INVESTIGATION OF SEX DIFFERENCES BETWEEN WITHINGS BODY CARDIO AND SPHYGMOCOR APPLANATION TECHNOLOGY

by

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Abstract

Introduction. Cardiovascular disease is one of the most prevalent risk factors for mortality in the world. Pulse wave velocity (PWV), a reflection of arterial stiffness has been shown to positively correlate with the advancement of cardiovascular disease and may be the best indicator of arterial health. There is an emerging technology revolution with a goal of monitoring fitness and health with a variety of mobile devices, often wearable in nature. The Withings platform is one of the most prevalent in this field with their Body Cardio scale dominating the market as the first comprehensive monitoring of whole-body health. This diagnostic bathroom scale is designed to be brought into homes with the goal of early recognition of increased pulse transit times. The scale detects individual pulse waves via a proprietary algorithm, yet due to regional differences in fat distribution, the proprietary algorithm may not account for this correlating factor. Also, no home device has been tested against laboratory gold standards with a goal of elucidating sex differences. Therefore, the **purpose** of this study was to compare the Body Cardio scale for accurate analysis of PWV compared to a laboratory gold standard (Sphygmocor, AtCor Medical). We hypothesized that the Body Cardio would yield greater variability lending to increased error of measure. **Methods.** Twenty healthy, normotensive, college-aged individuals (10 male, 10 female) utilized the Body Cardio scale in a laboratory setting to obtain body composition data and three independent PWV measurements, each followed by a standing PWV measurement with the SphygmoCor XCEL. Body composition data was obtained from the BodPod via air displacement plethysmography. All procedures were counterbalanced and occurred between 6am and 10am on weekdays. The subjects were instructed to avoid strenuous exercise and consumption of alcohol or caffeine within 12 hours of data collection. The surface of the Body Cardio scale was dampened to allow for maximal conduction and subjects were instructed to remain silent and still during all measurements. **Results.** Though the Body Cardio scale underestimated PWV respective to SphygmoCor in males by 0.703 m/s (6.3 ± 0.179 m/s vs. 6.9 ± 0.244 m/s) and 0.653 m/s in females (5.9 ± 0.179 m/s and 6.6 ± 0.244 m/s), though no significant differences were observed ($P > 0.05$). **Discussion.** It was anticipated that different regional distributions of fat across sexes would impact the accuracy of PWV measurement with the Body Cardio scale, yet no significant differences were observed. The ability of the Body Cardio to accurately measure pulse wave velocity at home for both sexes, despite these regional mass variations lends great ecological significance and promises a wider scope of real-time information for an individual's physician.

Chapter 1: Introduction

Cardiovascular disease (CVD) is widely known as the leading cause of death in the United States. The pervasiveness and severity of this disease in younger populations increases with each passing year. Assessment of cardiovascular health in a clinical setting is multi-faceted and dynamic; technology is rapidly changing in an effort to maintain pace with the failing hearts and vessels of individuals worldwide. The development of atherosclerotic plaques is credited for the decreased arterial elasticity in those with CVD, thus vessel distensibility within a cardiac cycle is greatly disrupted. Perhaps one of the most influential recent developments in the field of cardiology was the ability to evaluate the elasticity of vessels, and thus derive information about vessel status. Pulse wave velocity (PWV), a measure of the pulse transit time of a single bolus of blood, is a vastly utilized measure of vessel health, particularly in preventative cardiovascular medicine. Arterial stiffness, as determined by PWV, is now an invaluable biomarker in the determination of cardiovascular health status in preventative, diagnostic, and retroactive medicine (Vlachopoulos 2014, 2010).

Pulse Wave Velocity

Elucidation of pulse transit times, whether in a laboratory or clinical setting, provides invaluable information regarding vessel health from the perspective of elasticity and overall resistance. Low PWV values are inversely related with arterial distensibility. In individuals below 30 years of age, a standard range of reference is 4.7-7.6 m/s with females trending lower than males (Mattace-Raso 2010). An elevated PWV value serves as an indicator of stiffening in the central arterial system. A minimal, albeit detectable, stiffening throughout the entire vasculature is expected with aging as a result of a variety of physiological processes. However, within the central arterial system, specifically the arterial trunk, an increase in stiffness is known to contribute to a decline in cardiovascular health (Laurent 2001, Shirwany 2010, Vlachopoulos 2010). Appreciating this decrease in distensibility provides invaluable insights to current cardiovascular health in nearly all populations.

