Validity of Withings Pulse Wave Velocity Scale

Versus Gold Standard Applanation Tonometry and Body Composition Analysis

in a Young Healthy Population

By

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Abstract

Cardiovascular disease currently accounts for over 800,000 American deaths per year, serving as the leading cause of death nationwide. Pulse Wave Velocity (PWV) lends us information on cardiovascular health and is now considered a gold standard for measuring arterial health in adults. Deleterious changes in arterial compliance, in addition to a poor body composition, have been shown to be early risk factors in the onset of cardiopulmonary and arterial disease. The Withings Body Cardio Scale has been marketed to the general population for its ability to measure PWV and body composition in the home, however, there are no data that demonstrate the accuracy of this technology. **PURPOSE** The aim of this study was to determine the accuracy and reproducibility of the PWV and body composition features within the Withings Body Cardio (Withings, Issy-les-Moulineaux, France) in comparison to the gold standard in applanation tonometry (SphygmoCor, AtCor Medical, Itasca, Illinois, USA) and body composition analysis (BodPod, Life Measurement, Inc., Concord, CA, USA). We hypothesized that the equipment providing the measurements would not be statistically different. **METHODS** 20 normotensive healthy young adults (20 years +/- 1.1 years) enrolled in this study. Subjects were randomly sorted into groups for measurement order. Body composition analysis with BodPod was counterbalanced with the Withings Body Cardio scale. Two measurements with each operating system were obtained over a period of 30 minutes. Standing PWV measurements with SphygmoCor were utilized in order to maintain ecological validity with the scale. Three counterbalanced PWV measurements with each operating system were obtained over a period of sixty minutes for each individual. All data expressed as mean ± SEM. Statistical analysis was performed using two-tailed Student's t-tests. An *a priori* statistical significance was set at $p < 0.05$. **RESULTS** No significant differences

were found between body mass measurement between BodPod and Withings Body Cardio systems (BM_{BodPod} = 66.6 kg ± 2.6 kg, $BM_{Withings}$ = 66.8 kg ± 2.7 kg, p = 0.000). Significant differences were observed in measurement of fat mass (BM_{BodPod} = 8.8 kg ± 1.1 kg, $FM_{Withings}$ = 11.7 kg ± 1.0 kg, p = 0.003 and fat-free mass (FFM_{BodPod} = 57.9 kg ± 2.7 kg, $FFM_{Withings}$ = 55.0 kg ± 2.6 kg, p = 0.001). Less than 1 m/s difference was demonstrated between measurements with the SphygmoCor and the Withings Body Cardio systems ($PWV_{SphygmoCor}$ = 6.1 m/s ± 0.1 m/s, $PWV_{Withings}$ = 6.8 m/s ± 0.2 m/s, p = 0.000). **CONCLUSION** Statistical differences between BodPod and the bioelectrical impedance analysis of Withings Body Cardio used to measure fat mass and fat-free mass indicate that the Withings system is not accurate for use in a clinical setting. There were no clinical differences detected between devices in the measurement of PWV, suggesting the home-based system of tracking PWV using the Withings Body Cardio can be an accurate measurement of systemic pulse wave velocity. Monitoring cardiopulmonary health at home can be useful in providing clinical insight for longitudinal healthcare monitoring.

Introduction

The effects of cardiovascular disease have become increasingly prevalent in the modern world. Cardiovascular disease now accounts for over 800,000 deaths annually in the United States alone (Benjamin et al., 2017). Cardiovascular disease is composed of a large grouping of disease states and is most commonly linked to deleterious change within the major arteries of the thorax and heart. The ability to ascertain the health status of the arterial system is crucial to the understanding, diagnosis, and monitoring of cardiovascular disease.

The mechanical properties of healthy arteries serve an important role in the flow of blood. During systole, arteries must elicit compliance to increased volume and flow, allowing for accommodation of a fluid bolus within the ascending and descending aorta, carotid artery, and femoral artery. Through accommodation, adequate coronary and somatic perfusion, as well as the management of pressure can be achieved. With aging and disease-related stress, the major arteries of the body can experience a significant change in compliance and elasticity, impairing vascular function and cardiac performance. This disease process is known as atherosclerosis and is characterized by damage to the endothelial lining and intima of the artery. Following damage, these lesions are replaced by atherosclerotic plaques formed from calcified and collagenized lipid deposits (Palombo and Kozakova, 2015). Plaque buildup is associated with reduced arterial compliance and elasticity attributable to increased collagen deposition within the tissue. Over time, this buildup can exacerbate disease progression and is associated with a greater risk of overall mortality. As previously described, deleterious changes in arterial compliance have been shown to be an early risk factor of cardiovascular disease. Pulse wave velocity has been cemented as the gold standard for measurement of arterial stiffness and can provide a simple, rapid, and non-invasive approach to monitoring of cardiovascular health.

This measurement often performed using SphygmoCor (AtCor Medical, Itasca, Illinois, USA), is an effective method of determining cardiovascular risk and arterial stiffness. Measurement has been proven to be highly reproducible, accurate, and user-friendly. Standard procedure includes carotid to femoral measurement through the application of beat-to-beat blood pressure monitoring and Doppler ultrasound mediated standard applanation tonometry. Using the distance measured between the carotid and femoral sites and the time allotted between pressure waveforms, the pulse wave velocity of an individual may be calculated.

Key to the importance of the measurement of pulse wave velocity is its ability to remove much of the white-coat bias present within the assessment of arterial health through the use of blood pressure. Within clinical practice, an increased waveform velocity can signify reduced arterial compliance, often the result of stenosis, plaque buildup, and general cardiovascular disease. These disease properties result in increased aortic pressures, leading to a rapid ejection of blood through the arterial system, rather than the gradual accommodation of a fluid bolus, as seen within a healthy arterial system. This alteration can significantly increase the strain on the heart as a result of increased afterloads applied against contraction, a commonly implicated pathway towards advanced stage cardiovascular disease (Zhong et al., 2017).

Until recently, the sole methods of measurement of pulse wave velocity required a physician or research lab visit. However, with recent advances in healthcare technology, Withings has developed a home alternative for the measurement. The Withings Body Cardio Scale employs a system of proprietary algorithms to determine a variety of data about an individual. This device relies on Wi-Fi to transfer data to a smartphone or website. Unlike the SphygmoCor system, which requires a trained operator and clinical visit, the Body Cardio Scale is available for personal and individualized home use (Martin et al., 2016).

