Validity of the Elite HRV Smartphone Application for Examining Heart Rate Variability in a Field-Based Setting

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Abstract

Perrotta, AS, Jeklin, AT, Hives, BA, Meanwell, LE, and Warburton, DER. Validity of the elite HRV smartphone application for examining heart rate variability in a field-based setting. *J Strength Cond Res* 31(8): 2296–2302, 2017—The introduction of smartphone applications has allowed athletes and practitioners to record and store R-R intervals on smartphones for immediate heart rate variability (HRV) analysis. This user-friendly option should be validated in the effort to provide practitioners confidence when monitoring their athletes before implementing such equipment. The objective of this investigation was to examine the relationship and validity between a vagal-related HRV index, rMSSD, when derived from a smartphone application accessible with most operating systems against a frequently used computer software program, Kubios HRV 2.2. R-R intervals were recorded immediately upon awakening over 14 consecutive days using the Elite HRV smartphone application. R-R recordings were then exported into Kubios HRV 2.2 for analysis. The relationship and levels of agreement between $rMSSD_{ln}$ derived from Elite HRV and Kubios HRV 2.2 was examined using a Pearson product-moment correlation and a Bland-Altman Plot. An extremely large relationship was identified ($r = 0.92$; $p < 0.0001$; confidence interval [CI] 95% = 0.90–0.93). A total of 6.4% of the residuals fell outside the 1.96 ± *SD* (CI 95% = −12.0 to 7.0%) limits of agreement. A negative bias was observed (mean: −2.7%; CI 95% = −3.10 to −2.30%), whose CI 95% failed to fall within the line of equality. Our observations demonstrated differences between the two sources of HRV analysis. However, further research is warranted, as this smartphone HRV application may offer a reliable platform when assessing parasympathetic modulation.

Key Words autonomic modulation, R-R intervals, monitoring, athletes

Introduction

Heart rate variability (HRV) has become a popular, noninvasive, physiological assessment tool with practitioners for monitoring the activity of the autonomic nervous system (4,25). Previous literature has demonstrated how practitioners can examine the magnitude of autonomic modulation through examining resting heart rate (HR) and the variability between beat-to-beat (R-R) intervals in response to a training stress (6,25), psychological stress (7,26), alterations in blood volume (5), and hormonal fluctuations (13,15). It has been suggested that the very purpose of monitoring HRV is to develop insight into how an athlete adapts to a training stress during a training period or through competition (4). Insight into an athlete's autonomic nervous system response from a training stress may help integrative support staff and coaches adapt future training loads in an effort to facilitate improved recovery and increased performance potential (16,17).

The noninvasive nature of collecting R-R intervals through a valid and personal HR monitor has enhanced the ability to collect resting HR recordings for immediate and long-term HRV monitoring (19). When monitoring HRV in athletes, current evidence suggests a short-term collection period ranging from 5 to 10 minutes, immediately upon awakening, while in a supine position (23–25). However, the necessary time required to individually export R-R files, perform artifact corrections, and analyze each athlete's HRV may often prevent timely feedback to coaching staff, preventing the opportunity to make adjustments in training load for proceeding on field sessions. Furthermore, integrative support staff may be limited to only accessing recorded R-R files before training, when athletes tend to return HR monitors for data extraction. Such

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Table 1. Descriptive statistics (mean ± *SD*) of the participants studied.

	Mean ± *SD*
Age (y)	30.8 ± 11.7
Sex	
Male = 29	
Female = 8	
Height (cm)	177.9 ± 9.6
Weight (kg)	85.1 ± 14.3
BMI ($kg \cdot m^{-2}$)	26.8 ± 4.0