Body Composition

The drastic increase in cardiovascular disease prevalence within the past decade is far from unique. The persistence and exponential rise of obesity, both childhood and adult, has created a sector of the medical field entirely devoted to metabolic diseases and their implications. In an age where technology is at the core of nearly every aspect of life, the implementation of weight tracking applications has been revolutionary in weight-loss strategies and practices. Through a physiological lens, an overweight or obese individual carries a much greater risk for both all-cause and cardiovascular mortality, often in excess of a 4.0 relative risk factor (Lee 1999).

Superfluous weight, most commonly resulting from a poor diet and sedentary lifestyle, can lead to the development of increased serum cholesterol levels, hypertension, and severely reduced vessel elasticity. Understanding the impacts of obesity on cardiovascular health is clinically essential, but at the patient level, simple tracking of weight gain and weight loss trends has proven to be beneficial when striving towards fitness goals (Spring 2013).

SphygmoCor XCEL

Until recent developments, the determination of pulse transit times was only achievable in a laboratory or clinical setting. The SphygmoCor XCEL from AtCor Medical (New South Wales, Australia) is well recognized as the leading device in the field of pulse transit times, having been validated against the ARTERY Society's PWV Validation guidelines and cited extensively in peer-reviewed research articles (Butlin 2013, Butlin 2017, Reshetnik 2017). This device utilizes applanation tonometry at the carotid artery to yield an arterial waveform. Volumetric flow determination through a cuff at the femoral artery is combined with measured transit time between these two points as a unit per travel distance, a value that is obtained through manual measurement of the difference between various appreciated physiological landmarks (Butlin 2017).

Withings Body Cardio Scale

This recent development in clinical interpretation of arterial distensibility has coincided with an era of wellness-based technological advancement. Various companies have advanced their wristwatch and cellphone application platforms to include advanced cardiovascular data at the simple touch of a button. Withings is a strong competitor in this field, boasting an advanced bathroom scale that is one-of-a-kind. The Withings Body Cardio scale is designed for use in the home and can be purchased for less than $150 online. The scale provides weight and BMI measurements, triple component body composition, heart rate, and pulse wave velocity data. This data is tracked within the HealthMate application for up to eight different individuals per scale. Trending data is designed for interpretation both by the patient at home and by a clinician, utilizing the advantageous implementation of an online Patient Portal at most major medical centers worldwide (Griffin 2016). For example, if a patient noted an increasing trend in PWV over a period of several weeks, they could easily export this information from the HealthMate application to their Patient Portal as a direct message to their physician to receive real-time feedback on indications for their cardiovascular health.

This advanced bathroom scale shows promise to serve as an easily accessible and cheaper alternative to the clinical grade determination of PWV. Though PWV is reported simply on the Body Cardio scale, the biomechanical mechanisms behind this process are quite complex. A combination of ballistocardiography (BCG) and impedance plethysmography (IPG) enables the scale to determine aortic-leg PWV. When the user stands on the scale and minimizes motion, BCG can detect the extremely slight weight variations that cycle in direct concordance with the systolic ejection of a bolus of blood. This minute variation corresponds to the opening of the aortic valve, the timing of which is recorded for calculation (Campo 2017). IPG, however, measures small changes in electrical resistance. These cyclic variations are again coordinated to the cardiac cycle with the determination of the pulse wave arrival in the feet. The time-lapse between the ventricular ejection and planar bolus arrival allows for determination of PWV.

Though innovative in nature, the Body Cardio scale calculates PWV using a proprietary algorithm that determines pulse transit times without consideration of sex. Both IPG and BCG are affected by body mass distribution patterns (Campo 2017, Van Bortel 2012). It is understood that men and women have different regional fat mass profiles, and yet the proprietary algorithm for PWV determination remains non-discriminatory to sex. The lack of differentiation for determination of PWV raises a simple question: can the Body Cardio scale provide an accurate analysis of PWV in both sexes? The Body Cardio scale, to our knowledge, has not yet been tested against laboratory gold standards and thus sex differences in PWV variability have not been elucidated. The primary purpose of this study was to validate the Withings Body Cardio scale for accurate analysis of PWV with a specific focus on regional fat distribution variations by sex. We hypothesized that the mobile device would lend more variability, thus translating to a higher margin of error when compared to the gold-standard Sphygmocor XCEL. A significant error in this technology could translate to unnecessary clinical alarm in response to falsely elevated readings, or a lack of medical action due to erroneously low PWV values. Prior to implementation as an extension of clinical care, validation of this technology is essential for all populations.

