Appl Psychophysiol Biofeedback
DOI 10.1007/s10484-008-9054-1

Accuracy of the StressEraser® in the Detection of Cardiac Rhythms

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Abstract StressEraser® is a commercially marketed biofeedback device designed to enhance heart rate variability. StressEraser® makes its internal calculations on beat-to-beat measures of finger pulse intervals. However, the accuracy and precision of StressEraser® in quantifying interbeat intervals using finger pulse intervals has not been evaluated against standard laboratory equipment using R–R intervals. Accuracy was assessed by simultaneously recording interbeat intervals using StressEraser® and a standard laboratory ECG system. The interbeat intervals were highly correlated between the systems. The average deviation in interbeat interval recordings between the systems was approximately 6 ms. Moreover, correlations approached unity between the systems on estimates of heart period, heart rate, and heart rate variability. Feedback from StressEraser® is based on an interbeat time series that provides sufficient information to provide an excellent estimate of the dynamic changes in heart rate and heart rate variability. The slight variations between StressEraser® and the laboratory equipment in quantifying heart rate and heart rate variability are due to features related to monitoring heart rate with finger pulse: (1) a lack in precision in the peak of the finger pulse relative to the clearly defined inflection point in the R-wave, and (2) contribution of variations in pulse transit time.

Keywords Ambulatory monitoring · Heart period · Respiratory sinus arrhythmia · Baseline · Exercise

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In recent years, biofeedback devices have been marketed to the public as a means of dynamically assessing physiological activity (i.e., heart or respiration rate) and providing corresponding instructional feedback to the user for altering related physiological systems. The StressEraser® (Helicor) is a noninvasive biofeedback device that is commercially marketed and provides heart rate variability feedback when the user alters respiration depth and frequency. The StressEraser® assesses heart rate variability from pulse intervals recorded from the index finger. When using biofeedback devices, it is vital to know that the feedback provided to the user is based on a valid, accurate and sensitive physiological measure. However, it is unknown whether the pulse interval, as measured by the StressEraser®, is an accurate reflection of beat-to-beat heart rate variability, as typically assessed from an ECG. Thus, the purpose of the study is to compare the accuracy and precision of the StressEraser® in the recording of interbeat intervals against the interbeat intervals that are derived from the R-wave peaks of a standard laboratory ECG. The Biopac MP35 (Bipoac Systems, Goleta, CA, USA), a laboratory based physiological monitoring system, was chosen as the standard for comparison, since it is frequently used as both a teaching and research tool, has been cited in over 1200 published articles (Search Engine: HighWire Press), and has a precision of timing R–R intervals to the nearest ms. The current study contrasts the interbeat interval detections from both systems during baseline and exercise conditions.

Methods

Participants

Data were collected from 22 healthy participants between the ages of 18–35 (16 female, 6 male) during two 10-min conditions (sitting quietly and pedaling slowly on an exercise bike). The University of Illinois at Chicago Institutional Review Board approved the research protocol and informed consent was obtained from all participants prior to the beginning of the research session.

No demographic information (gender, race, ethnicity) was collected on the participants, since these variables were not hypothesized to influence the goals of the study. All participants were in good health, not taking any medications that would interfere with cardiac rhythms, abstained from caffeine for at least 2 h prior to the study, and abstained from smoking at least 1 h prior to the study.

Physiological Measures

Heart period data were continuously recorded simultaneously using two different monitoring systems: StressEraser® and Biopac. The Biopac system required three self-adhering electrodes (Meditrace) placed directly onto the skin on the upper chest and on the lateral surface of the abdomen. The StressEraser® was activated by asking participants to insert their finger into the pulse sensor. Data were reported from 21 participants during baseline and from 22 participants during exercise. Deviation scores in milliseconds were calculated by differencing the synchronized sequential R–R intervals from the Biopac from the pulse-pulse intervals from the StressEraser®. The distributions of this difference metric were analyzed.

