Reliability of Ultra-Short-Term Analysis as a Surrogate of Standard 5-Min Analysis of Heart Rate Variability

Hyun Jae Baek, PhD,[1] Chul-Ho Cho, PhD,[1] Jaegeol Cho, PhD,[1] and Jong-Min Woo, MD, MPH, PhD[2]

[1]DMC R&D Center, Samsung Electronics Co., Ltd., Suwon, Gyunggi Province, Korea.
[2]Department of Psychiatry, Seoul Paik Hospital, Inje University School of Medicine, Seoul, Korea.

Abstract

Background: *Despite the increasing demands of ultra-short-term heart rate (HR) variability (HRV) for practical ambulatory applications, there have been few studies that have investigated R-R interval recording for less than 5 min for HRV analysis. It has not been extensively validated, and, currently, no normative data for ultra-short-term HRV exist. The aim of this study was to investigate the relationship between standard 5-min and ultra-short-term HRV by collecting data from a large population consisting of a wide range of age groups.* ***Materials and Methods:*** *The 5-min R-R interval series were obtained from 467 healthy volunteers ranging from 8 to 69 years of age. The original R-R interval was segmented into 270, 240, 210, 180, 150, 120, 90, 60, 30, 20, and 10 s, and those HRV features most commonly reported within the literature were calculated and compared with those using the original 5-min R-R interval series. The Pearson correlation* r, *the* p *value by the Kruskal–Wallis test, and the Bland–Altman plot analysis computations were performed for each HRV variable calculated using different lengths of R-R interval series.* ***Results:*** *For each HRV variable, the minimum length of the R-R interval required to reliably estimate the 5-min HRV was identified. The results were different for each age group: 10 s for HR, 20 s for high-frequency, 30 s for root mean square difference, 60 s for proportion of the number of interval differences of successive NN intervals greater than 50 ms divided by total number of NNs, 90 s for low-frequency, normalized low-frequency, normalized high-frequency, and low-frequency/high-frequency, 240 s for standard deviation of successive NN interval differences and time–frequency, and 270 s for very low-frequency. In addition, the reference value for short-term HRV from normal healthy subjects was also presented.* ***Conclusions:*** *Some HRV variables calculated from R-R interval series shorter than 5 min were well matched with those calculated from the 5-min R-R interval. Thus, ultra-short-term HRV is likely to be a good surrogate method to assess trends in HRV.*

Key words: *autonomic nervous system, heart rate variability, ultra-short-term heart rate variability, cardiac monitoring*

Introduction

Heart rate (HR) variability (HRV) is a physiological phenomenon consisting of oscillations in consecutive heart beat intervals controlled by the autonomic nervous system. It is known to be one of the most promising methods to noninvasively investigate the sympathetic and parasympathetic functions of the autonomic nervous system. Sympathetic activity tends to increase HR, and its response is slow, whereas parasympathetic activity tends to decrease HR and mediates faster.[1] HRV has been studied extensively during the last decade for application in clinical practice for assessment of autonomic cardiovascular function and wellness, including monitoring of stress, sleep, or fatigue.[2–5] Traditionally, the electrocardiogram is used for HRV analysis; however, photoplethysmography (PPG) can also be used as an alternative owing to its ability to detect blood volume changes in the microvascular bed of tissue.[6] With PPG, pulse waves arise from blood volume changes in arterial tissues due to each heartbeat and can be used to estimate the variation of HR. Several studies have explored the possibility of pulse rate variability as an estimate of HRV and showed that PPG can be used for HRV during not only stationary but also nonstationary conditions, such as the tilt-table test, which causes significant changes in autonomic balance.[7–9]

The recommended length for HRV analysis is 24 h for long-term and 5 min for short-term monitoring.[10] Using 24-h HRV analysis, physiological regulations reflected in overall HR changes, including day–night difference, can be monitored because the subjects perform their usual daily activities during the HRV recording period. The long-term method has been used to assess cardiovascular mortality and the prognosis or early diagnosis of patients.[10] This analysis is difficult and not very reproducible. For short-term recording, 5-min HRV is considered methodologically adequate. Short-term measurements offer more practical advantages, including easy application in an out-of-hospital or laboratory setting and a simplified data process, although short-term recording depends on the recording condition.

Recently, studies on ultra-short-term HRV analysis using less than 5-min data have been performed according to the increased demands for various practical application in ambulatory HR monitoring devices. The ultra-short-term HRV in this area enables mobile ambulatory care by providing immediate test results to users.

Several studies have reported that some kinds of reliable parameters for assessing HRV could be derived from ultra-short recordings under 5 min. Nussinovitch et al.[11] compared HRV calculated from 5-min, 1-min, and 10-s recordings from 70 subjects and showed that the root mean square difference (RMSSD) of successive NN intervals seemed to be a reliable parameter for both 1-min and 10-s

 DOI: 10.1089/tmj.2014.0104

ultra-short-term HRV analysis. McNames and Aboy[12] also compared the accuracy of HRV calculated from data length spanning 10 s to 10 min as compared with those calculated from 5-min recording using the R-R interval database posted on PhysioNet. In this study, high-frequency (HF), standard deviation (SD) of successive NN interval differences (SDSD), and RMSSD had the best performance for ultra-short-term HRV. Salahuddin et al.[13] determined minimum data length required for reliable HRV parameters using ultra-short-term segments randomly sampled from 24-h Holter monitoring data of 6 subjects; they showed that time domain parameters derived using an R-R interval of less than 1 min were statistically sufficient to substitute for traditional 5-min HRV. The same research group also analyzed HRV features from 24 subjects at baseline and during the Stroop color word test with an ultra-short-term time frame of less than 5 min.[14] Their results indicated that ultra-short-term analysis of RMSSD within 30 s, HF within 40 s, and low-frequency (LF)/HF, normalized LF, and normalized HF within 50 s could be reliably performed.

Although there have been some attempts to investigate short-term HRV, it still remained a limitation with regard to study population. Investigations on short-term HRV should be performed with a large population consisting of different age groups, and the data should be collected with well-defined, controlled environments.

Recent technological advances have made possible a new generation of personal health devices in out-of-hospital environments that provide periodic health condition monitoring based on information exchange between a user and a professional. Application of ultra-short-term HRV analysis is desirable in order to increase the applicability of HRV to the common practitioner. It may provide detail on the changing effects of the autonomic nervous system on the heart and enable tracking of dynamic changes in real time for various applications such as stress, sleep, or fatigue. In addition, a shorter period of data for HRV analysis is better not only for the individual usability aspect, but also for the personal health device, which has limited processing power and memory capacity.

The aim of this study was to further investigate the relationship between standard 5-min and short-term HRV, which was segmented from a 5-min recording. Through a clinical trial, we collected HRV data from a wide range of age groups under a controlled environment and compared the results using statistical analysis.

