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# Autonomic Nervous Systems Activity Measurements of Female University Students of Free Fall at Tokyo Dome City Amusement Park Attraction

SHIGENORI SHIROUZU[1), TORAO OGIMA[2) and SOTETSU KATAYAMA[1)

**Abstract:** Autonomic nervous systems (ANS) activity was measured for female university students before, during, and after experiencing free fall on a Tokyo Dome City Amusement (TDCA) park attraction.

Among five subjects successfully measured, four showed a remarkable decrease in RR interval to 0.336 – 0.415 seconds from the start of free fall, indicating fear of free fall, even though the subjects themselves may not have been aware of any fear.

One subject did not exhibit fear before the free fall ride, and instead appeared to enjoy the experience and feelings.

**Key Words:** RR interval variability, time-frequency MAP, free fall, fear, very low frequency band

## 1. Introduction

In connection with our continued understanding of autonomic nervous system (ANS) activity in people over a long time period of time, for 24 hours, during sleep, during university lectures and examinations, we have employed one minute time frequency map of RR variability calculated with the SPWV (Smoothed Pseudo Wigner-Ville) method using only three values, average heart rate, minute measurements of parasympathetic (PSNS) and sympathetic (SNS) nervous activity.

However, a time frequency map of RR variability calculated using the SPWV method has a time resolution of almost 1 full beat. Hence the most suitable application area of this technique may be the study of instantaneous changes in ANS, such as associated with arousal from sleep, or those found at the instant a large earthquake strikes.

Sugano, et. al. reported on mental stress load due to the "2011 Off the Pacific Coast of Tohoku Earthquake". Remarkable decreases in RR interval due to the earthquake were observed in all seven test subjects. Also, these decreases in the frequency were below 0.04 Hz in all subjects, indicating frequency analysis beyond the band limits of the generally used LF and HF band is necessary in case of very large mental stress is expected.

In this study, we report on ANS activity measurements of university students during free fall on a Tokyo Dome City Amusement (TDCA) park attraction.

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1) Japanese Research Institute of Healthcare and Education
2) Toyo-Gakuen University

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## 2. Experiments

### 2-1 Subjects

Six female senior year students of Toyo-Gakuen University (TGU), the university nearest to TDCA, volunteered to participate in this study. Each student subject attached a measurement device to herself at TGU, then walked to TDCA and rode several thrilling attractions and roller coasters. Each subject then returned back to TGU on foot and detached the measurement device at the university. One limitation present in this study is that the individual test subjects each generally enjoy riding thrilling attractions and roller coasters. Each subject provided written consent to participate in the study. In addition, this study was approved by the Ethics Committee of the Japanese Research Institute of Healthcare and Education. Two subjects visited TDCA together per day. Measurements were performed on 11 March 2010 (subjects A, B), 12 March 2010 (subjects C, D), and on 19 March 2010 (subjects E, F).

### 2-2 Free Fall

For free fall measurements, the subjects rode the Tower Hacker (Intamin, Switzerland) at TDCA. Riders are strapped in on benches capable of moving vertically. The ride lifts the benches to an 80 m height, and after several seconds the benches are allowed to start free fall. The vertical free fall distance was approximately 50 m, achieved in about 2 seconds from initial release, and the maximum speed attained was approximately 98 km/h. After the free fall period, acceleration in the upward direction around a maximum of 5 G stops their movements. Total time necessary for one ride was about 90 seconds.

### 2-3 ANS Measurement

The measuring device used for this study was a small, lightweight ECG data logger (M-BIT) for all subjects. M-BIT electrode placement for ECG measurements involves a monitoring lead, which is similar to II lead. A body ground is unnecessary due to improved electronic circuit design. M-BIT is small and lightweight, allowing it to adhere to a subject's thorax using two electrodes. A good quality ECG signal can be acquired by attaching M-BIT near the position of a subject's heart.

Details of the M-BIT ECG data logger are publicly available. The M-BIT includes an ECG measuring circuit, an accelerometer, a temperature sensor, 32 M-bytes of memory, a USB connection plug, snap fasteners for electrodes, and a coin battery. M-BIT allows for 24 hour sustained measurement, data storage to memory, and USB communication in a stand-alone configuration, all packed into a compact size of 40 × 39 × 8 mm at a weight of 14 g. The ECG sampling frequency is 128 Hz.

