Agreement Between a Smartphone Pulse Sensor Application and Electrocardiography for Determining lnRMSSD

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Abstract

Esco, MR, Flatt, AA, and Nakamura, FY. Agreement between a smartphone pulse sensor application and electrocardiography for determining lnRMSSD. *J Strength Cond Res* 31(2): 380–385, 2017—The purpose of this study was to determine the agreement between a smartphone pulse finger sensor (SPFS) and electrocardiography (ECG) for determining ultra–short-term heart rate variability in 3 different positions. Thirty college-aged men ($n = 15$) and women ($n = 15$) volunteered to participate in this study. Sixty-second heart rate measures were simultaneously taken with the SPFS and ECG in supine, seated, and standing positions. The log transformed root mean square of successive R-R interval differences (lnRMSSD) was calculated from the SPFS and ECG. The lnRMSSD values were 81.5 ± 11.7 using ECG and 81.6 ± 11.3 using SPFS ($p = 0.63$, Cohen's $d = 0.01$) in the supine position, 76.5 ± 8.2 using ECG and 77.5 ± 8.2 using SPFS ($p = 0.007$, Cohen's $d = 0.11$) in the seated position, and 66.5 ± 9.2 using ECG and 67.8 ± 9.1 using SPFS ($p < 0.001$, Cohen's $d = 0.15$) in the standing position. The SPFS showed a possibly strong correlation to the ECG in all 3 positions (r values from 0.98 to 0.99). In addition, the limits of agreement (constant error ± 1.98 *SD*) were -0.13 ± 2.83 for the supine values, −0.94 ± 3.47 for the seated values, and −1.37 ± 3.56 for the standing values. The results of the study suggest good agreement between the SPFS and ECG for measuring lnRMSSD in supine, seated, and standing positions. Although significant differences were noted between the 2 methods in the seated and standing positions, the effect sizes were trivial.

Key Words parasympathetic, heart rate variability, athletic monitoring, sport technology

Introduction

Heart rate variability (HRV) is a noninvasive tool for assessing cardiac autonomic modulation (2). Because of the ability to reflect homeostatic perturbations related to physiological and psychological stress, it is becoming an emerging metric for the purpose of monitoring athletic responses to training (2). For example, HRV has been shown to be useful for guiding endurance training on daily basis (17), reflecting recovery status in response to heavy training loads (10,20), and evaluating or predicting changes in performance across a period of conditioning (5,7,11,14). Although many metrics of HRV exist, the log transformed root mean square of successive R-R interval differences (lnRMSSD) seems to be the preferred parameter for athletic monitoring in ambulatory conditions (2,25,28).

Traditional HRV recordings often involve fairly expensive equipment, such as electrocardiography (ECG) and specialized software, which is primarily found in research laboratories. A number of studies comparing mobile heart rate devices and ECG for determining HRV are available. Many suggest that Polar Heart Rate Monitors, such as the RS800G and S810 as well as the Suunto T6, are able to capture comparable beat-to-beat intervals for analysis of HRV indexes compared with ECG (26,30). However, most also require specialized knowledge to extrapolate HRV recordings to computer-based software programs. Therefore, these methods are not widely used by practitioners for the purpose of HRV measures in sportive settings, especially given that daily HRV recordings are preferred over random isolated measures (2,24,25).

Recently, an application developed for smartphone and tablet use named ithlete has been developed that has the capability of accurately measuring lnRMSSD within an ultra–short-time period (<60 seconds) with the use of a traditional heart rate strap and portable ECG receiver (8). This method seems promising because previous studies have shown that lnRMSSD can be accurately measured in approximately 60 seconds followed by a 60-second stabilization period and demonstrated sensitivity to training-induced changes in cardiac-parasympathetic activity (6,12,21,23). The ithlete

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application has been used with athletes in the field where it has been useful for reflecting training load, endurance performance, and training adaptation (5,7,9–11). In effort to enhance the convenience of obtaining lnRMSSD in the field, the application has recently been made compatible with a novel finger pulse sensor that allegedly measures lnRMSSD by pulse plethysmography.