Procedure

The data were collected in a research room at the UIC Brain-Body Center. At the beginning of the study, participants were escorted to the research room, wherein the StressEraser® was activated and the Biopac electrodes were attached. Heart period data were collected during two sequential conditions, baseline and exercise. During both conditions, the participants had the option to watch a movie. The baseline condition was included to assess the accuracy of the StressEraser® during periods of minimal movement. The exercise condition was included to assess accuracy of detection during a period of continuous movement when detections could be influenced by motion artifact. The clocks for the StressEraser® and Biopac systems were synchronized and the time was noted at the beginning and end of each condition.

During the baseline condition, participants were asked to sit on the seat of the recumbent stationary bicycle for 10 min. Immediately following conclusion of baseline data collection, participants were asked to remain seated and slowly pedal the stationary bicycle for 10 min. Participants were asked to pedal slowly in order to minimize motion-related artifacts. Following the conclusion of the exercise condition, the electrodes and StressEraser® were removed and participants were thanked for their assistance.

Data Analysis

The data analyses were structured to evaluate number of detection errors, ms deviations in the timing precision of interbeat intervals, and deviations in commonly used summary statistics of heart rate and heart rate variability. Across all data files, a total of 10,716 data points were analyzed during the baseline condition, and a total of 10,688 data points were analyzed during the exercise condition.

R-Wave Detection Errors

Sequential heart periods collected from StressEraser® and Biopac were aligned in adjacent columns of a data spreadsheet for each participant for each condition. Errors were defined as a difference of more than 100 ms between StressEraser® and Biopac data. Errors were assigned to one of five categories and resolved accordingly (Gamelin et al. 2006). A Type I error occurred when there was a single discrepant point between StressEraser® and Biopac. A Type I error was resolved by replacing the erroneous StressEraser® value with an interpolated value from the two adjacent StressEraser® R–R intervals. A Type II error occurred when the StressEraser® detected a long interval immediately followed by a short interval, and was resolved by averaging the two erroneous values. A Type III error occurred when the StressEraser® detected a short interval immediately followed by a long interval, and was likewise resolved by averaging the two erroneous values. A Type IV error occurred when the value of a StressEraser® datapoint was equivalent to 2 or 3 values in the Biopac data. The Type IV error was resolved by dividing the erroneous StressEraser® datapoint by 2 or 3 (according to the number of R-waves detected.) A Type V error occurred when the value of 2 or 3 StressEraser® datapoints were equivalent to 1 value in the Biopac data. The Type V error was resolved by summing the erroneous StressEraser® datapoints. While the errors in the Biopac data were not categorized, the errors in the Biopac data were identified via visual screening of the data to identify large atypical increases and decreases in sequential R–R intervals. These errors were resolved via integer arithmetic in a manner similar to the above description. Thus, files that required editing were corrected for both StressEraser® and Biopac.

Timing Precision of R–R Interval

To determine the extent to which the data recorded from each system differed in the timing precision of sequential interbeat intervals, difference scores were computed from data files collected from both systems. Absolute difference scores in ms were derived to describe differences between the StressEraser® and Biopac for each sequential interbeat interval.

Differences in Commonly Used Summary Statistics

Analyses were conducted to determine whether the beat-to-beat differences in interbeat interval between the systems would influence commonly used summary statistics of heart rate and heart rate variability.

Time-domain Analyses

For each data file, the mean interbeat interval, mean heart rate, and the ln variance of amplitude of respiratory sinus arrhythmia (RSA) were calculated using CardioBatch software (Brain-Body Center, University of Illinois at Chicago). CardioBatch incorporates procedures developed by Porges (1985). These procedures quantify the amplitude of RSA with age-specific parameters, sensitive to the maturational shifts in the frequency of spontaneous breathing. In these analyses, parameters were selected for adults and included the following steps: (1) sequential R–R intervals are resampled into 500 ms intervals to produce time-based data; (2) the time-based series is detrended by a 21-point cubic moving polynomial for baseline data and 51-point cubic moving polynomial for exercise condition (Porges and Bohrer 1990) that is stepped through the data to create a smoothed template and the template is subtracted from the original time-based series to generate a detrended residual series; (3) the detrended time series is bandpassed to extract the variance in the R–R interval pattern associated with spontaneous breathing in adults during baseline (i.e., 0.12–.40 Hz) and during mild exercise (i.e., 0.12–1.00 Hz); and (4) the natural logarithm (ln) of the variance of the bandpassed time series is calculated as the measure of the amplitude of RSA (Porges and Byrne 1992). These procedures are statistically equivalent to frequency domain methods (i.e., spectral analysis) that sum the spectral densities in the frequency band associated with spontaneous breathing for the calculation of the amplitude of RSA when R–R interval data are stationary (Porges and Byrne 1992). Ten minutes of R–R interval data for the StressEraser® and Biopac were analyzed across all participants during each condition. Average R–R interval, average heart rate, and RSA were quantified across each entire condition.