Though not the focus of this study, the Withings platform has also provided a user-friendly way to track much more than simply body weight. With detailed analyses of body composition in a triple-component manner, users receive data relating to fat mass, fat free mass, bone weight, and more. These data are simple to interpret and directly link to the HealthMate application for long-term tracking that can supplement weight loss and fitness goals. When paired with PWV data integrated into the same easy-to-use application, both providers and patients alike can receive a detailed picture regarding the state of the cardiovascular system.

Chapter 2: Methods

Participants

Twenty (10 male, 10 female) normotensive, college-aged individuals from the Boone, North Carolina area were recruited to participate in this study. The participants ranged from 18-25 years old with a mean age of 21.80 $\pm$ 1.96 years. All participants were physically active according to ACSM Physical Activity Guidelines (U.S. Department 2018). Exclusion criteria were a history of cardiovascular, metabolic, or respiratory disease. Descriptive statistics related to study population are included in Table 1. Participants received no monetary compensation for their time but were provided with their body composition data report produced by their BodPod analysis.

	Mean	SD
Age (yrs)	21.8	2.0
Male	22.1	2.0
Female	21.5	1.9
Height (cm)	172.8	7.5
Male	177.6	5.1
Female	167.8	6.1

Table 1. Description of study participants.

Study Design

The Appalachian State University Institutional Review Board approved all experimental procedures (IRB 17-0023). All instrumentation and protocols were thoroughly explained to participants and informed consent was obtained and documented. Each participant reported to the Vascular Biology and Autonomic Studies Laboratory between 6:00 and 9:00 in the morning. Participants were instructed to avoid consumption of alcohol and vigorous activity 12 hours prior to arrival time. Upon arrival, anthropometric data was collected, followed by body composition measurements via whole-body plethysmography. Participants then either underwent a standing

PWV measurement using an applanation tonometer or a PWV reading with the Withings Body Cardio scale; this order was counterbalanced throughout the study. The cycle of PWV reading was repeated three times.

Anthropometrics

Age and relative physical activity levels were self-reported. Body weight was measured using the BodPod platform scale. Height was measured using a stadiometer to the nearest 0.5 cm. Body composition was measured via whole-body plethysmography utilizing a BodPod (Life Measurement Inc., Concord, CA, USA). Body mass index was calculated as weight divided by height (kg/m^2) squared. Blood pressure and pulse wave velocity was obtained in the standing position utilizing the Sphygmocor XCEL applanation tonometer (AtCor Medical, Itasca, Illinois).

Body Composition

Body composition was obtained following standard protocol for air displacement plethysmography. Subjects dressed in minimal clothing (spandex, compression shorts, etc.) and a swim cap and were instructed to breathe normally as measurements were taken. Residual lung volume was estimated utilizing the Bod Pod software based on race, sex, and height inputs. Body mass for input was determined using the Bod Pod beam balance platform scale after calibration.

Central Arterial Stiffness

Pulse wave velocity and augmentation index measurements were obtained using the Sphygmocor XCEL. A standing blood pressure was obtained using the Sphygmocor XCEL and confirmed with manual auscultation. The tonometer was placed on the right common carotid artery and a blood pressure cuff was placed on the right femoral artery to occlude flow and measure pulse transit time. A basic tape measure was used to obtain measurements from the pulse point in the carotid artery to the sternal notch, from the sternal notch to the superior line of the femoral cuff, and from the femoral artery at the inguinal crease to the superior line of the femoral cuff based on appreciation of the aforementioned landmarks. These measurements were entered into the Sphygmocor XCEL along with subject height, sex, and age and used to calculate pulse wave velocity with the applanation tonometer. Quality control (QC) index was met with each accepted pulse wave measurement. If QC index failed, the measurement was repeated.

Body Cardio Scale

Subjects were entered into the HealthMate application on a laboratory computer prior to beginning PWV measurement. Five scale measurements were required for calibration of PWV measurement, all of which were completed prior to PWV measurement. The scale was dampened with a wet rag to simulate the humid environment of a home bathroom prior to each measurement. Subjects were instructed to step on the scale and stand still with their weight evenly distributed on both feet without speaking for the duration of the measurement.