Pulse plethysmography uses an infrared light source to illuminate subcutaneous tissue and a photograph detector for reflecting variation in the light caused by changes in the microcirculation from a peripheral site on the body (usually the finger or earlobe). Although a number of studies are available to show pulse plethysmography to accurately reflect beat-to-beat cardiac cycles compared with ECG (27), limited evidence exists examining the accuracy of the ithlete pulse finger sensor. Only 1 study showed that a range of HRV metrics extrapolated from the ithlete pulse finger sensor were accurate compared with ECG-derived recording (15). However, time and frequency domain parameters were analyzed over a longer recording period than the commercially available model that only provides lnRMSSD after an ultrashortened duration of less than 60 seconds. Furthermore, for the resting recording, only the supine position was evaluated (15). This is an important consideration because seated or standing positions are also used for tracking changes in athletic training status (4,5,19,22). For example, HRV-guided training has been shown to be superior to traditional training with daily HRV recorded in the standing position (17). In addition, recent reviews recommend that seated is the preferred position for daily HRV recording in high-level athletes (2,28). An upright posture may counteract potential effects of parasympathetic saturation observed in the supine position in highly fit athletes (18). Thus, determining the accuracy of the ithlete pulse sensor in various positions, spanning a greater range of resting heart rate values, is required. The purpose of this study was to determine the agreement between a smartphone pulse sensor and ECG for determining ultra–short-term HRV using lnRMSSD in 3 different positions in athletic, young adult subjects.

Methods

Experimental Approach to the Problem

This study was conducted to determine whether a smartphone pulse finger sensor (SPFS) could provide an accurate estimate of ultra–short-term lnRMSSD in supine, seated, and standing positions. The independent variable in this study was the lnRMSSD values measured using the SPFS, which was compared with the independent criterion variable of the ECG method. All measurements were taken on the same day for each subject.

Subjects

Thirty college-aged men ($n = 15$, age = 24.81 ± 4.15 years, weight = 90.13 ± 11.60 kg, height = 182.37 ± 5.93 cm) and women ($n = 15$, age = 21.31 ± 0.90 years, weight = 61.76 ± 6.91 kg, height = 162.07 ± 6.89 cm) volunteered to participate in this study. All participants were apparently healthy, free from cardiopulmonary or metabolic diseases, and self-reported as physically active. Participants were recruited from the university's athletic programs and kinesiology majors. The sample included Division-1 National Collegiate Athletic Association athletes (i.e., American Football and Swimming), strength and conditioning interns, and intramural club weightlifters. Because of the range of active participants, the sample was labeled as "athletic." Participants were asked to refrain from consuming sympathomimetics (e.g., pseudoephedrine and caffeine) or alcohol and avoid strenuous exercise for at least 12 hours before data collection. All the participants supplied written consent agreeing to the testing conditions. Data were collected in 1 visit to the Exercise Physiology Laboratory. The experimental protocol was granted ethical approval by the University of Alabama's Institutional Review Board for research involving human subjects.

Procedures

The participants were asked to lay supine on a comfortable gurney for electrode placement. Three Ag/AgCl surface electrodes were placed on the participant in a modified lead-II arrangement, where the right mid-clavicular notch served as the negative electrode, the fifth intercostal space in the mid-axillary line on the left side served as the positive electrode, and the left anterior-superior iliac crest served as the ground electrode. Before electrode placement, each site was cleaned by rubbing with alcohol swabs. The electrodes were connected to a Biopac MP100 data acquisition system (Goletta, CA) that was interfaced with a Dell personal computer.