The advantage that the Withings Body Cardio Scale presents in the measurement of an individual's cardiovascular health makes the product extremely desirable in the treatment and observation of patients. In addition, the ability of the scale to obtain a clinically accurate measurement at the time of waking allows individuals to receive a measurement reflective of their true cardiovascular health. This model could be especially beneficial to the general public for its ability to obtain measurements in the comfort of an individual's home without the assistance of a presiding healthcare professional. Therefore, the Withings Body Cardio Scale could provide a method of at-home observation of patient cardiovascular health for physicians, allowing for the application of the technology to clinical practice, in which patients could be accessed with the ability to gain day-to-day observation of cardiovascular health.

In addition to its measurement of pulse wave velocity, the Withings Body Cardio has been marketed for its ability to estimate body composition through foot-to-foot bioelectrical impedance analysis (BIA). This technology derives body composition, including fat mass and fat-free mass through the use of a safe and painless electrical current. The system is far less expensive and invasive than alternative forms of analysis such as dual X-ray absorptiometry (DEXA), air displacement plethysmography, and water displacement plethysmography (Buffa et al., 2014). BIA operates on the principle that the body can be simplified to a cylinder in which volume is estimated by length multiplied by cross sectional area. In turn, impedance is inversely related to cross sectional area. This principle also assumes homogeneity in material, and hence, in conduction. This conduction is made possible by the presence of water in tissue. However, in practicality, the body does not possess homogeneity in tissue composition, as various portions of the body may be composed of dramatically different levels of fat mass, thereby affecting location-specific conductivity (Buffa et al., 2014). In order to combat this problem, BIA now

operates via multiple frequencies in order to account for various levels of fluid conductance based on the percent water within each solution. Through a set of proprietary algorithms, data based on conductance can be used to calculate total body water. According to Kyle, et al. (2004), fat-free mass can then be estimated from total body water using the principle that fat mass only consists of around seven percent water.

However, BIA has repeatedly been implicated for a high level of error in measurement. This error is commonly attributed to two main culprits. First, the composition of adipocytes can vary greatly, especially in the case of perturbations to hydration status, thereby producing variance in the amount of total body water stored within the tissue. Secondly, insulating properties of adipose tissue deposited within the body can affect the impedance of adjacent fat-free tissue, thereby producing an erroneously high estimation of fat mass within the body (De Lorenzo, Andreoli, Matthie, and Withers, 1997). In a recent study conducted by Buffa, et al. (2014), measurement of body composition with BIA was compared to DEXA. It was found to produce an increase in percent error of close to nine percent, thereby indicating a contraindication to the use of bioelectrical impedance analysis within a clinical setting. Despite previous BIA systems decreased clinical relativity, the Withings Body Cardio scale may provide a cheap and effective method of at-home measurement of body composition, therefore increasing the relevance of the product.

While the Withings Body Cardio has been marketed to the general population for its ability to measure pulse wave velocity and body composition at home, there is no data that indicates the accuracy of these measures. The purpose of this study was to validate the pulse wave velocity and body composition features of the product in a young, healthy population through comparison of Withings' measurements to the gold standards in applanation tonometry

and body composition, SphygmoCor and BodPod, respectively. We hypothesized that the differences between the gold standards and Withings Body Cardio for pulse wave velocity and body composition will not produce statistically different measurements, thereby providing an economically affordable and effective method of at-home monitoring.

Materials and Methods

Subject Recruitment and Selection. Subjects were recruited following Appalachian State University Review Board (IRB 17-0023) guidelines. A total of twenty subjects (male n = 10, female n = 10) were engaged via face to face conversation or through an IRB registered, pre-approved email. The study was *a priori* powered using pilot data from our lab with means and standard deviation based on pulse wave velocity data. This data demonstrated that a sample size of 17 subjects was needed to detect differences at $\alpha = 0.8$ and $p = 0.05$. Subjects were of college age, between 18 and 25 years old (21.8 years ± 2.0 years), apparently healthy, normotensive, with no known disease, and without signs or symptoms of cardiovascular, metabolic, or renal disease. All subjects were derived from the student population at Appalachian State University. Descriptive characteristics of the subject population are provided within Table 1. Exclusion criteria of the study included the presence of chronic disease that might limit participation in physical activity or hinder laboratory measurement and the use of the Withings Body Cardio scale. Additionally, subjects consuming antihypertensive medications were excluded.

Pre-Participation Screening. Participants were screened upon arrival for the presence of disease or disease symptoms with a medical history form using the Appalachian State University Department of Health and Exercise Science Pre-Participation Guidelines. Participants were briefed of the study protocol by the investigator in order to gain consent. Following informed consent and screening of the pre-participation guidelines, subjects were permitted to enroll in the study. Table 1 provides the descriptive characteristics of the subject population included in the study.

Table 1. Subject descriptive data. Subject age (years), height (cm), mass (kg), systolic blood pressure (SBP, mm Hg), and diastolic blood pressure (DBP, mm Hg) presented as mean ± standard error of the mean (SEM). Descriptive range provided as minimum to maximum. Subjects were derived from a young, healthy, and normotensive population.

	N	Minimum	Maximum	Mean ± SEM
Age (Years)	20	18	25	21.8 ± 0.44
Height (cm)	20	160.0	187.3	172.8 ± 1.68
Mass (kg)	20	51.0	94.5	66.8 ± 2.78
SBP (mm Hg)	20	126	100	111.2 ± 1.77
DBP (mm Hg)	20	78	50	63.9 ± 1.43

Subjects were instructed to report to the Appalachian State University Vascular Biology and Autonomic Systems Laboratory (251 Industrial Park Drive Boone, NC 28607) on the morning of testing at 8:00 am. Subjects were instructed to refrain from the consumption of food, excess fluids, and stimulants in the twelve hours prior to testing. Additionally, subjects were instructed to refrain from exercise in the twelve hours of testing. Pre-participation screening and informed consent were obtained prior to data collection. Anthropometric data (sex, date-of-birth, height, and weight) was collected via the medical history form and a calibrated scale and stadiometer. Necessary anthropometric data was inputted into the Withings Health Mate © application in order to create a deidentified profile for each subject. This profile was used to connect to the Withings Body Cardio Scale, thereby allowing for the ability to monitor the scale's measurement.

Blood Pressure Measurement. Following collection of anthropometric data, subjects were instructed to be seated upon the examination table for five minutes prior to blood pressure measurement. A seated brachial blood pressure measurement was performed by a trained and experienced technician according to American Heart Association Guidelines with a medical grade stethoscope (Littmann Cardiology III ®, 3M, St. Paul, MN, USA) and sphygmomanometer Brachial blood pressure measurement was then repeated utilizing SphygmoCor (AtCor Medical, Itasca, Illinois). Subsequently, subjects were randomly assigned to the order of body composition analysis and pulse wave velocity measurement.