Materials and Methods

SUBJECTS AND DATA ACQUISITION

After written informed consent was obtained from each subject, PPG signals were collected in consecutively recruited volunteers. Subjects who were not willing to participate, those with cardiovascular disease, or those who had a history of major psychiatric diseases that can significantly affect HRV were excluded. Patients below 5 or above 70 years of age were also excluded. Demographic data are summarized in *Table 1*. Initially, 500 subjects were enrolled in this study, but 33 were excluded because PPG recording was not considered successful for HRV analysis. Finally, 467 subjects (249 men and 218 women) ranging in age from 8 to 69 (mean ± SD, 33.03 ± 13.16) years were included for this study. Before PPG acquisition, subjects were asked to perform a Stress Response Inventory—Modified Form (SRI-MF) of the past 2 weeks in order to investigate whether sympathetic or parasympathetic overactivity affected HRV analysis results. SRI-MF is a tool for measuring overall stress, including emotional, somatic, cognitive, and behavioral responses, using a 5-point numeric rating scale (from 0 = not at all to 4 = very much so) with a 22-item questionnaire.[15]

The experimental sessions were conducted during working hours, and data were acquired from subjects, except adolescents, who attended the health promotion center of Inje University Seoul Paik Hospital, Seoul, Korea. For 1 day prior to the examination, subjects were instructed to avoid calorie intake after 7 p.m., coffee after 4 p.m., and alcoholic beverages all day long. This helps us collect normal HRV data without sympathetic overactivity. We additionally recruited adolescent participants and asked them to follow the same instructions. After 5 min of sitting at rest in a comfortable chair, a continuous 5-min R-R interval series was recorded by a PPG fingertip

Table 1. Demographic Information

		AGE GROUP					
	TOTAL	10 YEARS	20 YEARS	30 YEARS	40 YEARS	50 YEARS	60 YEARS
Number	467	78	123	124	97	32	13
Sex (M/F)	249/218	36/42	47/76	78/46	67/30	16/16	5/8
Age (years)	33.03 ± 13.16	12.96 ± 2.82	26.59 ± 2.04	34.31 ± 2.75	44.41 ± 3.26	53.88 ± 3.19	65.92 ± 3.15
SRI-MF	21.7 ± 15.12	23.73 ± 16.12	24.59 ± 15.66	23.62 ± 14.38	16.46 ± 12.2	18.50 ± 17.85	10.85 ± 7.82
BF (%)	25.56 ± 7.00	NA	23.62 ± 7.87	25.22 ± 6.10	26.55 ± 6.12	28.82 ± 6.11	31.72 ± 7.77
BG (mg/dL)	83.77 ± 29.27	NA	86.42 ± 9.58	91.30 ± 8.34	102.63 ± 16.06	102.52 ± 20.50	106.23 ± 14.49

Age groups were divided as 10 years (under 19 years old), 20 years (20–29 years old), 30 years (30–39 years old), 40 years (40–49 years old), 50 years (50–59 years old), and 60 years (60–69 years old). Data are numbers of subjects or mean ± standard deviation values as indicated.

BF, body fat; BG, blood glucose; F, female; M, male; NA, not applicable; SRI-MF, Stress Response Inventory—Modified Form.

sensor (Freeze-Framer® 2.0; HeartMath LLC, Boulder Creek, CA) from the right-hand index finger using transmittance mode by means of the incorporated software. The Freeze-Framer consists of small hardware components including a PPG sensor with a strap that is connected to a black triangular sensor pod that is then connected to a computer by USB and software that performs functions regarding HRV analysis. The Freeze-Framer was chosen as the criterion measurement device of HRV as its precision and reliability have been established.[16–18]

At the end of the study, the pulse interval data were analyzed "off-line" by a blinded technician using Matlab version R2013a software (The Mathworks™ Inc., Natick, MA). The study protocol was approved by the Institutional Review Board of Inje University Seoul Paik Hospital and conformed to the declaration of Helsinki.

HRV ANALYSIS

For each 5-min recording, we selected for comparison segments with different durations: 10, 20, 30, 60, 90, 120, 150, 180, 210, 240, and 270 s. Including the original 5-min data, this resulted in 12 pulse–interval data for each subject, with a total of 5,604 pulse–interval data (467 for each duration). The pulse interval is known as the R-R interval mentioned throughout this article. The HRV analysis was performed in the time and frequency domain according to the methodological standards recommended by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology for Heart Rate Variability.[10] The time and frequency measures of HRV most commonly reported within the literature were investigated.

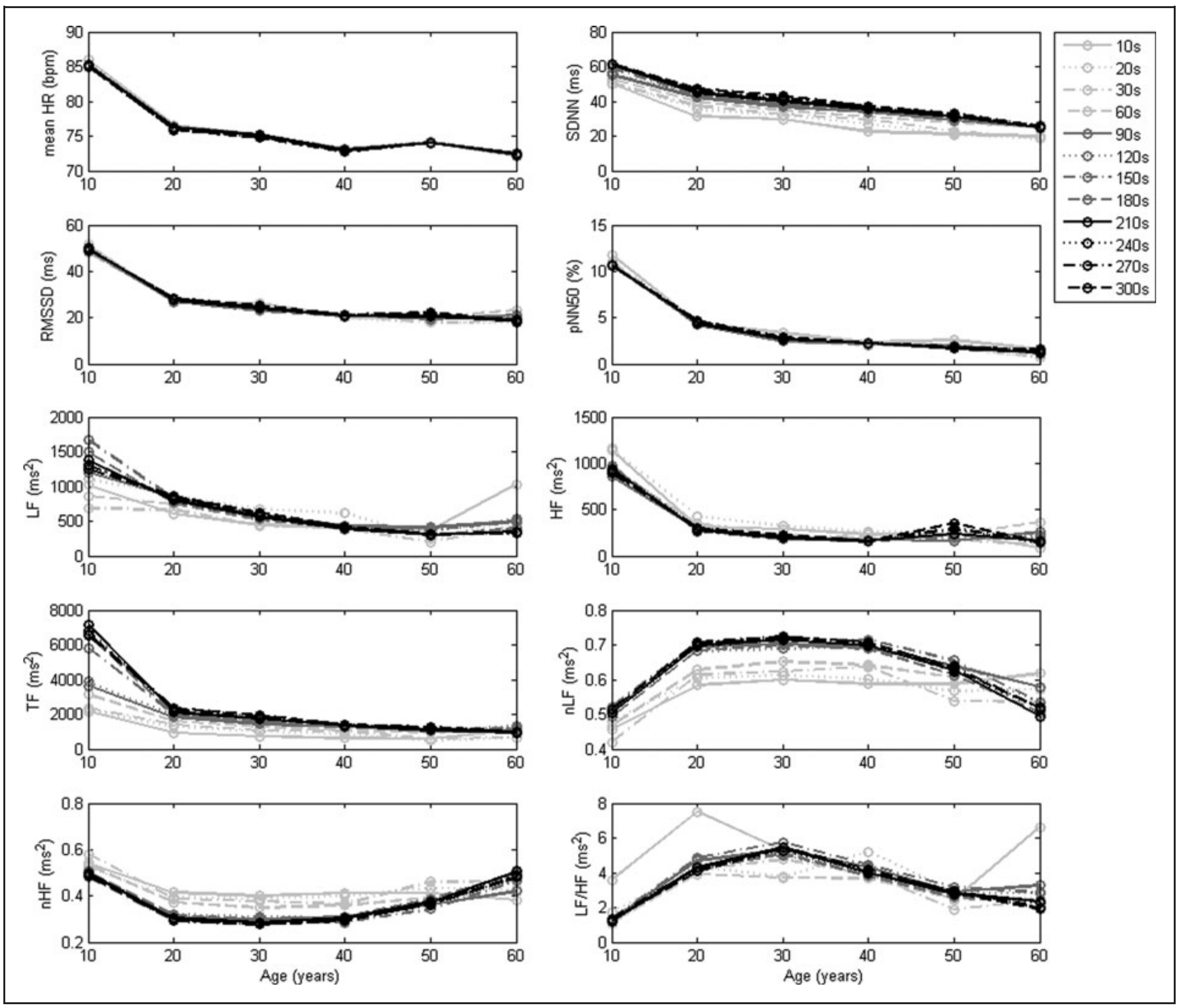

Fig. 1. Heart rate variability variables were plotted against age grouping. Different lengths of R-R interval series were used: 10 s, 20 s, 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 270 s, and 300 s. HF, high-frequency; HR, heart rate; LF, low-frequency; nHF, normalized high-frequency; nLF, normalized low-frequency; pNN50, proportion of the number of interval differences of successive NN intervals greater than 50 ms divided by total number of NNs; RMSSD, root mean square difference; SDNN, standard deviation of the NN interval; TF, time–frequency.

