2012

Test-retest reliability of noninvasive ambulatory impedance cardiography during aerobic exercise

Benjamin Germain
University of Central Florida

TEST-RETEST RELIABILITY OF NONINVASIVE AMBULATORY IMPEDANCE CARDIOGRAPHY DURING AEROBIC EXERCISE

by

BENJAMIN GERMAIN

A thesis submitted in partial fulfillment of the requirements
for the Honors in the Major Program in Interdisciplinary Studies
in the College of Sciences
and in The Burnett Honors College
at the University of Central Florida
Orlando, Florida

Fall Term 2012

Thesis Chair: Dr. Jeffery Cassisi

Abstract

Impedance cardiography is an important tool in determining a person's hemodynamic properties. The makers obtained through thoracic impedance have been shown to be of great importance when monitoring critical care patients. Technological developments have made this process noninvasive and ambulatory, opening up new possibilities for potential use. A study was conducted by remotely monitoring healthy subjects (n=5), who performed an 8-minute mild-to-moderate aerobic exercise protocol, followed up by a four minute cognitive stress test. Testing was conducted onsite at Kennedy Space Center in association with the National Aeronautics and Space Administration using the MW1000A (MindWare Technologies LTD, Gahanna, OH) ambulatory impedance cardiography monitoring (ICG) device.

The current study was conducted in order to establish the test-retest reliability of the ICG during aerobic exercise and cognitive stress across a 2 week period. For the purpose of this study Heart Rate (HR), Left Ventricular Ejection Time (LVET) Stroke Volume (SV), Cardiac Output (CO), and Pre-Ejection Period (PEP) were acquired and analyzed during three phases. The phases were, walking on a level treadmill, walking at incline, and an at rest mental arithmetic stress test. Testing has shown that the MW1000A device can provide accurate ambulatory impedance cardiography monitoring with no significant difference between testing intervals. The simple application of electrodes makes this device easy to use and requires little training. Its non-invasive properties render employing ICG both a simple and effective means of determining the hemodynamic properties of a subject.

Dedications

I would like to dedicate this to my family. Who have always supported and encouraged me throughout my endeavors. I do not know where I would be today without you.

Acknowledgement

I would like to express my deepest gratitude to all those who made my thesis possible. I wish to thank my thesis chair and mentor throughout this entire process (and some), Dr. Jeffery Cassisi for his invaluable support and guidance. I also would like to thank Dr. Corey Bohil and Dr. Thomas Fisher for being exemplary thesis committee members. Having all three members help advance both my thesis and my overall scientific process.

Thank you to the National Aeronauts and Space Administration (NASA) for supporting this project. I would personally like the thank Dr. Luis Moreno for allowing me to opportunity to work on this project, as well as all supporting staff at NASA 's Kennedy Space Center .

Finally I would like to thank all of my family and friends who have supported and encouraged me throughout this experience.

Table of Contents

List of Tables

List of Figures

Introduction

The Autonomic Nervous System (ANS) is constantly active in balancing internal systems at a nonconscious level. The ANS is part of the peripheral nervous system and controls non-conscious visceral functions. The ANS affects heart rate, digestion, respiration rate, salivation, perspiration, pupil diameter, urination, and sexual arousal. This system is generally active to keep our bodies at a sub-excitement level in order to maintain homeostasis, conserve energy and to mitigate a "wear and tear" scenario; whereas, the sympathetic nervous system (SNS) is known for initiation of the flight-or-fight response mode. This flight-or-fight mode occurs when a person encounters a prompt that requires a vigorous response. The body then reacts accordingly by dilating the pupils, increasing heart rate, dilating bronchioles, inhibiting digestion, increasing rennin in kidney and promoting ejaculation. This reaction occurs in order to stimulate the body so that it may decide to stay and "fight" the stimulus or decide "flight" and avoid it. This mode however cannot stay activated for too long as is requires more energy and hinders the digestive system. As more energy is needed, more oxygen must be brought into and properly distributed throughout the body; to accomplish such a task cardiac output must then increase accordingly. SNS activation can then be attributed to increasing blood flow.

Impedance Cardiography (ICG)

Impedance cardiography (ICG) is a way of non-invasive data acquisition through thoracic impedance to accurately, safely and unobtrusively measure cardiovascular functions such as heart rate (HR), left ventricular ejection time (LVET), stroke volume (SV), cardiac output (CO), and pre-ejection period (PEP). Impedance is the resistance of electrical current through the thorax. A small current is passed through the thoracic cavity traveling through the channel of least resistance which is the blood filled aorta. As the blood volume increases and decreases, during systole and diastole, as does the impedance measurements.

ICG is the premier technique in determining hemodynamic properties non-invasively. Previous to this development, the only system to acquire a subjects hemodynamic properties was through invasive pulmonary artery catherization (also known as the Swan-Ganz catheter) which requires hospital stay, holds possible risk, and is by no means ambulatory (Jones, 2011). Current noninvasive techniques have been proven to be clinically comparable to that of an invasive pulmonary artery catherization (Van De Wate, Miller, Vogel & Mount, 2003). ICG functions by transmitting a physically undetectable current through the upper thoracic cavity (400 microamps, 100 kHz). The current seeks the path of the least resistance which is the blood filled aorta. The ICG then measures the baseline impedance (resistance) of this current during the systolic cardiac phase, which is the pumping of oxygenated blood throughout the body. Each cardiac contraction changes the corresponding blood volume and therefore the resistance fluctuates attributing to volumetric expansion of the aorta. ICG is then broken down into data points used to determine hemodynamic parameters. Combining Electrocardiography (ECG) and ICG together gives researchers a variety of information about ANS functioning in general, as well as the cardiovascular system specifically.

Once limited to critical care patients, technological advances making ICG noninvasive has opened up monitoring potential having it to be implemented widely though out various settings. McFetridge-Durdle et al. (2008) states that “ICG has been shown to improve the management of patients with decompensated heart failure, emergent dyspnea , cardiac resynchronization therapy and hypertension.”. Making the application of ICG a valuable tool in health care.

ICG and Exercise

The hemodynamic profile associated with increased blood pressure induced by physical exercise appears to be myocardial. It is characterized by elevated heart rate, CO and a decrease in peripheral resistance. Organisms properly prepare for demanding tasks through hemodynamic accordance. In laboratory settings, active stressor tasks elicit a more dominate myocardial response, whereas passive tasks invoke a vascular response (Gregg et al., 1999). During active physical exertion, a possible beneficial observable parameter of impedance is CO. CO is a key parameter in determining health function of a subject. Oxygen delivery throughout the organism is a function of CO. The cardiovascular system acknowledges increase and decrease in metabolic needs due to physical exertion and/or psychological factors and adjusts blood flow output accordingly. Failure to meet the appropriate needs would result in aerobic metabolism decay, an accumulation of metabolic waste and lack of energy, ultimately resulting in cellular atrophy (Ziegele et al., 2006). Hemodynamic monitoring observes this arrangement in relation to CO, examining the amount of oxygenated blood being distributed throughout the system. A correlation can then be drawn between cardiac output and metabolic demand, denoting stress. In a testing environment, if a subject is not encountering physical demands, then an increase in metabolic demand signifies psychological stress.

ICG and Psychological Stress

Psychophysiological research currently employs the use of ICG and Heart Rate Variability (HRV) markers of autonomic responses. These markers have been employed to measure various psychological constructs. These constructs are directly related to the physiological marker showing a variation in readings during stress reactions (Moreno, 2010). During psychological stress, PEP, HRV and CO increase; while SV decreases (Rousselle, Blascovich & Kelsey, 1995). It is, therefore, feasible to monitor a subject's ICG and use the live data to determine an "at risk" worker's psychological stress levels while they are actively engaged in the field.

A related concept is known as the 'reactivity' hypothesis of cardiovascular disease. Gregg et al. (1999) states that "excessive cardiovascular response to episodic psychosocial stress is a risk factor for later development of hypertension and coronary heart disease". Hemodynamic profile might also play a role in determining such a claim. Blood pressure regulation is homeostatic. Meaning that stress induced increase of one parameter, either being CO or Total Peripheral Resistance (TPR), usually follows by a decrease in the other in a normative healthy human. A three phase model theory of human stress coping has been developed. 'Activation' is the period of physiological defensive preparation; 'resistance' is the period of stress coping and 'exhaustion' being an unsuccessful resolution of the given threat resulting in a damaging period (Selye, 1993). Hemodynamic response to brief stressors has the ability to outlast the actual stressor, sometimes by days or even weeks (Gregg et al., 1999). Exposure to intense brief stress, such as the threat of physical injury, initiates a higher level of prolonged arousal post stressor.

The American Psychiatric Association (1994) designates an extreme case of the latter to be post-traumatic stress disorder.

Challenge and threat appraisals are cognitive categories that trigger their own specific hemodynamic responses. Challenge appraisals arise when a particular stressor or task is deemed to be adequately dealt with amidst the current available resources. These challenge appraisals are in coordination with an adaptive effort. In opposition, a threat appraisal is signified by the lack of necessary resources in order to cope with the given stimulus (Moreno, 2010). Consequently, a threat appraisal brought on by an inadequacy in resources, causes avoidance which fosters a lack of effective action. These behavioral manifestations, caused by challenge or threat appraisals, are also in accordance with distinguishable patterns associated with vascular vs. cardiac autonomic response, respectively (Moreno, 2010).

The Masking Hypothesis

Clearly, psychological stress can affect the cardiovascular system. However, concurrent physical and psychological activity also has an effect on ICG markers. Sorting out the relative contributions by physical stress to hemodynamic change within a situation can be a challenge. This is particularly a problem in high activity situations such as field work.