Body Composition Analysis. Assessment of body composition was accomplished utilizing whole body air displacement plethysmography (BodPod, Life Measurement, Inc., Concord, CA, USA). Subjects were instructed to wear compression shorts and an additional sports bra if necessary. Height and weight were previously measured using a stadiometer (to the nearest 0.5 cm) and a beam balance platform scale. Body mass index was calculated as mass (kg) divided by height (m) squared. Body composition was calculated as percent fat mass (%) and percent fat-free mass (%). Following body composition analysis with the BodPod, subjects were instructed to step onto the Withings Body Cardio (Withings, Issy-les-Moulineaux, France) barefoot. Subjects were instructed to remain quiet and still until a successful measurement was confirmed. This protocol was repeated for a total of two trials of each system.

Pulse Wave Analysis. Pulse wave analysis measurements were obtained using the SphygmoCor XCEL (AtCor Medical, Itasca, Illinois, USA). Seated brachial blood pressure measurements were obtained using the SphygmoCor XCEL. Pulse wave analysis was performed alongside this

seated blood pressure measurement, but was not examined within this comparative study, as the Withings system does not produce this data.

Pulse Wave Velocity Measurement. Carotid-femoral pulse wave velocity measurements were obtained using SphygmoCor XCEL. Measurement was performed by a trained technician. The subject was instructed to stand barefoot within range of the SphygmoCor system. Standing brachial blood pressure assessment was performed after the subject had stood at rest for three minutes. The femoral sphygmomanometer cuff was placed around the right thigh. Measurement (in cm) of aortic length was approximated manually with a basic tape measure. This was accomplished by palpation of carotid pulse and estimation of femoral bifurcation, measurement of carotid artery to sternal notch, sternal notch to cuff, and femoral bifurcation to cuff. Measurement of pulse wave velocity was performed while upright, in order to replicate the conditions present when using the Withings Body Cardio, by applanation tonometry via palpation of the carotid artery with a doppler pen.

Following measurement of pulse wave velocity with the SphygmoCor system, the subject was instructed to step onto the Withings Body Cardio scale. The subject remained on the scale until a successful measurement of pulse wave velocity was confirmed. This protocol was repeated an additional two times in order to obtain a total of three measurements with each system.

Statistical Analysis. Data was collected from the BodPod, SphygmoCor, and Withings Health Mate © application. Average value of each measurement and standard error of the mean was calculated and used for subsequent analysis. Statistical analysis relied on IBM SPSS version 14 (SPSS Inc., Chicago, IL, USA). Bland-Altman analysis was utilized to analyze pulse wave

velocity and body composition data. Bias was calculated as the criterion-reference measurement minus the General Wellness Product measurement. A two-tailed Student's t-tests were performed to calculate the mean difference and 95 % confidence intervals of the data. These intervals were used to create the Bland-Altman plots. Regression analysis was performed to evaluate for proportional bias and Pearson correlation coefficient. Mean Absolute Percent Error (MAPE) presents the error as a percentage of the overall mean and indicates the degree of error. Additionally, repeated measures ANOVA was conducted to analyze variance attributable to sex difference between devices. An *a priori* significance of $p < 0.05$ was utilized.
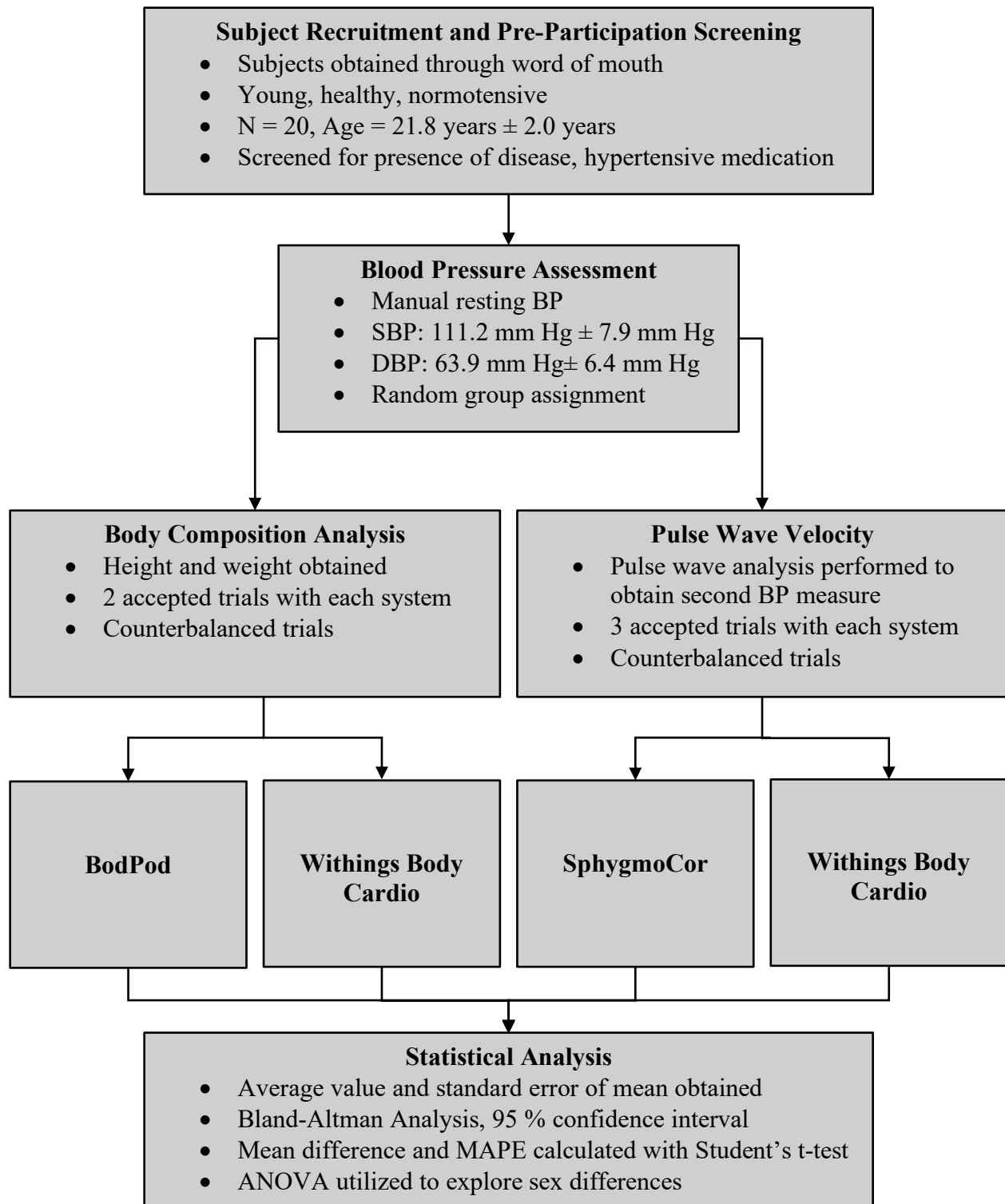
Subject Recruitment and Pre-Participation Screening
- Subjects obtained through word of mouth
- Young, healthy, normotensive
- N = 20, Age = 21.8 years ± 2.0 years
- Screened for presence of disease, hypertensive medication