Table 2. Values for Each Heart Rate Variability Variable for the Total Subject Population According to Different Durations of Input R-R Interval Series

VARIABLE	DATA LENGTH											
	300 S	270 S	240 S	210 S	180 S	150 S	120 S	90 S	60 S	30 S	20 S	10 S
HR	76.24 (10.36)	76.33 (10.37)	76.41 (10.43)	76.48 (10.47)	76.54 (10.48)	76.54 (10.48)	76.57 (10.54)	76.55 (10.61)	76.54 (10.72)	76.57 (10.83)	76.58 (11.00)	76.66 (11.24)
SDNN	44.73 (27.51)	44.10 (28.19)	43.54 (29.31)	42.95 (29.36)	42.13 (27.41)	41.48 (25.63)	40.59 (22.74)	39.77 (22.19)	37.61 (22.37)	35.11 (22.73)	33.71 (24.16)	31.25 (27.99)
RMSSD	28.68 (18.95)	28.49 (19.06)	28.35 (19.34)	28.17 (19.36)	27.81 (18.73)	27.87 (19.10)	28.00 (19.08)	27.86 (19.00)	27.62 (19.72)	27.91 (22.30)	28.05 (24.75)	28.69 (29.57)
pNN50	4.36 (4.87)	4.32 (4.87)	4.26 (4.89)	4.26 (4.93)	4.20 (4.93)	4.17 (4.96)	4.20 (5.04)	4.17 (5.04)	4.19 (5.15)	4.29 (5.59)	4.28 (5.94)	4.71 (7.42)
LF	716.44 (1,326.2)	716.54 (1,433.1)	708.94 (1,515.3)	701.66 (1,647.1)	701.99 (1,993.4)	777.24 (2,266.4)	701.77 (1,280.9)	704.98 (1,296.2)	593.61 (884.35)	512.80 (799.46)	753.75 (1,261.4)	588.35 (1,344.6)
HF	347.44 (600.65)	336.27 (556.36)	342.44 (582.56)	335.00 (589.73)	335.25 (613.48)	333.52 (654.09)	346.71 (604.56)	325.88 (523.78)	368.42 (676.04)	351.79 (736.00)	465.82 (1,182)	417.18 (1,286.1)
TF	2,650 (12,463)	2,590.6 (12,367)	2,595.7 (13,396)	2,597 (14,564)	2,442.4 (12,253)	2,285.2 (9,606.3)	1,935.7 (4,005.4)	1,841.3 (3,608.4)	1,615.6 (3,194.4)	1,329.4 (2,083.9)	1,219.6 (2,087.6)	1,005.5 (2,333.7)
VLF	1,586.1 (11,115)	1,537.8 (10,941)	1,544.3 (11,876)	1,560.4 (12,842)	1,405.1 (10,044)	1,174.4 (6,980.5)	887.18 (2,415.2)	810.39 (2,279)	653.62 (2,559.6)	464.81 (1,187.9)	NA	NA
nLF	0.67 (0.19)	0.67 (0.19)	0.66 (0.19)	0.66 (0.20)	0.65 (0.20)	0.67 (0.20)	0.65 (0.20)	0.66 (0.2)	0.61 (0.22)	0.58 (0.24)	0.58 (0.25)	0.57 (0.27)
nHF	0.33 (0.19)	0.33 (0.19)	0.34 (0.19)	0.34 (0.20)	0.35 (0.20)	0.33 (0.20)	0.35 (0.20)	0.34 (0.20)	0.39 (0.22)	0.42 (0.24)	0.42 (0.25)	0.43 (0.27)
LF/HF	3.86 (4.73)	3.92 (4.74)	3.77 (4.74)	3.86 (5.03)	3.70 (4.85)	4.25 (5.60)	3.78 (4.85)	4.05 (5.09)	3.21 (4.31)	3.55 (7.47)	3.78 (7.56)	5.23 (17.74)

Age groups were divided as 10 years (under 19 years old), 20 years (20–29 years old), 30 years (30–39 years old), 40 years (40–49 years old), 50 years (50–59 years old), and 60 years (60–69 years old). Data are mean (standard deviation) values.

HF, high-frequency; HR, heart rate; LF, low-frequency; NA, not applicable; nHF, normalized high-frequency; nLF, normalized low-frequency; pNN50, proportion of the number of interval differences of successive NN intervals greater than 50 ms divided by total number of NNs; RMSSD, root mean square difference; SDNN, standard deviation of the NN interval; TF, time-frequency; VLF, very low-frequency.

Table 3. Correlation Coefficient and Kruskal–Wallis Test for Time Domain Variables According to Different Durations of Input R-R Interval Series

