CX (Polar) heart rate monitor for running. RRI data were collected using specially designed software.

RRI is the time interval between R waves seen on EKG (heart rate reciprocal) and has been used in many stress evaluation studies. For example, when comparing RRI measurements in different tasks, a high value indicates that the task causes relatively little stress. Furthermore, RRI data rarely have missing or exceptionally large values, and, therefore, in the present study, taking this into account, the median RRI (RRI_M) for the duration of each task was used in our analyses.

The subject sample included one male student (subject A) in whom the 15-min measurements were repeated in the green and non-green environments, respectively. The subject was instructed not to eat and drink or drink anything for at least 1 h before measurements. Furthermore, the experimental period was set as a sunny autumn day, taking into account the effect of temperature, weather conditions, and the effect of crowds, i.e., measurements were started when there were no people walking around.

2.2 Intraindividual Variations in RRI while Resting

RRI_M with eyes closed and eyes open in the green and non-green environments are shown in Figure 2. First, when focusing on the variation in RRI_M in the same task, we found that measurements varied by approximately 100–200 ms. We believe that was because of the subject's physical and psychological condition, such as fatigue and mood. Therefore, because RRI_M greatly varied within the individual, a t-test was performed of the mean RRI_M in the green and non-green environments, using data obtained from the 15-min measurement. As a result, in the non-green environment, RRI_M decreased from when the subject's eyes were closed to when they were opened, after which it tended to increase when their eyes were closed to when they were open; however, no statistically significant differences were noted. In contrast, in the green environment, there was no significant difference between the eyes being opened and the eyes being closed. However, when the eyes were closed after being open, RRI_M decreased significantly (p value: 5%).

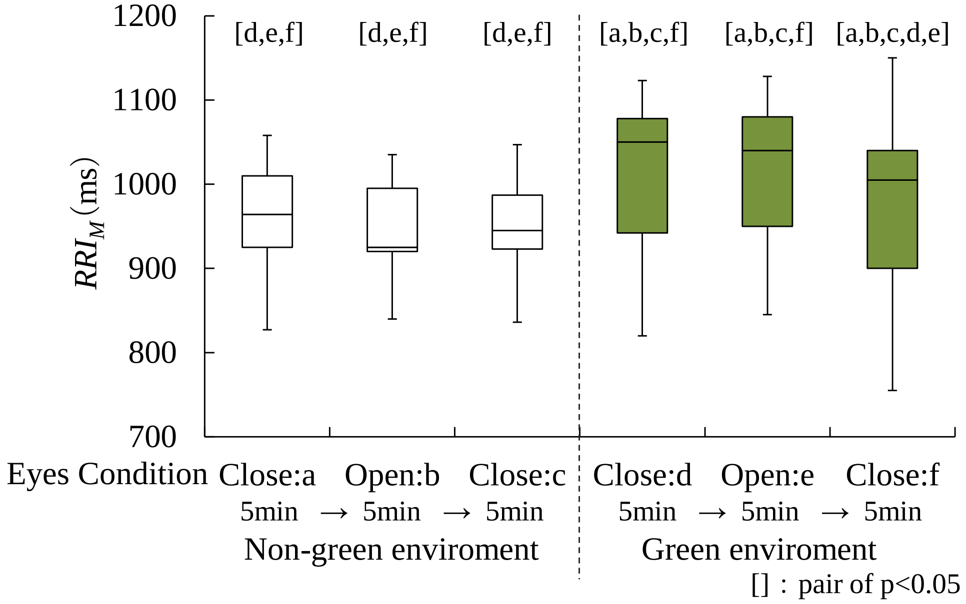


Figure 2. RRI_M in the green and non-green environments

On comparing the two environments, in each task, RRI_M was found to be significantly greater in the green environment than in the non-green environment. Therefore, subject A experienced less stress while resting in the green environment than in the non-green environment. The reason why RRI_M medically extremely when the eyes were closed after being open in the green environment should be explained. Also, the variance of the RRI_M in the green environment is larger. At the present time, data for clarifying the above cause has not been acquired. This point will be a future subject.

3. Heart Rate Characteristics while Walking (Walking Experiment)

In chapter 2 (rest experiment), despite the consistent experimental environment, we found major variations in RRI_M caused by the condition of the individual at the time. In the present study, considering such intraindividual variations in heart rate, we examined the effect of walking on heart rate in green environments.