Blood Pressure Assessment
- Manual resting BP
- SBP: 111.2 mm Hg ± 7.9 mm Hg
- DBP: 63.9 mm Hg± 6.4 mm Hg
- Random group assignment

Body Composition Analysis
- Height and weight obtained
- 2 accepted trials with each system
- Counterbalanced trials

Pulse Wave Velocity
- Pulse wave analysis performed to obtain second BP measure
- 3 accepted trials with each system
- Counterbalanced trials

BodPod

Withings Body Cardio

SphygmoCor

Withings Body Cardio

Statistical Analysis
- Average value and standard error of mean obtained
- Bland-Altman Analysis, 95 % confidence interval
- Mean difference and MAPE calculated with Student's t-test
- ANOVA utilized to explore sex differences

Figure 1. Study design and protocol. Subjects were screened and informed consent was given.

Body composition analysis and pulse wave velocity measurement performed. Statistical analysis

performed with an *a priori* significance of $p < 0.05$.

Results

Body Composition Analysis. Body composition analysis of the Withings Body Cardio was compared with BodPod. Measurement of body mass, fat mass, and fat-free mass in kilograms are presented as mean ± standard error of the mean in Table 2. Data is presented by sex, as well as by a total measurement. A graphical representation for the measurement of body mass is presented within Figure 2. Significant differences in the measurement of body mass, p = 0.000, were obtained between systems. The mean difference in body mass between the two systems was calculated to be 0.2 kg with a confidence interval of -0.41 and 0.18, respectively, as shown in Figure 3. Regression analysis produced a Pearson correlation coefficient of 0.47 with an evidence of proportional bias (p < 0.05). Analysis of variance (ANOVA) showed no effect of sex on body mass measurement between systems. Mean absolute percent error (MAPE) was determined to be 0.15 %.

The measurement of fat mass between systems is graphically represented in Figure 4 as mean ± standard error of the mean. Significant differences in the measurement of fat mass, p = 0.003, were obtained between systems. The mean difference in the measurement of fat mass was determined to be 2.91 kg with a confidence interval of -2.91 and 8.73, respectively, as shown in Figure 5. Regression analysis of the fat mass measurement data produced a Pearson correlation coefficient of 0.16 and no evidence of proportional bias. Analysis of variance (ANOVA) indicated that sex differences had no effect on the measurement of fat mass between devices. MAPE was calculated to be 25.8 %.

The measurement of fat-free mass between systems is graphically represented in Figure 6 as mean ± standard error of the mean. Significant differences in the measurement of fat-free

mass, p = 0.001, were determined between systems. The mean difference in the measurement of fat-free mass was determined to be 2.87 kg with a confidence interval of -9.04 and 3.30, respectively, as shown in Figure 7. Regression analysis of the fat-free mass measurement data produced a Pearson correlation coefficient of 0.06 and no evidence of proportional bias. Analysis of variance (ANOVA) indicated no effect of sex on fat-free mass measurement between the Withings Body Cardio and BodPod systems. MAPE was calculated to 5.6 %.

Table 2. Body composition data of Withings and BodPod. Data presented as mean ± SEM. BM = Body Mass, FM = Fat Mass, FFM = Fat-Free Mass. Significant differences were measured across all values.

	Body Mass (kg)	Fat Mass (kg)	Fat-Free Mass (kg)
Withings	66.8 ± 2.7	11.7 ± 1.0	55.0 ± 2.6
BodPod	66.6 ± 2.6	8.8 ± 1.1	57.9 ± 2.7
P Value	0.000	0.003	0.001

Figure 2. Mean body mass measurement by Withings and BodPod systems. Data not differentiated by sex. Data presented by mean ± SEM. BM$_{\text{Withings}}$ = 66.8 kg ± 2.7 kg. BM$_{\text{BodPod}}$ = 66.6 ± 2.6 kg. P = 0.000.
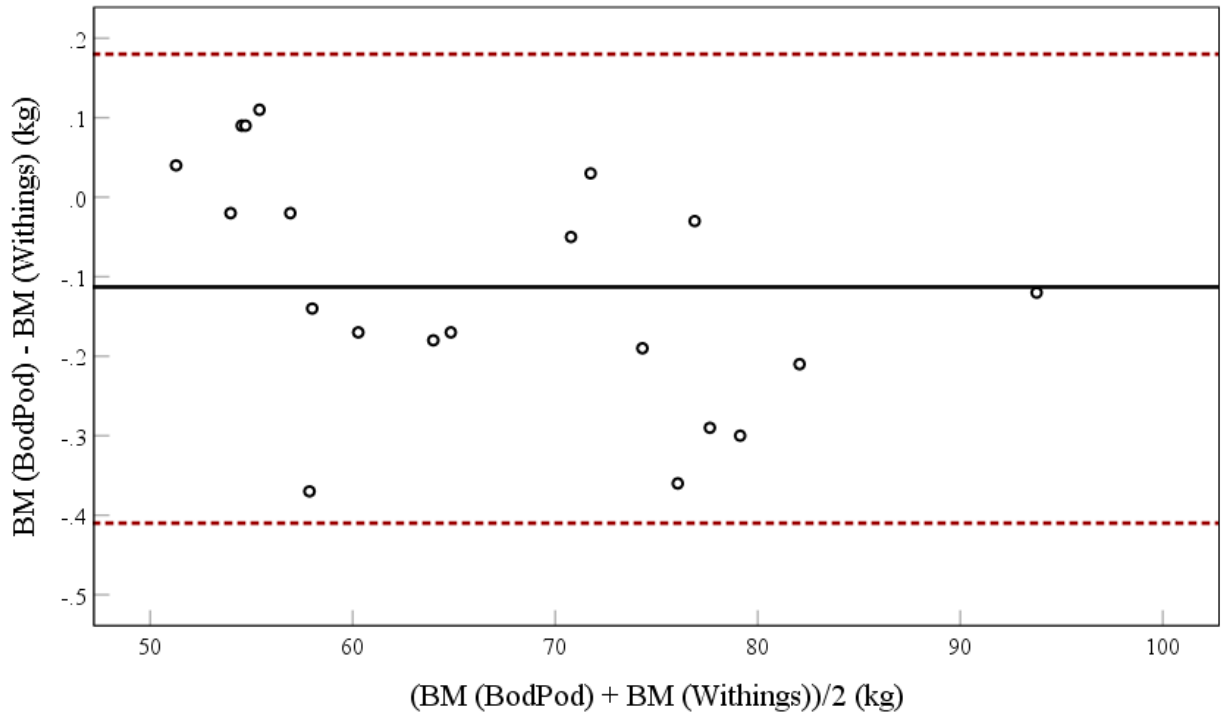
Figure 3. Mean difference with 95 % confidence intervals of body mass measurement between Withings and BodPod.