VARIABLE, AGE GROUP	DATA LENGTH										
	270 S	240 S	210 S	180 S	150 S	120 S	90 S	60 S	30 S	20 S	10 S
HR											
10 years	0.9958[c]	0.9943[c]	0.9934[c]	0.9907[c]	0.9827[c]	0.9695[c]	0.9466[c]	0.9421[c]	0.8615[c]	0.8084[c]	0.7378[c]
20 years	0.9995[c]	0.9983[c]	0.9961[c]	0.9941[c]	0.9922[c]	0.9897[c]	0.9838[c]	0.9767[c]	0.9665[c]	0.9625[c]	0.9392[c]
30 years	0.9996[c]	0.9988[c]	0.9972[c]	0.9944[c]	0.9919[c]	0.989[c]	0.985[c]	0.9814[c]	0.9731[c]	0.9663[c]	0.9558[c]
40 years	0.9998[c]	0.9991[c]	0.998[c]	0.9963[c]	0.9938[c]	0.9907[c]	0.9877[c]	0.9852[c]	0.9732[c]	0.9681[c]	0.951[c]
50 years	0.9999[c]	0.9996[c]	0.9992[c]	0.9985[c]	0.9978[c]	0.9956[c]	0.9918[c]	0.9859[c]	0.9835[c]	0.9814[c]	0.9757[c]
60 years	1[c]	0.9998[c]	0.9995[c]	0.9991[c]	0.9984[c]	0.9972[c]	0.9964[c]	0.9947[c]	0.9851[c]	0.9835[c]	0.984[c]
Total	0.9992[c]	0.9984[c]	0.9972[c]	0.9955[c]	0.993[c]	0.9893[c]	0.9835[c]	0.9793[c]	0.9622[c]	0.952[c]	0.9321[c]
SDNN											
10 years	0.998[c]	0.9917[c]	0.9906[c]	0.9808[c]	0.9554[b]	0.8616[b]	0.8216[b]	0.6736	0.7858	0.7295	0.728
20 years	0.9938[c]	0.9847	0.9536[b]	0.9262[b]	0.8859[a]	0.8623[a]	0.7867	0.7383	0.608	0.5657	0.5721
30 years	0.9726[b]	0.9511[a]	0.9327	0.8706	0.8373	0.7981	0.7187	0.6198	0.5045	0.4393	0.2396
40 years	0.9943[c]	0.9816[c]	0.9575[b]	0.9419[b]	0.9227[b]	0.8971[a]	0.8338	0.7344	0.6311	0.4936	0.1969
50 years	0.9898[c]	0.9738[c]	0.9509[c]	0.919[c]	0.8802[c]	0.6955[b]	0.6307[c]	0.5453[b]	0.4626	0.4973	0.4596
60 years	0.9991[c]	0.9974[c]	0.9969[c]	0.9953[c]	0.9887[c]	0.9766[c]	0.9356[c]	0.8901[b]	0.8781[b]	0.8644[b]	0.8681
Total	0.9949[b]	0.9866[b]	0.9783	0.9619	0.934	0.8531	0.802	0.7044	0.6971	0.664	0.6203
RMSSD											
10 years	0.9957[c]	0.9928[c]	0.9882[c]	0.9666[c]	0.9629[c]	0.9184[c]	0.9033[c]	0.8255[b]	0.8538[b]	0.8014[b]	0.7618
20 years	0.9981[c]	0.9862[c]	0.9682[c]	0.9508[c]	0.9433[b]	0.9281[b]	0.8619[b]	0.8348[b]	0.7586[b]	0.6379[b]	0.6219[b]
30 years	0.9291[c]	0.9043[c]	0.8932[b]	0.7884[b]	0.7316[b]	0.6754[b]	0.6477[b]	0.5588[b]	0.3904[a]	0.3261[a]	0.2094[a]
40 years	0.998[c]	0.994[c]	0.9756[c]	0.9416[c]	0.9315[c]	0.9143[c]	0.8697[c]	0.7531[b]	0.7229[b]	0.6238[a]	0.4475
50 years	0.9843[c]	0.9783[c]	0.9807[c]	0.9648[c]	0.9251[c]	0.6876[c]	0.6011[c]	0.5767[c]	0.5212[b]	0.5189[b]	0.4437[b]
60 years	0.9987[c]	0.9946[c]	0.9929[c]	0.9901[c]	0.9849[c]	0.9793[c]	0.9573[c]	0.9431[c]	0.8308[c]	0.8116[c]	0.7978[b]
Total	0.9869[c]	0.9797[c]	0.9707[b]	0.9427[b]	0.929[b]	0.8894[b]	0.8608[b]	0.8107[a]	0.7716[a]	0.7162	0.636
pNN50											
10 years	0.9965[c]	0.9895[c]	0.9833[c]	0.9685[c]	0.9548[c]	0.9237[c]	0.8954[c]	0.8586[c]	0.793[c]	0.7026[c]	0.5226[c]
20 years	0.9977[c]	0.9937[c]	0.9888[c]	0.9839[b]	0.9753[b]	0.9608[b]	0.9477[b]	0.9199[b]	0.8641[b]	0.8162	0.642
30 years	0.9944[c]	0.985[c]	0.976[b]	0.9624[b]	0.947[b]	0.929[b]	0.9005	0.8451	0.7257	0.5361	0.4058
40 years	0.9963[c]	0.9933[c]	0.9813[c]	0.9759[c]	0.9651[b]	0.9464[b]	0.9114[b]	0.8538	0.7779	0.6809	0.5495
50 years	0.9963[c]	0.9891[c]	0.9839[c]	0.9708[c]	0.9318[c]	0.869[c]	0.7991[c]	0.6597[c]	0.8562[b]	0.8335[b]	0.5139
60 years	0.9995[c]	0.998[c]	0.9874[c]	0.9868[c]	0.972[c]	0.9753[c]	0.952[b]	0.9634[b]	0.9247[b]	0.9247[b]	0.9247[b]
Total	0.9978[c]	0.9938[c]	0.9892[b]	0.9831[b]	0.9746[b]	0.9604[b]	0.9447[b]	0.9168[b]	0.8719	0.7994	0.6528

Age groups were divided as 10 years (under 19 years old), 20 years (20–29 years old), 30 years (30–39 years old), 40 years (40–49 years old), 50 years (50–59 years old), and 60 years (60–69 years old).

By Kruskal–Wallis test, [a]$p > 0.05$, [b]$p > 0.1$, [c]$p > 0.5$.

HR, heart rate; pNN50, proportion of the number of interval differences of successive NN intervals greater than 50 ms divided by total number of NNs; RMSSD, root mean square difference; SDNN, standard deviation of the NN interval.

Table 4. Correlation Coefficient and Kruskal–Wallis Test for Frequency Domain Variables According to Different Durations of Input R-R Interval Series

