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Research Article

A Pilot Study Exploring the Relationship between Short-Term HRV and Self-Rated Health Status among Elderly People

Abstract

Introduction: Establishing a personalized health care system can enable elderly people to access health care in their familiar community or home environments to achieve aging in place. The aims of this study are twofold:1) to explore the relationship between heart rate variability (HRV analysis) and subjective self-rated health status among elderly people, and 2) to examine whether HRV parameters serve as alternative subjective-measure indices that can be used to detect and monitor the physical and mental health status of elderly people.

Method: 101 adults aged 64-91 years old were included in the community. The 5-minute resting ECG was measured and participants were required to complete the Physical Activity for the Elderly (PASE), EuroQol-5D (EQ-5D) and Chinese Health Questionnaire-12 (CHQ).

Results: The correlation analysis showed HRV index (LF/HF ratio) had a positive relationship with age and CHQ, but negatively correlated with BMI. The clustering analysis also showed subgroup III (frail group) had the characteristics of being older and having lower BMI, lower physical levels, poor quality of life and self-rated health compared with subgroups I and II (relatively young and normal groups, respectively). Also, we found that the LF/HF ratio might be negatively correlated with EQ utility in subgroups II. Positive relationships were observed between HRV indices such as RMSSD, LF, HF and CHQ in subgroup III.

Discussion: HRV represents not only an objective biomarker but also a potential candidate for evaluating self-rated health. Development and utilization of HRV devices to establish a personalized health care monitoring system can achieve successful aging in the community among elderly people.

Introduction

The elderly people aged 65 or over in Taiwan will reach 14% in 2018 and reach up to 20% by 2025, making it a super-aged society. The health status of elderly people from health/sub-health to disability is a continuous dimension. Although about 80% of elderly people in Taiwan have at least one chronic disease or health condition, the statistics show that the population of those with health and sub-health status is 2.32 million, approximately 83.5% of the total, based on their functional status [1]. If we can create appropriate eldercare programs and monitor the health of these individuals, we would be better able to detect health problems, delay the time at which people enter the disability stage, and thus reduce costs while also improving their quality of life.

The global elderly friendly city construction plan was implemented by the World Health Organization in 2005. In ide@ Taiwan 2020 Policy: White Paper report presented a plan to create a New Taiwan equipped with an “i-d-e-a” intelligent network by 2020 to improve the quality of life for older people. In particular, this program proposes a policy of Smart Health Care, with two main goals: one is Smart Living, which aims to use technology to help elderly people to live safely and healthy; the other is Smart Care, which aims to enable people access health care in their familiar community or home environments to achieve aging in place [2].

In the ide@ Taiwan 2020 Policy: White Paper report, an increased focus on biomedical research and innovative technologies for age-related health needs and conditions are encouraged as investments in healthy and active aging. Coughlin and Lau noted that technology can and will play an important role in keeping older people healthy, active and

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engaged in society [3], thus helping to achieve successful aging in place [4,5]. Establishing a personalized health care monitoring system can provide a safer and more familiar environment for elderly people.

Heart rate variability (HRV)

The autonomic nervous system (ANS) can be divided into the sympathetic and the parasympathetic systems, both of which often antagonize each other to maintain a balance. HRV analysis in the time and frequency domains is a noninvasive and convenient tool for assessing the function of the ANS [6]. Chen et al. noted that the most widely applied time domains include the Mean, SDNN and RMSSD, while the frequency domains used most often include the LF power, HF power and the LF/HF ratio [7].

Short-term ECG recording is a reliable tool to obtain these HRV measures [6,7]. Moreover, short-term HRV analysis has been increasingly applied in recent years due to its suitability for ambulatory care and short-term patient monitoring, and due to the almost instant receiving of test results [8].