Frequency-domain Analyses

For each data file, the AR spectrum power (ms^2) was computed using the MATLAB software suite. A moving polynomial filter (51 points) was applied to all data files prior to frequency analysis, in order to remove frequency components below 0.12 Hz. The frequency bands defining RSA (HF) for each condition were identical to those used in the time-domain analyses for baseline (.12–.40 Hz) and exercise (.12–1.00 Hz). Each series of inter-beat-intervals was interpolated at 4 Hz. Spectral decomposition was by the modified covariance method of fitting an AR model of order 16 to the interpolated file, then performing a 256 point FFT on the AR model. Central frequency was defined as the component of the AR spectrum within the RSA frequency band containing the most power. This AR spectrum power was then transformed (using natural log) to stabilize the distribution of spectral densities and to provide a metric comparable to the time-domain analyses.

Results

Interbeat Interval Detection Errors

The number and type of errors in the StressEraser® data during each condition are displayed in Table 1 Sixteen errors in the StressEraser® data could not be categorized as Type I–V. Thus, the Type VI error was defined as a cluster of erroneous data points that required multiple additions (5 or less) and a division to resolve. Seven additional StressEraser® data sequences could not be edited or classified and were removed from further analyses by cropping. The number of data points that were cropped ranged between 6 and 60, and were always at either the end or beginning of the file.

Table 1 Description and distribution of errors in StressEraser® data

Type of error	Description of error	Baseline ($n = 10716$)	Exercise ($n = 10688$)	Percentage of errors relative to total number of data points (Baseline + exercise)
I	Single interval of discrepancy	0	1	.005%
II	Long interval and short interval	0	0	0%
III	Short interval and long interval	15	42	.27%
IV	Too few intervals detected	1	3	.02%
V	Too many intervals detected	123	161	1.33%
VI	Complex error	6	10	.07%

For the entire data set of interbeat intervals, 145 detections errors occurred during the baseline condition in a data set consisting of 10,716 interbeat intervals and 217 detection errors occurred during the exercise in a data set consisting of 10,688 interbeat intervals. StressEraser® recorded few errors during the baseline condition (1.35%) and exercise condition (2.03%).

Timing Precision of Interbeat Interval

Deviation scores in millisecond were calculated by differencing the synchronized sequential interbeat intervals from both systems. Tables 2 and 3 present the standard deviation, range, and mean absolute deviation (in ms) of the difference between sequential interbeat intervals for the two systems during baseline and exercise.

The mean absolute deviations between the two systems were 5.5 ms during baseline and 6.17 ms during exercise. Correlations between the sequential pulse-to-pulse intervals for StressEraser® and R–R intervals for Biopac were calculated for data during baseline and exercise. The correlations, as presented in Tables 2 and 3, uniformly approached unity.

Bland-Altman plots for the data are presented in Fig. 1 (baseline) and Fig. 2 (exercise). The figures illustrate the number of deviations, relative to the average values of the StressEraser® and Biopac, that fall within ± 2 SD of the mean for each condition.

Ogive plots, which highlight the cumulative percentage of errors by deviation in ms during baseline and exercise, are presented in Figs. 3 and 4.