a circumstance with limited turnover time may impact the capability of practitioners to make decisions for imminent training sessions without any direction from HRV. Perhaps the most common, yet overlooked, obstacle when working in a team setting is the failure to return HR monitors for data extraction. Such a situation can lead to athletes training without an HR monitor whereby HR-derived training loads become absent. Recent literature has proposed practitioners are often limited to athlete adherence and what measures are most practical when monitoring physiological variables such as HRV (4,22). Current evidence toward smartphone applications (apps) capable of syncing with a personal HR monitor for collecting R-R intervals has provided a user-friendly software for the instant analysis of HRV (3,8). Furthermore, HRV smartphone apps often provide the option to export raw R-R data files directly to the practitioner's computer through email. The idea of team sport athletes possessing their own personal HR monitor, compatible with an HRV smartphone app capable of collecting R-R intervals, that can be exported to the practitioner before training would be a convenient and optimal experience for both athletes and coaching staff. The purpose of this investigation was to examine the relationship between a popular smartphone app, Elite HRV, and its validity to examine a vagal-related HRV index as expressed through rMSSD when compared with a commonly accessible and used computer software program, Kubios HRV 2.2 (27), in a field setting. In conducting this investigation, we hypothesized that the smartphone application, Elite HRV, would be identified as a valid platform for examining rMSSD when compared with a commonly used HRV analysis software program, Kubios HRV 2.2.

Methods

Experimental Approach to the Problem

This is a validation study design where the relationship and level of agreement in $rMSSD_{ln}$ derived from a smartphone application and a validated computer software program was examined over a 14-day period. A Pearson product-moment correlation was used to identify the level of relationship along with a Bland-Altman Plot to demonstrate the level of agreement.

Subjects

A sample consisting of 29 males and 8 females, with a mean age (SD) 30.8 (11.7), recreational athletes acting as participants each took part in a 14-day field study in which testing

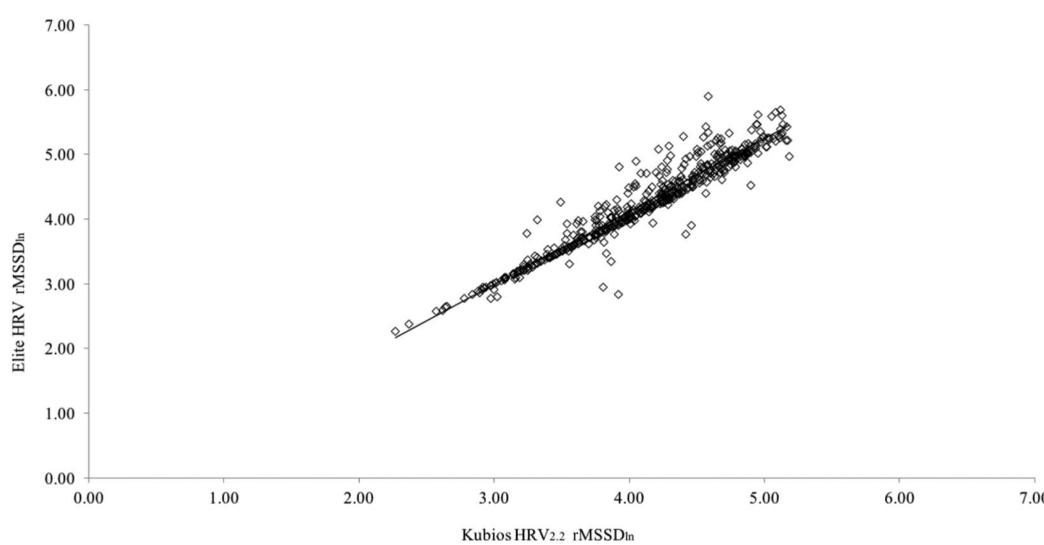

Figure 1. Relationship between $rMSSD_{ln}$ derived from Elite HRV smartphone app and Kubios HRV 2.2 ($r = 0.92$; CI 95% = 0.90–0.93; $p < 0.0001$). HRV = heart rate variability; CI = confidence interval.