Statistical Analysis

All data are presented as mean $\pm$ SD and was collected during the same time of day. An rmANOVA was employed for comparisons between Sphygmocor and Nokia hardware device output with subject sex as the grouping variable. Mauchly's test for sphericity was completed to ensure normality. All descriptive data was compared by a univariate analysis between sexes.

Chapter 3: Results

Statistical Analysis

Data was collected from each device's respective database (SphygmoCor, Withings HealthMate). These data were de-identified and complied into a secure database. The average of three obtained pulse wave velocity measurements were utilized for analysis. A Bland-Altman analysis was conducted. A one-sample t-test was performed to derive mean difference and 95% confidence intervals for the respective Bland-Altman plots. In an effort to evaluate for proportional bias and determine Pearson correlation coefficient, regression analyses were performed. The error is presented as a percentage of the overall mean as a Mean Absolute Percent Error (MAPE) and serves as an indication of the degree of error. Subsequently a repeated measures ANOVA was utilized to analyze variance as a product of sex differences between the respective devices.

Blood Pressure

Blood pressure was obtained prior to each measurement of PWV with the SphygmoCor sphygmomanometer. These data are presented in Table 2. In males, a mean blood pressure of 114/64 was obtained. The mean female blood pressure was 109/63.

Systolic BP			
	Mean	SD	95% CI
Male (n=10)	114	7	109-119
Female (n=10)	109	8	103-115
Combined (n=20)	111	8	108-115
Diastolic BP			
	Mean	SD	95% CI
Male (n=10)	64	8	58-70
Female (n=10)	63	4	61-66
Combined (n=20)	64	6	61-67

Table 2. Blood pressure data by sex. All values provided in mmHg. SD: standard deviation. 95% CI: 95% confidence interval.

Body Composition

A two-component method of body composition was derived from air displacement plethysmography (BodPod). These data are presented in Table 3, stratified by sex, and are graphically depicted in Figures 2 and 3. A 95% confidence of (-0.41, 0.18) is depicted in Figure 4. Regression analysis yielded a Pearson correlation coefficient of 0.47. with evidence of a proportional bias ($P<0.05$). A 0.15% MAPE was calculated.

Body Cardio						
	BM		FM		FFM	
	Mean	SD	Mean	SD	Mean	SD
Male (n=10)	75.67	9.29	7.28	3.53	68.19	7.50
Female (n=10)	57.85	5.82	10.24	5.77	47.58	3.10
Combined (n=20)	66.76	11.86	8.76	4.90	57.89	11.96
BodPod						
	BM		FM		FFM	
	Mean	SD	Mean	SD	Mean	SD
Male (n=10)	75.67	9.29	10.56	4.29	64.94	7.56
Female (n=10)	57.85	5.77	12.78	4.54	45.09	4.07
Combined (n=20)	66.76	11.79	11.67	4.45	55.01	11.77

Table 2. Body composition data. All values listed in kg. BM: body mass, FM: fat mass, FFM: fat free mass, SD: standard deviation.