Deviations of Commonly Used Summary Statistics

Summary statistics were generated each participants, for StressEraser® and Biopac, during each condition. Average interbeat interval, average heart rate, ln RSA (i.e., high frequency heart rate variability), central frequency and spectral power were calculated. Paired *t*-tests were then conducted to evaluate differences in the summary statistics between the StressEraser® and Biopac during the baseline and exercise conditions (Tables 4 and 5, respectively). There was slight, but significant difference between the two devices in quantifying interbeat interval with the Biopac being approximately 0.2 ms shorter. This difference was shorter than the precision of the sampling rate (i.e., 1 ms) and is most likely due to the variations in pulse transit time. Since the measurement of heart rate was not as precise as heart period, the devices did not differ on the measurement of heart rate. Also, since the heart rate variability measures (e.g., RSA and power) were calculated from the interbeat interval values, there was a slight, but significant difference

Table 2 Descriptive statistics (mean, SD, range) and correlations between StressEraser® and Biopac data during baseline

Participant	SD of mean deviation	Range of mean deviation (ms)	Mean deviation (ms)	Mean absolute deviation (ms)	Correlation*
1	7.14	−19 to 20	.01	5.94	.988
2	5.48	−12 to 15	.08	4.43	.992
3	4.13	−25 to 25	.02	3.16	.997
4	8.88	−75 to 62	−.05	6.00	.991
5	5.13	−17 to 25	.02	4.09	.996
6	6.35	−61 to 53	.01	4.62	.996
7	6.46	−17 to 20	.01	4.93	.996
8	7.28	−44 to 51	−.01	6.06	.995
9	6.13	−13 to 24	.16	4.93	.988
10	8.38	−39 to 44	.00	6.69	.991
11	10.76	−37 to 60	−.00	7.95	.988
12	7.34	−16 to 19	−.04	6.15	.995
13	3.51	−22 to 15	.03	2.65	.997
14	12.42	−97 to 79	−.06	9.35	.989
15	8.36	−33 to 40	.06	6.49	.986
16	7.65	−28 to 19	.03	6.26	.997
17	4.74	−29 to 28	.01	3.77	.975
18	8.99	−43 to 55	.09	7.06	.995
19	11.97	−87 to 84	.03	7.73	.989
22	4.92	−15 to 15	−.01	3.99	.995
23	5.49	−24 to 20	−.02	4.31	.999
Mean (SE)			.02 (.01)	5.55 (.37)	

* All correlations significant at $p < .000$

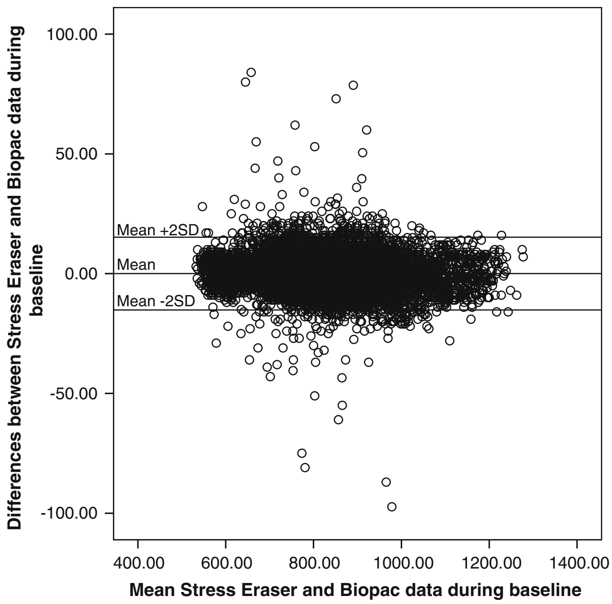

Fig. 1 Bland-Altman plot for baseline data (by subject)