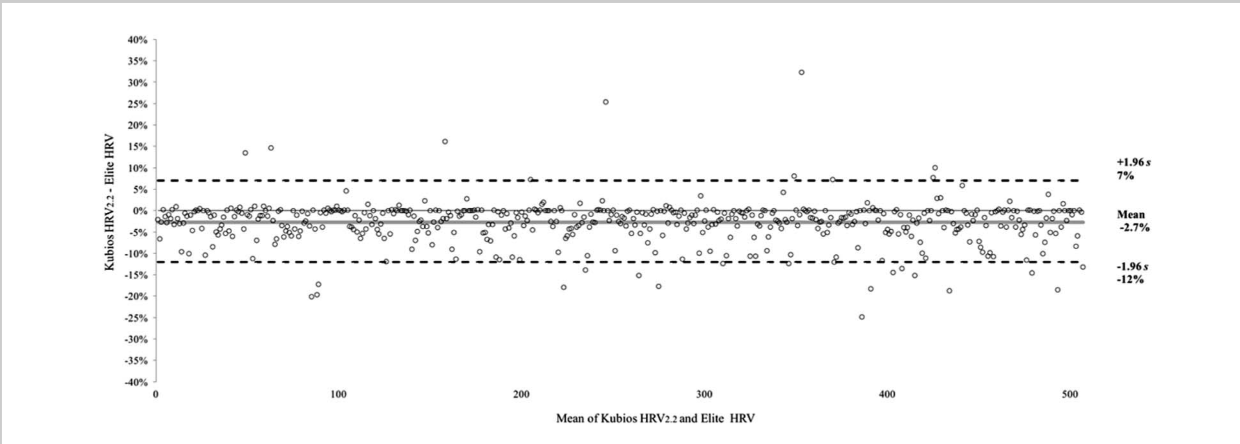

Figure 2. Bland-Altman plot comparing % residuals in $rMSSD_{ln}$ derived from Elite HRV and Kubios HRV 2.2. The solid line represents the mean bias (−2.7%; CI 95% = −3.1 to −2.3%). The 2 dashed lines outside the mean represent 95% levels of agreement (1.96 *SD*; 7 to −12%). The dashed line in the middle represents the line of equality (0%). HRV = heart rate variability; CI = confidence interval.

occurred away from a laboratory setting. Characteristics are provided in Table 1. All participants were asked to provide informed written consent before the initiation of testing in accordance with guidelines of the Clinical Research Ethics Review Board at the University of British Columbia, which approved collection of data for this study. All participants completed the Physical Activity Readiness Questionnaire for Everyone (29). Additional information regarding the participants' health history was also collected through administration of additional questionnaires during the 17 days.

Procedures

Data collection occurred in a field-based setting where all participants lived in a dormitory living environment for the entire study period. Participants were provided a Polar H7 HR monitor (Polar Electro Oy, Kempele, Finland) with a sampling frequency of 1,000 Hz. Previous literature has demonstrated the use of a Polar H7 as a valid HR monitor when recording R-R intervals for HRV analysis (10). Participants were previously educated on how to operate their designated HR monitor and smartphone application (Elite HRV) before the start of data collection. Participants were instructed to record 10 minutes of resting HR, double the identified minimum time frame required for examining time-domain indices (28) over 14 consecutive days immediately upon awakening in the supine position. The extended recording length was implemented as each participant was able to provide the time in the effort to capture additional cardiac cycles for analysis. A time-domain indices, rMSSD (i.e., root mean square of successive R-R intervals), was selected to reflect alterations in vagal modulation and was preferred because of its enhanced reliability in demonstrating parasympathetic activity when compared with other power spectral density indices (1). Both breathing rate and depth were left uncontrolled for and participants were instructed to relax and breathe at a natural rate. Previous investigations have identified rMSSD to possess robust statistical properties capable of negating significant influence toward R-R interval length from respiratory sinus arrhythmia when not controlling for breathing rate and depth (21). All raw R-R data files were exported to a laptop computer at the completion of the 14 days using Elite HRV's email exporting option. All smartphone-generated $rMSSD_{ln}$ values were recorded manually by the investigators each morning after collection during the entire study period.

All R-R files were exported from the Elite HRV smartphone application by email into a separate computer for analysis using Kubios HRV 2.2. Each file was corrected for ectopic beats and artifact before analysis using an artifact correction method provided in Kubios HRV 2.2. A medium level of artifact correction identifying R-R intervals varying above or below 0.25 seconds compared with the average was chosen to help preserve the variability while addressing the presence of any artifacts. Kubios HRV 2.2 uses a piecewise cubic spline interpolation method to generate corrupted or missing values. It has been recommended this technique of artifact correction be used for occasional artifacts and ectopic beats when examining R-R intervals (20).