3.1 Outline of the Walking Experiment

In the same experimental environment as that used in the rest experiment, RRI was measured while resting for 10 min and then while walking for 10 min for a total of 20 min in a green environment and in a non-green environment. The subject sample included three male students (subjects B, C, and D) for whom measurements were repeated 15 times each in a green environment and in a non-green environment. With regard to the walking speed, to prevent the influence of exercise load, subjects were free to walk at their own pace. Furthermore, the mean walking speed was measured using the speed sensor included in the

RS800CX heart rate monitor (s3+ slide sensor W.I.N.D), and when the difference in the mean speed of earlier measurements was ≥0.3 km/h, measurements were repeated. Other experimental conditions and measurement equipment were the same as in the rest experiment.

3.2 Stress Evaluation Taking Intraindividual Variations in Heart Rate into Consideration

The measurements for one subject are shown in Figure 3. We found that RRI differed while resting and walking, and a major decrease in RRI was observed immediately after the subject started walking. As seen in Figure 2, RRI_M while resting (RRI_R) varied according to the subject's condition upon taking the measurements under the same experimental conditions; thus, it was difficult to use RRI_M while walking (RRI_W) as is to measure stress. As RRI_W is thought to be caused by conditions at the time of the measurement that are concerned with RRI_R immediately before the measurements, and, therefore, to verify this, we investigated the relationship between RRI_W and RRI_R. As an example, the results of subject D are shown in Figure 4. Although RRI_W and RRI_R showed slight variation in the non-green environment, in both environments R^2 was ≥0.5.