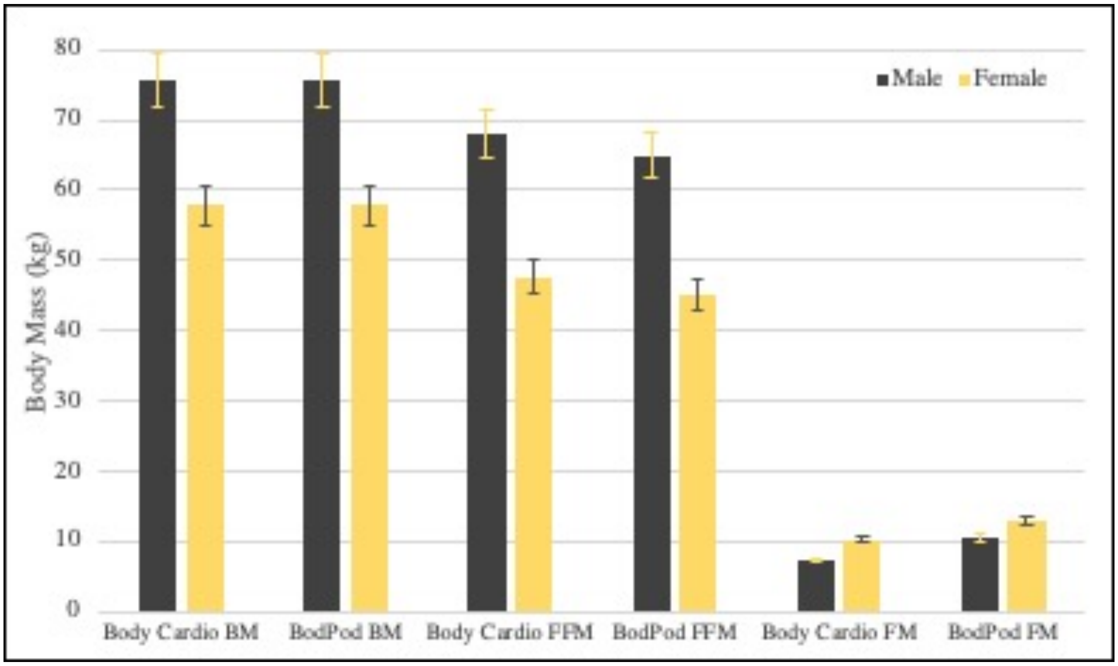

Figure 2. Body composition data. All values listed in kg. Standard error bars represent 95% confidence interval. BM: total body mass. FM: fat mass. FFM: fat-free mass. N=20.

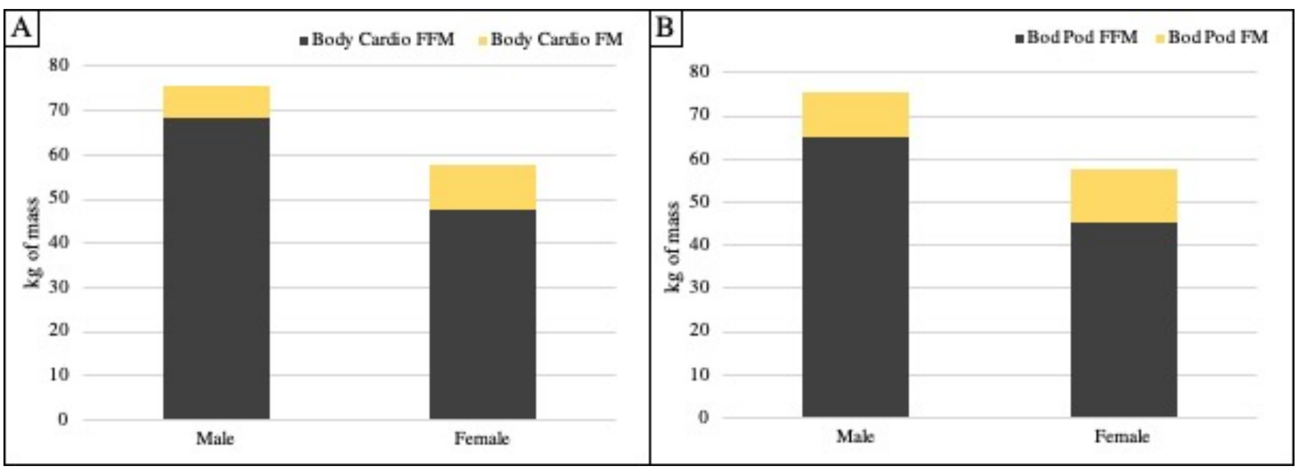

Figure 3. (A) Fat mass and fat free mass divisions of male and female subjects (n=20) as reported by Body Cardio scale in kg. **(B)** Fat mass and fat free mass divisions of male and female subjects (n=20) as reported by BodPod.