The impact factors of HRV

In general, the HRV is influenced by factors such as age, gender, body mass index (BMI), exercise and emotions [8-19]. Several studies demonstrated the effects of age and gender on HRV [8-11]. For example, Bonnemeier et al., found that the significant gender-related differences in HRV decreased with aging in healthy subjects [9], while Voss et al. reported that effects of gender on short-term HRV indices disappeared in individuals older than 55 years [8]. Abhishekh et al., found that among 189 subjects aged 16-60, SDNN, RMSSD, LF power negatively correlated with age, suggesting reduced autonomic regulation of the heart over time. However, the LF/HF ratio correlated positively with age, indicating a relative increase in sympathetic activity along with age [10]. Zulfiqar et al. investigated 344 subjects aged 10-99 and concluded that RMSSD presented a U-shaped pattern instead of a linear decrease with aging [11]. This suggested that there was an overall reduction in autonomic control of the heart with increasing age. Sympathetic tone predominates and vagal tone diminished with the aging process [10]. However, a previous study showed that the eighth decade reversal of the decrease in HRV-parasympathetic function and its subsequent increase were key determinants of longevity [11].

ANS activity is also involved in body weight regulation [12,13]. For example, Dietrich et al. investigated 1,742 subjects aged ≥50 and found that for every unit increase in BMI, SDNN, LF and LF/HF would decrease by 0.7%, 1%, and 1.5%, respectively. Moreover, higher BMI was associated with a decrease in all HRV parameters, except HF [12]. In another study, Molfino et al., found that mean BMI was inversely related to HF, while its relationship with LF was marginally significant. The HF in individuals with BMI<20 was significantly higher than that seen in subjects with a lower value [13].

The level of physical activity might also influence HRV parameters [14,15]. For example, Buchheit et al., showed that the increases in total daily energy expenditure and physical activity intensity were associated with higher global HRV and vagal-related indices in older adults [14]. More recently, Soares-Miranda et al. found that greater total leisure-time activity and walking were associated with more favorable and specific indices of ANS in older adults [15].

Additionally, HRV can be associated with subjective self-rated emotional status, such as depression, stress, pain, and even the quality of life [16-19]. Wang et al. found that individuals with major depression had lower values of SDNN, RMSSD and HF and higher values of LF and LF/HF ratio compared to the control group. There was a positive correlation ($r = 0.335$) between depressive severity index and LF/HF ratio [16]. Not surprisingly, a significant positive correlation has been found between stress perception scales with LF/HF ratio [17]. Koenig et al. also found that there was a significant correlation between the total pain index and HF, LF, and LF/HF ratio [18]. In another study, HRV in the time domain index was significantly higher in patients with heart failure who perceived a better quality of life [19].

However, most studies which found that HRV is associated with a particular disease or negative emotional status examined middle-aged or younger individuals, and there is little research examining HRV and subjective health status among elderly people living in the community. From a preventive perspective, early detection and intervention are important. Therefore, the aims of this study are twofold: 1) to explore the relationship between heart rate variability (HRV analysis) and subjective self-rated health status among elderly people, and 2) to examine whether HRV parameters serve as alternative subjective-measure indices that can be used to detect and monitor the physical and mental health status of elderly people. The pilot study can provide insights to help map subjective health onto the objective HRV indicators among elderly people living in the community.

Methods

Settings and participants

The sample size for a correlation was determined using G*power software [20]. We used an alpha of 0.05, a power of 0.80, a medium effect size ($\rho = 0.3$) for a two-tailed test. The required minimal sample size was determined to be 82. A total of 101 adults aged 64-91 years old were included in the community of one southern city in Taiwan. None of the participants reported significant functional disability problem. The study was approved by Human Research Ethics (No. REC-104-085).