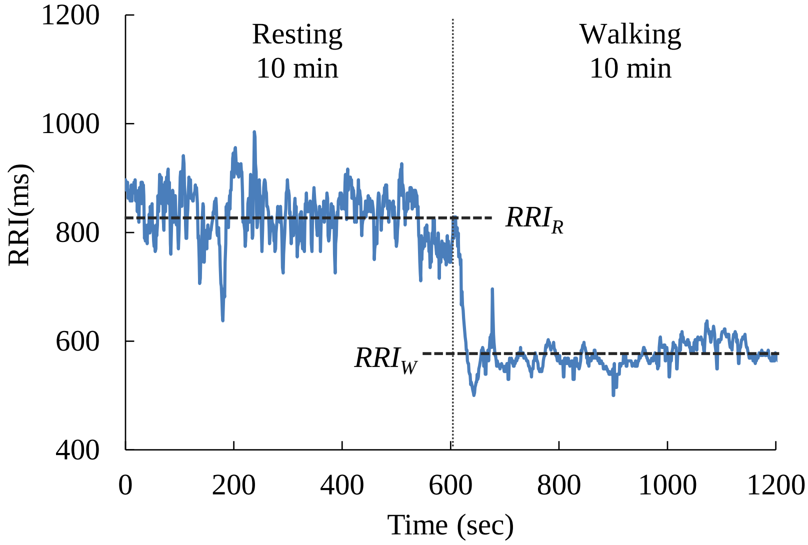


Figure 3. A type of RRI while resting and walking

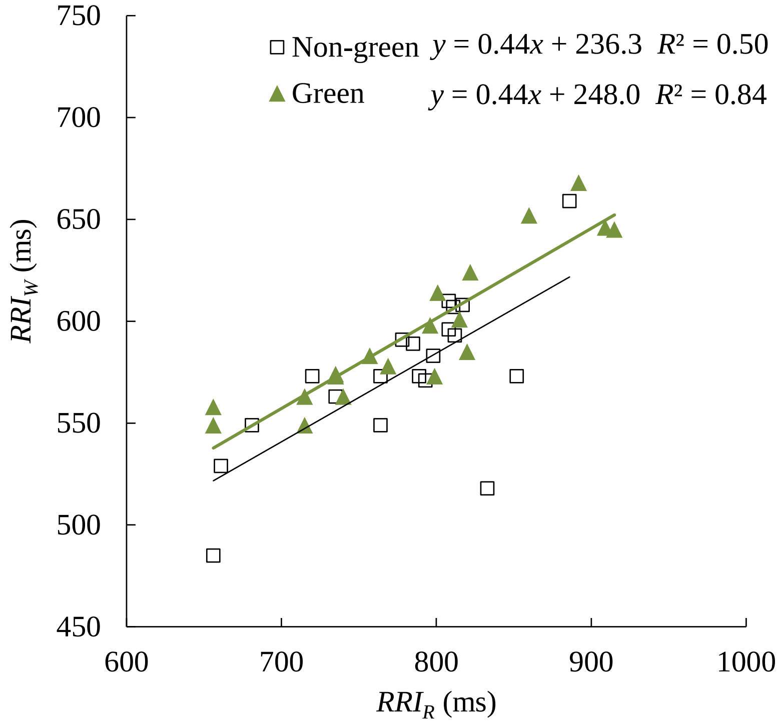


Figure 4. Relationship between RRI_R and $RRIw$ (subject D)

For the most part, the decrease in RRI from rest to walking (increased heart rate) was attributed to exercise loading. When the same exercise load was applied, it appears that the lower RRI, the lower the amount of stress in that spatial environment. As studies to date have interpreted this as the difference in RRI (or heart rate) immediately after resting and walking, we decided to use decrease in RRI while walking as calculated using the formula below (1) in our analyses.

$$\text{Decrease in RRI while walking} = RRI_R - RRIw \tag{1}$$

Upon examining the relationship between decrease in RRI while walking and RRI_R, as shown in Figure 5, a clearer relationship was found than when $RRIw$ was used. Furthermore, even with the same RRI_R in the non-green and green environments, we found that the decrease in RRI while walking was smaller in the green environment. This indicates that regardless of the subject's condition at the time of measurement, compared to the non-green environment, in the green environment, the decrease in RRI when changing from rest to walking was smaller, and that even in similar walking, increase in heart rate was inhibited.

Figure 6 shows decreases in RRI of the three subjects in this experiment while walking. In all subjects, the amount of decrease in RRI while walking was significantly lower in the green environment than in the non-green environment (p value: 5%). Therefore, for the three subjects in this experiment, the increase in heart rate (RRI decrease) was lower when walking in the green environment than when walking in the non-green environment, signifying that there was a stress-decreasing effect.

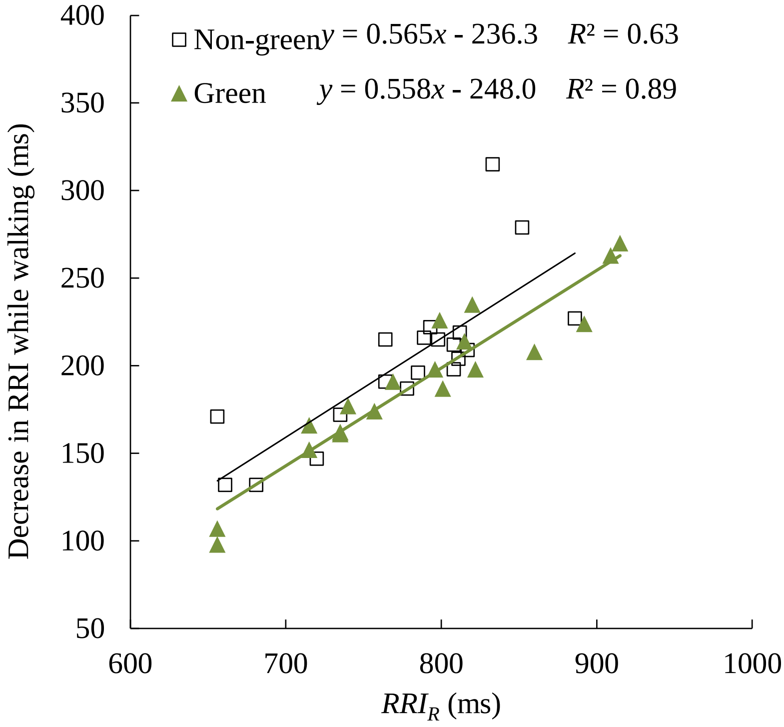


Figure 5. Relationship between RRI_R and decrease in RRI while walking (subject D)