Statistical Analyses

Raw rMSSD data were log transformed using the natural log rhythm for addressing any nonuniformity of error. All values as identified as outliers where included in the data set and its analysis. As previously stated in the procedures section, we believed the standardization throughout the data collection period, its filtering, logarithmic transformation, and its analysis would allow for the identification of any outliers to largely be due to biological errors, resulting from physiological perturbations in homeostasis which was the

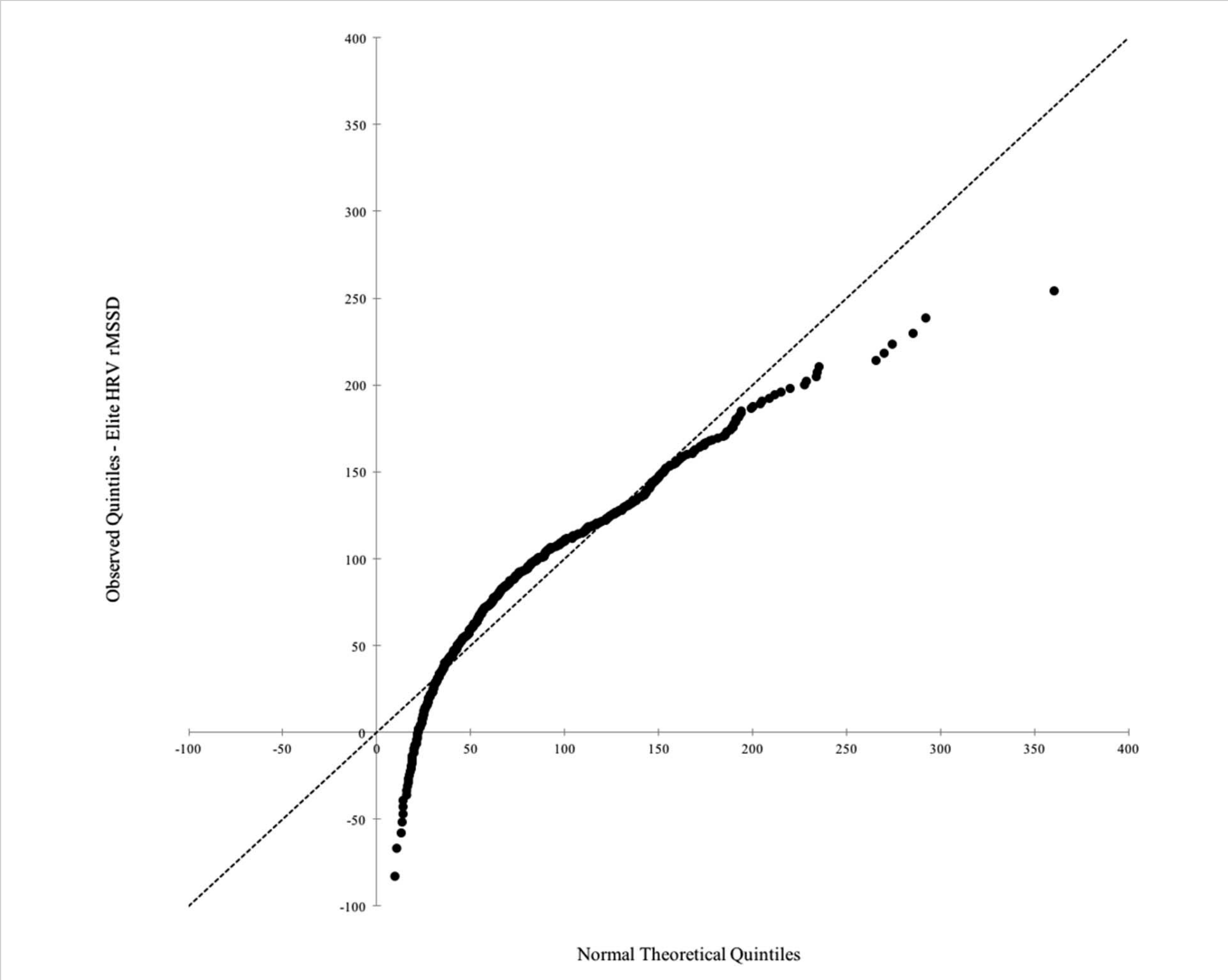

Figure 3. Q-Q plot comparing the theoretical rMSSD quintiles to the observed rMSSD quintiles derived from Elite HRV. HRV = heart rate variability.

very purpose for examining HRV. Levels of agreement between Kubios HRV 2.2 and Elite HRV were assessed using a Bland-Altman Plot (2), comparing the % residuals between each method to the average values. Reasonable agreement was defined as <5% of the residuals residing outside 1.96 SD (confidence interval [CI] 95%) from the mean. Bias was shown using a CI 95% and its position relative to the line of equality. A Pearson product-moment correlation expressed the strength of relationship between Elite HRV and Kubios HRV 2.2. A correlation coefficient of $r > 0.90$ (CI 95%) was chosen to indicate an acceptable level of relationship (12). Statistical analysis was completed using Microsoft Office Excel 2010.