For the pulse finger sensor method, an infrared pulse sensor (ithlete; HRV Fit Ltd., Southampton, UK) was inserted into the headphone connection of an iPad2 (Apple Inc, Cupertino, CA). This method calculates lnRMSSD from pulse wave variability after a 55-second recording period. Although raw outputs of the pulse intervals are not available for manual inspection, the built-in algorithm removes excessively short (i.e., $<$500 ms) or long (i.e., $>$1,800 ms) intervals to exclude ectopic beats (8). The lnRMSSD value is multiplied by 20 and automatically displayed on the iPad2 screen by the mobile ithlete application. According to the manufacturer, the modification (i.e., lnRMSSD × 20) provides a more easily interpretable figure (8). Therefore, the values reported in this article are modified lnRMSSD values.

While in the supine position, the ECG was initiated to record heart rate and rhythm. Then, the participant's left index finger was inserted into the mobile pulse finger sensor, and the application was initiated. After a 1-minute stabilization period, the "start recording" indicator of the ithlete application displayed on the iPad2 screen was pressed by a technician to commence the ithlete recording. The 1-minute stabilization period was allowed because this has been previously shown to be an appropriate period for heart rate stabilization during ultrashortened recording periods (12). Before pressing the indicator, the technician counted down from "3" to "1," where the ithlete recording began at the count of "1." The Biopac ECG was marked simultaneously at the count of "1" by another technician to indicate on the ECG when the pulse finger sensor recording began. During the last 3 seconds of the ithlete recording, the technician counted down from "3" to "1" in synch with the time count displayed on the smartphone application. The Biopac was marked a second time at the count of "1" to indicate when the pulse finger sensor recording ended. This method allowed for simultaneous lnRMSSD recording of both the pulse finger sensor and ECG at precise time recording segments. After the supine recording, the participant was provided a chair and asked to sit comfortably with the back supported. After a 1-minute stabilization period, the recording procedures were initiated. After the procedures in the seated position, the participant was asked to stand. After a 1-minute stabilization period, the same recording procedures were again initiated. No attempt was made to control from breathing frequency because sensitivity of RMSSD to breathing patterns is very low (2).

Statistical Analyses

All data were analyzed with SPSS version 22.0 (Somers, NY) and Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA). Mean and SDs were determined for adjusted lnRMSSD values from the SPFS and ECG that were measured in the supine, seated, and standing positions. The values were compared between the 2 devices with paired T-tests. Cohen's *d* statistic determined the effect sizes of the differences in lnRMSSD values, and Hopkin's scale of magnitude was used where an effect size of 0–0.2 was trivial, 0.2–0.6 was small, 0.6–1.2 was moderate, 1.2–2.0 was large, and >2.0 was very large (16). Pearson product-moment correlations were used to quantify the relationships between the SPFS and ECG values. The Bland-Altman method was used in which the difference between the 2 methods was plotted against their average values (1). This method identifies the 95% confidence interval (CI) for the differences to estimate precision (±1.96 *SD* of the difference) (27). In addition, as suggested by Schafer and Vagedes (27), the ratio of half the 95% CI and the mean of the average values was calculated to assess the quality of agreement where a "good" agreement was considered if the ratio was less than 0.1, "moderate" agreement was considered if the ratio was 0.1–0.2, and "insufficient" agreement if the ratio was greater than 0.2 (27). Significance for the correlation (i.e., trend) between the differences and mean values of the adjusted lnRMSSD values was determined as $p \leq 0.05$.

Results

Results comparing the SPFS and ECG values are depicted in Table 1. Compared with the lnRMSSD obtained using the ECG, the SPFS measures showed to be nonsignificantly different in the supine position ($p = 0.627$) but significantly different in the seated ($p = 0.007$) and standing ($p < 0.001$) positions. However, the effect sizes for the comparisons of the 2 methods across the 3 positions were considered to be trivial (Cohen's *d* ranged from 0.01 to 0.15), suggesting no practical differences exist. The correlation coefficients were strong between the SPFS and ECG for each position. Figure 1 depicts the Bland-Altman Plots for all 3 positions. The 95% CI (constant error [CE] ± 1.96 *SD* of residual scores [SPFS − ECG]) ranged from 2.70 above to 2.96 below the CE of −0.13 in the supine position, from 2.53 above to 3.47 below the CE of −0.94 in the seated position, and from 2.18 above to 4.93 below the CE of −1.37 in the standing position (Figure 1). The SPFS method showed a ratio of half the 95% CI of the difference to the mean of the averages of 0.02 of the supine values, 0.02 of the seated values, and