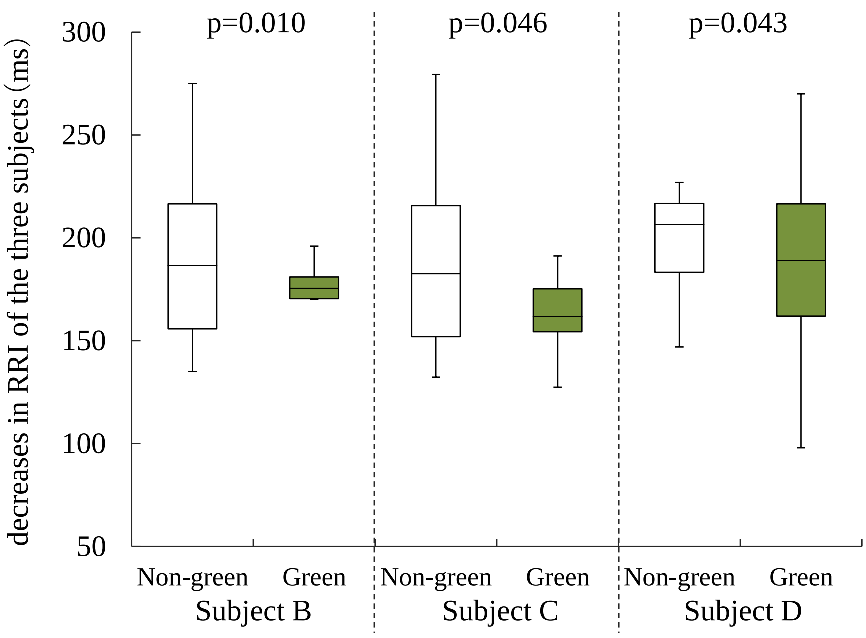


Figure 6. Decreases in RRI of the three subjects

4. The Rate of Stress Relief and Gender Differences (Multi-Person Experiment)

In chapter 3 (walking experiment), to evaluate stress while walking, using difference (decrease in RRI while walking) based on RRI while resting immediately before walking was shown to be effective. Because this was an index that did not depend on the conditions at the time of measurement, there was no need to verify the conditions by repeated measurements. Therefore, this chapter focused on the number of subjects rather than the number of measurements taken per individual, and it examined the rate of stress relief brought about by walking in the green environment and gender differences.

4.1 Outline of the Multi-Person Experiment

In this experiment, considering the number of subjects and moving the measurement site, we changed to the Kouraku ryokudo (photo 2), which is a green environment located adjacent to the non-green environment (Tokyo Dome City). The Kouraku ryokudo is a walking space located next to Koishikawa kourakuen, which, like Rikugi-en Garden, is a designated special place of beauty. It is a greenway exclusively for pedestrians that was designed with a landscape rich in greenery as a convenient and pleasant place for people who use the greenway.

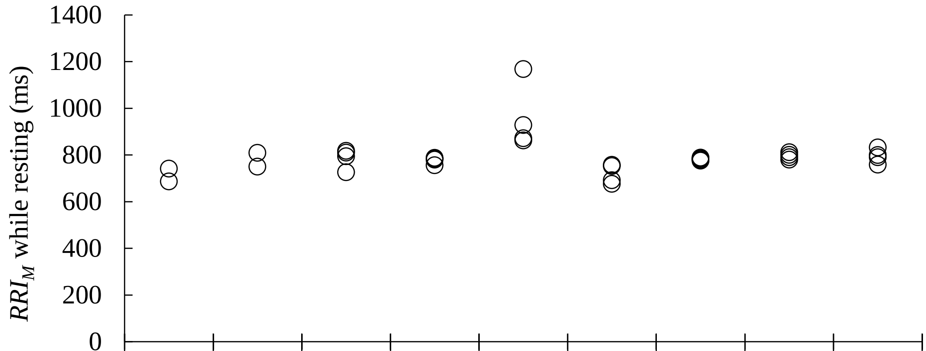
Photo 2. Green environment of multi-person experiment

Measurements while resting were taken at the same waypoints (common places: Interior lobby in Tokyo Dome City) for both environments, after which subjects headed towards the green environment or non-green environment, and measurements were taken while walking. The subject sample included five male students (male A, B, C, D, and E) and four female students (female A, B, C, and D), for a total of nine subjects. Each subject measurement was taken twice, including while resting at the common place for 5 min → walking for 5 min in the green environment, and while resting at the common place for 5 min → walking for 5 min in the non-green environment.' Considering the influence of stimulation order, in the first and second measurements, the order of the green environment and non-green environment were switched. All other experimental conditions were the same as for the resting and walking experiments.