Measurements

The resting state ECG was measured for five minutes. All the participants were then required to complete three questionnaires to evaluate their level of physical activity, quality of life, and health status, including the Physical Activity for the Elderly (PASE), EuroQol-Five Dimensions (EQ-5D), and Chinese Health Questionnaire-12 (CHQ) instruments. These measurements were described as follows:

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Short-Term (five-minute) resting state heart rate variability recordings

The resting state ECG was measured continuously for five minutes with all participants at their resting state using a Check My Heart Handheld HRV (Daily Care Bio Medical Inc., Taiwan). The raw ECG data were exported for further analysis. Six HRV parameters were used as the main HRV indices, including Mean RR intervals, SDNN, RMSSD in time analysis and the power of the LF (frequency band 0.04-0.15 Hz), HF (frequency band 0.15-0.4 Hz), LF/HF ratio in frequency analysis.

Physical activity scale for the elderly (PASE)

The Physical Activity Scale for the Elderly (PASE) is an instrument that measures the level of physical activity for individuals aged 65 and older. It contains self-reported questions related to occupational, household and leisure activities over the past one-week period [21].

The scoring method is based on an individual weighting of the activities, and the total score is between 0-360. The higher score, the greater level of physical activity. Ku et al., found that this Chinese version of PASE has good reliability (r = 0.87) and was suitable for assessing the physical activity among older Taiwanese individuals [22]. In the present study, the Cronbach alpha was 0.72, demonstrating acceptable internal consistency.

EuroQol-Five Dimensions (EQ-5D)

EQ-5D is a standardized instrument used to measure the quality of life. This questionnaire was divided into two parts: one contains five health-oriented questions, and the other the EQ-VAS [23]. The former can be obtained by a time trade-off (TTO) according to the degree of severity, with a value ranging from 0 to 1. The EQ-VAS are with a minimum score of 0 and a maximum of 100 [23]. Haywood, Garratt and Fitzpatrick suggested that the EQ-5D was good for use with older people, due to its reliability (Cronbach alpha = 0.73) and validity particularly when a substantial change in health was expected [24]. The Cronbach alpha was 0.78 in the present study, demonstrating acceptable internal consistency.

Twelve-item chinese health questionnaire (CHQ)

The Chinese Health Questionnaire (CHQ) is based on the General Health Questionnaire framework proposed by Godberg in 1972, and was developed by Cheng and Willams for use with Chinese populations [25]. The higher score, the worse the self-rated health.

CHQ-12 is widely used among Chinese populations worldwide, and has good psychometric properties and Cronbach's alpha for internal consistency ranged from 0.79 to 0.84 [26-29]. For example, Chen et al. validated the use of the CHQ-12 among the elderly, and found that the results were as valid as those obtained with the general population survey [26]. Yang, Huang and Wu found that the CHQ-12 could be used for epidemiological studies and in community health care to screen for mental disorder in mainland China [27]. Wang, Gorenstein and Andrade examined a Brazilian Chinese community and found that the CHQ-12 presented comparable psychopathologic patterns, psychometric properties and factorial structures with this group to those seen in a Taiwanese population [28]. Barbato et al. found that the bilingual Chinese/Italian version of the CHQ-12 showed good reliability and validity, and was thus considered a suitable instrument for cross-cultural research on psychological distress in a Chinese population living in Italy [29]. The Cronbach alpha for internal consistency was 0.82 in present study which also showed its internal consistency.

Data analyses

HRV parameters: With regard to data processing, the research team took the raw data and calculated the HRV parameters using the related algorithm. The five-minute heart rate recording data were retrieved and the HRV parameters calculated, including the time domain and frequency domain (Fast Fourier Transform-based) parameters, according to recommendations by the Task Force of the European Society of Cardiology [6]. In the time analysis the parameters included mean RR intervals, SD of normal RR beats (SDNN), and the square root of the mean squared differences between successive RR intervals (RMSSD). In the frequency analysis, the power of the LF, HF and LF/HF ratio were calculated as indices.

Statistical analyses

All HRV parameters were normalized by logarithm transformation. Pearson's and Spearman's rank rho correlations were calculated between the HRV parameters and other variables, including age, BMI, PASE, EQ-5D and CHQ. K-mean clustering was used to search for heterogonous elderly subgroups to compare their performance between HRV parameters and three questionnaires. R software version 3.1.1 was used to analyze the data [30]. The significance level was set at $p < 0.05$.