There are currently two hypotheses addressing this issue. The “masking hypothesis” states that during concurrent physical and psychological stress a response will be no greater than the most demanding stressor (Rousselle, J., Blascovich, J., & Kelsey, R. 1995). Meaning that if the physical stressor causes a greater response, then the psychological stressor response will be over shadowed and not visible, or vice versa. The second hypothesis, known as “synergistic”, states that concurrent physical and psychological stress will yield a response greater than an independent stressor alone (Rousselle, Blascovich & Kelsey, 1995). Assuming that physiological aerobic stress causes a greater response then psychological, the masking hypothesis purposes that aerobic exercise during a time of psychological stress is beneficial. Also that cardiovascular response to stress is dominantly influenced by metabolic demands. In contraposition, the synergistic hypothesis implies that combining psychological and physical stress may not be beneficial; as such an act causes more bodily challenge in alleviating cardiovascular response to psychological stress. In addition, cardiovascular response is not solely influenced by metabolic demand in response to stress leading to the possible exhaustion of metabolic resources. Holding such as true, the synergistic hypothesis suggests that concurrent exercise during psychological stress may actually increase cardiovascular stress response and accumulate physiological risk, as opposed to the common idea of "exercising to relieve stress" (Rousselle, Blascovich & Kelsey, 1995). Studies have shown (Myrtek and Spital, 1986; Roth et al., 1990; Siconolfi et al., 1984, Rousselle et al., 1995) the synergistic hypothesis to be true in that aerobic exercise concurrent with psychological stress yields higher stress response than a single stressor alone.

Measuring ICG Parameters

ECG methodologies have long been used to determine the electrical activity of the heart. An ECG possesses the ability to identify the amplitude and timing of electrical signals as they pass through the cardiac tissue (Geffnera, 2010). This is most often used to derive HR and HRV measures. ICG is a technique measuring impedance to detect the properties of blood flow in the chest cavity. Figure 1 juxtaposes the traditional ECG wave against the waveform generated by

ICG. to illustrate the computation of the various derived parameters of ICG..

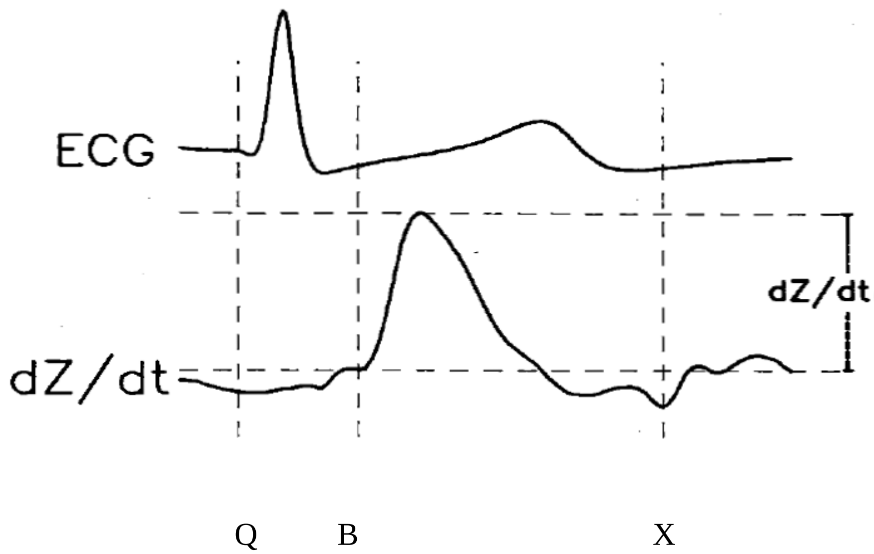


Figure 1: Illustrative electrocardiogram (ECG) and dZ/dt (ICG) wave forms within an ensemble window (Dash lines denote relevant reference points.) During systole of the cardiac cycle, the B point represents the opening of the aortic valve and the X point represents the closure of the aortic valve. The Q point references the beginning of the QRS complex of the ECG tracing. (Adapted and modified from Sherwood et al, 1990)

Q location denotes initial depolarization of the interventricular septum prior to activation of the ventricular myocardium (Lozano et al. , 2007). B point (msec) and X point (msec): The B and X points are landmarks along the dZ/dt waveform. The B point corresponds to the opening of the aortic valve or the beginning of mechanical systole. The end of mechanical systole is characterized by the X point, which delineates the closure of the aortic valve (see *Figure* 1). Pre-ejection Period (PEP - mesc): PEP begins with the Q wave from the ECG and ends with the B point. PEP represents time taken for one full ventricular depolarization (the electrical stimulation of ventricles). Left Ventricular Ejection Time (LVET - msec): is the total time from B to X points. Impedance (Z0): Z0 represents the maximum deflection along the impedance waveform. Stroke Volume (SV, milliliters - ml) is the volume of blood pumped from one ventricle of the heart with each beat. Cardiac Output (CO, liters per minute - lpm) is the total amount of blood pumped through the heart in one minute. The acquisitions of SV and CO are derivatives of dZ/dt. From Z0, SV and CO are calculated values from Kubicek's equation (see *Figure* 4). Other formulas are available in order to derive SV and CO from Z0 (Moreno, 2011). A relationship between CO, HR and SV can be seen in the equation CO=HR x SV.

These data points have been found to signify a multitude of different conclusions. PEP reflects myocardial contractility, which is a common index of sympathetic cardiac control. The onset of PEP is defined by the instant of Q point in an ECG (see *Figure* 2) (Lozano et al. , 2007). There is a slight controversy as to where the PEP should start. Some studies define the beginning of PEP to the peak of the Q/Start of R wave (R onset). This study implements the Society for Psychophysiological Standards Committee on ICG, recommendation of employing the onset of the Q wave (Q onset) as the initiation of PEP. However, it is also stated that in the absence of an obvious Q onset then the R onset may be used as a valid alternative (Lozano et al. , 2007).

Reliability and Validity of ICG Parameters

The "gold" standard for observing hemodynamic parameters is currently held by the direct Fick and Dye-Dilution methods. The direct Fick method requires that an invasive catheter be placed into the pulmonary artery. A study conducted by Richard et al. (2001) examined the reliability of impedance during mild-maximum exercise as compared to the Fick and Dye. This study employed the Physio Flow PF-03 (Manatec Biomedical) to determine CO (CO_{imp}) during rest and mild steady state exercise while simultaneously measuring CO with the direct Fick method (CO_{Fick}). Testing protocols consisted of a subject performing a graded exercise test in the upright position on an electronically braked bicycle ergometer. After 10 minutes of rest the subject began an initial workload of 20% of their theoretical maximal power as determined by Hansen's equation. After 3 minutes of warm up, power was increased by 20-35 W every minute until maximal load was achieved. In order to determine repeatability, the subject repeated the same testing protocols three days later. Measurements of CO_{Fick} were made at rest, end of warm-up period, every 2 minutes post warm-up and at peak effort.

In order to determine validity of the evaluation a regression analysis was calculated for each subject during the two tests (CO_{imp1} and CO_{imp2}). Fisher's "Z" was used in order to estimate a true correlation. Differences between CO_{imp1} and CO_{imp2} were tested to determine normalcy in order to achieve statistically proper parametric analysis; with a paired t-test implemented on the differences between CO_{imp1} and CO_{imp2} (Richard et al., 2001).

A regression analysis was drawn between CO_{imp2} and CO_{Fick} and plotted against each other for each set of simultaneous determination. Results show that the two methods were statistically significant with r=0.94 see *Figure 2* below.

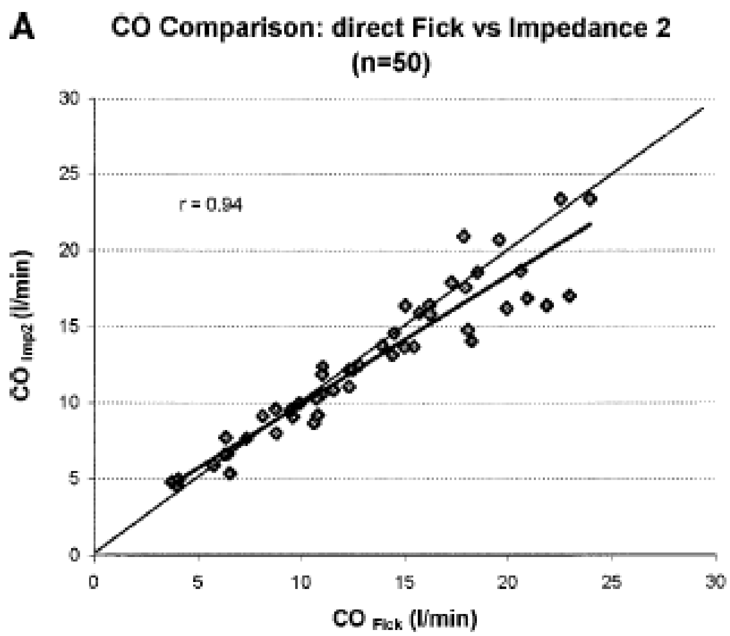


Figure 3: Plot of CO_{imp2} versus CO_{Fick} in the same individuals. Identity line is represented (Richard et al. 2001).

In order for a measurement to prove valid for scholarly purposes it must be appropriately designated as reliable. Test-retest reliability is the consistency of a set of measurements over time when measuring the same phenomenon. The *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, states the following conditions must to be fulfilled in order to establishment reliability: the same measurement procedure, the same observer, the same measuring instrument, used under the same conditions, in the same location and repetition over a short period of time.

The Richard et al. (2001) experiment also demonstrated the reproducibility of ICG through test-retest reliability. A three day gap between testing was short enough so that no changes in the subjects physiological status were likely, yet the inter trial interval was long enough for sufficient recuperation from the previous test. CO determined through impedance during both tests (CO_{imp1} and CO_{imp2}) resulted in an average difference of .009, with a standard deviation of 16% with the CO_{Fick} obtaining a standard deviation between 5-10%. However Richard et al. (2001) sates “The average difference observed between the two measurements was not significant and was not influenced by the amount of flow.” The author concludes that measuring CO through the impedance device satisfies reproducibility and reliability from resting to maximum effort (Richard et al. , 2001)..

Test-retest reliability of ICG parameters with fixed noninvasive laboratory equipment have been established in another study as well. Saab et al. (1993) conducted an experiment in which ICG was measured during static cold pressure challenges over time. First the subjects were affixed to a Grass polygraph (Model 7D) in order to obtain ECG, phonocardiogram, dZ/dt and respiration. While simultaneously using the Minnesota Impedance Cardiograph (Model 3048) to record impedance cardiography (dZ/dt and Z_0) while storing the data for posthoc evaluation (Saab et al. , 1993). One test implemented a 4 C° bag of ice water placed on the subject’s forehead for 100 seconds. Test two was comprised of placing the subject's arm into a 4 C° bucket of ice water for 100 seconds. With test three being the placement of the subject’s left foot into a 4 C° bucket of ice water for 100 seconds. All three tests were completed on the same day concurrently. Two weeks later, in order to eliminate any undesired variable such as social or circadian influences, methodological standardization of the test-retest interval; the facility, time of day, experimenters, procedures, electrode application, and posture were all identical to the original test. Procedures described by Cronbach, Glaser, Nanadam and Rajaratnam (1972) were implemented in order to determine reliability. "The reliability analyses indicate that the three cold pressor tests produce stable responses over a 2-week interval with very little, if any, attenuation. (Saab et al., 1993)" Comparisons with this study and previous cold pressor test further validate test re-test reliability. However it is to be noted that Q, LVET/PEP and SV shows highest variation. *Table I* below, which was pulled directly from Saab et al. (1993), charts the testing variation.