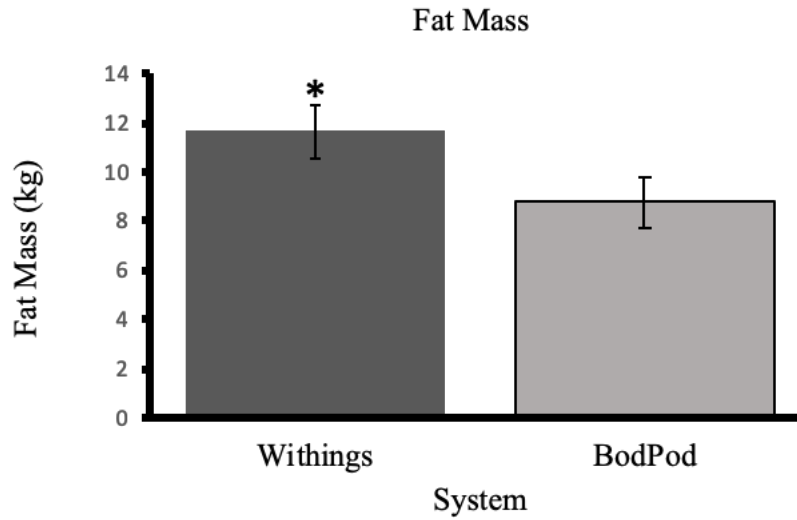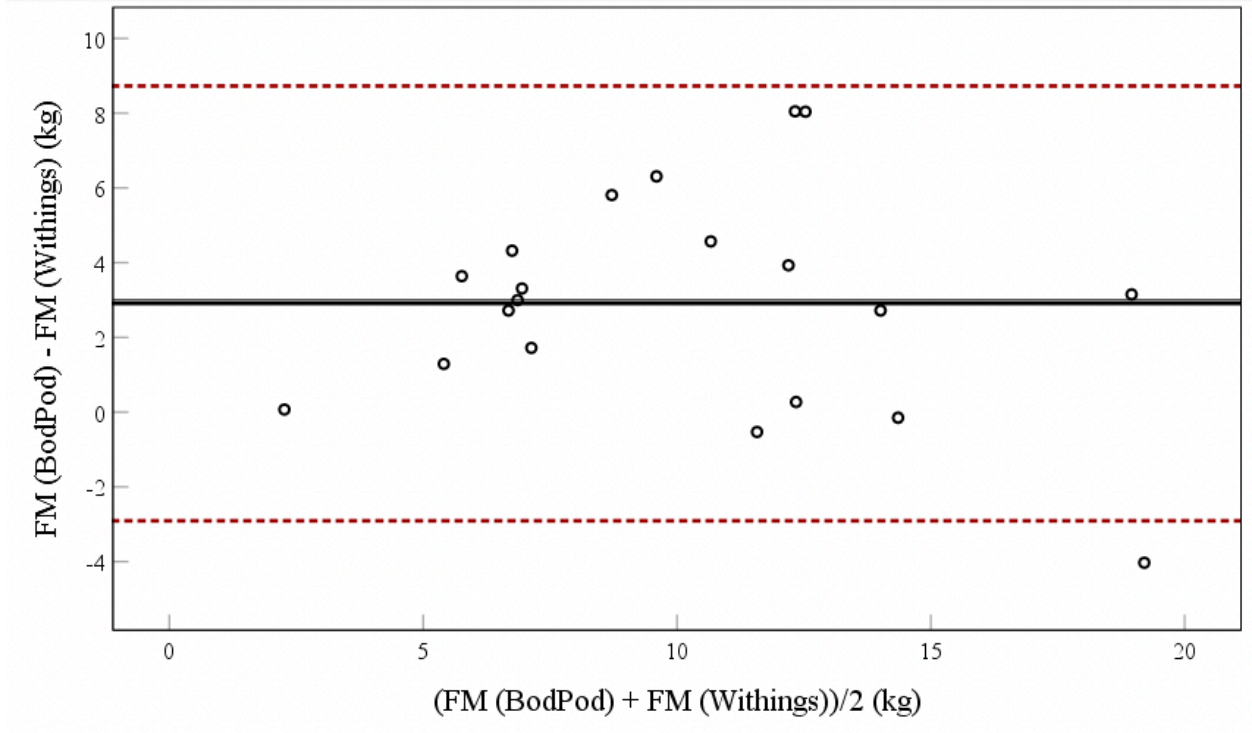**Figure 4.** Mean fat mass measurement by Withings and BodPod systems. Data not differentiated by sex. Data presented by mean $\pm$ SEM. $FM_{Withings} = 11.7$ kg $\pm$ 1.0 kg. $FM_{BodPod} = 8.8 \pm 1.1$ kg. P = 0.003.

Figure 5. Mean difference with 95 % confidence intervals of fat mass measurement between
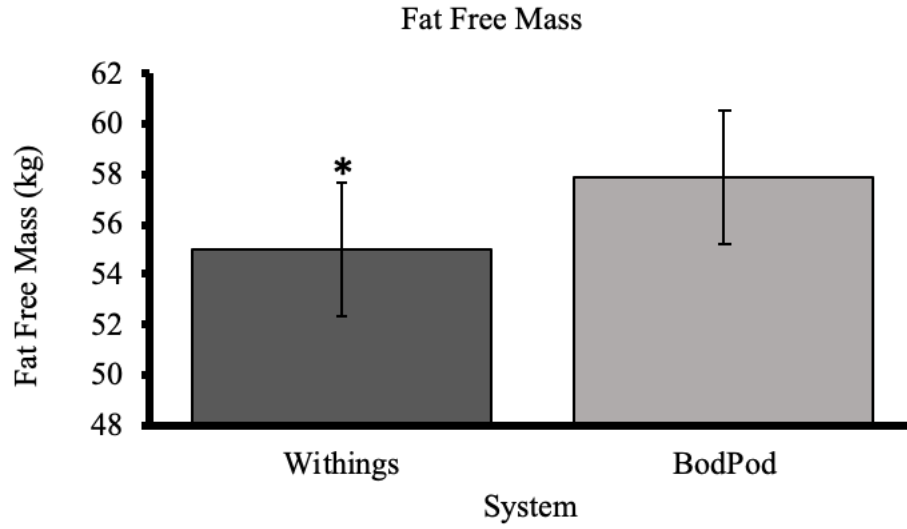
Withings and BodPod.