Results

Basic Information of all variables among participants

The results of the questionnaires and short-term HRV analysis in the time and the frequency domains were shown in Table 1. A total of 66 women and 35 men were included in this study. No significant differences were observed between women and men in terms of BMI, PASE, VAS, and CHQ, although there were significant differences for age and EQ-5D. None of the parameters of the HRV time and frequency domains were significantly different between the women and men.

Correlations between short-term HRV parameters and other variables

As shown in Table 2 for all samples in the study, we found age was positively correlated with LF/HF ratio (Pearson's r = 0.20, $p < 0.05$), but the BMI was negatively correlated with the LF/HF ratio (r = -0.21, $p < 0.05$). In psychological measurements, only the CHQ was positively correlated with the LF/HF ratio (Spearman's rho = 0.21, $p < 0.05$), showing that the worse the self-rated health, the higher the LF/HF ratio. However, the SDNN or RMSSD in time domain did not correlated with age, BMI, and the psychological measurements.

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K-means clustering

We used K-mean clustering, based on the distance between the results from the normalized variables, to search for heterogonous elderly subgroups to compare their performance between HRV parameters and questionnaires. Theoretically, the heterogeneity should be maximal between groups and should be minimal within a group after adequate subgrouping. In the correlation analysis (Table 2), we found that the LF/HF ratio was the most relevant index, which was independent of RMSSD. Previous study also suggested that RMSSD may be a novel and independent risk factor for mortality [31]. We thus selected the LF/HF ratio and RMSSD as the grouping variables. K-means clustering analysis suggested that dividing the participants into three subgroups was optimal. Several characteristics differentiated the three groups, as shown in Figure 1. Subgroup I and II were named the "relatively young group" and "normal group", respectively. Subgroup III was characterized as the "frail group", because these included the individuals who were the oldest, had the lowest of BMI, the least amount of physical activity (PASE), the lowest quality of life (EQ utility) and the worst self-rated health (CHQ) among all the participants.

This study further examined the correlations among all measurements in the three subgroups. Figure 2 shows that the LF/HF ratio might be negatively correlated with EQ utility in subgroups II (normal group). Positive relationships were observed between HRV indices such as RMSSD, LF, HF and CHQ in subgroup III (frail group).

Table 1: Basic information of all variables among participants.

	All (N=101)		Women (N=66)		Men (N=35)		T-test P value
	Mean	SD	Mean	SD	Mean	SD	
Age	76.40	6.53	75.15	6.20	78.76	6.59	0.009**
BMI	23.88	3.27	23.70	3.52	24.22	2.78	0.419
PASE	104.45	74.96	98.95	64.70	114.81	91.40	0.366
EQ-5D	0.88	0.19	0.85	0.22	0.93	0.10	0.015*
VAS	73.98	18.07	73.29	19.13	75.18	16.25	0.619
CHQ	2.11	2.54	2.47	2.82	1.50	1.86	0.052
Mean R-R	856.25	140.87	860.20	123.83	848.81	170.20	0.728
SDNN	34.32	32.56	35.74	38.04	31.65	18.46	0.470
RMSSD	26.25	20.01	27.72	22.32	23.47	14.60	0.253
LF	185.39	570.92	232.82	696.24	95.96	139.08	0.128
HF	119.72	244.53	140.88	290.88	79.83	107.74	0.132
LF/HF ratio	1.53	1.43	1.64	1.61	1.33	1.01	0.237

** p <0.01; * p <0.05.

Discussion

This exploratory analysis is consistent with previous studies and reveals some interesting findings. First, a positive correlation between the age and LF/HF ratio indicated higher sympathetic activity relative to parasympathetic activity with an increase in age, consistent with previous studies [10,32]. However, BMI can be a protective factor because of its negative correlation with LF/HF ratio among elderly people. Second, higher scores of the CHQ indicated lower self-rated health. This study found that the CHQ score was positively associated only with the LF/HF ratio, but failed to show a significant associations with the other HRV parameters, similar to the findings of previous studies. For example, Wang et al., found a positive correlation between the depressive severity index and LF/HF ratio [16]. Lucini et al., found a significantly positive correlation was found between stress perception scales and the LF/HF ratio [17]. In addition, Narita et al., found that anxiety trait scores were only significantly associated with the LF/HF ratio [33].