Table 1: Generalizabilty Coefficents (G and G) for Assessing 2-week cold Pressor test Stability Measure.*

			Task (n = 14)			Delta (n = 14)		
Measure[a]	Number of sessions	Baseline (n = 42)	Head	Hand	Foot	Head	Hand	Foot
HR	1	.82	.81	.91 (.88)	.92	.62	.90 (.86)	.88 (.83)
	2	.90	.90	.95 (.94)	.96	.77	.95 (.92)	.94 (.91)
$\dot{Q}$	1	.74	.69	.71 (.67)	.83	.59 (.58)	.39 (.37)	.90
	2	.85	.82	.83 (.80)	.91	.74 (.73)	.57 (.54)	.95
SV	1	.86	.87	.78	.87	.51	.53	.91
	2	.92	.93	.88	.93	.68	.69	.95
HI	1	.87	.82	.75	.91	.69	.47	.89
	2	.93	.90	.86	.96	.82	.64	.94
PEP/LVET	1	.84	.82	.66	.70	.47	.26	.50
	2	.91	.90	.80	.83	.64	.42	.67
SBP	1	.45	.58	.85	.85	.81	.77	.75
	2	.62	.74	.92	.92	.90	.87	.86
DBP	1	.72	.80	.78	.87	.84	.85	.86
	2	.83	.89	.87	.93	.91	.92	.92
TPR	1	.74	.77	.81 (.79)	.82	.87 (.85)	.75 (.73)	.81
	2	.85	.87	.89 (.88)	.90	.90 (.92)	.86 (.84)	.90

Note: G^* is given in parentheses only when it differs from G.
[a]HR = heart rate; $\dot{Q}$ = cardiac output; SV = stroke volume; HI = Heather Index; PEP/LVET = preejection period/left ventricular ejection time; SBP = systolic blood pressure; DBP = diastolic blood pressure; TPR = total peripheral resistance.

Ambulatory Measurement of ICG

While the direct methods to measure ICG such as the Fick method and the Dye-dilution method are known to have an accuracy of within 5%-10% variation, both of these processes are invasive and not ideal for frequent evaluation and/or exercise evaluations. Furthermore, fixed noninvasive laboratory equipment presents challenges for measuring ICG in situations of exertion or activity. Therefore, accurate and reliable noninvasive and ambulatory methods are necessary.

Ambulatory monitoring is the prolonged monitoring of a subject’s physiology in which they are free to move around with no physical restrictions. The ability to measure the body's physiological responses in the natural environment with real time ambulatory data can prove to be invaluable information. Ambulatory monitoring data-acquisition has been increasingly available with the advancement of modern technologies; this has also been extended to remote hemodynamic monitoring. Real time ambulatory monitoring of ICG has many potential applications. It can possibly be a contributing factor in determine the health of any person dealing in an extraneous activity work environment.

Only one study was identified to determine the reliability of ICG measurement during ambulatory monitoring. McFetridge-Durdle et al. (2008) study examined the reliability of the Ambulatory Impedance Monitor (AIM) system during postural changed in hypertensive subjects. Subjects were instrumented and then requested to sit for a 5 minute rest period. A 30 second ICG reading was taken before the five minutes where over. After the five minute rest period was complete subjects stood up and 30 seconds of ICG were recorded. These reading were stored in the AIM device for posthoc examination. This concluded the test. A noticeable difference in sitting and standing ICG was observed. Upon standing data showed a predictable increase in HR, decrease in SV, constant CO and significant decrease in LVET ($p<.001$). During a postural change from sitting to standing, fluid shifts occur from upper to lower extremities. This drastic shift causes an unbalance in cardiovascular activity. In order to restore cardiovascular balance the autonomic nervous system responds by increase of HR to compensate for the decrease in SV and CO (CO= HR x SV). These cohesive results derived HR (r=81) to be highly repeatable with SV (r=.54), CO (r=.56), PEP (r=.59), and LVET (r=.74) to be moderately repeatable in youths over a two month period (McFetridge-Durdle et al. , 2008).

The Problem Statement

The Mindware Technologies provides an ambulatory instrument to monitor a subjects ECG and ICG from a remote location. The MindWare Bio-Potential and Transducer Ambulatory Monitor (MW1000A, MindWare Technologies LTD, Gahanna, OH) is a noninvasive ambulatory monitoring device designed to accomplish accurate ICG readings remotely. This device is capable of acquiring numerous indicators of stress response while transmitting constantly to a remote location. Thoracic impedance (Z_0), pulsatile impedance/time changes (dZ/dt), and electrocardiography (ECG) are all used to calculate cardiac function which is then translated into hemodynamic waveforms (see *Figure 3*).

The MW1000A must first be examined in order to confirm the system's reliability. To confirm the reliability of this device an experiment was designed with the ability to determine test-retest reliability. This was achieved by testing five subjects under identical conditions of aerobic exercise (submaximal treadmill testing) and psychological stress (serial 7s) with a minimum of two weeks between trials.

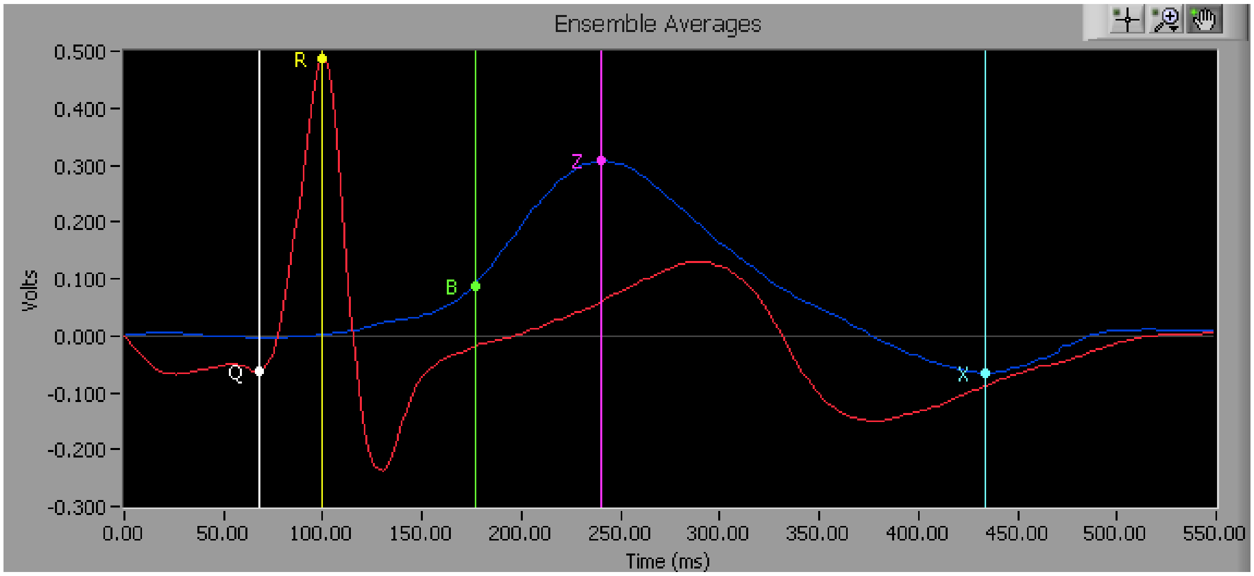


Figure 4: Data from a feasibility test that reveals ECG and dZ/dt wave form within 550 msec ensemble window.

Method

This experiment was conducted in accordance with Nation Aeronautics and Space Administration (NASA) and Innovative Health Applications on site at Kennedy Space Center as approved by the Institutional Review Board with Dr. Luis Moreno as principle investigator, Pam Miles as subject monitor, Alycen LaBarca as fitness professional/kinesiologist and Benjamin Germain as research assistant.

Subjects

This experiment was set around the current NASA employed firefighters. The firefighters were solicited to participate with full details of the experiment and volunteered with no monetary compensation. All subjects participated in a regularly scheduled fitness programs (2-3 times weekly), which included either an aerobic exercise program or an aerobic exercise program plus 60-min yoga session. The first six volunteers with diurnal work shifts were selected for the experiment. The ongoing fitness program was managed and conducted by an independent-contractor professional trainer. The assessments were conducted at the fire stations' gym in which the fitness services was being held for the subjects convenience. Each subject participant was assessed after completion of the day's exercise session.

Procedure

As per the Medical Examination Requirements for the Kennedy Space Center Clinical Operations (OCH-I-0106, Section 7, Subpart 14), N-Type Physical Examination for a KSC fire fighter consisting of medical evaluation and the specific physical examination, includes a diagnostic symptom-limited stress test. All subjects retained a current medical certification from the Occupational Health Facility (OHF). Medical screening for co-morbid conditions was conducted by principal investigator. All subjects read and signed a written consent form approved by the Institutional Review Board before their participation.

Five subjects (4 males, 1 female) were able to complete both trials. *Table 2* displays the demographic parameters as following: age (years) = 52.8±5.7, height (cm) = 176.8±9.9, weight (kg) = 77.7±20.5, and body mass index (BMI) = 24.5±4.1. The individual thoracic lengths were also measured with a mean of 18.4±4.3 cm; however, for the purposes of this study, the default value of 25 cm was used for the initial evaluation of the data.