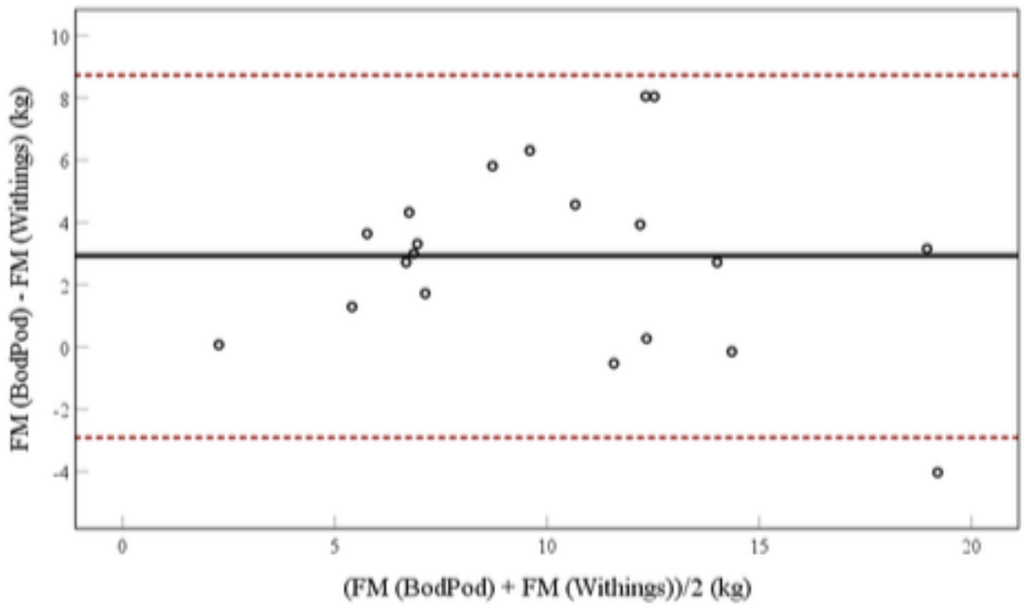

Figure 4. Mean Difference and 95% confidence intervals of body composition between Withings Body Cardio scale and SphygmoCor, AtCor Medical Tonometer.

Pulse Wave Velocity

Table 3 depicts mean pulse wave velocity (PWV) and standard error for each device by sex. Figure 4 graphically displays the aforementioned data. The mean difference between devices was established to be 0.68 m/s; 95% confidence intervals were (-0.16, 1.51) as is depicted in Figure 5. A Pearson correlation coefficient of 0.49 was derived from regression analyses and evidence of proportional bias ($P < 0.05$). A repeated measures ANOVA indicated no effect of sex on PWV measurement between the SphygmoCor and Withings Body Cardio. A 9.7% MAPE was calculated.

Body Cardio						
	PWV (m/s)	SD	SE	Min.	Max.	95% CI
Male (n=10)	6.3	0.54107	0.17110	5.7	7.3	5.9-6.6
Female (n=10)	5.9	0.58841	0.18607	5.2	7.0	5.5-6.4
Combined (n=20)	6.1	0.57216	0.12794	5.2	7.0	5.8-6.4
SphygmoCor						
	PWV (m/s)	SD	SE	Min.	Max.	95% CI
Male (n=10)	7.0	0.76802	0.24287	6.3	8.6	6.4-7.5
Female (n=10)	6.6	0.77417	0.24481	5.4	7.7	6.0-7.2
Combined (n=20)	6.8	0.77247	0.17273	5.4	8.6	6.4-7.1

Table 3. Pulse Wave Velocity (PWV) data from Withings Body Cardio scale and SphygmoCor Applanation Tonometry. All values depicted in m/s. SD: standard deviation, SE: standard error, Min: minimum, Max: maximum, 95% CI: 95% confidence interval.