Results

When examining the $rMSSD_{ln}$ values produced through Kubios and Elite HRV, our results demonstrated an extremely large relationship ($r = 0.92$; $p < 0.0001$; CI 95% = 0.90–0.93) as seen in Figure 1. A total of 6.4% of the residuals fell outside of the 1.96 ± *SD* (CI 95% = −12.0; 7.0%) limits of agreement as observed in Figure 2. A negative bias was identified (mean: −2.7%; CI 95% = −3.10; −2.30%) with a CI 95% failing to reside within the line of equality as displayed in Figure 2.

rMSSD values derived from Elite HRV were nonnormally distributed (Kurtosis = 1.3; Skewness = 1.1) and are expressed using a Q-Q plot as seen in Figure 3. rMSSD values derived from Kubios HRV 2.2 were normally distributed. These observations prevented further analysis between non–log-transformed rMSSD values from Kubios and Elite HRV. $rMSSD_{ln}$ values derived from Elite HRV demonstrated a normal distribution (Kurtosis: −0.6; Skewness: −0.3); a visual examination using a Q-Q plot can be seen in Figure 4.

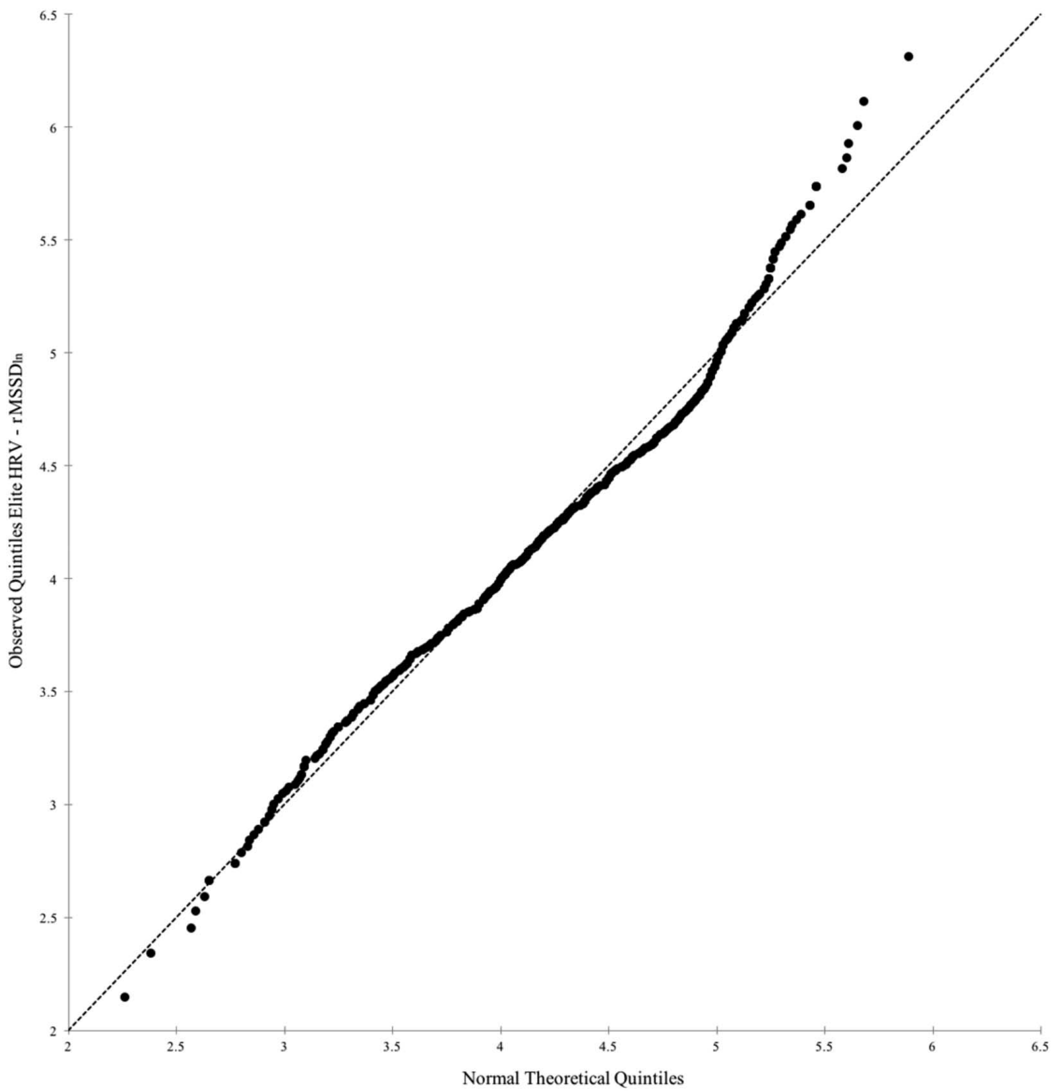

Figure 4. Q-Q plot comparing the theoretical $rMSSD_{ln}$ quintiles to the observed $rMSSD_{ln}$ quintiles derived from Elite HRV. HRV = heart rate variability.

Discussion

The purpose of this investigation was to examine the relationship and validity of an HRV smartphone app commonly accessible to all smartphone operating systems for assessing autonomic modulation as expressed through a parasympathetic index, rMSSD, in a field-based setting. The correlation we observed ($r = 0.92$; CI 95% = 0.90–0.93, $p < 0.0001$) demonstrated an extremely large relationship between Elite HRV and Kubios HRV 2.2 and is in agreement with previous literature examining the validity of other smartphone applications (3,8). However, when identifying new instruments for the purpose of replacing or interchangeable use, further statistical support beyond a strong correlation focusing on the limits of agreement should be implemented (2,9). The results from the Bland-Altman analysis demonstrated 6.4% of the $rMSSD_{ln}$ residuals fell outside the levels of agreement set at CI 95% (Figure 2). Furthermore, a negative bias was observed (mean: −2.7%; CI 95% = −3.10 to −2.30%) with its CI 95% failing to reside within the line of equality as seen in Figure 3. When visually examining all residuals, our results indicate larger discrepancies with a negative bias toward larger $rMSSD_{ln}$ values (Figure 2).

A potential explanation for the lack of agreement observed in this study compared with previous investigations examining HRV smartphone applications may have been due to the difference in R-R interval recording periods.