Table 2: Subjects' Demographic Data

Subject	Age (Years)	Height (cm)	Weight (kg)	BMI	Thoracic Length)	Gender
1	48.0	176.5	64.4	20.7	19.4	M
2	61.0	186.7	93.0	26.7	19.5	M
3	55.0	185.4	104.3	30.3	21.0	M
4	53.0	172.7	72.6	24.3	19.8	M
6	47.0	162.6	54.4	20.6	10.5	F

Each test session was done in an enclosed physical fitness room in which we utilized a standard treadmill with only one subject at a time. Mindware Technologies LTD equipment was used in order to obtain ECG reading as well as impedance cardiography remotely. Each subject's ECG leads were attached by means of the Quinton Quik-Prep Patient Preparation System Applicator. This applicator implements specially designed disposable skin conductance electrodes that gently abrade the prepared subject's skin for cleaner, less artifact readings. ECG was placed in the Lead II configuration on the subject's anterior chest (*see Figure* 4)

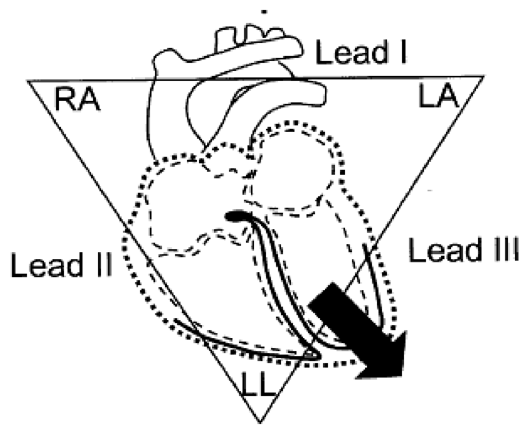


Figure 5: Lead II configuration as represented by Einthoven's triangle superimposed on the cardiac conduction system and electrical dipole vector for the R wave of the ECG complex (Adapted and modified from Berntson et al, 2004)

The Negative ECG is placed on all subjects in their upper right pectoral area adjacent to the deltopectoral triangle. The positive ECG lead is placed on the subjects left side at the approximate point of Thoracic rib 11-9. The ECG is then grounded into the right side of the patient's body around the oblique muscle area. Leads are then hardwired into MW1000A which wirelessly transmitted, via 802.11 WiFi, to the computer screen for real time monitoring.

The impedance cardiography electrodes are standard skin conductance electrodes in which we manually prepared and placed on the skin. The Quinton Quik-Prep was briefly tested for use with ICG. However acquired readings using the Quinton Quik-Prep resulted in nosier, less clear results. Therefore the Quik-Prep system was not employed in ICG electrode placement. Electrode lead 1 (positive) is placed on the subjects sternal notch with electrode lead 2 (negative) placed on the xiphoid process. These two electrodes output the electrical current (400 micro amps) for ICG. Electrode lead 3 (positive) was placed on the subjects vertebral column approximately 3 cm higher then Electrode 1. Electrode lead 4 (negative) was placed on the vertebral column approximately 3 cm lower then electrode lead 2. Lead 3 and 4 are the receiver electrodes for the current passing through the subject's thoracic cavity. ECG and ICG electrodes were all connected to the Ambulatory Impedance Cardiograph MW1000A transmitter which wirelessly transmitted, via 802.11 WiFi, remotely to the computer in the room for real-time hemodynamic monitoring. The subject's age, height, age, and length of sternum were all recordedPrior to data acquisition a couple of dry test runs were ran in order to determine unforeseen variables. Due to circumstances we were not able to obtain a HR monitor and, therefore, relied on the HR monitor attached to the treadmill. Alycen LaBarca, our kinesiologist, confirmed the treadmills HR reading by physically acquiring comparable readings. However, the specific treadmill began to have mechanical malfunctions; therefore, we were forced to switch to an adjacent treadmill machine. This machine did not have HR acquisition capabilities. Instead we ran the test two more times acquiring HR through physical means. We determined that the subject would reach an ideal 60-70% max HR by walking 4.0 mph at a 5.0° gradient. Max HR is determined by subtracting the subjects age from 220. Two minutes of baseline vitals were acquired before physical exertion began. . The subject then proceeded to begin the 8-minute physical assessment test, which was adapted from the Ebbeling submaximal treadmill test. The research assistant (RA) then proceeded to start the treadmill at 2.5 miles per hour (mph) for the first minute. At minute two the RA increased treadmill speed to 3.0 mph. At minute three the RA increased treadmill speed to 3.5 mph. At minute four the RA increased speed to 4.0 mph. 4.0 mph is the top speed used in the experiment. At minute 5 the RA increased the gradient to 5.0° at a constant 4.0 mph. This then stayed constant until the physical excursion portion was over at minute 8. At minute 8, the subject was safely slowed and brought off the machine for five minutes of cool down. The subject sat down in a chair with proper posture having their back flat against the chairs back. It was noticed that if the subject sat in a hunched position the data began to acquire artifact. After five minutes of cool down, all personnel left the room, with the exception of the subject and the RA. The RA then thoroughly explained to the subject the process of the cognitive testing which would be achieved through Serial Sevens testing. The subject would be shown an index card with a previously determined randomized four digit number largely printed onto it. The RA then marked the beginning of cognitive testing. The subject was to mentally consecutively subtract seven from the given number as fast as possible, with as little errors as possible, for four minutes while giving the results orally. The subject's responses were then checked for correctness by the RA who had a pre-determined answer sheet. If the subject said an incorrect response the RA would correct him/her and they would continue from the correct number. After the four minutes of serial sevens was complete the data-acquisition software was turned off and the testing was complete. All electrodes where removed from the subject and they were free to go. Follow up testing was completed a minimum of two weeks prior to initial testing. The same facilities, experiments, procedures, equipment and time of day were adequately achieved. During the second trail, the subject was given a different number for the serial sevens test then they have previously seen in order to deter test learning. It was our intention to test all six subjects twice. Subject 5 (of 6) only received one testing session due to scheduling conflicts and therefore his data is not enumerated into the results.

Results

Test-Retest Correlations

Different statistical approaches were used to evaluate the test-retest correlations for the various measures derived from ICG. This was required due to having a relatively low number of subjects, and the repeated measures nature of the physiological data. Thus any statistical approach would need to control for autocorrelation. Therefore a traditional Pearson Product Moment Correlation would not provide an accurate estimate. The first approach used to estimate test-retest correlation was the Structural Equation Modeling, employed in order to establish the invariance of the latent variables over time which is analogous to test-retest reliability (Joreskog & Sorbom, 1981). Using this approach, the four observations of each measure at week 1 and week 2 were treated as separate latent variables. Then the correlation between the two latent variables were calculated using LISREL). The means and standard deviations of each measure at each week are presented in *Table* 3.

The next approach to calculating the test-retest reliability used intraclass correlation coefficients (ICC) (Shrout & Fleiss, 1979). The ICC for the four observations of each measure at week 1 and week 2 were calculated by individual using Medcalc. Then the average ICC between the two weeks was computed. These are found in Tables 3 through 18. Lastly Bland-Altman Plots were calculated for the four observations comparing the difference scores between week 1 and week 2. These are displayed in *Figures 5* through *19*.

Table 3: Mean and standard deviation

	Week 1		Week 2		
Measure	Mean	SD	Mean	SD	Latent r
HR					
Walking	94.477	11.4136	94.9388	11.4859	0.57
Incline	123.844	15.1277	123.231	10.7594	0.96
Stress	85.2992	15.0261	87.2529	17.4753	0.92
LVET					
Walking	263.38	35.9803	278.975	41.3711	0.87
Incline	230.595	30.5407	227.2	35.4351	0.43
Stress	306.94	43.1547	291.89	34.3836	0.65
SV					
Walking	752.06	276.707	615.274	299.6	0.71
Incline	816.055	500.198	588.775	321.278	0.62
Stress	828.189	422.041	593.614	374.091	0.85
CO					
Walking	70.5581	25.3274	54.4315	24.0554	0.62
Incline	98.7183	50.5557	70.7544	39.4543	0.77
Stress	71.2295	33.5092	49.0003	24.8085	0.67
PEP					
Walking	120.36	13.6106	122.525	13.0459	0.31
Incline	112.19	13.4821	112.2	25.372	0.77
Stress	125.62	23.3458	130.91	15.552	0.63

Table 4: Intraclass Correlation Heart Rate Reliability Treadmill Walking:

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.9423	.9703	.3710 to .9962	.5413 to .9961
2	.7230	.8392	-.4257 to .9794	-1.4824 to .9896
3	.6396	.7802	-.5488 to .9719	-2.3934 to .9858
4	.9645	.9819	.5640 to .9977	.7212 to .9988
6	.9058	.9506	.1343 to .9936	.2367 to .9968
Average	0.83504	0.90444		

Figure 6: Bland-Altman Plot for Method Comparison – Heart Rate Treadmill Walking

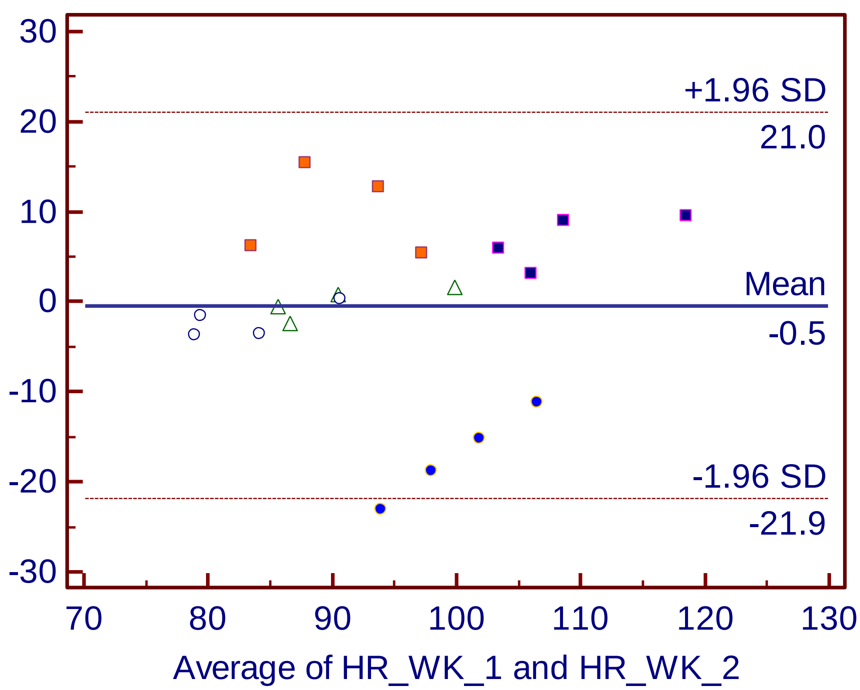


Table 5: Intraclass Correlation Heart Rate Reliability Treadmill Incline

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.6017	.7513	-.5867 to .9683	-2.8396 to .9839
2	.6841	.8124	-.4867 to .9760	-1.8962 to .9878
3	.8314	.9080	-.1739 to .9881	-.4211 to .9940
4	.8754	.9336	-.01262 to .9914	-.02556 to .9957
6	.8191	.9006	-.2111 to .9872	-.5351 to .9936
Average	0.76234	0.86118		