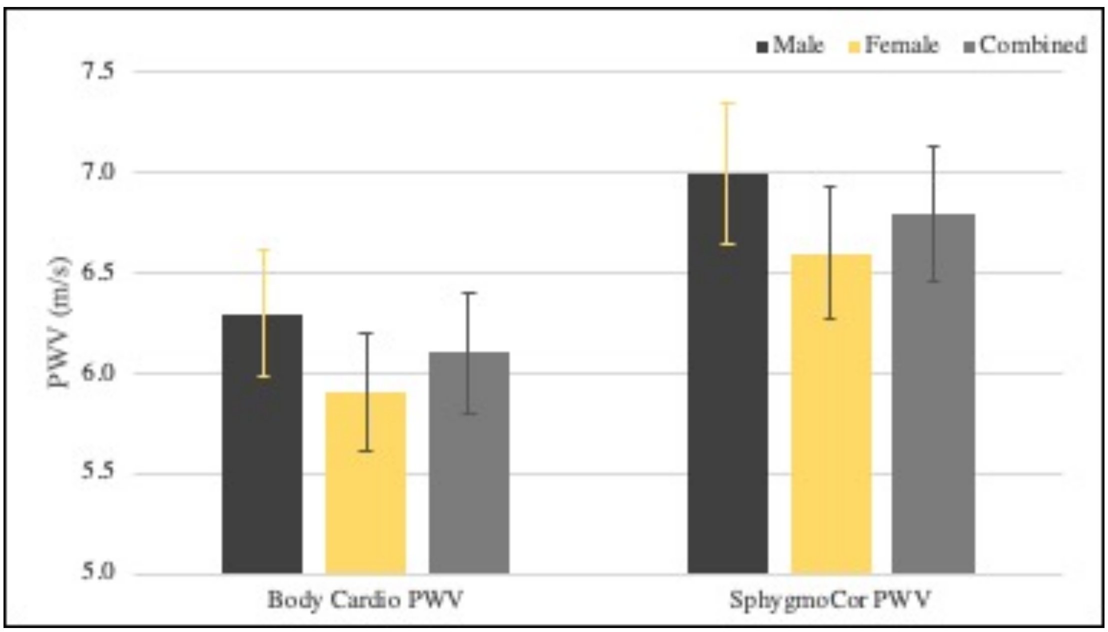

Figure 5. Pulse Wave Velocity of Withings Body Cardio scale and SphygmoCor AtCor Medical Tonometer (reference device) by sex and combined. All values represented in m/s.

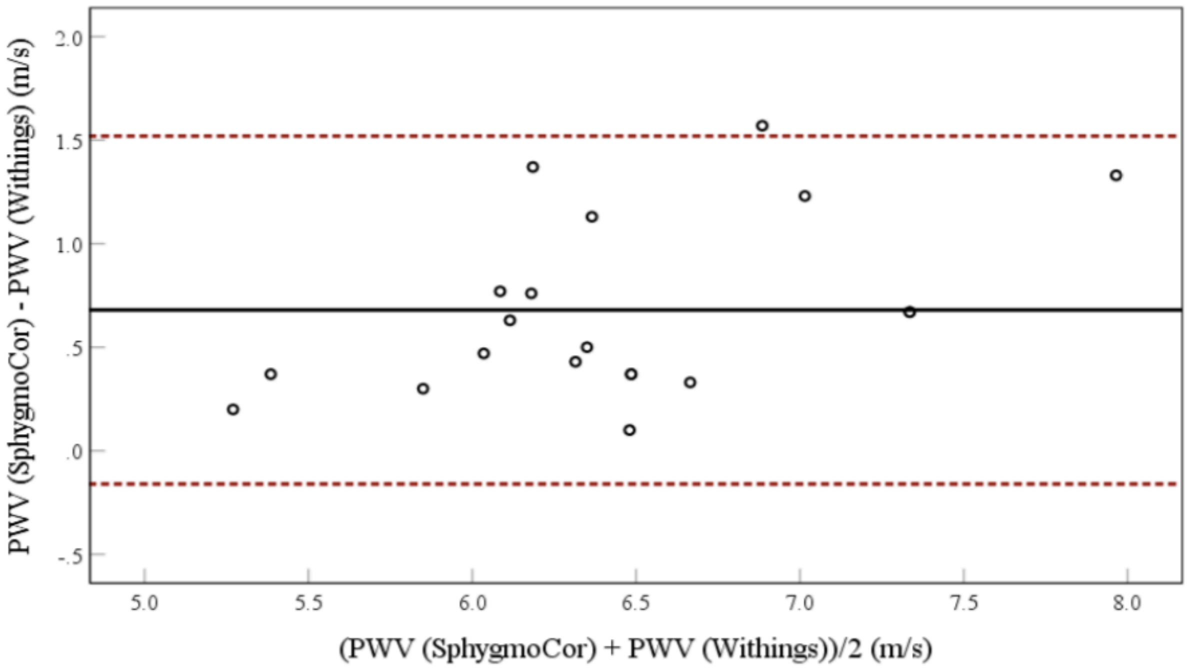

Figure 6. Mean Difference and 95% confidence intervals of Pulse Wave Velocity between Withings Body Cardio scale and SphygmoCor, AtCor Medical Tonometer.