Based on the concept of health heterogeneity of elderly people, we further divided our samples by K-means clustering. There were three subgroups and exhibited distinct characteristics in the clustering analysis. In particular, subgroup III (frail group) were older and had lower BMI, lower physical activity levels, poor quality of life, and poor self-rated health compared with subgroups I and II, as shown in Figure 1. Further correlation analysis, as shown in Figure 2, revealed that different HRV indices might be correlated with specific psychometric measurements. For example, we found that the

Table 2: Pearson's and Spearman's correlations of HRV parameters with other variables.

			Spearman's Correlation										
			(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
Pearson's Correlation	AGE	(A)	1	-0.01	0.06	0.03	0.11	-0.02	0.20*	-0.34***	-0.24*	-0.12	0.01
	BMI	(B)	-0.05	1	-0.19	-0.15	-0.29	-0.18	-0.21*	0.01	0.02	0.10	-0.06
	SDNN#	(C)	0.08	-0.19	1	0.83***	0.90***	0.86***	0.10	-0.01	-0.01	0.01	-0.02
	RMSSD#	(D)	0.02	-0.18	0.83***	1	0.77***	0.94***	-0.22*	-0.11	-0.16	0.01	0.02
	LF#	(E)	0.12	-0.29**	0.90***	0.78***	1	0.81***	0.31**	-0.10	-0.16	0.05	0.06
	HF#	(F)	-0.01	-0.19	0.85***	0.94***	0.82***	1	-0.26**	-0.11	-0.10	0.07	-0.06
	LF/HF#	(G)	0.22*	-0.18	0.16	-0.17	0.38***	-0.22*	1	0.04	-0.13	-0.02	0.21*
	PASE	(H)								1	0.47***	0.20	-0.10
	EQ-5D	(I)									1	0.44***	-0.43***
	VAS	(J)										1	-0.16
	CHQ	(K)											1

log transformed

*** p <0.000; ** p <0.01; * p <0.05

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HRV indices had a positive relationship with self-rated health (CHQ) in the subgroup III (frail group) and HRV was found negatively correlated with quality of life (EQ) in the subgroups II (normal group). Our findings showed the heterogeneous health profiles of elderly people and different level of correlations between HRV and the psychometric measurements might exist among healthy or sub-healthy older people. It is suggested that appropriate monitoring and person-centered interventions with the feasibility of applying HRV should be considered for those groups.

The feasibility of applying HRV in different domains has been increased by recent research. For example, Lanata et al. used a complexity index from personalized wearable devices to monitor HRV and assess patients with mental disorders [34]. Hautala et al., found that short-term assessment of ANS is a potential tool to quantify the experience of pain among low back pain patients [35]. Moreover, Thayer et al., indicated that HRV can be a potential marker of health [36]. Similarly, Okruszek et al., stated that monitoring HRV parameters might offer a practical and cost-effective solution to assessing the processes associated with recovery progress or symptom relapse [37].