Figure 7: Bland-Altman Plot for Method Comparison – Heart Rate Treadmill Incline

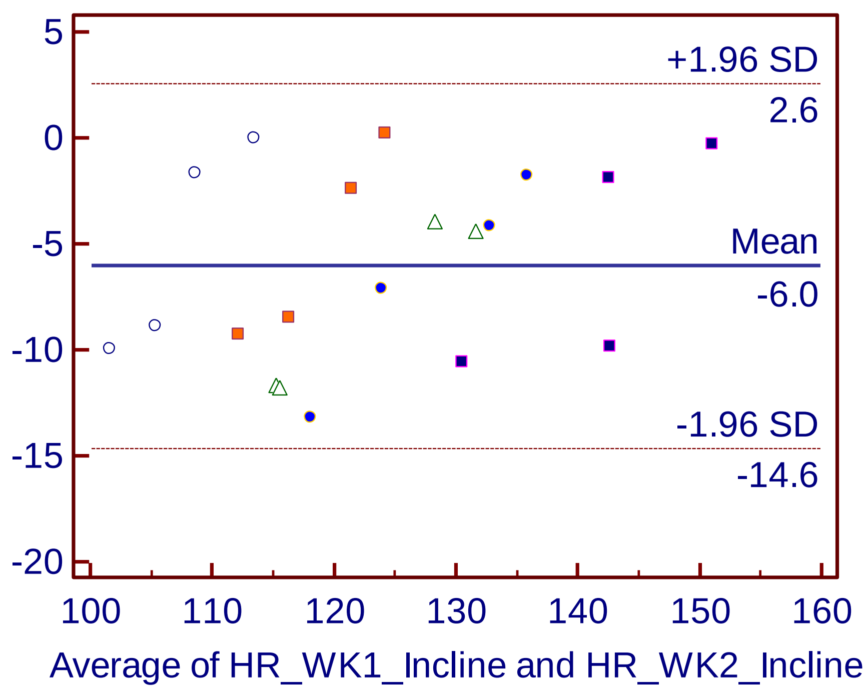


Table 6: Intraclass Correlation Heart Rate Reliability Cognitive Stress

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.7675	.8685	-.03401 to .9831	-1.0308 to .9915
2	.9487	.9737	.4218 to .9966	.5933 to .9983
3	.9781	.9889	.7085 to .9986	.8294 TO .9993
4	.6398	.7803	-.5446 to .9719	-2.3915 TO .9858
6	.4035	.5750	-.7355 to .9464	-5.5618 to .9725
Average	0.74752	0.83728		

Figure 8: Bland-Altman Plot for Method Comparison – Heart Rate Cognitigve Stress

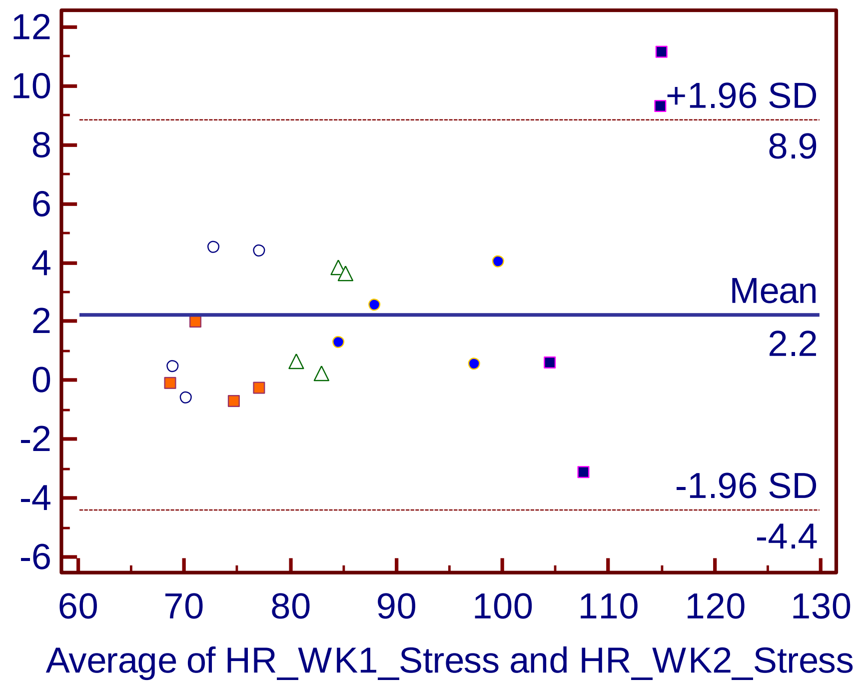


Table 7: Intraclass Correlation LVET Reliability Treadmill walking

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.6777	.8079	-.4957 to .9754	-1.9657 to .9876
2	.8848	.9389	.02876 TO .9921	.05592 to .9960
3	.07872	.1460	-.8590 TO .8652	-12.1858 to .9447
4	.3853	.5563	-.7452 to .9441	-5.8506 to .9713
6	.1657	.2842	-.8340 to .9114	-10.0509 to .9536
Average	0.438444	0.54666		

Figure 9: Bland-Altman Plot for Method Comparison – LVET Treadmill walking

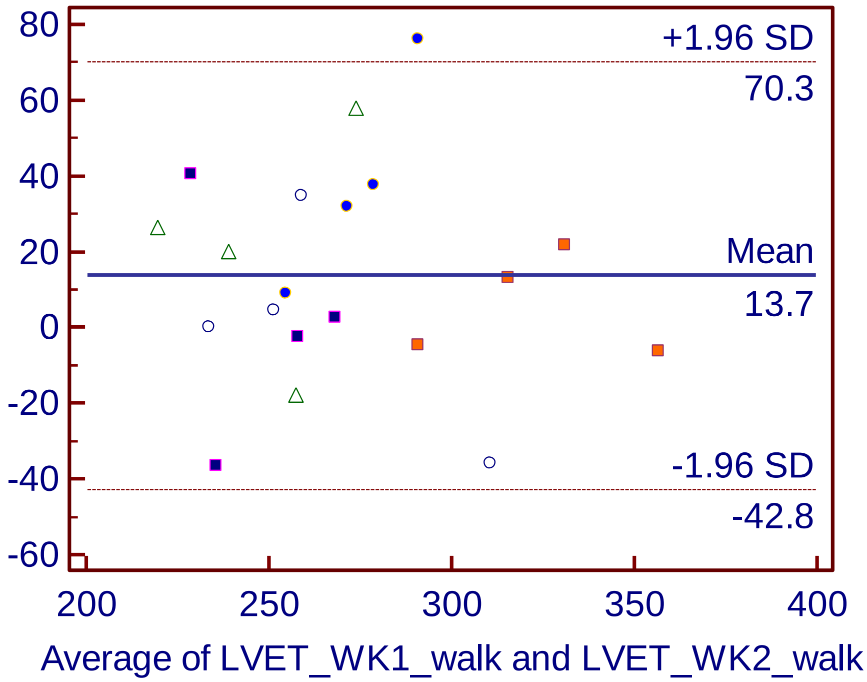


Table 8: Intraclass Correlation LVET Reliability Treadmill incline

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.5463	.7066	-.6383 to .9627	-3.5301 to .9810
2	-.3632	-1.1409	-.9413 to .7564	-32.0539 to .8613
3	.3525	.5213	-.7617 to .9398	-6.3914 to .9690
4	.6191	.7647	-.5682 to .9700	-2.6321 to .9848
6	-.1207	-.2746	-.9033 to .8475	-18.6784 to .9174
Average	0.2068	0.11542		

Figure 10: Bland-Altman Plot for Method Comparison – LVET Treadmill incline

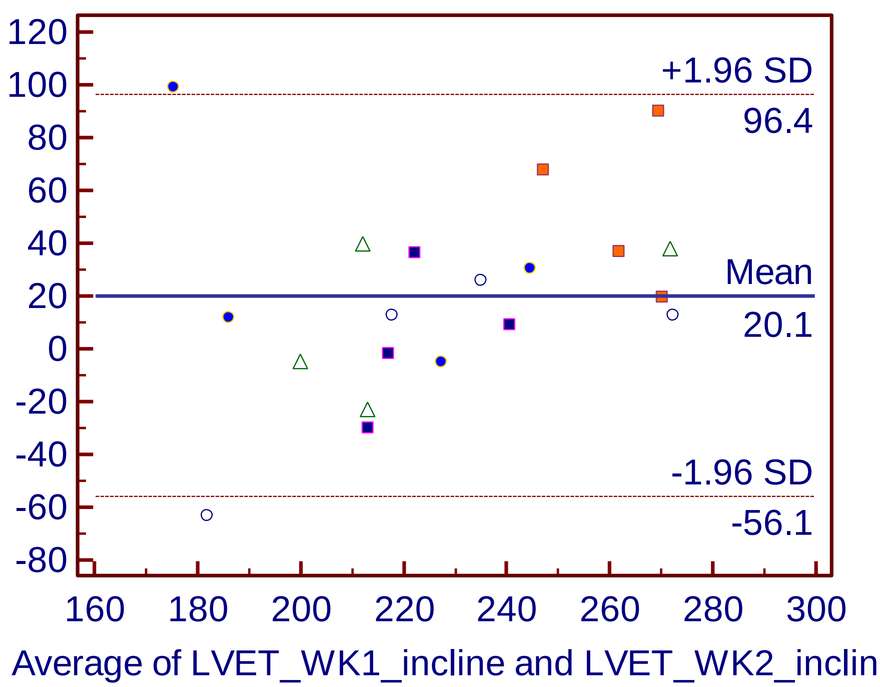


Table 9: Intraclass Correlation LVET Reliability Treadmill Cognitive Stress

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.1081	.1950	-.8511 to .9009	-11.4280 to .9479
2	-.5373	-2.3227	-.9618 to .6458	-50.2995 to .7848
3	.4630	.6329	-.7000 to .9536	-4.6676 to .9762
4	.9414	.9698	.3640 to .9961	.5337 to .9980
6	.02305	.04507	-.8730 to .8835	-13.7434 to .9381
Average	0.19965	-0.095986		