Table 1. Comparison of lnRMSSD values derived from ECG and the SPFS ($n = 30$).*

						Limits of agreement				
Value	Mean ± *SD*	*p*	Cohen's *d*	*r*	*SEE*	CE ± 1.96 *SD*	Ratio	Upper	Lower	Trend
Supine										
ECG	81.47 ± 11.70									
SPFS	81.60 ± 11.32	0.627	0.01	0.99	1.42	0.13 ± 2.83	0.02	2.70	2.96	0.27
Seated										
ECG	76.53 ± 8.23									
SPFS	77.47 ± 8.21	0.007	0.11	0.98	1.73	0.94 ± 3.47	0.02	2.53	3.47	0.01
Standing										
ECG	66.46 ± 9.20									
SPFS	67.83 ± 9.06	<0.001	0.15	0.98	1.79	1.37 ± 3.56	0.03	2.18	4.93	0.07

*CE = constant error; ratio = the ratio of half the 95% CI and the mean of the average values; ECG = electrocardiography; SPFS = smartphone finger sensor; CI = confidence interval.

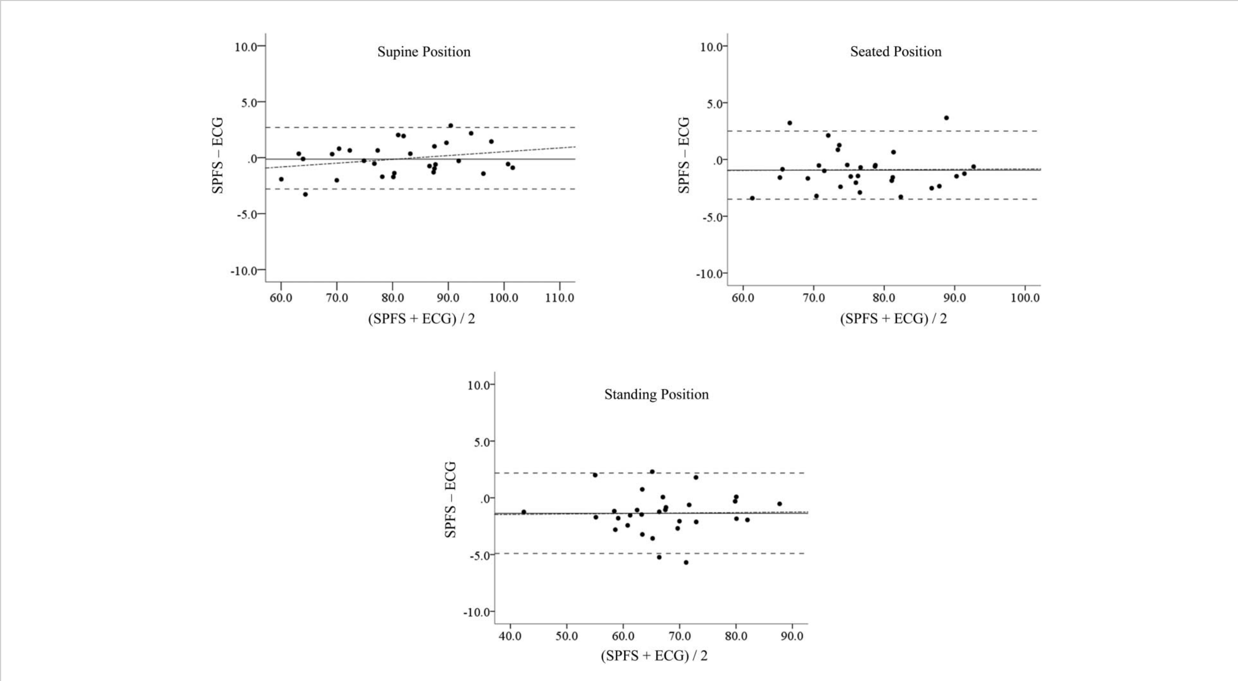

Figure 1. Bland-Altman plots comparing the corrected RMSSD values from the smartphone finger sensor (SPFS) with the criterion electrocardiogram (ECG). The solid lines represent the mean bias, whereas the outside dashed lines represent the 95% limits of agreement. The dashed-dotted regression lines represent the trend between the differences and mean values.

0.03 of the standing values; hence, all 3 positions showed "good" agreement (Table 1). The trend between the differences and mean of the SPFS and ECG were not significant ($p \leq 0.05$) in any position, suggesting no proportional biases existed.

Discussion

This investigation determined the level of agreement between lnRMSSD values measured using an SPFS and gold standard ECG method. The correlation procedures between the SPFS and criterion in all 3 positions showed the coefficients to be strong, and the *SEE* values ranged from 1.42 to 1.79. In terms of mean differences, the SPFS provided lnRMSSD values that were not significantly different than ECG in the supine position. However, statistically significant mean differences were found between the SPFS and ECG values in the seated and standing positions, although the differences that were detected were considered trivial according to the Cohen's *d* procedure. The finding of statistical significance along with a trivial effect size may be due to having a larger sample size than needed for sufficient power of the paired *t*-test procedure (29). This is a common issue in sport science as significant *p* values do not always correspond to practical significance in "real-world" settings (16). Thus, we would like to encourage the reader to view the statistical outcomes collectively and not just the *p* value of the paired *t*-test. It should also be noted that the *t*-test has been suggested as an inadequate method to verify agreement of HRV measures between pulse variability and ECG as it is unable to detect lack of precision (27). Instead, the Bland-Altman method