Most previous studies examining the utilization and

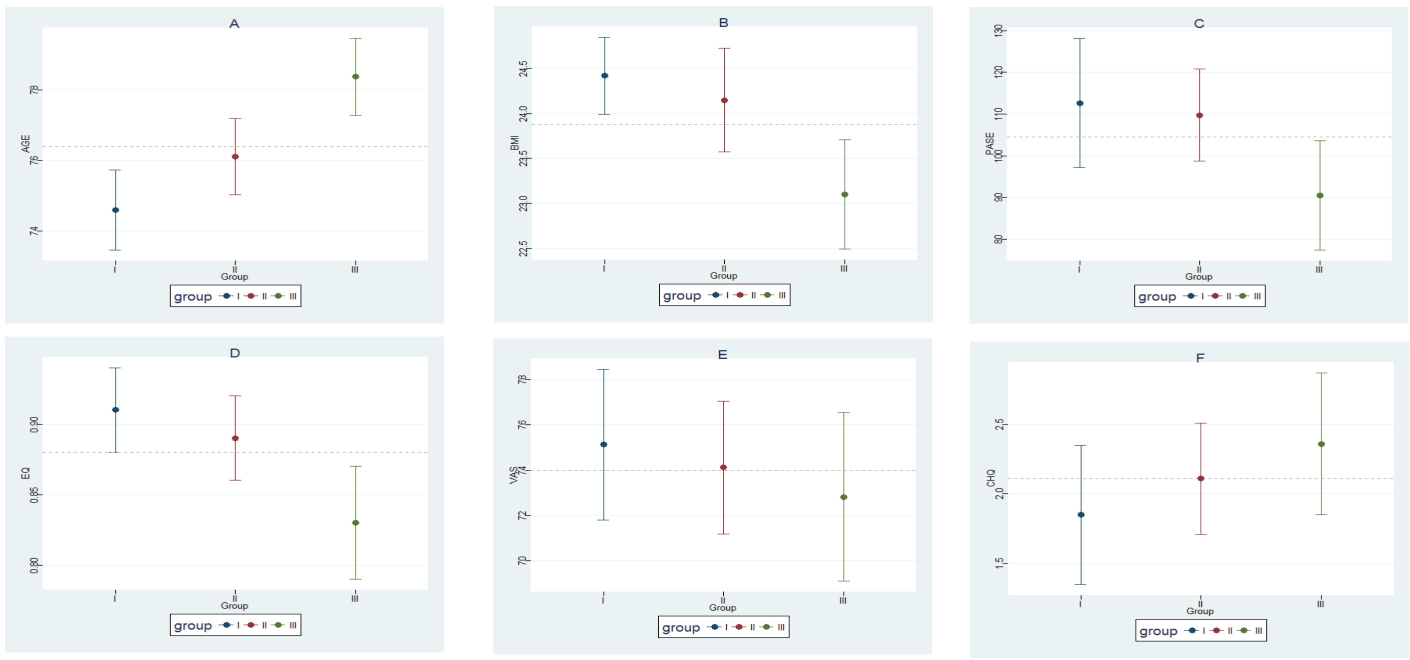

Figure 1: Different conditions among the three groups by using RMSSD and LF/HF ratio. (A) AGE, (B) Body Mass Index, BMI, (C) The Physical Activity for the Elderly Scale, PASE, (D) EQ, (E) Visual Analog Scale, VAS, and (F) Chinese Health Questionnaire, CHQ. Several characteristics differentiate the three groups. The BMI, PASE, EQ, and VAS scores tended to be the lowest, while AGE and CHQ tended to be the highest in subgroup III, the 'frail group' (The gray dotted lines in the figures represent the means of all participants.