VARIABLE, AGE GROUP	DATA LENGTH										
	270 S	240 S	210 S	180 S	150 S	120 S	90 S	60 S	30 S	20 S	10 S
LF											
10 years	0.9987[c]	0.9928[c]	0.9893[c]	0.9829[b]	0.9636[c]	0.9607[c]	0.9014[b]	0.4101	0.7083	0.6708[b]	0.4430
20 years	0.9964[c]	0.9914[c]	0.9519[c]	0.9346	0.8706[c]	0.8559[c]	0.7732[c]	0.7589	0.6934	0.5888	0.6081
30 years	0.944[c]	0.9311[b]	0.9401[b]	0.8637[a]	0.8632[b]	0.8547[a]	0.7182[b]	0.6425	0.5929	0.7051	0.4155
40 years	0.9952[c]	0.9846[c]	0.9722[b]	0.9618[b]	0.9433[c]	0.9166[c]	0.8705[b]	0.7902	0.6443	0.4854	0.0919
50 years	0.992[c]	0.9838[c]	0.9632[c]	0.9378[c]	0.9477[c]	0.8353[c]	0.8127[c]	0.7787[c]	0.3215	0.2719[b]	0.2284[a]
60 years	0.9996[c]	0.9983[c]	0.9987[c]	0.9988[c]	0.9987[c]	0.9979[c]	0.9862[c]	0.942[c]	0.9934[b]	0.992[c]	0.9921[c]
Total	0.993[c]	0.986[b]	0.9703[b]	0.9454	0.9195[c]	0.929[b]	0.8636[a]	0.5338	0.6298	0.5813	0.4156
HF											
10 years	0.9916[c]	0.993[c]	0.9887[c]	0.9566[c]	0.9482[c]	0.9295[c]	0.8941[c]	0.8886[b]	0.8915[b]	0.8445[b]	0.8309
20 years	0.9898[c]	0.9793[c]	0.9365[b]	0.8979[b]	0.9037[b]	0.8852[c]	0.8036[b]	0.7495[c]	0.6118[b]	0.4249[b]	0.4917[a]
30 years	0.9061[c]	0.8836[c]	0.8564[b]	0.7467[c]	0.6627[c]	0.613[c]	0.5902[c]	0.5094[c]	0.3876[c]	0.3366	0.1465[b]
40 years	0.9948[c]	0.9882[c]	0.9773[c]	0.9573[c]	0.9243[c]	0.8728[c]	0.7987[c]	0.6668[c]	0.5913[b]	0.426[b]	0.2973
50 years	0.9942[c]	0.9898[c]	0.9941[c]	0.9858[c]	0.8943[c]	0.4613[c]	0.2702[c]	0.2263[c]	0.1452[c]	0.2028[c]	0.1154[b]
60 years	0.9981[c]	0.9946[c]	0.9933[c]	0.9904[c]	0.9845[c]	0.9811[c]	0.9457[c]	0.9407[c]	0.5138[b]	0.5079[c]	0.5175[a]
Total	0.9833[c]	0.975[c]	0.9538[b]	0.9091[b]	0.8635[b]	0.8211[b]	0.7784[b]	0.7527[b]	0.6919[a]	0.6709[a]	0.6294
TF											
10 years	0.9998[c]	0.9993[c]	0.9991[c]	0.9984[c]	0.9925[b]	0.8488[b]	0.831[b]	0.329	0.7061	0.7115	0.701
20 years	0.9939[c]	0.9844[b]	0.9147[b]	0.8788[b]	0.8116[a]	0.7778	0.6853	0.6771	0.4993	0.4284	0.5139
30 years	0.9858[b]	0.971[a]	0.9541	0.9222	0.9099	0.8603	0.7296	0.5571	0.5156	0.4855	0.3614
40 years	0.9957[c]	0.9854[b]	0.9596[b]	0.9484[b]	0.9431[b]	0.9251[a]	0.855	0.7662	0.6304	0.3781	0.0478
50 years	0.9884[c]	0.9587[c]	0.9072[c]	0.8391[c]	0.7585[c]	0.5376[b]	0.4373[b]	0.341[b]	0.2184	0.2343	0.1792
60 years	0.9996[c]	0.9985[c]	0.9982[c]	0.9971[c]	0.9933[c]	0.9853[c]	0.8831[c]	0.7731[b]	0.948[a]	0.9456	0.9468
Total	0.9997[b]	0.9989[a]	0.9979	0.9968	0.9895	0.8216	0.7939	0.3495	0.5508	0.5574	0.5397
VLF											
10 years	0.9998[c]	0.9994[c]	0.9993[b]	0.9992[b]	0.9934[a]	0.8296	0.672	0.1518	0.331	0.0369	0.0335
20 years	0.9812[b]	0.9517[b]	0.7788[b]	0.7276	0.6318	0.5984	0.4898	0.4718	0.1887	0.0914	0.0211
30 years	0.9822[b]	0.9661[a]	0.9449	0.9254	0.9108	0.8696	0.6442	0.3724	0.3236	0.1157	0.088
40 years	0.9917[c]	0.9718[b]	0.9371[b]	0.9275[b]	0.9141	0.8976	0.8245	0.7251	0.5742	0.2406	0.0584
50 years	0.9938[c]	0.9774[c]	0.9508[b]	0.9446[b]	0.9297[b]	0.9359[a]	0.822[a]	0.2806	0.2264	0.0513	0.5729
60 years	0.9975[c]	0.9989[c]	0.9985[c]	0.9896[c]	0.9774[c]	0.9454[b]	0.6393[b]	0.5274[b]	0.8762	0.0886	0.0487
Total	0.9997[b]	0.9991	0.9984	0.9979	0.9899	0.7943	0.6187	0.1688	0.2705	0.0319	0.0357

continued →

Table 4. Correlation Coefficient and Kruskal–Wallis Test for Frequency Domain Variables According to Different Durations of Input R-R Interval Series *continued*

VARIABLE, AGE GROUP	DATA LENGTH										
	270 S	240 S	210 S	180 S	150 S	120 S	90 S	60 S	30 S	20 S	10 S
nLF											
10 years	0.9756[c]	0.9421[c]	0.9197[c]	0.87[b]	0.8491[c]	0.846[c]	0.7549[c]	0.6631[b]	0.5197	0.4205[b]	0.272[a]
20 years	0.9787[c]	0.9632[c]	0.9381[c]	0.9081[c]	0.9048[c]	0.8631[c]	0.8622[c]	0.7861	0.6694	0.5812	0.4137
30 years	0.9245[c]	0.9009[c]	0.8895[c]	0.8585[b]	0.8378[c]	0.782[b]	0.7663[c]	0.6924	0.5841	0.4226	0.3478
40 years	0.9885[c]	0.9735[c]	0.9758[c]	0.9487[b]	0.9356[c]	0.91[c]	0.8695[c]	0.7442[a]	0.6694	0.382	0.3331
50 years	0.9921[c]	0.9635[c]	0.9553[c]	0.8976[c]	0.8947[c]	0.8562[c]	0.8344[c]	0.88059[c]	0.5987[a]	0.6211[b]	0.2704[c]
60 years	0.9861[c]	0.9807[c]	0.9774[c]	0.9766[c]	0.9816[c]	0.9492[c]	0.9099[c]	0.8874[c]	0.7945[c]	0.7798[c]	0.7334[b]
Total	0.9725[c]	0.9555[c]	0.945[c]	0.9167[b]	0.9048[b]	0.8696[b]	0.8452[b]	0.7652	0.6676	0.5065	0.3869
nHF											
10 years	0.9756[c]	0.9421[c]	0.9197[c]	0.87[b]	0.8491[c]	0.846[c]	0.7549[c]	0.6631[b]	0.5197	0.4205[b]	0.272[a]
20 years	0.9787[c]	0.9632[c]	0.9381[c]	0.9081[c]	0.9048[c]	0.8631[c]	0.8622[c]	0.7861	0.6694	0.5812	0.4137
30 years	0.9245[c]	0.9009[c]	0.8895[c]	0.8585[b]	0.8378[c]	0.782[b]	0.7663[c]	0.6924	0.5841	0.4226	0.3478
40 years	0.9885[c]	0.9735[c]	0.9758[c]	0.9487[b]	0.9356[c]	0.91[c]	0.8695[c]	0.7442[a]	0.6694	0.382	0.3331
50 years	0.9921[c]	0.9635[c]	0.9553[c]	0.8976[c]	0.8947[c]	0.8562[c]	0.8344[c]	0.88059[c]	0.5987[a]	0.6211[b]	0.2704[c]
60 years	0.9861[c]	0.9807[c]	0.9774[c]	0.9766[c]	0.9816[c]	0.9492[c]	0.9099[c]	0.8874[c]	0.7945[c]	0.7798[c]	0.7334[b]
Total	0.9725[c]	0.9555[c]	0.945[c]	0.9167[b]	0.9048[b]	0.8696[b]	0.8452[b]	0.7652	0.6676	0.5065	0.3869
LF/HF											
10 years	0.9787[c]	0.8524[c]	0.8359[c]	0.7633[b]	0.7293[c]	0.786[c]	0.6887[c]	0.5086[b]	0.2746	0.3359[b]	0.0776[a]
20 years	0.9797[c]	0.9762[c]	0.949[c]	0.9496[c]	0.9068[c]	0.8934[c]	0.7541[c]	0.6992	0.4299	0.4555	0.2398
30 years	0.9818[c]	0.9816[c]	0.9443[c]	0.9312[b]	0.9179[c]	0.8991[b]	0.8475[c]	0.796	0.546	0.5237	0.1518
40 years	0.9579[c]	0.9535[c]	0.9468[c]	0.9347[b]	0.8958[c]	0.9194[c]	0.8339[c]	0.7579[a]	0.493	0.2275	0.1259
50 years	0.9807[c]	0.9687[c]	0.9334[c]	0.8109[c]	0.7878[c]	0.7331[c]	0.6831[c]	0.6441[c]	0.5845[a]	0.5579[b]	0.1032[c]
60 years	0.9854[c]	0.9294[c]	0.8677[c]	0.8585[c]	0.8451[c]	0.8403[c]	0.7982[c]	0.7723[c]	0.6901[c]	0.7668[c]	0.7914[b]
Total	0.9782[c]	0.9761[c]	0.9466[c]	0.9317[b]	0.9101[b]	0.8933[b]	0.8151[b]	0.7153	0.5308	0.3717	0.1503

Age groups were divided as 10 years (under 19 years old), 20 years (20–29 years old), 30 years (30–39 years old), 40 years (40–49 years old), 50 years (50–59 years old), and 60 years (60–69 years old).

