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Brief report

Accuracy of the LifeShirt® (Vivometrics) in the detection of cardiac rhythms

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Abstract

The use of heart rate measures in research requires accurate detection and timing of beat-to-beat values. Numerous technologies are available to researchers; however, benchmarking of a specific apparatus is seldom conducted. Since heart rate variability provides a portal to the neural regulation of the heart, accurate detection and timing of beat-to-beat values is essential to both basic physiological research and the clinical application of heart rate variability measures. The current study evaluated the accuracy of an ambulatory system, the LifeShirt® (Vivometrics), relative to a standard laboratory-based heart rate monitoring equipment (Biopac), during baseline and exercise conditions. LifeShirt® performed equivalently to the Biopac during both conditions, experienced few errors of detection, generated similar times between sequential heart periods, and produced similar summary indices of heart rate and heart rate variability.
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Keywords: Ambulatory monitoring; Heart period; Respiratory sinus arrhythmia; Baseline; Exercise

Accurate detection and timing of beat-to-beat heart rate is necessary in medical, psychophysiological, and physiological research. To obtain accurate measurements with millisecond accuracy, researchers have been limited to laboratory-based equipment. An ability to obtain accurate beat-to-beat measures of heart rate in an ambulatory device would provide important opportunities to evaluate the dynamic regulation of the heart in contexts consistent with naturally occurring demands. Vivometrics recently introduced a noninvasive physiological monitoring system (LifeShirt®) with capabilities to monitor multiple physiological parameters including *R–R* intervals and several respiratory parameters. While several researchers have used the LifeShirt® system in various studies (Grossman, 2004; Keenan, 2004; Keenan and Wilhelm, 2005a,b; Wilhelm et al., 2003) or acknowledged the potential applicability of the LifeShirt® in future studies (Bruton and Thomas, 2006; Stefanov et al., 2004), the accuracy and precision of the LifeShirt® in the detection of beat-to-beat heart rate has yet to be tested against a standard laboratory-based heart rate monitoring equipment. Thus, the purpose of the study is to compare the accuracy and precision of heart rate detections by the ambulatory LifeShirt® with the values generated by a laboratory-based physiological monitoring system. The Biopac MP35 (Bipoac Systems, Goleta, CA, USA) 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 millisecond. The current study contrasts the *R*-wave detections from both systems during baseline and exercise conditions.

1. Methods

1.1. Data archive

The analyses used de-identified data from a data archive at the Brain-Body Center at the University of Illinois at Chicago. The data were collected from 15 individuals between 2003 and 2006 during routine benchmarking of equipment and the training of research assistants. The analyses and manuscript development were exempted by the University of Illinois at Chicago IRB. Age and other demographic information (gender, race, and ethnicity) were not collected, since these variables were not hypothesized to influence the goals of the study. All data were collected from individuals in good health.

1.2. Physiological measures

Heart period data were continuously recorded simultaneously using two different monitoring systems: LifeShirt® and Biopac. Each system required three

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self-adhering electrodes (Meditrace) placed directly onto the skin on the upper chest and on the lateral surface of the abdomen. The electrodes for each system were adjacent, but not overlapping. Each device applies a proprietary algorithm to detect the peak of the *R*-wave from the digitized ECG. The LifeShirt® samples the ECG at 200 Hz and the Biopac samples the ECG at 1000 Hz.

1.3. 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 restroom, and asked to remove their shirt to put on the LifeShirt®. Once the LifeShirt® was fitted, the participants returned to the research room, wherein the LifeShirt® was activated and the Biopac electrodes were attached. Heart period data were collected during two sequential conditions: baseline and exercise. The baseline condition was included to assess the accuracy of the LifeShirt® during periods of minimal movement. The exercise condition was included to assess the accuracy of detection during a period of continuous movement when detections could be influenced by motion artifact. The clocks for the Vivometrics and Biopac systems were synchronized and the time was noted at the beginning and the end of each condition.

During the baseline condition, participants were asked to sit on the seat of the recumbent stationary bicycle for 10 min. Participants were given the option to listen to music, read or sit quietly. 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 10–12 mph in order to minimize motion-related artifacts. Following the conclusion of the exercise condition, the electrodes and the LifeShirt® were removed and participants were thanked for their assistance.