We detected time locations of the R wave on the ECG signal based on a robust real time QRS detection algorithm currently in broad use worldwide. In this algorithm, ECG signals undergo band pass filtering using a frequency band of 5 to 11 Hz, where most components of QRS peaks exit, and are then differentiated. Absolute values are determined and averaged over an 80 millisecond window, resulting in conversion to hill like waveforms. The R wave is located at points where the waveform exceeds a certain defined threshold level.

We selected a 512 second length for RR interval time series data surrounding the event of interest, i.e. the free fall. All mistakenly identified R peak and false RR intervals within this selected portion of RR interval data were corrected. The RR interval time series was then re-sampled at a frequency of 2 Hz, and high-pass filtered with a cut-off frequency 0.04 Hz. Time frequency analysis was performed next, resulting in a time frequency map (TFM), high frequency (HF, 0.15 Hz - 0.40 Hz) and low frequency (LF, 0.04 Hz - 0.15 Hz) components, and a respiration frequency with a 0.5 second time resolution. Para-sympathetic and sympathetic nervous system activity can then be taken as HF and LF/HF, respectively.

## 3. Results and Discussion

Since the duration of free fall is very short at 2 seconds, it is difficult to find the correct location in the RR interval time series data corresponding to free fall. For this purpose, we also measured acceleration at a 128 Hz sampling frequency, and used a wave form composed of the short free fall and subsequent deceleration as time location makers.

Figures 1 through 5 show the results corresponding to free fall for respective subjects A, B, C, D, and E. For subject F, the height of the R peaks were small from the start, indicating that the measuring device attachment point was not at the sweet spot, and furthermore, due to the intense tension, a large electromyogram contaminated the ECG signal around the free fall time, making detection of R peaks was impossible here.

The uppermost curves in each figure show vertical acceleration. Specific freefall waveform markers are found near the central portion of each curve. The second, third, and fourth curves in the figures show para-sympathetic nervous system (PSNS) activity, respiration frequency, and sympathetic nervous system (SNS) activity, respectively, at a time resolution of 0.5 seconds. The fifth curve from the top shows RR intervals, while a time frequency map occupies the lowermost part of each figure. The most fundamental result relates to RR intervals.

The behaviors of RR intervals around the time of free fall, and the mental conditions of subjects were divided into two groups. Group I (Figs. 1, 2, 3, and 5) and group II (Fig 4). Although each test subject volunteered to participate in this study and each stated their like of thrilling rides, the Group I subjects felt fear relating to free fall.

Figure 1 shows one example of test subject RR interval behavior while riding the free fall attraction. At around 11:35:30, when subject A's turn came and she sat down on the bench and relaxed for a while, her RR interval lengthened and PSNS activity increased.

However, the RR interval began to decrease when the bench started to rise up, and continuously decreased during the next 90 seconds on the attraction, during the vertical rise, several seconds waiting at the top, and the subsequent free fall. The RR interval reached its minimum value of 0.415 seconds at a time several seconds after the free fall. The RR interval then takes several tens of seconds to return to the prior level.

Similar to what happens during an earthquake, the large tension or fear may shorten the RR interval to as little as 0.415 seconds (**Fig. 1**, subject A), 0.384 seconds (**Fig. 2**, subject B), 0.336 seconds (**Fig. 3**, subject C), or 0.380 seconds (**Fig. 5**, subject E). These