is a preferred procedure for evaluating agreement (27). This approach suggested that the SPFS displayed tight limits of agreement to the ECG in each position. Furthermore, according to Schafer and Vagedes (27), the ratio of half the 95% CI of the differences and the mean of the average values provide qualitative information in regard to the agreement. When this ratio was calculated for all 3 positions, each value was less than 0.1 (actual ratios were 0.02–0.03). Therefore, it can be determined that SPFS showed good agreement to the gold standard ECG in supine, seated, and standing positions. In practical terms, after a brief period of stabilization of approximately 1 minute, the SPFS seems to be a suitable surrogate to ECG for determining lnRMSSD in an ultrashortened duration (i.e., <60 seconds). Because lnRMSSD recordings of less than 1 minute after a 1-minute stabilization period have been shown to provide excellent accuracies compared with longer, more traditional recording durations (6), the SPFS examined in the study may provide an acceptable measure to record HRV in practical settings.

Pulse rate variability is considered an accurate reflection of beat-to-beat cardiac intervals, as long as every pulse cycle is correctly detected (27). Indeed, reported agreement between pulse rate variability and ECG-derived HRV is generally very good, which especially applies to the supine position as the agreement deteriorates somewhat during upright position (27). For instance, RMSSD was previously shown to be significantly higher with pulse plethysmography compared with ECG in the standing position, yet displayed acceptable limits of agreement and a strong correlation coefficient (3). This concurs with the current findings as the trivial difference between SPFS and ECG was enough to be detected as significant with the paired *t*-test procedure in the standing and seated positions, although good agreement remained with the Bland-Altman method. The precise rationale for this finding cannot be clarified with the methodology used. However, the change in the mechanical properties of the vasculature that occurs with an adjustment in body position may slightly influence the agreement between HRV determined with pulse wave variability and ECG. As shown by Guzik et al. (13), arterial stiffness increased during head-up tilt in young healthy subjects, most likely due to increased sympathetic activation leading to vasoconstriction. Therefore, a speculative explanation of the slight deterioration in mean accuracy using the SPFS in seated and supine positions reported in the current study may be due to an orthostatic stress-induced increase in sympathetic activation leading to heightened arterial stiffness and decreased pulse wave velocity.