Figure 6. Mean fat-free mass measurement by Withings and BodPod systems. Data not differentiated by sex. Data presented by mean ± SEM. $FFM_{Withings} = 55.0$ kg ± 2.6 kg. $FFM_{BodPod} = 57.9 ± 2.7$ kg. P = 0.001.
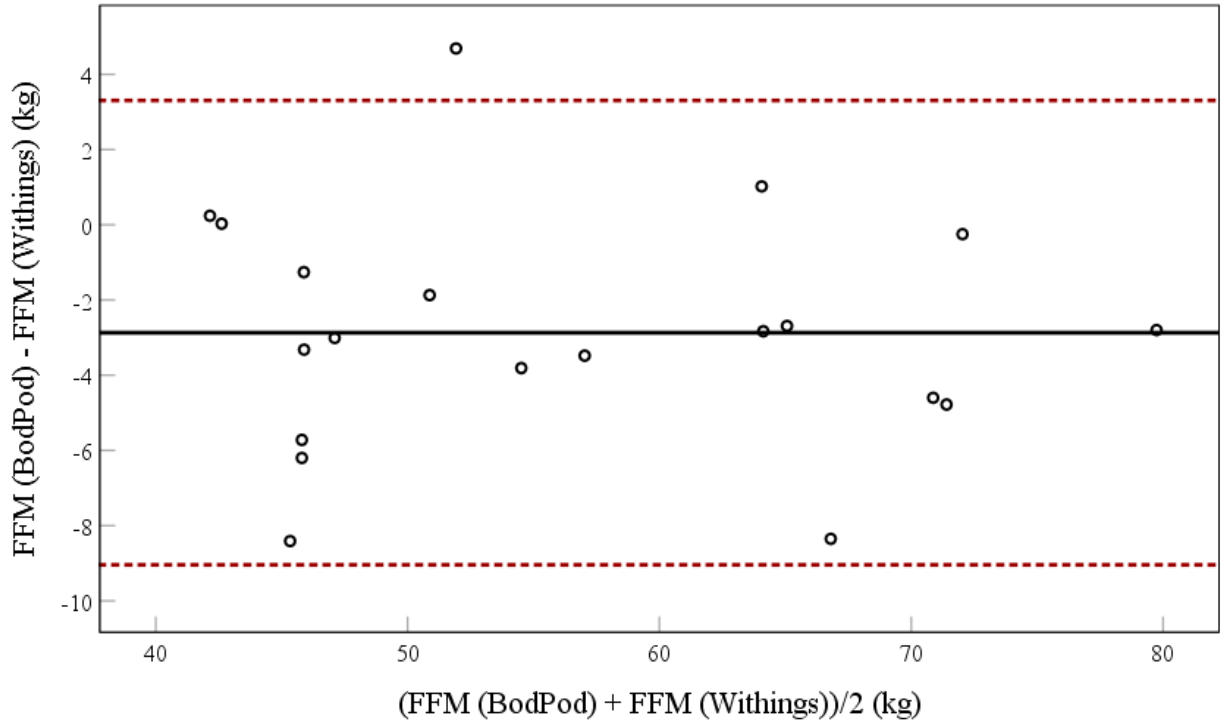
Figure 7. Mean difference with 95 % confidence intervals of fat-free mass measurement between Withings and BodPod.

Pulse Wave Velocity Measurement. Pulse wave velocity measurement of the Withings Body Cardio was compared with the gold standard SphygmoCor. Measurement of pulse wave velocity and heart rate by device are presented as mean ± standard error of the mean in Table 3. Data is presented by sex, as well as by a total measurement. No significant differences were determined in the measurement of heart rate between systems, $p = 0.681$. A graphical representation for the measurement of pulse wave velocity as mean ± standard error of the mean is presented within Figure 8. Significant statistical differences in the measurement of pulse wave velocity, $p = 0.000$, were obtained between systems. The mean difference in pulse wave velocity between the two systems was calculated to be 0.68 m/s with a confidence interval of -0.16 and 1.51 respectively, as shown in Figure 9. Regression analysis produced a Pearson correlation coefficient of 0.49

with an evidence of proportional bias ($p < 0.05$). Analysis of variance (ANOVA) showed no effect of sex on body mass measurement between systems. MAPE was determined to be 9.7 %.

Table 3. Mean pulse wave velocity and heart rate measurement between Withings and SphygmoCor systems. Data presented as mean ± SEM. PWV= pulse wave velocity (m/s)

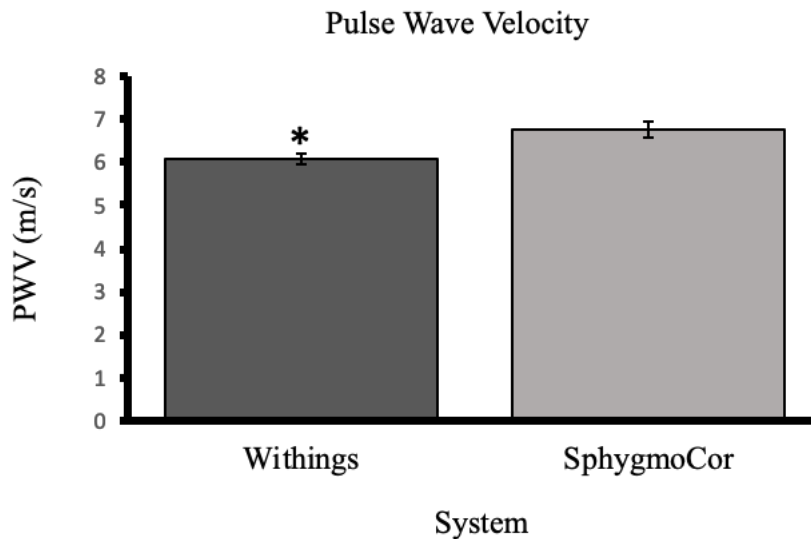|	PWV$_{Withings}$ (m/s)	PWV$_{SphygmoCor}$ (m/s)	HR$_{Withings}$ (bpm)	HR$_{SphygmoCor}$ (bpm)
Total	6.1 ± 0.1	6.8 ± 0.1	73.1	73.5
P Value	0.000		0.681	