By Kruskal–Wallis test, [a]$p > 0.05$, [b]$p > 0.1$, [c]$p > 0.5$.

HF, high-frequency; LF, low-frequency; nHF, normalized high-frequency; nLF, normalized low-frequency; TF, time–frequency; VLF, very low-frequency.

The HRV time domain analysis was quantified by means of different indices: the mean HR, the SD of the NN interval, RMSSD, and the proportion of the number of interval differences of successive NN intervals greater than 50 ms divided by total number of NNs (pNN50). For the HRV frequency domain analysis, the pulse–interval data were transformed to an evenly sampled (4 Hz) time series by cubic spline interpolation, and both the mean and linear trends were removed. The power spectral density was estimated by the nonparametric periodogram method. The spectral parameters time–frequency (TF) (≤ 0.4 Hz), LF (0.04–0.15 Hz), and HF (0.15–0.4 Hz) were obtained by the sum of the power in the relevant frequency range in the spectrum. Normalized LF (nLF) and HF (nHF) values were calculated by dividing LF and HF power by total power (TF). Finally, the LF/HF ratio was also derived.

STATISTICAL ANALYSIS

The mean and SD values were obtained for HRV variables calculated using different lengths of the R-R interval and compared with those calculated using the 5-min R-R interval according to each age group of subjects. To correlate the HRV variables according to different lengths of R-R interval with the standard 5-min variable, we used the Pearson *r* correlation in order to investigate the linear relationship between short-term HRV and 5-min HRV. Like all the other biological variables, HRV is not normally distributed.[19] Therefore, the Kruskal–Wallis test was additionally used to test the null hypothesis between groups. The function returns the *p* value for the null hypothesis that all samples in each group are drawn from the same population. The null hypothesis is rejected when the *p* value is less than the critical value. If the *p* value is near zero, this casts doubt on the null hypothesis and suggests that at least one sample mean is significantly different than the other sample means. The choice of a critical *p* value to determine whether the result is judged "statistically significant" is left to the researcher. It is common to declare a result significant if the *p* value is less than a critical value of 0.05 or 0.01. In this study, it was assumed that short-term HRV was not significantly different from the standard 5-min HRV if the *p* value, the result of the Kruskal–Wallis test, was greater than 0.05. All analysis results are presented with regard to the entire test population as well as each age group.

Results

Table 1 shows general subject information. SRI-MF scores of all age groups were similar to those investigated for normal, healthy people by Choi et al.[15] (17.15 ± 14.36 for males, 23.44 ± 15.34 for females). Also, the mean ± SD values of the body fat percentage and blood glucose level obtained in the beginning of the experimental session were within normal ranges for each age group. Therefore, we concluded that at the time of the experiments, the subject condition was not biased to sympathetic or parasympathetic function. Because the body fat percentage and blood glucose were obtained by the routine health check-up procedure, those of teenage participants were not available. *Figure 1* shows the age-related changes in mean HRV variables for different lengths of R-R interval data in HRV calculations. As is already known, the age-related decline in time domain HRV variables that occurs with advancing age could be observed. The frequency domain HRV variables except LF/HF and normalized value also showed age-related decreases. This phenomenon was also maintained for HRV variables calculated with R-R interval data of short length. The nHF as well as nLF did not show any age-related relationship, and LF/HF tends to increase with age for the 10–30-year-old age group, but decreases for the 40–60-year-old age group. The mean and SD of each HRV variable for different lengths of R-R interval used for analysis are summarized in *Table 2*.

There are correlations between HRV variables calculated using standard 5-min and reduced-length R-R interval data, as shown in *Table 3* for time domain variables and *Table 4* for frequency domain variables, respectively. As expected, the correlation coefficient declined with decrease of R-R interval length for all age groups and HRV parameters. A correlation coefficient of >0.7, which indicates a strong relationship, was achieved when the R-R interval was longer than 10 s for HR, 60 s for SD of the NN interval, 20 s for RMSSD, 20 s for pNN50, 90 s for LF, 60 s for HF, 90 s for TF, 120 s for very LF, 60 s for nLF, 60 s for nHF, and 60 s for LF/HF.[20] Statistical insignificance was also determined by *p* value calculated from the Kruskal–Wallis test and presented as >0.05, >0.1, and >0.5 in *Tables 3* and *4*. Specific data, including Pearson correlation coefficient and *p* value, were summarized for each age group as well as the total dataset.

Table 5 summarized the minimal duration of R-R interval data that can be used as a good surrogate for 5-min RR-interval data in HRV analysis. Compared with the previous study,[13] which performed a similar investigation using Holter electrocardiography from 6 subjects, the minimum duration required to estimate 5-min HRV was

Table 5. Shortest R-R Interval Length for Reliable Heart Rate Variability (HRV) Variables That Showed Insignificant Difference Compared with HRV Variables Calculated Using Standard 5-Min R-R Interval Data

HRV VARIABLE	LENGTH (S)	CORRELATION	*P* VALUE	LENGTH (S)[13]	*P* VALUE[13]
HR	10	0.9321	0.5879	10	1.000
SDNN	240	0.9866	0.1280	70	0.064
RMSSD	30	0.7716	0.0905	10	0.057
pNN50	60	0.9168	0.1278	20	0.744
LF	90	0.8636	0.0975	30	0.244
HF	20	0.6709	0.1863	10	0.080
TF	240	0.9989	0.0971	NA	NA
VLF	270	0.9997	0.2663	50	0.225
nLF	90	0.8452	0.6357	20	0.647
nHF	90	0.8452	0.6357	20	0.549
LF/HF	90	0.8151	0.6357	20	0.601

HF, high-frequency; HR, heart rate; LF, low-frequency; NA, not applicable; nHF, normalized high-frequency; nLF, normalized low-frequency; pNN50, proportion of the number of interval differences of successive NN intervals greater than 50 ms divided by total number of NNs; RMSSD, root mean square difference; SDNN, standard deviation of the NN interval; TF, time–frequency; VLF, very low-frequency.