Mobile technology offers many possibilities related to physiological monitoring in ambulatory conditions. Incidentally, a few studies are available to compare smartphone applications with ECG for HRV determination (8,15). For instance, similar to the current study, the ithlete with heart rate monitor strap and wireless ECG transmitter has been shown to provide a strong correlation and tight limits of agreement with the laboratory ECG method in the supine position (8). Since then, the same mobile device has been implemented in several studies examining physiological changes in response to physical training in athletes (7,9–11). The pulse finger sensor version of ithlete that was examined in the current study is newer compared with the model that was used within the aforementioned studies. The pulse finger sensor has an advantage over the older method because it only requires insertion of the index finger into the portable sensor that is connected to a smartphone or iPad, instead of having to put on a moistened chest strap before initiating a measure, making it even more convenient for use. Previously, Heathers (15) extrapolated time and spectral indices from the ithlete pulse finger sensor to compare with ECG-derived parameters at rest, during attentional loading and moderate-intense exercise in ten young adults. The pulse finger sensor showed an accuracy of $\pm 2\%$ and 5% for low-frequency and high-frequency spectral powers, respectively, over all points during extended recording time epochs (15). Our findings extend the work of Heathers (15) by showing good agreement not only in the supine position but also in seated and standing positions of the commercially available model that provides lnRMSSD after an ultrashortened period of less than 60 seconds.

The inclusion of various positions and ultra–short-term recordings are important features of the study because it pertains to athletic monitoring. First, there is not a general consensus as to which position is best for recording HRV. Although the supine position is well tolerated in athletes, it does not promote the most appropriate position for morning measures because the subject may be at risk of falling back to sleep. In addition, extremely low heart rates with concurrent low HRV have been noted as parasympathetic saturation of the sinoatrial node may be present when an elite aerobically trained athlete assumes a supine position (18,24). However, the seated and standing positions may be more sensitive for tracking changes in autonomic activity in response to training in elite athletes (2,18). Second, ultra–short-term lnRMSSD recording periods of approximately 60 seconds have shown to provide good agreement with traditional recommended short-term recording periods of 5 minutes (6,12,23). In addition, ultrashortened HRV recordings have been effective for monitoring athletic response to training (7,9–11).

There are a few limitations of the study that should be noted. First, only healthy young adults served as the sample of subjects. Therefore, the results should not be generalized to older adults or clinical populations. Furthermore, in terms of athletic monitoring, the study design did not include longitudinal analysis across a training period. However, because the version of ithlete that uses a heart rate monitor strap and wireless ECG transmitter has been effectively used in studies examining athletic responses to long-term training, one has to speculate that the SPFS will be effective for these purposes, as well. Another limitation of the current study is that the SPFS was only tested on 1 Apple product. Therefore, difference among mobile device brands cannot be determined.

In conclusion, no significant mean differences and tight limits of agreement were found between the SPFS and ECG for the supine position. Although significant mean differences were reported in the seated and standing positions, the differences were trivial. In addition, tight limits of agreement were considered tight in both positions. Therefore, it can be concluded that the SPFS provided good agreement with the gold standard ECG for measuring ultra–short-term lnRMSSD in supine, seated, and standing positions in a group of athletic participants.

Practical Applications

For HRV monitoring to be effectively implemented for athletic monitoring purposes, data must be collected near daily. The financial cost and time-consuming nature of traditional HRV field tools limit their use among sports teams. The SPFS used within this study provides a convenient and affordable alternative to traditional HRV tools that may enhance use among sports teams for monitoring athletes. The SPFS and application facilitate quick and convenient, unsupervised data collection without the need for transferring data to specialized software for analysis. This reduces the burden on athletes and coaches which often deters teams from incorporating HRV in their monitoring protocols.

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