Sampling periods for each participant varied beyond the predetermined 10 minutes, as some participants lost track of time. The Elite HRV smartphone application used in this investigation did not permit specific selections or the partitioning of R-R intervals beyond that of the total recording period collected (i.e., ≥10 minutes). When examining R-R recordings, longer sampling lengths have been shown to increase variance in R-R cycles and vagal-related HRV indexes (28). For this reason, it has been advised against comparing repeated measures in HRV that were derived from different sampling lengths (28). However, for the purpose of this investigation, all R-R sampling periods, regardless of the recording length, were compared against themselves and such violations therefore would not exist. Alternatively, the differences in residuals observed may be indicative of discrepancies in the artifact correction techniques provided in Elite HRV and Kubios HRV 2.2. The large residuals observed in this study may have been elicited from an extended sampling period beyond that of the predetermined 10-minute recording period. Such a prolonged period may have increased the potential for the collection of ectopic beats and artifacts (28). Furthermore, HRV analysis derived from shorter recording periods have indicated greater sensitivity to artifact correction techniques, potentially explaining the magnitude of residuals currently observed between short and long recording periods (28).

A medium level of artifact correction which identifies R-R intervals varying above or below 0.25 seconds compared with the average was chosen to help preserve the variability while addressing the presence of any artifacts when analyzing all R-R intervals through Kubios HRV 2.2. Kubios HRV 2.2 uses a piecewise cubic spline interpolation method to generate corrupted or missing values, a preferred method for smoothing curves using a third degree polynomial (14). To our knowledge, the technique and level of artifact correction implemented in Elite HRV is not made known. As such, a comparison between each technique of artifact removal was not possible. There remains a lack of standardized recommendations in the literature on how best to edit R-R recordings containing artifact. It has been suggested practitioners hold a minimum requirement in normal R-R intervals of 80% before editing artifacts for further analysis of HRV (20). Further investigations toward the artifact removal techniques from available smartphone applications are required in the effort to provide practitioner's confidence in the HRV values produced.