Figure 8. Mean pulse wave velocity measurement by Withings and BodPod systems. Data not differentiated by sex. Data presented by mean ± SEM. PWV$_{Withings}$ = 6.1 m/s ± 0.1 m/s. PWV$_{BodPod}$ = 6.8 m/s ± 0.1 m/s. P = 0.000
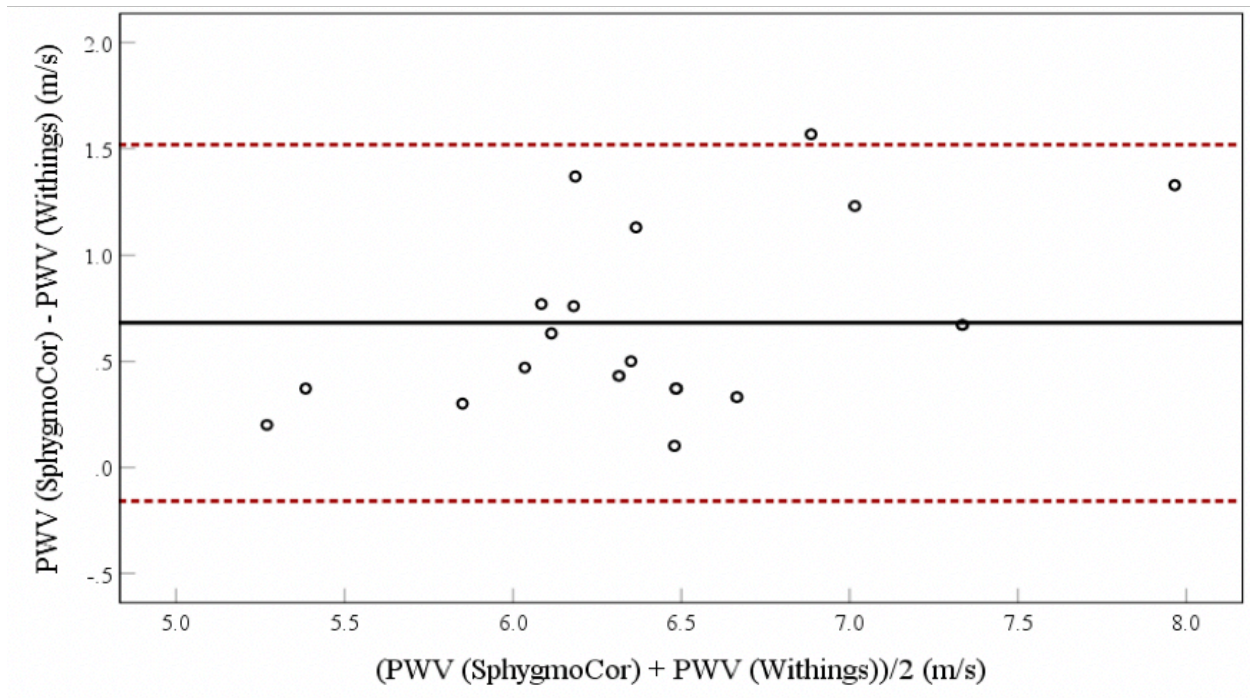
Figure 9. Mean difference and 95 % confidence intervals of pulse wave velocity between Withings and SphygmoCor.

Individual systolic blood pressure measurements obtained manually were compared to the same subject's standing pulse wave velocity measurements obtained with the SphygmoCor system. A linear regression analysis was performed and generated an R^2 correlation of 0.1179, suggesting a minimal relationship within the data. Graphical representation of the linear regression analysis can be found in Figure 10. Subsequently, a second linear regression analysis (Figure 11) was performed to analyze the correlation between systolic blood pressure and Withings Body Cardio pulse wave velocity measurements. An R^2 correlation of 0.01208 was obtained, suggesting an extremely minimal relationship between the Withings PWV measurement and systolic blood pressure.
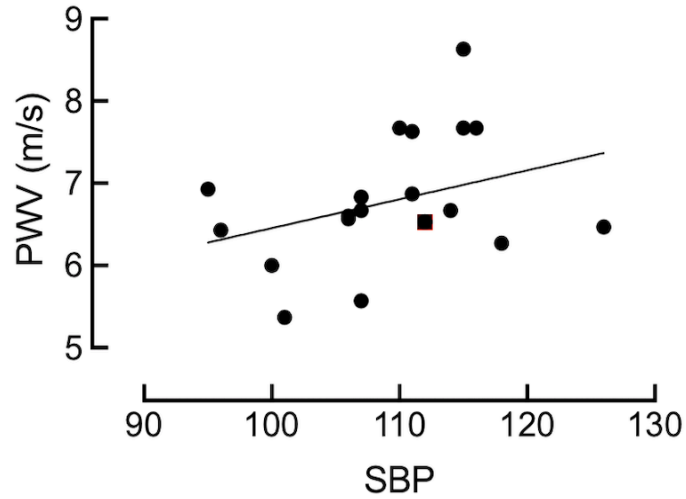
Figure 10. Comparison of SphygmoCor pulse wave velocity measurement to systolic blood pressure. Data not differentiated by sex. R^2 Correlation = 0.1179.
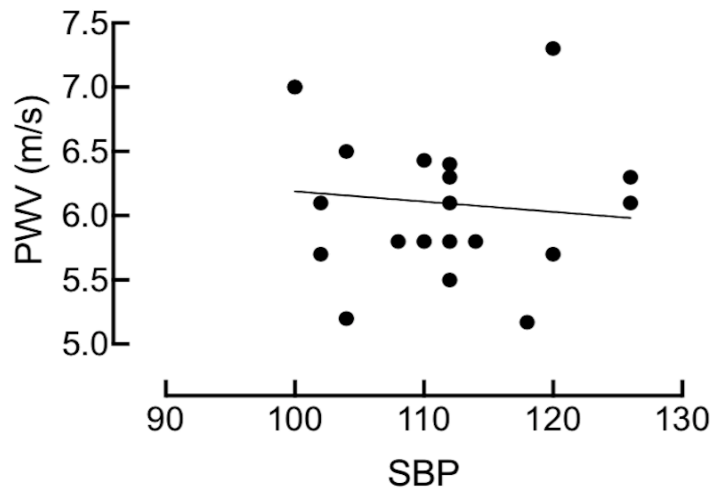

Figure 11. Comparison of Withings pulse wave velocity measurement to systolic blood pressure. Data not differentiated by sex. R^2 Correlation = 0.01208.