4.2 Stress Evaluation Taking Interindividual Variations in Heart Rate into Consideration

Fire 7 shows RRI_R (RRI_M while resting) for all subjects. Although Male A showed great variation in RRI_M, we found that in all other subjects, stable measurements were obtained with a standard deviation of ≤30 ms. Meanwhile, in terms of interindividual differences, we found major variations of approximately 200 ms. Therefore, to compare individuals, decrease in RRI while walking ($RRI_R - RRI_W$), such as seen with formula (2), or the value standardized by RRI_R (hereafter referred to as decrease in RRI while walking) can be used.

$$\text{Decrease rate in RRI while walking} = \frac{\text{RRI}_\text{R} - \text{RRI}_\text{W}}{\text{RRI}_\text{R}} \qquad (2)$$



	Female A	Female B	Female C	Female D	Male A	Male B	Male C	Male D	Male E
Average (ms)	713.5	779.5	786.8	776.8	957.3	719.0	781.8	795.3	794.8
Standard deviation	27.5	29.5	36.1	12.2	124.3	35.9	4.8	11.5	26.4

Figure 7. RRI_R (RRI_M while resting) for all subjects

Figure 8 shows the in the walking RRI decrease rate in green and non-green environments. In most subjects, a smaller decrease in RRI while walking was noted in the green environment than in the non-green environment. Furthermore, upon performing a t-test for both environments, we found a difference with a significance level of 5%. Therefore, results indicated that heart rate was inhibited more while walking in the green environment than in the non-green environment for all subjects overall. Furthermore, female A and males B and E showed the opposite tendency; however, in the other six subjects, decrease in RRI while walking was smaller in the green environment for both measurements. In particular, male A and females B and C showed a major difference between the two environments, and, therefore, it is thought that walking in green environments has a stress-decreasing effect.

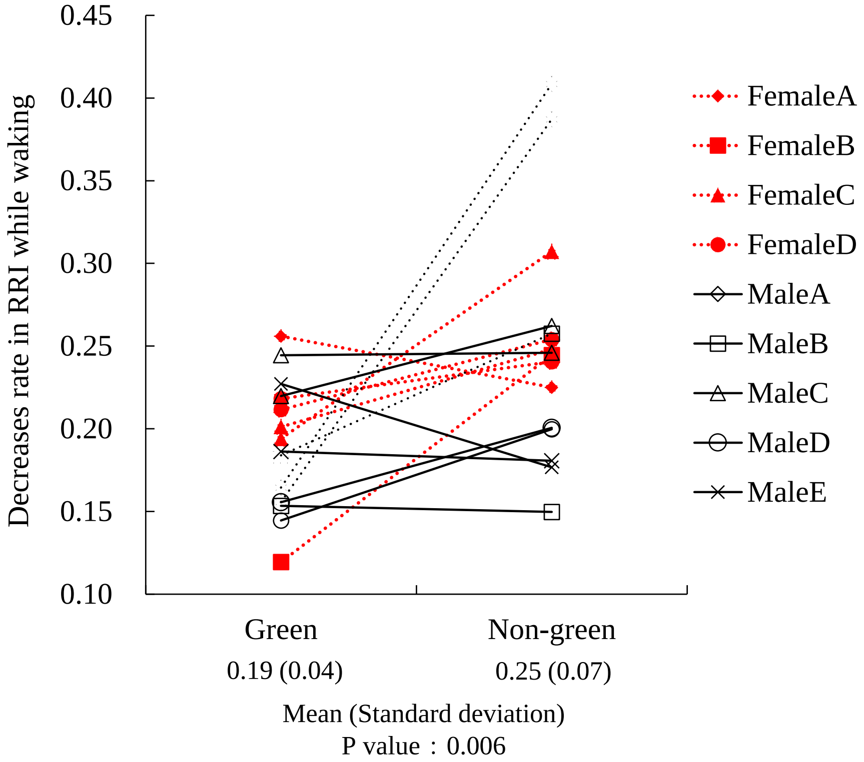


Figure 8. Decrease rate in RRI while walking in Green and non-green environments

Next, we examined gender differences. Figure 9 shows the walking RRI decrease rates for male and female subjects. Although there was no clear difference found between both environments for male subjects, among female subjects, values were significantly smaller in the green environment than in the non-green environment (significance level of 5%). Accordingly, although the sample size was small, we can say that the stress-decreasing effect of walking was greater in female subjects than in male subjects.