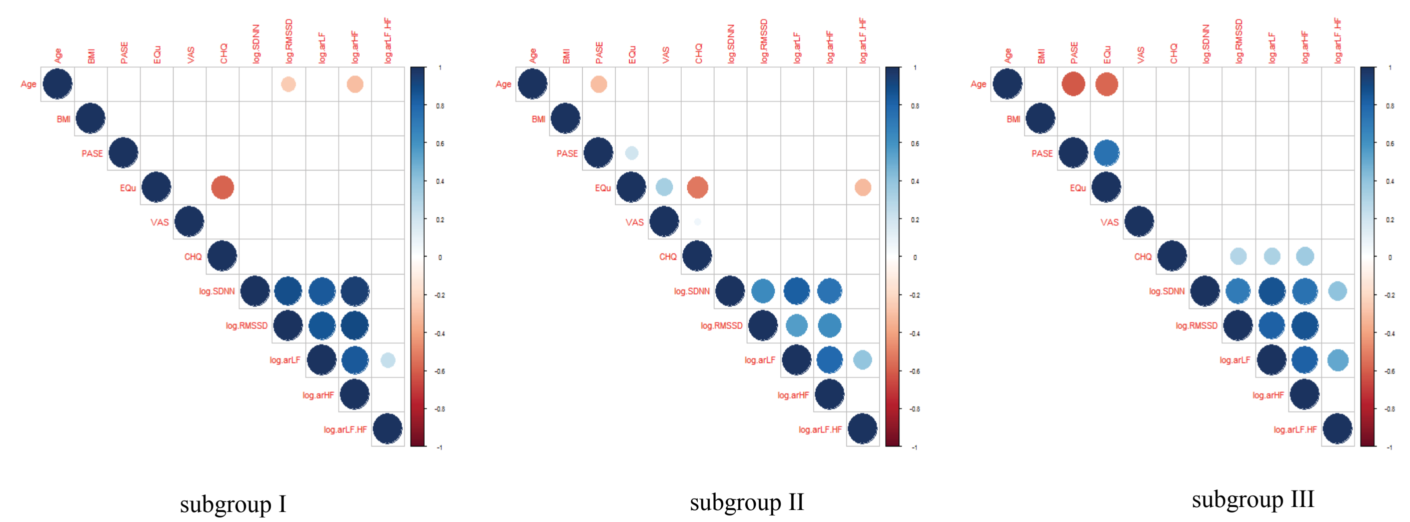

Figure 2: A visualization of a Spearman's correlation matrix between different measurements among the three groups. The color intensity and size of the circles are proportional to the correlation coefficients, and those left blank have no significant coefficient. Positive correlations are displayed in blue and negative correlations in red.

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development of HRV have focused on specific disease-related issues. However, from a preventive perspective, early detection and intervention might be more important among elderly people. Therefore, the present study examined a group of elderly people living in the community and our findings indicated that HRV parameters with the feasibility of application among heterogeneous subgroup can be not only an objective biomarker, but also a potential candidate as an alternative subjective-measure index, which can early detect and monitor the mental status of elderly people.

Several limitations exist with this study, and thus some caution should be taken with regard to its results. First, larger sample sizes are encouraged in future works to establish a forecasting model. Second, we did not take account of common diseases among the participants which can be further studied their possible contribution to ANS activity. Third, a longitudinal follow-up is needed to explore the temporal relationship of HRV and self-rated health among elderly people. Fourth, the issue of sampling rate should be considered. Our present study was fixed to 250 Hz. and the range of sampling frequency of 250-500 Hz. has been recommended previously [6]. However, that the HRV parameters could be affected by sampling frequency needs to be investigated in the future work.

Our study has some strengths. Importantly, our results try to explore the associations between the psychological measurements and vital signs will provide an insight to map subjective health onto the objective HRV indicators. Secondly, based on the health heterogeneity of elderly people, our study found the subgroups of health characteristics and exhibited the feasible application of HRV among different groups. Furthermore, unlike most previous studies that only included patients with specific clinical problems, from a preventive perspective, our study focused on elderly people in the community. Early detection and intervention are crucial to numerous healthy and sub-healthy elderly people, the feasibility of applying the HRV which could use as the screening and warning tools can be established in the health care monitoring system at an early stage. Therefore, our data which comes from a Chinese population of community-dwelling older adults can serve as a pilot study in order to better utilize HRV devices in the future.

In summary, we found the LF/HF ratio can be a potential candidate for evaluating self-rated health and recommend the further utilization and development of HRV devices to establish a person-centered health care monitoring system in order to achieve successful aging in place among heterogeneous older populations.

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