Discussion

The use of personal health devices, such as activity trackers, scales, and mobile phone health and fitness applications has increased significantly in the last decade. These tools provide a simple, user-friendly method of at-home monitoring of personal health and fitness. The Withings Body Cardio scale is part of a new generation of health devices that provide detailed information beyond a simple step counter or heart rate monitor. The purpose of this study was to compare Withings' measurements of body composition analysis and pulse wave velocity to gold standards in the field.

Body Composition Analysis. Comparison of body composition measurement and analysis between the Withings Body Cardio scale and the BodPod, the gold standard in air displacement plethysmography, yielded no significant difference in the measurement of body mass. Mean difference was a mere 0.2 kg with a MAPE of 0.15 %, well within the error limit or 1.5 % as set by Ball and Altena in their comparison of BodPod and DEXA body composition analysis (2004). The similarity in the two measurements can be attributed to the method of mass sampling and is reflected within the Bland-Altman analysis in Figure 3. Variance in measurement does persist, however it lies within the confidence interval set. Most electric bathroom scales now rely on sampling of strain in order to determine mass. This method of measurement of body mass is relatively simple in comparison to measurement of body composition through bioelectrical impedance, which may point to the higher percent error in these measurements.

Sampling of fat mass between devices produced a mean difference in measurement of 2.91 kg with a MAPE of 25.8 %. This MAPE is well above the error limit of 1.5 % set by Ball and Altena, thereby indicating that analysis of fat mass with Withings BIA system is not accurate. In addition, measurement of fat-free mass produced a mean difference of measurement

of 2.87 kg with a MAPE of 5.6 %. While estimation of fat-free mass was more accurate than

estimation of fat mass, it still falls outside of the excepted error range. For this reason, the

Withings Body Cardio's measurement of body composition cannot be accepted as accurate in

comparison to gold standard air displacement plethysmography.

One of the main sources of error in Withings Body Cardio may be the use of bioelectrical

impedance as a source of measurement. This system relies heavily upon proper hydration in

order to determine body composition. If subjects were inadequately hydrated, whether being

under or over hydrated, significant alterations in current flow could have been produced. During

this study, hydration status was not closely monitored, rather individuals were instructed to

refrain from the consumption of excess fluids. While this could have contributed to a main

source of error within the study, the protocol also reflects the day-to-day changes present in

hydration status for individuals. The Withings Body Cardio is marketed as a method of at-home

measurement of body composition analysis, in which the algorithm would be exposed to a large

range of hydration status fluctuations. These common fluctuations in hydration further support

the conclusion that Withings' use of bioelectrical impedance as a method of body composition

analysis is not accurate for at-home measurement, as the system is unable to account and

standardize for these alterations in current flow.

Pulse Wave Velocity Measurement. The Withings Body Cardio scale was compared with the gold

standard in the determination pulse wave velocity through applanation tonometry, SphygmoCor,

in order to determine the accuracy of the Withings measurement. The mean difference between

the two systems was calculated to be 0.68 m/s with a mean percent error of 9.7 %. While error is

present, the ARTERY Society, a leading source on the measurement of arterial health, states that

an "acceptable" clinical accuracy rating in the measurement of pulse wave velocity may not

exceed a mean difference greater than 1.0 m/s and a standard deviation of 1.5 m/s (Clinical Task Force for Pulse Wave Velocity v3). While previous data examined the mean ± the standard error of the mean, providing a mean difference of 0.7 m/s, the standard deviation of the Withings pulse wave velocity measurement was calculated to be 0.57 m/s, well within the acceptable range stated by the ARTERY Society.

Overall, data collected with the two devices indicates that the Withings Body Cardio scale is capable of providing an affordable, acceptably accurate, and reproducible measurement of pulse wave velocity. The Withings Body Cardio system may provide an economic and readily available method of at-home monitoring of cardiovascular and arterial health. The scale, when paired with Withings' Health Mate © phone application or website, allows for both detailed historical storage and simplified presentation of data, thereby providing users with an opportunity to track arterial health over time. While not yet verified for accuracy in clinical populations, the Withings Body Cardio and Health Mate © application could provide physicians with a new method of patient monitoring, allowing for detailed tracking of disease progression and treatment. The ability of the Withings Body Cardio to aid in the prediction of cardiovascular disease-related complications through the system's pulse wave velocity measurement strengthens the importance of these findings.

While a previous study (Campo, et al., 2017) has already observed and described the accuracy of the pulse wave velocity measurement of the Withings Body Cardio, key flaws in study design limited conclusions on the accuracy of the device. Most importantly, Campo, et al. compared the standing Withings Body Cardio pulse wave velocity measurement to SphygmoCor measurement in the supine position. It is well known that gravity is a major contributor to alterations in pulse wave velocity; heart mechanics become significantly altered under decreased

afterload and increased venous return within a supine state. Ultimately the data produced between the devices was not comparable, as Withings' algorithm did not take into account the alterations in pulse wave velocity due to postural differences. In contrast, this study sought to elucidate the true accuracy of the Withings Body Cardio through comparison of pulse wave velocity measurement in the same posture. Again, the measurement of pulse wave velocity calculated by the Withings Body Cardio system was found to be acceptably accurate.

Limitations and Future Direction. This study was completed within a small cohort of college-aged, apparently healthy individuals. While a total of twenty subjects, ten males and ten females, were recruited and sampled for data collection, variance due to sex differences may have produced error in analysis. This small sample size also limits the impact of the study, as the relatively small sample size could have hidden proportional bias necessary to determine sensitivity. As stated previously, hydration status was also not controlled tightly, which may have led to error attributable to water content in the measurement of body composition using the Withings Body Cardio scale. Possible future directions of the study include analysis of the Withings Body Cardio pulse wave velocity measurement in elderly and clinical populations, such as those suffering from cardiovascular, pulmonary, renal, or metabolic disease. Validation of the pulse wave velocity measurement could produce significant impacts in the clinical setting. In recent studies within Chinese clinical populations, the use of health applications significantly impacted positive patient incomes, highlighting the relevance of this technology in the management and treatment of disease (Lu et al., 2018). Additional investigation is needed to determine the health benefits associated with the use of the Withings Health Mate © application.

Conclusion. The Withings Body Cardio scale provides users with a variety of useful health information. The system's online application allows for user-friendly monitoring of health

progress. That said, this study highlighted inaccuracies in the device's determination of body composition through measurement of fat mass and fat-free mass. Ultimately, the system's reliance on bioelectrical impedance to calculate composition is grossly inaccurate. In contrast, the Withings system did produce an acceptable level of accuracy, well within the ARTERY Society's general guidelines. The Withings Body Cardio may supply an accurate and affordable method of at-home monitoring of arterial health.

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