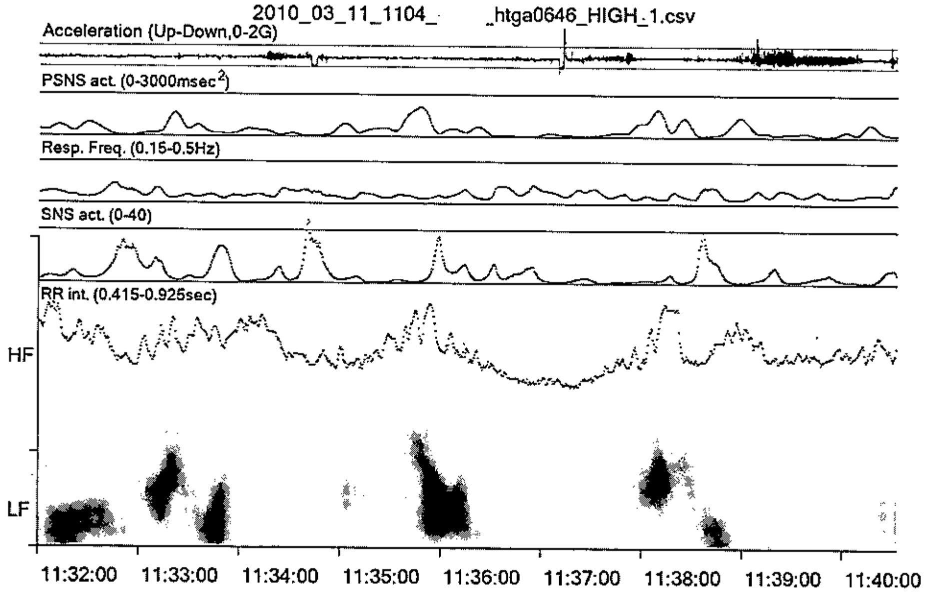

**Fig. 1** RR interval, time-frequency map, extracted PSNS and ANS activity, respiration frequency of subject A (Group I) before, during, and after free fall.

The uppermost curves show vertical acceleration. Specific waveforms of free fall near the central portion of the curves are taken as time marker locations. The second, third, and fourth curves show para-sympathetic nervous systems (PSNS) activity, respiration frequency, and sympathetic nervous systems (SNS) activity, respectively. The fifth and lowermost curve shows RR intervals, while a time frequency map is shown in the lowest region of the figure.

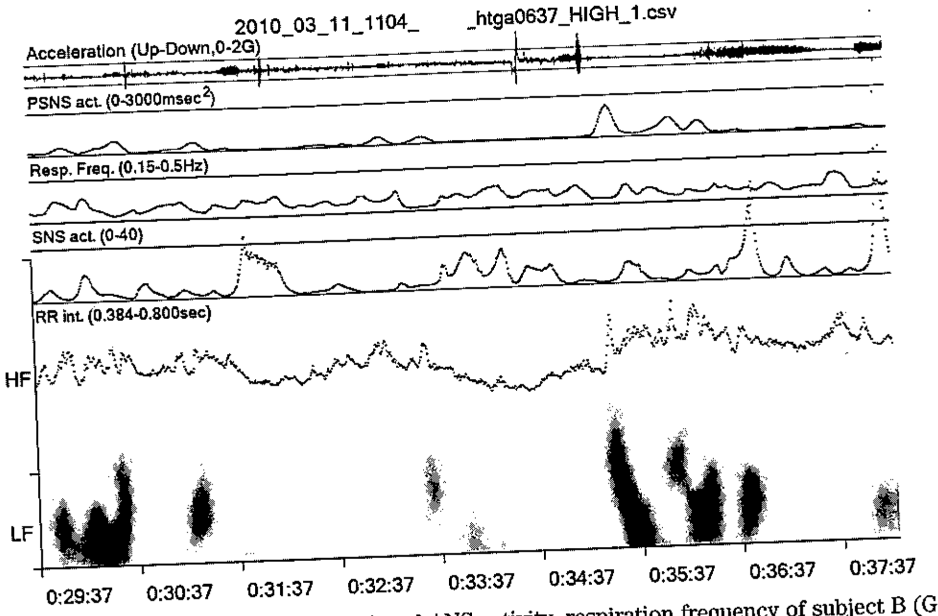

**Fig. 2** RR interval, time-frequency map, extracted PSNS and ANS activity, respiration frequency of subject B (Group I) before, during, and after free fall.

The uppermost curves show vertical acceleration. Specific waveforms of free fall near the central portion of the curves are taken as time marker locations. The second, third, and fourth curves show para-sympathetic nervous systems (PSNS) activity, respiration frequency, and sympathetic nervous systems (SNS) activity, respectively. The fifth and lowermost curve shows RR intervals, while a time frequency map is shown in the lowest region of the figure.