In conclusion, we identified an extremely large correlation between $rMSSD_{ln}$ values elicited through Elite HRV and Kubios HRV 2.2. However, the limits of agreement were not met as 6.4% of the residuals fell outside of the predetermined priori (CI 95%). Furthermore, a negative bias in the mean residuals (−2.7%) whose CI 95% failed to overlap the line of equality was observed. It is also recommended that further investigations between HRV smartphone applications and various software programs disclose the technique and level of artifact correction used.

Practical Applications

The use of a smartphone application for assessing HRV in athletes has become popular among integrative support staff, particularity in team sports. This option is often viewed as efficient and practical when monitoring athletes in a team setting, as the app is capable of collecting, analyzing, and exporting vagal-related HRV indexes directly to the practitioner for further examination and recording. The ability to analyze, store, and export HRV recordings may be most practical for noncentralized athletes and with teams traveling with minimal staff. This option would allow for the continuing physiological support from practitioners not traveling, provided internet access is available for exporting data. In conjunction with the level of validity a sport science assessment tool offers, its ability to remain reliable may be equally as important as its validity. The ability of an instrument to reliably produce similar results when repeated multiple times should be of great importance to integrative support staff when desiring to monitor the long-term development of their athletes. Current evidence demonstrates sport science instruments commonly elicit larger sampling errors as the value being measured increases (18), an issue that may become problematic when measuring large HRV values. However, the logarithmic transformation of the raw rMSSD values have been suggested to correct this nonuniformity of error whereby applying a similar magnitude of error for all values measured (11). Although this investigation solely examined the validity of a popular smartphone HRV application, recent reviews have postulated that the occurrence of reoccurring errors after automatic filtering should not prevent practitioners from effectively monitoring their athletes when this filtering method is standardized for each analysis (4). Although this study demonstrated an unsatisfactory level of agreement between Kubios HRV 2.2 and Elite HRV, the relationship observed as expressed through the Pearson's product-moment correlation was nearly perfect and may encourage practitioners to implement its use baring all future comparisons and the long-term monitoring of their athlete to continue to be derived from the same smartphone application.