Figure 11: Bland-Altman Plot for Method Comparison – LVET Cognitive stress

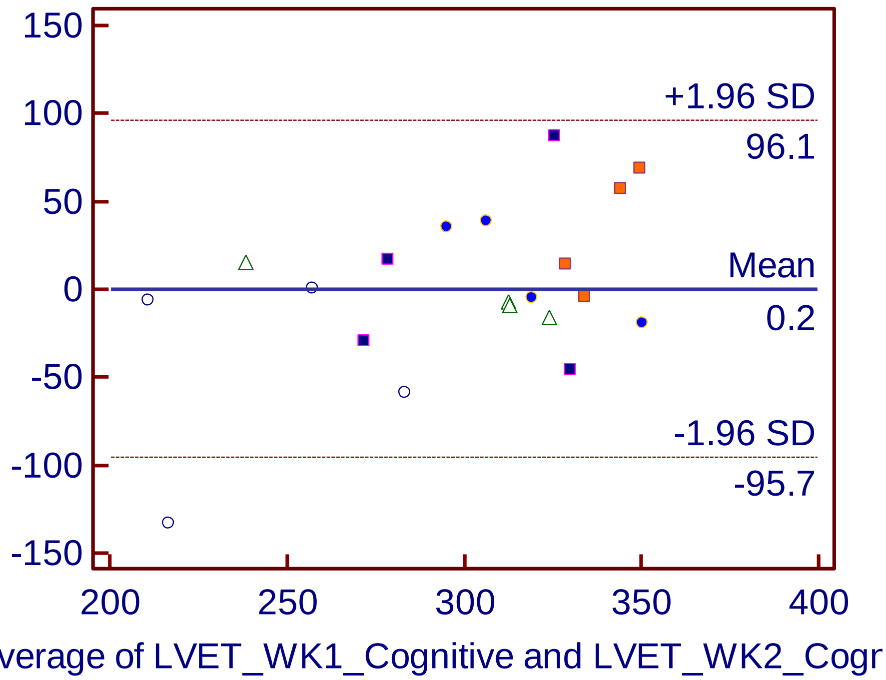


Table 10: Intraclass Correlation SV Reliability Treadmill Walking

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.6726	.8043	-.5027 to .9750	-2.0217 to .9873
2	.9219	.9594	.2289 to .9947	.3725 to .9974
3	.9732	.9864	.6532 to .9982	.7902 to .9991
4	.5639	.7212	-.6230 to .9645	-3.305 to .9819
6	-.2533	-.6783	-.9257 to .8039	-24.9120 to .8913
Average	0.57566	0.5586		

Figure 12: Bland-Altman Plot for Method Comparison – SV Treadmill Walking

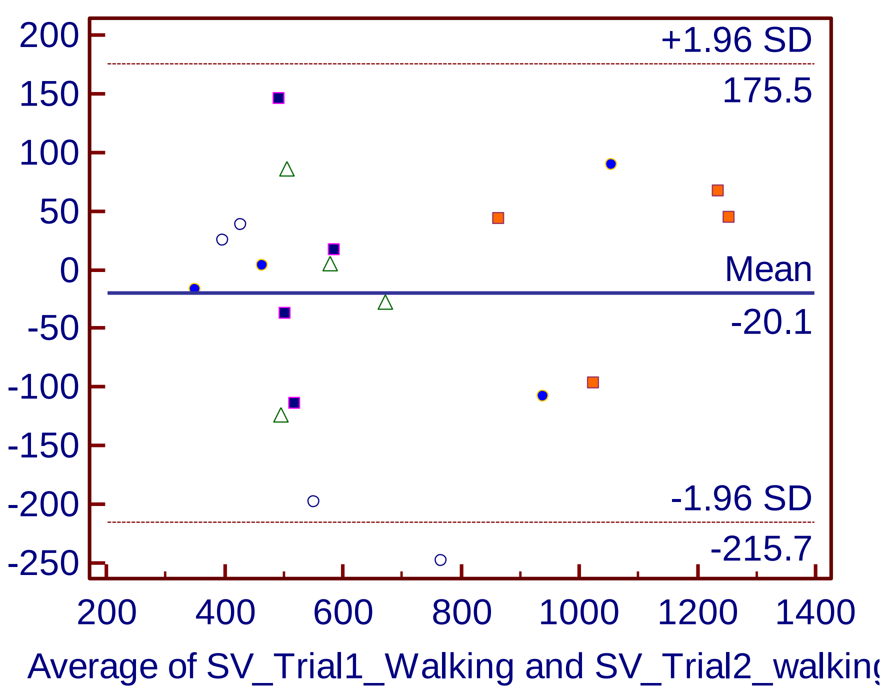


Table 11: Intraclass Correlation SV Reliability Treadmill Incline

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.5463	.7066	-.6383 to .9627	-3.5301 to .9810
2	-.3632	-1.1409	-.9413 to .7564	-32.0539 to .8613
3	.3525	.5213	-.7617 to .9398	-6.3914 to .9690
4	.6191	.7647	-.5682 to .9700	-2.6321 to .9848
6	-.1207	-.2746	-.9033 to .8475	-18.6784 to .9174
Average	0.2068	0.11542		

Figure 13: Bland-Altman Plot for Method Comparison – SV Treadmill Incline

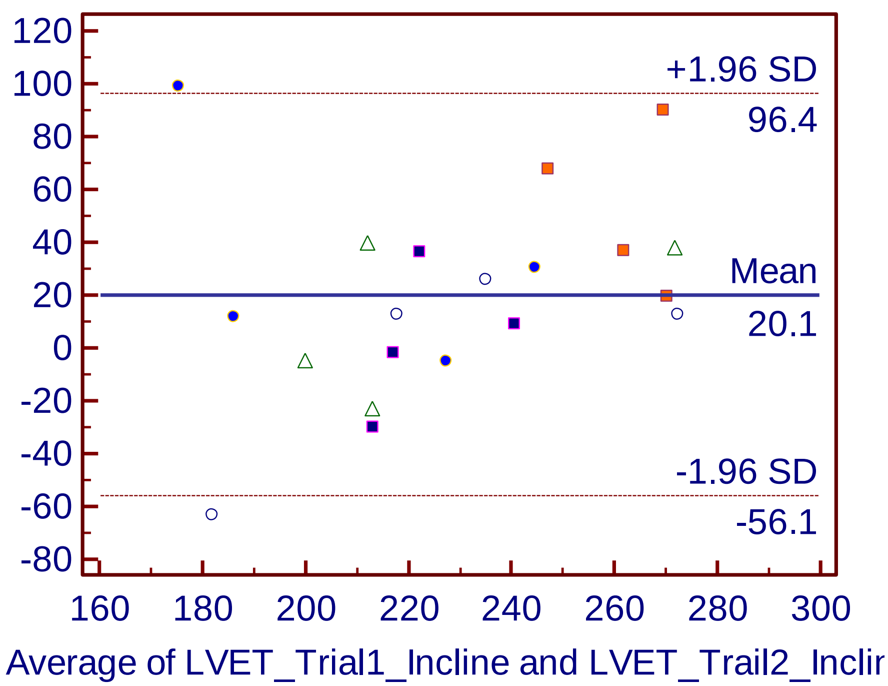


Table 12: Intraclass Correlation SV Reliability Cognitive Stress

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.4922	.6597	-.6802 to .9569	-4.2535 to .9780
2	.3429	.5107	-.7662 to .9386	-6.5550 to .9683
3	.9570	.9780	.4937 to .9972	.6610 to .9986
4	.9543	.9766	.4694 to .9970	.6389 to .9985
6	.2327	.3776	-.8115 to .9225	-8.6098 to .9597
Average	0.59582	0.70052		

Figure 14: Bland-Altman Plot for Method Comparison – SV Cognitive Stress

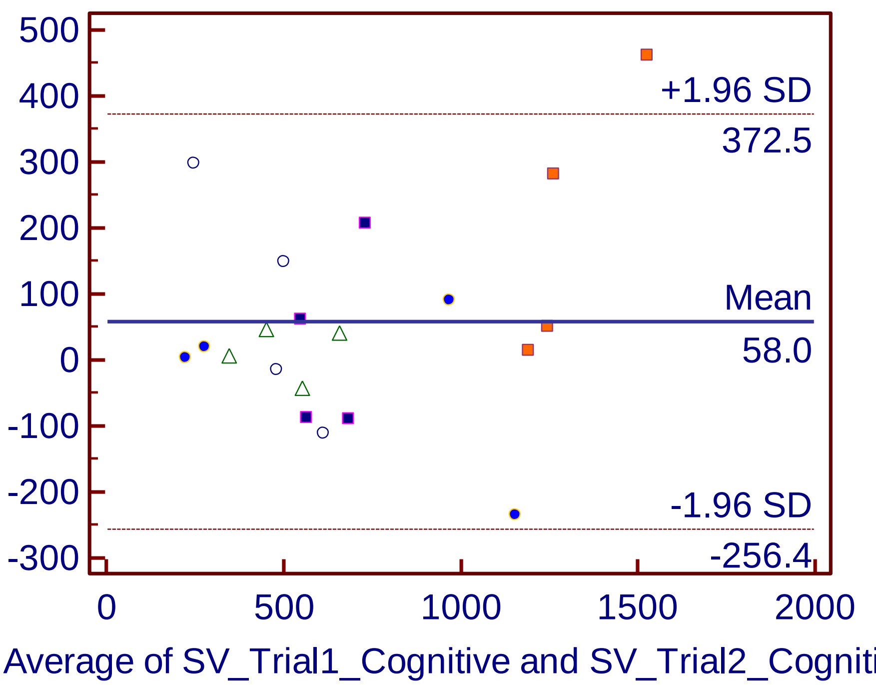


Table 13: Intraclass Correlation CO Reliability Treadmill Walking

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.5476	.7077	-.6372 to .9628	-3.5133 to .9811
2	.9761	.9879	.6855 to .9984	.8134 to .9992
3	.9684	.9839	.6025 to .9979	.7525 to .9990
4	.7174	.8354	-.4352 to .9789	-1.5408 to .9893
6	-.02842	-.05850	-.8847 to .8717	-15.3424 to .9314
Average	0.636216	0.69128		