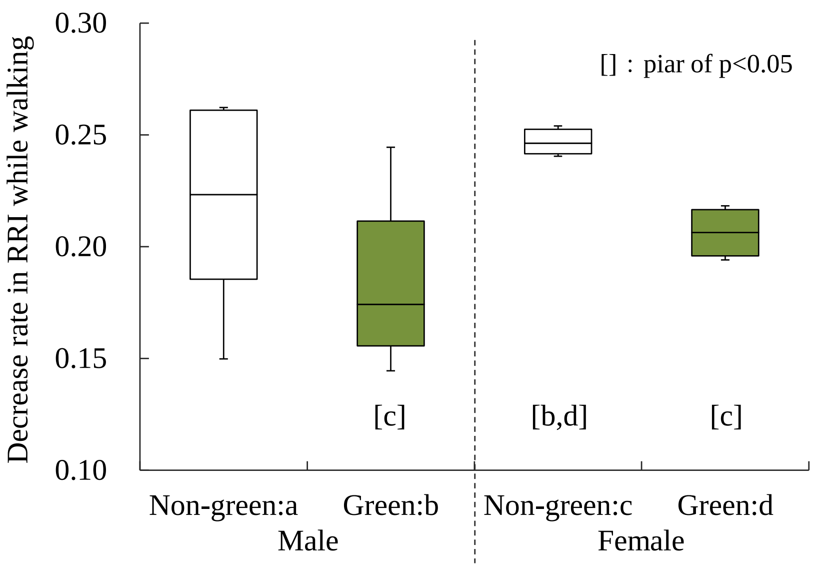


Figure 9. Decrease rates in RRI while walking for male and female subjects

5. Conclusions

In the present study, we measured heart rate repeatedly in multiple subjects in urban green and non-green environments. With the measurements obtained, we developed a stress evaluation index taking intraindividual and interindividual differences in heart rate into account, and we then used this index in an attempt to examine the stress-decreasing effect of walking in green environments. On the basis of our investigation, we came to the following conclusions.

RRI measurements were first repeated while resting in a green environment and non-green environment (rest experiment). We found that RRI_M greatly differed for each condition of the subject. Upon performing a t-test on the basis of this result for the subject concerned, RRI_M was significantly greater in the green environment than in the non-green environment.

Next, measurements were repeated for resting → walking (walking experiment). Although RRI_M while resting (RRI_R) varied for each measurement, we found a strong correlation with RRI_M (RRI_W) immediately after walking. Therefore, for the three subjects in this experiment, analysis according to decrease in RRI while walking ($RRI_R - RRI_W$) demonstrated that it was significantly smaller in the green environment than in the non-green environment.

The same experiment as the walking experiment was conducted with a larger subject sample (multiperson experiment). First, we confirmed that the heart rate level while resting varied greatly depending on the individual, and, therefore, the decrease in RRI while walking (the decrease in RRI while walking standardized by RRI_R) was defined as the index, taking such interindividual variations in heart rate into consideration. Upon evaluating the stress-decreasing effect of walking in green environments using this index, we observed such effects in six out of the nine subjects (nine out of the 12 subjects when combined with the walking experiment). Furthermore, in terms of gender difference, this effect was clearly more evident in female than in male subjects.

In the present study, we included 12 subjects and examined gender differences; however, in the future, to gather more evidence, we hope to increase the subject sample size and perform analyses taking into account individual characteristics, such as age, physical capacity, and personal preferences. Furthermore, it goes without saying that RRI has a lower limit; therefore, the index should be examined taking this lower limit into account. Furthermore, we hope to extract and evaluate factors that cause stress in walking spaces from multiple perspectives, according to the characteristics of heart rate variations based on RRI data over time and vital reaction data, such as salivary cortisol levels, amylase levels, and brain wave analysis. The purpose of this research is to develop indices that consider them about individual differences and individual variation. In other words, it is only a basic examination on stress evaluation by heartbeat. After solving the above problems, we would like to create a low-stress space and propose such as changing the route, using various indicators, and lead to the idea of "healthy town planning". This point will be a future subject.

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