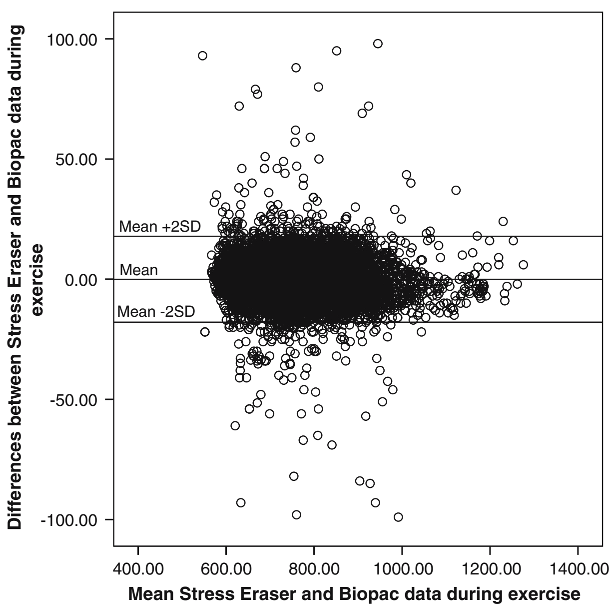

Fig. 2 Bland-Altman plot for exercise data (by subject)

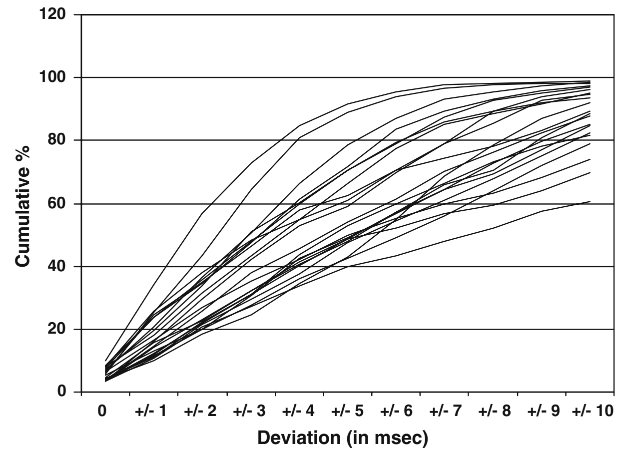

Fig. 3 Cumulative percentage by deviation in ms for each participant during baseline

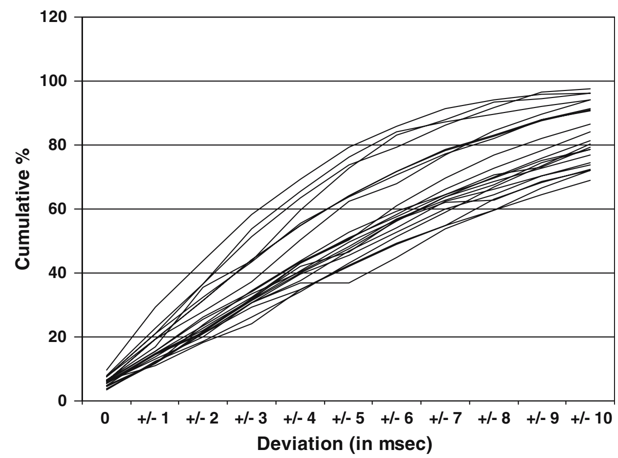

Fig. 4 Cumulative percentage by deviation in ms for each participant during exercise

between the two devices. However, although there were slight differences on interbeat interval, RSA, and spectral power, the correlations between the StressEraser® and the Biopac on each of the metrics listed in Table 4 and Table 5 approached unity (i.e., .99–1.0).

Discussion

The above analyses demonstrate that the StressEraser®, a biofeedback device sold as a consumer product to alter heart rate variability, is reasonably accurate in detecting interbeat intervals from pulse to pulse intervals. As expected, pulse intervals were highly correlated with R–R intervals as derived from a standard ECG, with a .99 correlation during baseline and .98 correlation during exercise. The correlations were higher than previously reported in studies that compared pulse intervals with R–R intervals (.968 correlation reported in Barry and Mitchell 1987; .982 correlation reported in Jennings et al. 1987). However, the pulse detector in the StressEraser® was not as precise as a standard ECG. As reported in Heilman and Porges (2007), the average difference between the detection of interbeat intervals between two ECG systems (LifeShirt® and Biopac) was .95 ms during baseline and 1.17 ms during exercise. In this study, the average difference between the pulse detection and R–R detection was 5.55 ms during baseline and 6.38 ms during exercise. The decrease in the precision of interbeat interval detection in the StressEraser®

Table 3 Correlations and descriptive statistics (mean, SD, range) between StressEraser® and Biopac data during exercise