Figure 15: Bland-Altman Plot for Method Comparison – CO Treadmill Walking

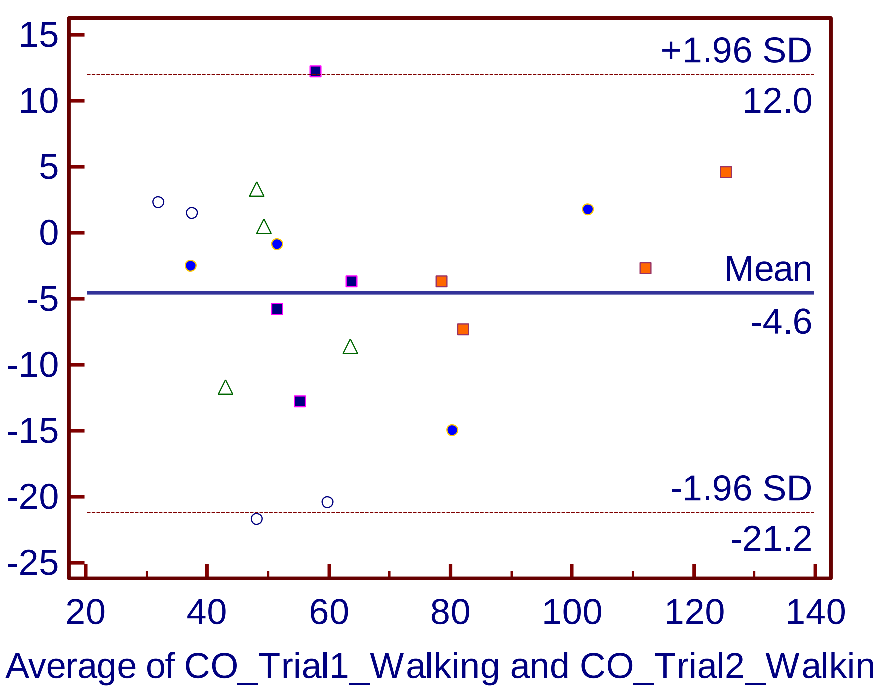


Table 14: Intraclass Correlation CO Reliability Treadmill Incline

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	-.6875	-4.3993	-.9763 to .4818	-82.3608 to .6503
2	.3484	.5168	-.7636 to 9393	-6.4600 to .9687
3	.7877	.8813	-.2941 to .9847	-.8332 to .9923
4	.3954	.5667	-.7399 to .9454	-5.6891 to .9719
6	-.3098	-.8979	-.9340 to .7811	-28.3013 to .8771
Average	0.10684	-0.66648		

Figure 16: Bland-Altman Plot for Method Comparison – CO Treadmill Incline

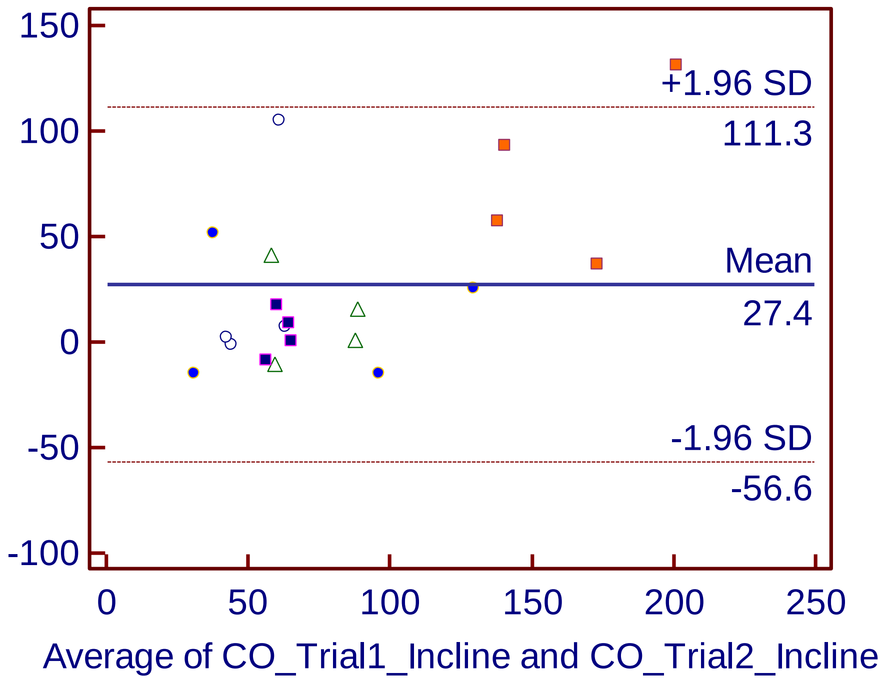


Table 15: Intraclass Correlation CO Reliability Cognitive Stress

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.5470	.7072	-.6378 to .9628	-3.5211 to .9810
2	.6022	.7517	-.5862 to .9683	-2.8335 to .9839
3	.9525	.9757	.4541 to .9969	.6246 to .9984
4	.9304	.9640	.2849 to .9953	.4435 to .9977
6	.2211	.3622	-.8156 to .9207	-8.8475 to .9587
Average	0.65064	0.75216		

Figure 17: Bland-Altman Plot for Method Comparison – CO Cognitive Stress

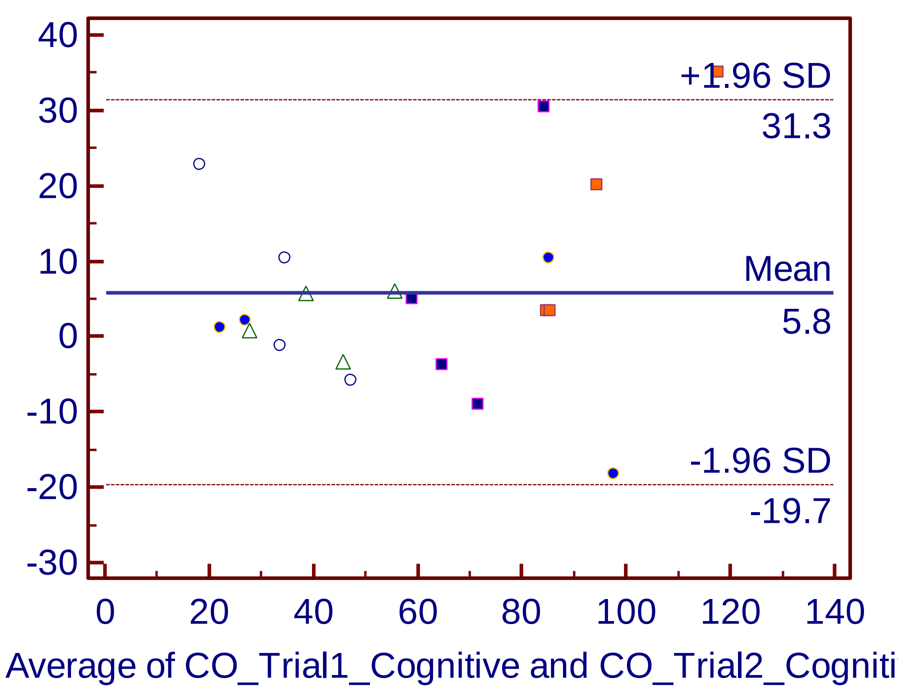


Table 16: Intraclass Correlation PEP Reliability Treadmill Walking

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.7430	.8526	-.3895 to .9811	-1.2762 to .9905
2	.6450	.7842	-.5383 to .9724	-2.3319 to .9860
3	-.3323	-.9953	-.9371 to .7711	-29.8060 to .8708
4	-.07921	-.1720	-.8953 to .8589	-17.0954 to .9241
6	.5277	.6908	-.6536 to .9607	-3.7731 to .9800
Average	0.300838	0.23206		

Figure 18: Bland-Altman Plot for Method Comparison – PEP Treadmill Walking

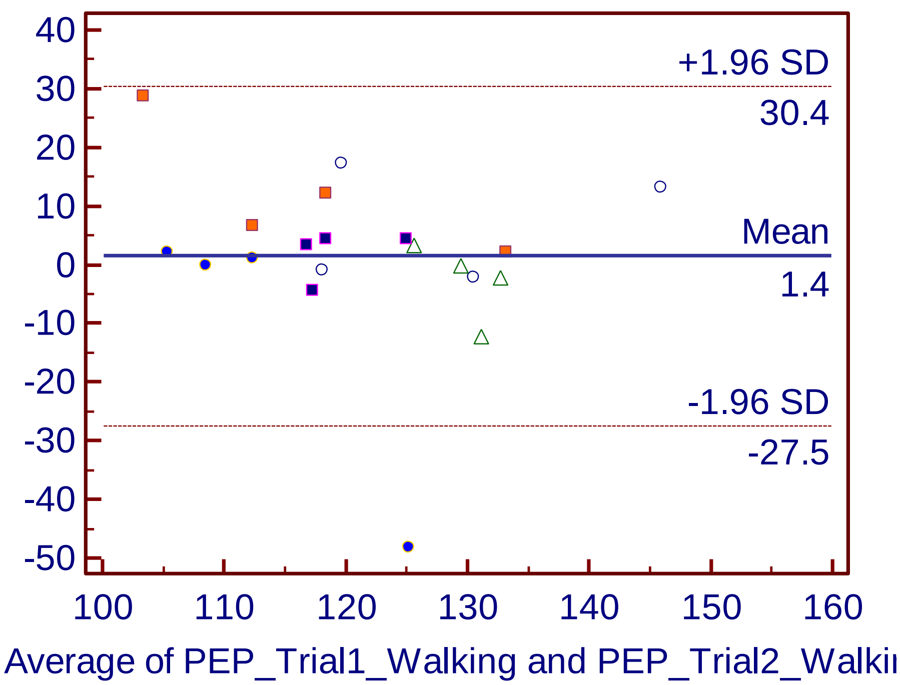


Table 17: Intraclass Correlation PEP Reliability Treadmill Incline

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.4596	.6297	-.7022 to .9532	-4.7164 to .9760
2	-.4967	-1.9740	-.9574 to .6770	-44.9158 to .8074
3	.6792	.8090	-.4936 to .9756	-1.9492 .9876
4	-.4464	-1.6128	-.9516 to .7105	-39.3389 to .8308
6	.3868	.5579	-.7444 o .9443	-5.8260 to .9714
Average	0.1165	-0.31804		