1.4. Data analysis

The data analyses were structured to evaluate number of detection errors, millisecond deviations in the timing precision of *R–R* intervals, and deviations in commonly used summary statistics of heart rate and heart rate variability. Across all data files, a total of 11,182 data points were analyzed during the baseline condition, and a total of 13,082 data points were analyzed during the exercise condition.

1.4.1. R-wave detection errors

Sequential heart periods collected from LifeShirt® 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 20 ms between LifeShirt® 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 LifeShirt® and Biopac. A Type I error was resolved by replacing the erroneous LifeShirt® value with an interpolated value from the two adjacent LifeShirt® *R–R* intervals. A Type II error occurred when the LifeShirt® 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 LifeShirt® 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 LifeShirt® data point was equivalent to 2 or 3 values in the Biopac data. The Type IV error was resolved by dividing the erroneous LifeShirt® data point by 2 or 3 (according to the number of *R*-waves detected.) A Type V error occurred when the value of 2 or 3 LifeShirt® data points was equivalent to 1 value in the Biopac data. The Type V error was resolved by summing the erroneous LifeShirt® data points. 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 that might be caused by ventricular arrhythmias or movement. These errors were resolved via integer arithmetic in a manner similar to the above description. Thus, files that required editing were corrected for both LifeShirt® and Biopac.

1.4.2. 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 *R–R* intervals, difference scores were computed from data files collected from both systems. Absolute difference scores in millisecond were derived to describe differences between the LifeShirt® and Biopac for each sequential *R–R* interval.

1.4.3. Differences in commonly used summary statistics

Analyses were conducted to determine whether the slight beat-to-beat changes in *R–R* interval between the systems would influence commonly used summary statistics of heart rate and heart rate variability.

1.4.4. Time-domain analyses

For each data file, the mean *R–R* interval, mean heart rate, ln variance of the *R–R* intervals and the ln variance of amplitude of respiratory sinus arrhythmia (RSA) were calculated using MXedit software (Brain-Body Center, University of Illinois at Chicago). MXedit incorporates procedures developed by Porges (1985) that quantify the amplitude of RSA using parameters that are sensitive to the frequency of spontaneous breathing that are specific to each experimental condition. In the analysis of the baseline condition, (1) sequential *R–R* intervals were resampled into 500 ms intervals to produce time-based data; (2) the time-based series was detrended by a 21-point cubic moving polynomial (Porges and Bohrer, 1990); (3) the detrended time series was bandpassed to extract the variance in the *R–R* interval pattern associated with spontaneous breathing in adults (i.e., .12–.40 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 (Riniolo and Porges, 1997). In the analysis of the exercise condition, sequential *R–R* intervals were resampled into 250 ms intervals, then detrended by a 51-point cubic moving polynomial prior to the application of a bandpass filter associated with spontaneous breathing in adults during exercise (i.e., .12–1.00 Hz.) 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 LifeShirt® and Biopac were analyzed across all participants during each condition. Average *R–R* interval, average heart rate, ln variance and RSA were quantified across each entire condition (i.e., 600 s epochs).

1.4.5. Frequency-domain analyses

For each data file, the AR spectrum power (ms^2) was computed using Biosignal software (University of Kuopio). A linear detrend (1st order) was applied to all data files prior to frequency analysis. 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). The interpolation rate was set at 4 Hz, and the AR model order was set at 16. The AR spectrum power was then transformed (using natural log) to stabilize the distribution of the spectral densities and to provide a metric comparable to the time-domain analyses.

2. Results

2.1. R-wave detection errors

For the entire data set of *R–R* intervals, only three detection errors occurred during the baseline condition in a data set consisting of 11,182 *R–R* intervals and only 24 detection errors occurred during the exercise in a data set consisting of 13,082 *R–R* intervals. LifeShirt® recorded few errors during the exercise condition (.18%), and fewer during the baseline condition (.03%).

The number and type of errors in the LifeShirt® data during each condition are displayed in Table 1. Three errors in the LifeShirt® 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. Two additional errors that could not be classified as