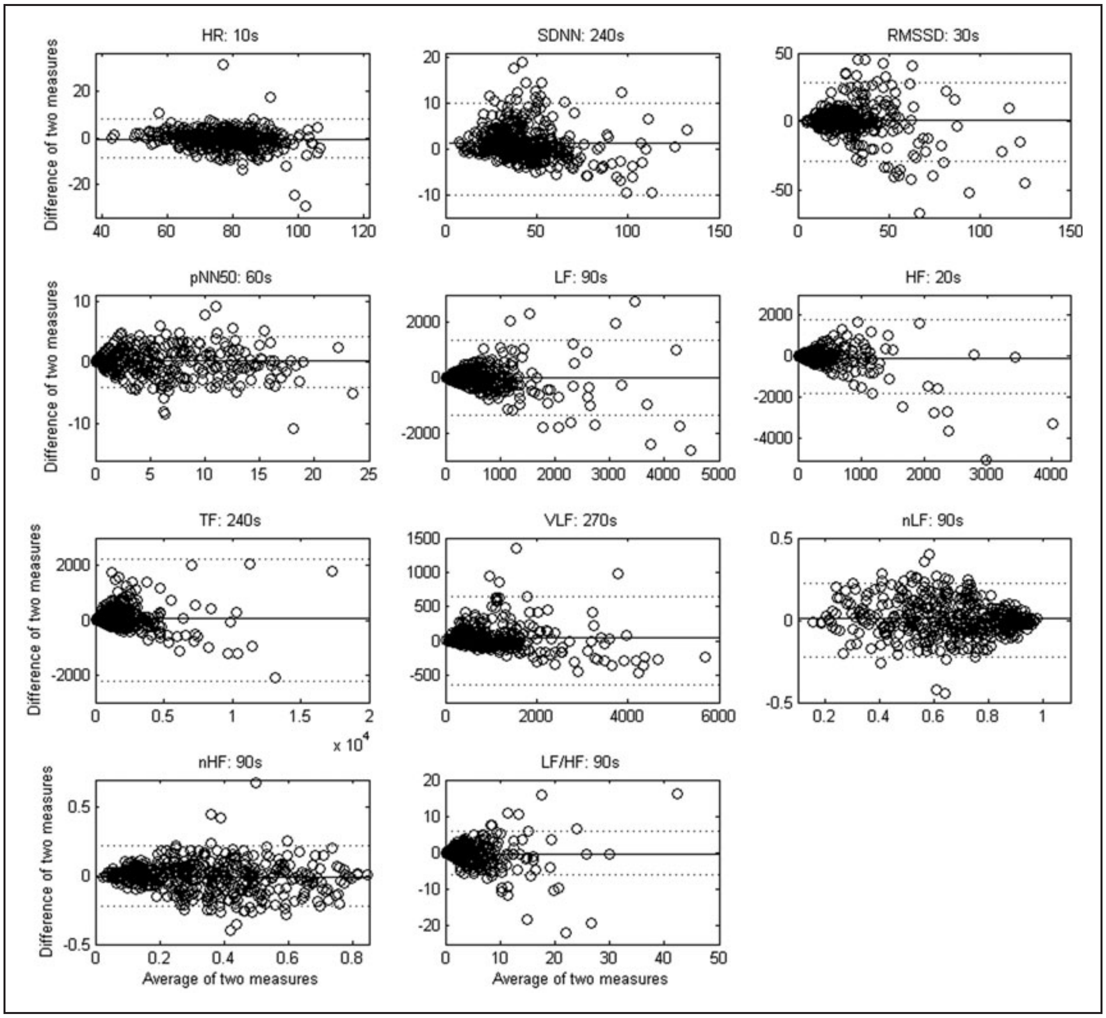

Fig. 2. Bland–Altman plots of agreement for heart rate variability variables derived by the 5-min variability analysis of R-R interval series and variability of minimum length of R-R interval series identified by the present investigation (the specific time length is given above each panel). Panels show the average of 5-min and short-term heart rate variability indices plotted against the difference. The mean difference (solid horizontal line) and the agreement limits (mean ± 1.96 standard deviation, dashed horizontal lines) are also given. HF, high-frequency; HR, heart rate; LF, low-frequency; nHF, normalized high-frequency; nLF, normalized low-frequency; pNN50, proportion of the number of interval differences of successive NN intervals greater than 50 ms divided by total number of NNs; RMSSD, root mean square difference; SDNN, standard deviation of the NN interval; TF, time–frequency; VLF, very low-frequency.

longer in the present study with the exception of mean HR. Mean HR calculated using the 10-s R-R interval series was reliable in both the previous and the current study. Because high correlation does not automatically imply good agreement, Bland–Altman plots for each HRV variable derived by the 5-min variability analysis of R-R interval series and variability of minimum length of R-R interval series identified by the present investigation were used as shown in *Figure 2*. The plots show the average difference (solid line) and agreement limits for the two approaches (dashed line, ±1.96 SD).

Discussion and Conclusions

HRV is well known as a noninvasive, reliable tool for assessing the autonomic nervous system. The use of HRV has rapidly expanded in widespread areas, including cardiovascular, neurofunctional, and preventive medicine studies, and it is also being increasingly used in several non-medical applications, including stress and sports-related monitoring.[2–5,21–23] Currently, nominal 24-h long-term recording and short-term 5-min recording are regarded as being the appropriate option for HRV analysis. However, the necessity of HRV analysis using an R-R interval shorter than 5 min for real-world applications continues to rise owing to increasingly ubiquitous mobile devices and the ability to take short-term assessment with nearly instantaneous displaying of results. Therefore, there is a great need for representative studies to provide reference values for short-term HRV analysis. In this work, we aimed to evaluate HRV using investigation of the reduced time frame of R-R interval series applied to a large population of a wide range of age groups.

Although the minimum required R-R interval length varies, the results in the present study are in agreement with previously published literature. Similar to Schroeder et al.[24] and Nussinovitch et al.,[11] our investigation also supports the proposal that RMSSD calculated from ultra-short-term recording was found to be as reliable as those calculated from the 5-min recording for HRV evaluation (30 s in this study, 10 s in previous studies[11,24]). The discrepancy between results may be due to experimental conditions. Previous studies[11,24] included a small number of subjects (63 and 70, respectively; 467 in this study) and also did not include young subjects (mean age, 41.5 and 52 years, respectively; 33 years in this study).

Similar to McNames and Aboy,[12] our result also supports that not only RMSSD but also HF calculated using ultra-short-term R-R interval series could be a good surrogate to those calculated using standard 5-min intervals. Salahuddin et al.[13] performed similar statistical analysis methods and also reported the shortest R-R interval length for reliable HRV features that showed an insignificant difference compared with HRV calculated using 5-min R-R interval series. Their result also indicated that RMSSD and HF can be estimated with ultra-short-term HRV, but the minimum required R-R interval length was different compared with our result (10 s for both). The plausible reason for this discrepancy may be the difference in age distribution of study subjects. They recruited only 6 subjects whose age range was 20–36 (mean ± SD, 27 ± 4.2) years. The correlation coefficients and p value shown in *Tables 3* and *4* for younger age groups of 20 years and 30 years also showed that 10-s R-R interval data were sufficient to estimate RMSSD and HF. We could confirm the fact that HRV measures can be very sensitively affected by age-dependent factors and that the research on HRV should be performed with a wide range of age groups to draw any meaningful conclusion that can be applied to the general population.

In this regard, our study has a strength in that the sample size was much larger than previous studies and distributed quite equally according to age groups. We recruited 467 subjects ranging in age from 8 to 69 (mean ± SD, 33.03 ± 13.16) years. Gender ratio was also balanced: 53.32% and 46.68% for males and females, respectively.