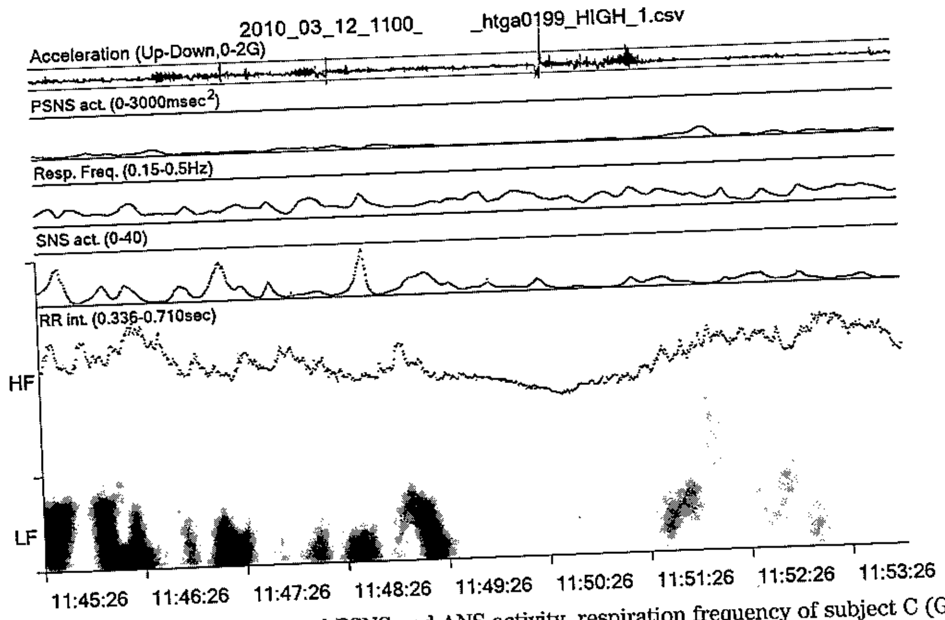

**Fig. 3** RR interval, time-frequency map, extracted PSNS and ANS activity, respiration frequency of subject C (Group I) before, during, and after free fall.

The uppermost curves show vertical acceleration. Specific waveforms of free fall near the central portion of the curves are taken as time marker locations. The second, third, and fourth curves show para-sympathetic nervous systems (PSNS) activity, respiration frequency, and sympathetic nervous systems (SNS) activity, respectively. The fifth and lowermost curve shows RR intervals, while a time frequency map is shown in the lowest region of the figure.

significant RR interval changes encompassing a decrease to these minimum values and then a subsequent return to prior levels cannot be achieved by the autonomic nervous system alone. Co-operation with other physiological mechanisms is necessary. Hence these changes in RR intervals take time, and their corresponding frequency is very low (less than 0.04Hz). This makes time frequency maps about 60 seconds before and after the free fall very specific, such as just a white area (PSNS is very small, and SNS

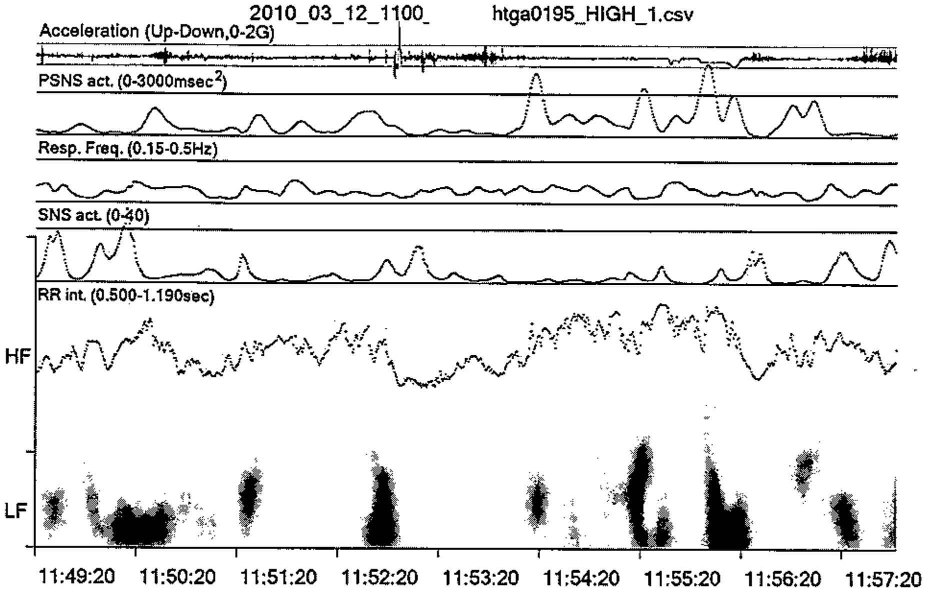

**Fig. 4** RR interval, time-frequency map, extracted PSNS and ANS activity, respiration frequency of subject D (Group II) before, during, and after free fall.

The uppermost curves show vertical acceleration. Specific waveforms of free fall near the central portion of the curves are taken as time marker locations. The second, third, and fourth curves show para-sympathetic nervous systems (PSNS) activity, respiration frequency, and sympathetic nervous systems (SNS) activity, respectively. The fifth and lowermost curve shows RR intervals, while a time frequency map is shown in the lowest region of the figure.