Chapter 4. Discussion

This study aimed to assess the accuracy of pulse wave velocity (PWV) measurement of the Withings Body Cardio scale utilizing the SphygmoCor applanation tonometry as a reference. These accuracies were evaluated with specific regard for the implications of sex differences in regional fat distribution as related to PWV measurement. To the knowledge of the research team, no prior validation of this technology has been completed to date. Previous studies have indicated that the implementation of wearable and home wellness technologies provide beneficial results towards goals in those fields (Pevnick 2018). Companies such as Withings, Apple, Garmin, and Fitbit are rapidly expanding their platforms products to provide consumers with real-time health data from the technologies utilized use on a daily basis. The Body Cardio scale, sold by Withings, is perhaps one of the most advanced bathroom scales of this wellness technology movement, promising information about body weight, body composition, heart rate, and PWV. The utilization of PWV measurements from the Body Cardio scale shows promise when considering a real-time analysis of vessel health at home. Prior to implementation into clinical practice, the accuracy of these data must be validated for both sexes. An assessment of this ground-breaking technology was both the charge and aim of this research.

The implications of elevated pulse transit times are well understood and are thus discussed briefly in this work. As an indirect measure of arterial distensibility, elevated pulse transit times serve as an indication of stiffer arteries (Aortic Stiffness Predictor, PWV Retrospective). This loss in central arterial elasticity is positively correlated with an increased risk of all-cause mortality and cardiovascular mortality (Laurent 2001). During the systolic component of pulsatile flow, the arterial pressure drastically increases as each bolus of blood is pushed through the vasculature. Arterial elasticity allows for the absorption of this increased pressure. Through the measurement of pulse wave velocity, distensibility can be derived inversely to speed. A slower pulse wave velocity indicates a higher vessel elasticity, and thus a healthier cardiovascular system (Asmar 1995).

Blood Pressure. Blood pressure was collected as a preliminary analysis of vessel health. Hypertension has been directly linked to a reduction in vascular elasticity and was thus analyzed to ensure normality of vessel condition in this population. The average blood pressure of 111/64 indicated a normotensive population (Pickerning, 1982). In recruiting a normotensive subject group, the validity of PWV measurements with the Body Cardio scale in comparison to the SphygmoCor could be evaluated without adjustment for a confounding hypertensive state.

Body Composition. Evaluation of body composition as determined by the Body Cardio scale in comparison to the BodPod was completed and no significant difference was observed in the determination of fat and fat free masses across sexes. It is well understood that men and women have differing regional fat distributions and thus it was hypothesized that this would heavily impact the ability of the bioelectrical impedance (BIA) mechanism of proprietary analysis for PWV (Kyle 2004). Body composition analysis is not discussed in detail in this work but yielded a confidence that erroneous body mass measurements would not affect the variability of the PWV measurements. Though our population retained relatively low body fat percentages (13.1% combined), the absence of significant variation between Body Cardio and SphygmoCor PWV values indicated that the Body Cardio scale is not negatively affected by varying regional fat distributions.

Pulse Wave Velocity. The ARTERY society has provided an "acceptable" accuracy rating in difference of PWV measurements when validating devices. A mean difference less than or equal to 1.0 m/s and a standard deviation of less than or equal to 1.5 m/s provides an indication of relative accuracy. A mean difference of 0.68 m/s and 0.57 m/s (men and women respectively) is within acceptable agreement according to the ARTERY guidelines, and thus can be accepted as a clinically non-significant variation (Wilkinson 2010). The confirmed accuracy of the Body Cardio scale PWV measurements as determined by our research provides exceptional clinical promise for implementation.

Clinical Application. It should be noted that the Body Cardio scale reported PWV values lower than those obtained from the SphygmoCor tonometer in nearly every subject. Though these data were within a physiologically reasonable range, this discrepancy should be appreciated when utilizing the Body Cardio scale for clinical application. A lack of statistical difference between male and female populations also shows promise for extrapolation to other subgroups utilizing this scale.

Limitations and Future Research. This study was limited first and foremost by population size. A secondary round of investigation and data analysis could provide more robust and informative data. Our population was composed largely of similar individuals – aerobically active college-aged individuals, often with a high level of performance-based fitness. Recruitment of overweight, sedentary individuals of the same age group could provide a beneficial reference for variation in this population. Understanding the data in this subpopulation, specifically variations from reference sources, could also provide much needed conclusions prior to extrapolation into the larger clinical population.

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