Participant	SD of mean deviation	Range of mean deviation	Mean deviation (ms)	Mean absolute deviation (ms)	Correlation*
1	7.23	−31 to 27	.00	5.89	.990
2	5.92	−14 to 15	.00	4.88	.992
3	11.11	−61 to 24	−.91	7.60	.959
4	13.46	−84 to 72	.03	8.42	.956
5	7.10	−54 to 46	−.06	5.12	.986
6	8.38	−98 to 77	.01	5.30	.988
7	12.82	−67 to 88	.07	8.43	.954
8	9.02	−37 to 59	.05	6.90	.992
9	5.05	−12 to 14	.16	4.14	.991
10	7.46	−25 to 17	−.03	6.04	.985
11	9.18	−43 to 44	−.06	6.82	.997
12	9.52	−35 to 27	.00	7.36	.959
13	4.87	−32 to 22	−.10	3.60	.983
14	10.21	−99 to 98	.02	7.25	.988
15	10.89	−42 to 44	.00	8.32	.977
16	10.72	−93 to 95	−.03	7.12	.951
17	7.79	−93 to 93	.03	4.43	.951
18	14.55	−69 to 69	−.08	9.45	.977
19	10.72	−82 to 79	.02	7.47	.983
20	8.83	−17 to 37	.07	6.80	.998
21	7.06	−54 to 46	−.06	5.08	.986
23	4.91	−14 to 12	.00	3.98	.998
Mean (SE)			−.04 (.04)	6.38 (.35)	

* All correlations significant at $p < .000$

Table 4 Paired *t*-tests and correlations between the summary statistics computed on data collected from StressEraser® and Biopac during the baseline condition

	Mean (SD) for StressEraser®	Mean (SD) for Biopac	*t*-values, significance	Correlation
Interbeat interval (ms)	820.28 (115.40)	820.06 (115.40)	$t(20) = -4.69$, $p < .000$	1.000
Heart rate	74.98 (10.74)	74.98 (10.74)	$t(20) = -.33$, $p < .75$	1.000
RSA (ln)	6.50 (.78)	6.35 (.80)	$t(20) = -6.24$, $p < .000$	.990
Central frequency	.22 (.08)	.22 (.08)	$t(20) = -.57$, $p < .58$	.997
Power (ln)	9.43 (.99)	9.30 (1.02)	$t(20) = -3.90$, $p < .001$	.989

Table 5 Paired *t*-tests and correlations between the summary statistics computed on data collected from StressEraser® and Biopac during the exercise condition

	Mean (SD) for StressEraser®	Mean (SD) for Biopac	*t*-values, significance	Correlation
Interbeat interval (ms)	765.70 (102.37)	765.47 (102.38)	$t(21) = -4.71$, $p < .000$	1.000
Heart rate	80.05 (10.10)	80.06 (10.11)	$t(21) = 1.19$, $p < .25$	1.000
RSA (ln)	7.37 (1.09)	7.30 (1.12)	$t(21) = -6.30$, $p < .000$	.999
Central frequency	.24 (.10)	.23 (.10)	$t(21) = -1.45$, $p < .16$	.999
Power (ln)	9.36 (1.33)	9.26 (1.35)	$t(21) = -2.32$, $p < .03$	.989

can be attributed to two properties of the pulse measurement. First, the pulse interval is not solely dependent on the R–R interval, but also incorporates variations in pulse transit time (i.e., R-wave to finger pulse time). Pulse transit time may vary due to peripheral vascular resistance. Second, the pulse wave is mechanical and thus, would not parallel the precision of detecting the well-articulated inflection point in the ECG of the peak of the R-wave.

In summary, the feedback from the StressEraser® is based on an interbeat time series that provides sufficient information to provide an excellent estimate of the dynamic changes in heart rate and heart rate variability.

Acknowledgments The project described was supported by NIH Grant Number R21 MH067446. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIH. We would like to thank Helicor for providing the StressEraser® devices for evaluation as described in the manuscript.

Disclosure S.W. Porges is a member of the Helicor Scientific Advisory Board.

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