One limitation of this article is that the present study was performed with only Koreans. Currently, investigations on ethnic difference in HRV are still controversial. For example, Wang et al.[25] reported that no ethnic or gender differences were found for any HRV measure, whereas Choi et al.[26] found ethnic differences in frequency domain HRV variables. In our experience, individual differences are likely to be a larger source of heterogeneity than ethnicity. The mean HRV variables for each age group were within the normal range of HRV variables that were investigated among Americans,[27] and this supports our opinion. Another imitation would be that lack of information on early-life adversity, socioeconomic status, or parenting style, which can affect the dynamic vitality of the autonomic nervous system. Finally, the use of 5-min as opposed to 24-h R-R interval series is another limitation. However, the present study is helpful because both 5-min and 24-h measurements of HRV have been reported to show reasonable agreement, and both are predictive of mortality following myocardial infarction.[28]

To summarize, we have investigated correlation and agreement between standard 5-min and short-term HRV variables by means of Pearson correlation analyses, Kruskal–Wallis tests, and Bland-Altman plots for large populations. For each HRV variable, the minimum length of the R-R interval to estimate reliable 5-min HRV was identified. In addition, the reference value for short-term HRV that was investigated among normal healthy subjects was also presented. For almost all HRV variables calculated using R-R interval series shorter than 5 min, age dependence has also been found.

In conclusion, even though the absolute values of HRV parameters calculated using ultra-short-term R-R interval series are not exactly matched with those calculated using 5-min R-R interval variability, based on the results of 467 subjects presented in this article, ultra-short-term HRV is suggested to be a good surrogate method to assess trends in HRV measures.

Acknowledgments

This work was supported by Samsung Electronics.

Disclosure Statement

H.J.B., C.-H.C., and J.C. are employees of Samsung. J.-M.W. declares no competing financial interests exist.

REFERENCES

1. Ghuran A, Malik M. Heart rate variability—State of the art. *Card Electrophysiol Rev* **1999;**3:283–285.
2. Kleiger RE, Stein PK, Bigger JT Jr. Heart rate variability: Measurement and clinical utility. *Ann Noninvasive Electrocardiol* **2005;**10:88–101.
3. Baek HJ, Lee HB, Kim JS, Choi JM, Kim KK, Park KS. Nonintrusive biological signal monitoring in a car to evaluate a driver's stress and health state. *Telemed J E Health* **2009;**15:182–189.
4. Gouin J, Wenzel K, Deschenes S, Dang-Vu T. Heart rate variability predicts sleep efficiency. *Sleep Med* **2013;**14:e142.
5. Patel M, Lal SKL, Kavanagh D, Rossiter P. Applying neural network analysis on heart rate variability data to assess deriver fatigue. *Expert Syst Appl* **2011;**38:7235–7242.
6. Allen J. Photoplethysmography and its application in clinical physiological measurement. *Physiol Meas* **2007;**28:R1.
7. Charlot K, Cornolo J, Brugniaux JV, Richalet JP, Pichon A. Interchangeability between heart rate and photoplethysmography variabilities during sympathetic stimulations. *Physiol Meas* **2009;**30:1357–1369.
8. Lu G, Yang F, Taylor JA, Stein JF. A comparison of photoplethysmography and ECG recording to analyse heart rate variability in healthy subjects. *J Med Eng Technol* **2009;**33:634–641.
9. Gil E, Orini M, Bailon R, Vergara JM, Mainardi L, Laguna P. Photoplethysmography pulse rate variability as a surrogate measurement of heart rate variability during non-stationary condition. *Physiol Meas* **2010;**31:1271–1290.
10. Task Force Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology. Heart rate variability, Standards of measurement, physiological interpretation, and clinical use. *Eur Heart J* **1996;**17:354–381.
11. Nussinovitch U, Elishkevitz KP, Katz K, Nussinovitch M, Segev S, Volovitz B, Nussinovitch N. Reliability of ultra-short ECG indices for heart rate variability. *Ann Noninvasive Electrocardiol* **2011;**16:117–122.

12. McNames J, Aboy M. Reliability and accuracy of heart rate variability metrics versus ECG segment duration. *Med Biol Eng Comput* **2006;**44:747–756.

13. Salahuddin L, Cho J, Jeong MG, Kim D. Ultra short term analysis of heart rate variability for monitoring mental stress in mobile settings. *Conf Proc IEEE Eng Med Biol Soc* **2007;**4656–4659.

14. Salahuddin L, Jeong MG, Kim D. Ultra short term analysis of heart rate variability using normal sinus rhythm and atrial fibrillation ECG data. *Conf Proc e-Health Netw Applic Serv* **2007;**240–243.

15. Choi SM, Kang TY, Woo JM. Development and validation of a modified form of the stress response inventory for workers [in Korean]. *J Korean Neuropsychiatr Assoc* **2006;**45:541–553.

16. McCraty R, Atkinson M, Lipsenthal L. *Emotional self-regulation program enhances psychological health and quality of life in patients with diabetes*. Publication No. 00-006. Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath, **2000.**

17. McCraty R, Atkinson M, Tomasino D. Impact of a workplace stress reduction program on blood pressure and emotional health in hypertensive employees. *J Altern Complement Med* **2003;**9:355–359.

18. Hebruqyes G, Keffer S, Abrahamson C, Horst SJ. Exploring the effectiveness of a computer-based heart rate variability biofeedback program in reducing anxiety in college students. *Appl Psychophysiol Biofeedback* **2011;**36:101–112.

19. Bigger JT Jr, Fleiss JL, Steinman RC, Rolnitzky LM, Kleiger RE, Rottman JN. Correlations among time and frequency domain measures of heart period variability two weeks after acute myocardial infarction. *Am J Cardiol* **1992;**69:891–898.

20. Garccia E. A tutorial on correlation coefficients. Technical report. **2010.** Available at http://web.simmons.edu/~benoit/lis642/a-tutorial-on-correlation-coefficients.pdf (last accessed March 28, 2014).

21. Kaikkonen P, Hynynen E, Mann T, Rusko H, Nummela A. Heart rate variability is related to training load variables in interval running exercises. *Eur J Appl Physiol* **2012;**112:829–838.

22. Stein PK, Pu Y. Heart rate variability, sleep and sleep disorders. *Sleep Med Rev* **2012;**16:47–66.

23. Thayer JF, Ahs F, Fredrikson M, Sollers JJ, Wager TD. A meta-analysis of heart rate variability and neuromonitoring studies: Implications for heart rate variability as a marker of stress and health. *Neurosci Biobehav Rev* **2012;**36:747–756.

24. Schroeder EB, Whitsel EA, Evans GW, et al. Repeatability of heart rate variability measures. *J Electrocardiol* **2004;**37:163–172.

25. Wang X, Ding X, Su Shaoyong, Li Z, Riese H, Thayer JF, Treiber F, Snieder H. Genetic influence on heart rate variability at rest and during stress. *Psychophysiology* **2009;**46:458–465.

26. Choi JB, Hong S, Nelesen R, Bardwell WA, NatarajanL, Schubert C, Dimsdale JE. Age and ethnicity difference in short-term heart-rate variability. *Psychosom Med* **2006;**68:421–426.

27. McCraty R, Watkins A. *Autonomic assessment report: A comprehensive heart rate variability analysis interpretation guide and instructions*. Boulder Creek, CA: Institute of HeartMath, **1996.**

28. Fei L, Copie X, Malik M, Camm AJ. Short- and long-term assessment of heart rate variability for risk stratification after acute myocardial infarction. *Am J Cardiol* **1996;**77:681–684.

Address correspondence to:
Jong-Min Woo, MD, MPH, PhD
Department of Psychiatry
Inje University Seoul Paik Hospital
9 Mareunnae-ro, Jung-gu
Seoul, 100-032
Korea

E-mail: jongmin.woo@gmail.com

Received: May 22, 2014
Revised: July 23, 2014
Accepted: July 25, 2014