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References

1. Al Haddad, H, Laursen, PB, Chollet, D, Ahmaidi, S, and Buchheit, M. Reliability of resting and postexercise heart rate measures. *Int J Sports Med* 32: 598–605, 2011.
2. Bland, JM and Altman, D. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 327: 307–310, 1986.
3. Boos, CJ, Bakker-Dyos, J, Watchorn, J, Woods, DR, O'Hara, JP, Macconnachie, L, and Mellor, A. A comparison of two methods of heart rate variability assessment at high altitude. *Clin Physiol Funct Imaging*, 2016. Epub ahead of print.
4. Buchheit, M. Monitoring training status with HR measures: Do all roads lead to Rome? *Front Physiol* 5: 73, 2014.
5. Buchheit, M, Laursen, P, Al Haddad, H, and Ahmaidi, S. Exercise-induced plasma volume expansion and post-exercise parasympathetic reactivation. *Eur J Appl Physiol* 105: 471–481, 2009.
6. Daanen, HA, Lamberts, RP, Kallen, VL, Jin, A, and Van Meeteren, NL. A systematic review on heart-rate recovery to monitor changes in training status in athletes. *Int J Sports Physiol Perform* 7: 251–260, 2012.
7. Delaney, J and Brodie, D. Effects of short-term psychological stress on the time and frequency domains of heart-rate variability. *Percept Mot Skills* 91: 515–524, 2000.
8. Flatt, AA and Esco, MR. Validity of the ithleteTM smart phone application for determining ultra-short-term heart rate variability. *J Hum Kinet* 39: 85–92, 2013.
9. Giavarina, D. Understanding Bland Altman analysis. *Biochem Med (Zagreb)* 25: 141–151, 2015.
10. Giles, D, Draper, N, and Neil, W. Validity of the Polar V800 heart rate monitor to measure RR intervals at rest. *Eur J Appl Physiol* 116: 563–571, 2016.
11. Hopkins, WG. Measures of reliability in sports medicine and science. *Sports Med* 30: 1–15, 2000.
12. Hopkins, WG and Manly, BF. Errors in assigning grades based on tests of finite validity. *Res Q Exerc Sport* 60: 180–182, 1989.
13. Huovinen, J, Kyrolainen, H, Linnamo, V, Tanskanen, M, Kinnunen, H, Hakkinen, K, and Tulppo, M. Cardiac autonomic function reveals adaptation to military training. *Eur J Sport Sci* 11: 231–240, 2011.
14. Kamath, M and Fallen, E. Correction of the heart rate variability signal for ectopics and missing beats. In: *Heart Rate Variability.* Malik, M and Camm, AJ, eds. Armonk, NY: Futura, 1995. pp. 75–85.
15. Leicht, AS, Hirning, DA, and Allen, GD. Heart rate variability and endogenous sex hormones during the menstrual cycle in young women. *Exp Physiol* 88: 441–446, 2003.
16. Manzi, V, Castagna, C, Padua, E, Lombardo, M, D'Ottavio, S, Massaro, M, Volterrani, M, and Iellamo, F. Dose-response relationship of autonomic nervous system responses to individualized training impulse in marathon runners. *Am J Physiol Heart Circ Physiol* 296: H1733–H1740, 2009.
17. Manzi, V, Iellamo, F, Impellizzeri, F, D'Ottavio, S, and Castagna, C. Relation between individualized training impulses and performance in distance runners. *Med Sci Sports Exerc* 41: 2090–2096, 2009.
18. Nevill, AM and Atkinson, G. Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. *Br J Sports Med* 31: 314–318, 1997.
19. Nunan, D, Donovan, G, Jakovljevic, D, Hodges, L, Sandercock, G, and Brodie, D. Validity and reliability of short-term heart-rate variability from the Polar S810. *Med Sci Sports Exerc* 41: 243, 2009.
20. Peltola, MA. Role of editing of R–R intervals in the analysis of heart rate variability. *Front Physiol* 3: 148, 2012.
21. Penttilä, J, Helminen, A, Jartti, T, Kuusela, T, Huikuri, HV, Tulppo, MP, Coffeng, R, and Scheinin, H. Time domain, geometrical and frequency domain analysis of cardiac vagal outflow: Effects of various respiratory patterns. *Clin Physiol* 21: 365–376, 2001.
22. Plews, DJ, Laursen, PB, Le Meur, Y, Hausswirth, C, Kilding, AE, and Buchheit, M. Monitoring training with heart rate-variability: How much compliance is needed for valid assessment? *Int J Sports Physiol Perform* 9: 783–790, 2014.
23. Plews, DJ, Laursen, PB, Stanley, J, Kilding, AE, and Buchheit, M. Training adaptation and heart rate variability in elite endurance athletes: Opening the door to effective monitoring. *Sports Med* 43: 773–781, 2013.
24. Schmitt, L, Regnard, J, Desmarets, M, Mauny, F, Mourot, L, Fouillot, JP, Coulmy, N, and Millet, G. Fatigue shifts and scatters heart rate variability in elite endurance athletes. *PloS One* 8: e71588, 2013.
25. Stanley, J, Peake, JM, and Buchheit, M. Cardiac parasympathetic reactivation following exercise: Implications for training prescription. *Sports Med* 43: 1259–1277, 2013.
26. Taelman, J, Vandeput, S, Spaepen, A, and Van Huffel, S. Influence of mental stress on heart rate and heart rate variability. In: *4th European Conference of the International Federation for Medical and Biological Engineering.* Antwerp, Belgium: Springer, 2009. pp. 1366–1369.
27. Tarvainen, MP, Niskanen, JP, Lipponen, J, Ranta-Aho, P, and Karjalainen, P. Kubios HRV–a software for advanced heart rate variability analysis. In: *4th European Conference of the International Federation for Medical and Biological Engineering.* Antwerp, Belgium: Springer, 2009. pp. 1022–1025.
28. Variability, HR. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation* 93: 1043–1065, 1996.
29. Warburton, D, Jamnik, VK, Bredin, S, and Gledhill, N. The 2014 physical activity readiness questionnaire for everyone (Par-Q+) and electronic physical activity readiness medical examination (ePARmed-X+). *Health Fitness J Can* 7: 80–83, 2014.