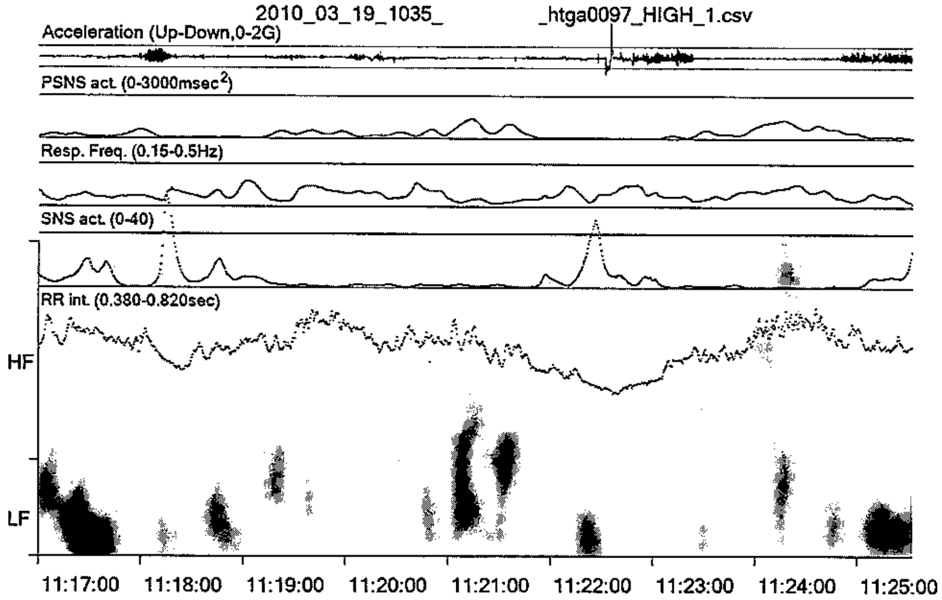

**Fig. 5** RR interval, time-frequency map, extracted PSNS and ANS activity, respiration frequency of subject E (Group I) before, during, and after free fall.

The uppermost curves show vertical acceleration. Specific waveforms of free fall near the central portion of the curves are taken as time marker locations. The second, third, and fourth curves show para-sympathetic nervous systems (PSNS) activity, respiration frequency, and sympathetic nervous systems (SNS) activity, respectively. The fifth and lowermost curve shows RR intervals, while a time frequency map is shown in the lowest region of the figure.

activity is also very small), or a small light gray area in the lowest region (PSNS is very small, but SNS activity shows a certain level).

The most interesting point in Group I subject RR interval behavior is that it started its remarkable decrease when the attraction's bench started moving, i.e. far before the actual free fall. The expectation of free fall caused the remarkable decrease of RR intervals for the Group I subjects, indicating they felt fear relating to free fall, even though the individual subjects themselves may not have been aware of that fear.

Figure 1 shows that the RR interval and the PSNS activity of subject A increased at around 11:38:15. After a further 15 seconds or so, they show a remarkably rapid drop, while SNS activity increased. This is due to mental stress caused by an interview conducted by the person supervising the experiment, a young medical school student who may have been considered attractive by the subject. The rapidness of this drop suggests that drops on this order can be controlled by the autonomic nervous system alone.

The RR interval behavior of subject D (Group II subject) shown in **Fig. 4** differs greatly from that of the Group I subjects. Subjects C (Fig. 3 group I) and D visited TDCA together. The difference of free fall times shown in Figs 3 and 4 is due to time management error induced by manually engaging the M-BIT start button and recording the start time. Hence we used acceleration waveform of free fall as a marker for comparison.

Just prior to free fall, although the RR interval of subject C is remarkably small, the RR interval and PSNS activity of subject D is still large. During free fall the RR interval decreased rapidly to 0.500 seconds, and then the PSNS activity decreased and SNS activity increased. The increase of the RR interval was relatively small. These results suggest astonishment due to the free fall and its effect continued for approximately 20 seconds. After around 60 seconds, subject D's RR interval and PSNS activity increased, indicating that she enjoyed the free fall and astonishment.

Group II subject did not experience fear before free fall. Instead she was simply astonished, and enjoyed the experiences and feelings.

## 4. Summary

Among five subjects succeeded in measurement, four subjects showed a significant decrease in RR interval to 0.336 - 0.415 seconds compared to the start of the free fall ride, indicating they felt fear relating to free fall, even though they may not have been aware of the fear.

One subject did show fear before free fall, only astonishment, and appeared to enjoy the experiences and feelings.

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