Figure 19: Bland-Altman Plot for Method Comparison – PEP Treadmill Incline

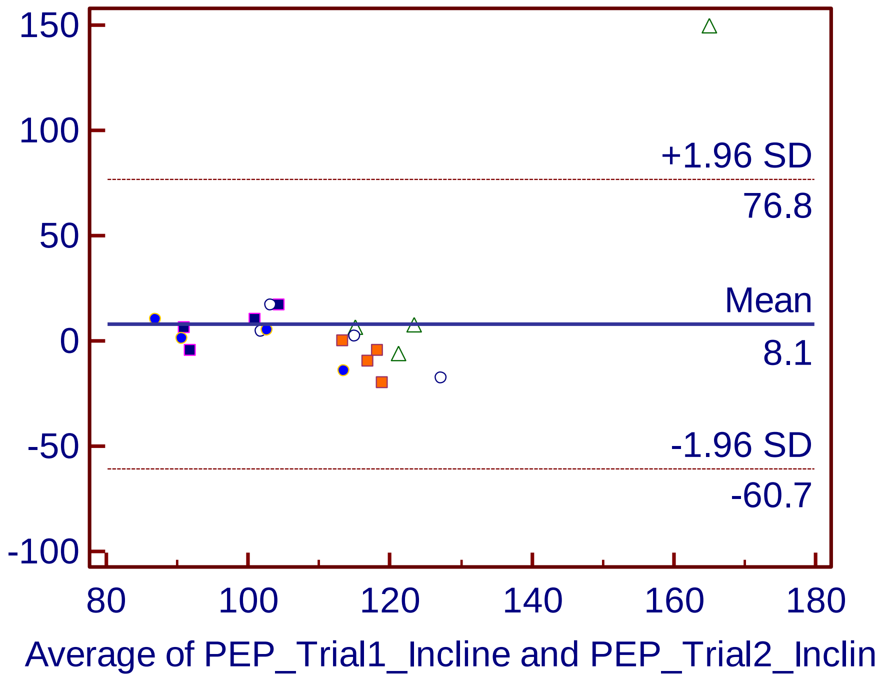


Table 18: Intraclass Correlation PEP Reliability Cognitive Stress

Subject	Single Measure ICC	Average Measure ICC	CI (Single Measure)	CI (Average Measure)
1	.9161	.9562	.1932 to .9943	.3238 to .9972
2	-.1538	-.3636	-.9093 to .8377	-20.0524 to .9117
3	.6812	.8103	-.4908 to .9757	-1.9281 to .9877
4	.4781	.6469	-.6900 to .9553	-4.4516 to .9771
6	.8602	.9249	-.07414 to .9903	-.1602 to .9951
Average	0.55636	0.59494		

Figure 20: Bland-Altman Plot for Method Comparison – PEP Cognitive Stress

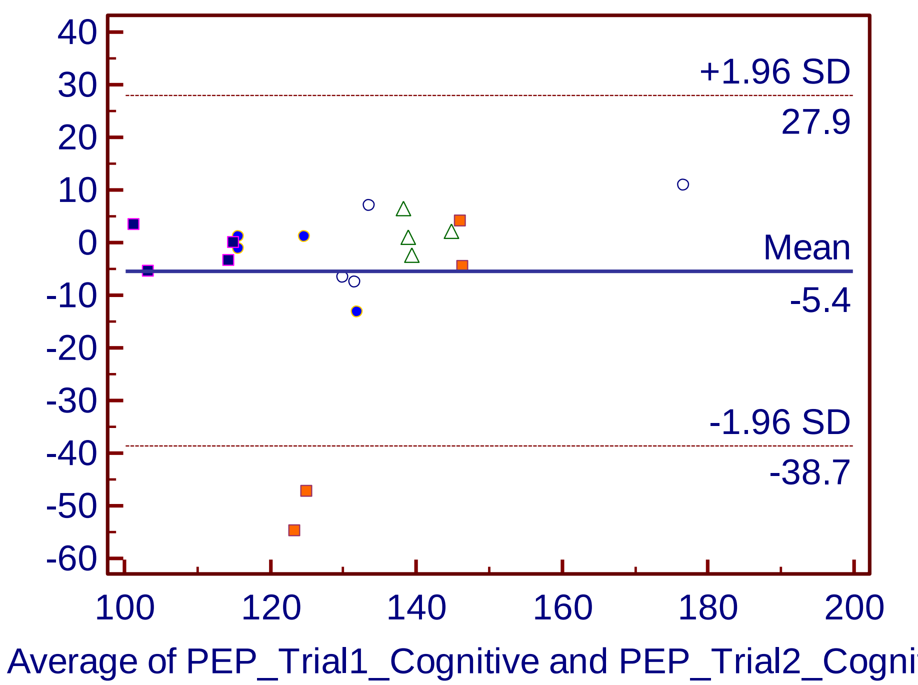


Table 19:Summary of Test-Retest Correlations above .60

Measure	Latent r	Average ICC
HR		
Walking	✗	✓
Incline	✓	✓
Stress	✓	✓
LVET		
Walking	✓	✗
Incline	✗	✗
Stress	✓	✗
SV		
Walking	✓	✗
Incline	✓	✗
Stress	✓	✓
CO		
Walking	✓	✓
Incline	✓	✗
Stress	✓	✓
PEP		
Walking	✗	✗
Incline	✓	✗
Stress	✓	✓
Total Count	12/15	7/15

Table 20:Summary of Significants Week 1 – Week 2 Differences on the Bland-Altman Plot

Measure	Number of Significant Differences*
HR	
Walking	1
Incline	0
Stress	2
LVET	
Walking	1
Incline	2
Stress	1
SV	
Walking	1
Incline	2
Stress	1
CO	
Walking	2
Incline	1
Stress	1
PEP	
Walking	1
Incline	1
Stress	2
Total Count	19/300

*20 Comparisons per Measure

Within Subject Repeated Analysis of Variance

Separate 2 Week x 3 Phase (Waking, Incline, Stress) x 4 (Observation) Repeated Measures Analysis of Variance (RMANOVA) were conducted with the primary cardiovascular measures derived from the ICG.

Heart Rate (HR)

No significant main effect for Week was obtained. A significant main effect for Phase was obtained, $F(2, 4) = 127.017$, $p < .000$, $\eta p2 = .969$. Pairwise comparisons indicated that each Phase was significantly different from one another at the p. $< .05$ level. Review of the HR means by Phase indicates that the highest level of HR was obtained in the Incline Phase (M=123.530, SD=5.647) followed by Walking (M=94.708, SD=4.484), and Stress (M=86.276, SD=7.109). These relationships are found in Figure 20.

Left Ventricular Ejection Time (LVET)

No significant main effect for Week was obtained. A significant main effect for Phase was obtained, $F(2, 4) = 14.685$, $p = .002$, $\eta p2 = .786$. Pairwise comparisons indicated that each Phase was significantly different from one another at the p. $< .05$ level. That is, the LVET during the incline Phase (M=228.898, SD= 8.912) was significantly shorter than the walking phase (M=271.178, SD=13.999), and the walking phase was significantly shorter than the Stress Phase (M=299.415, SD=16.162). These relationships are found in Figure 21.

Figure 21: Estimated Marginal Means of H. 1= Level walking, 2= Incline walking, 3= Cognitive stress.

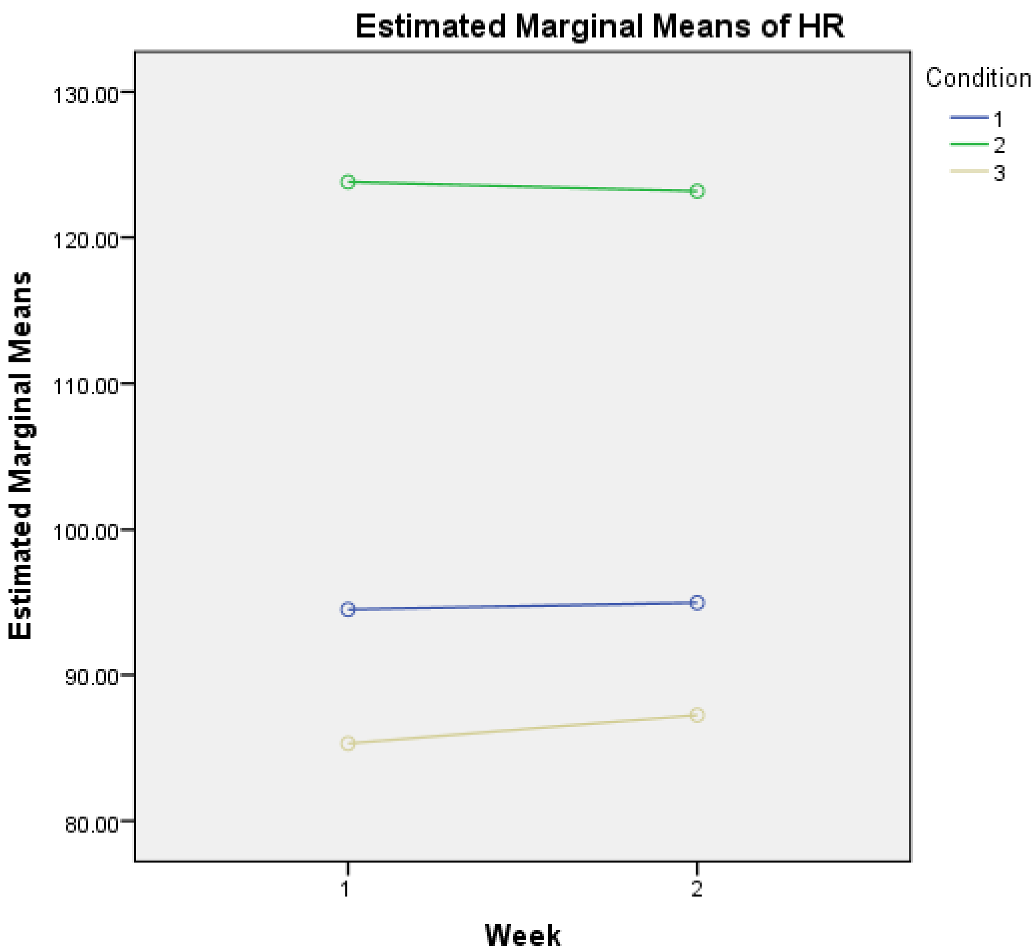
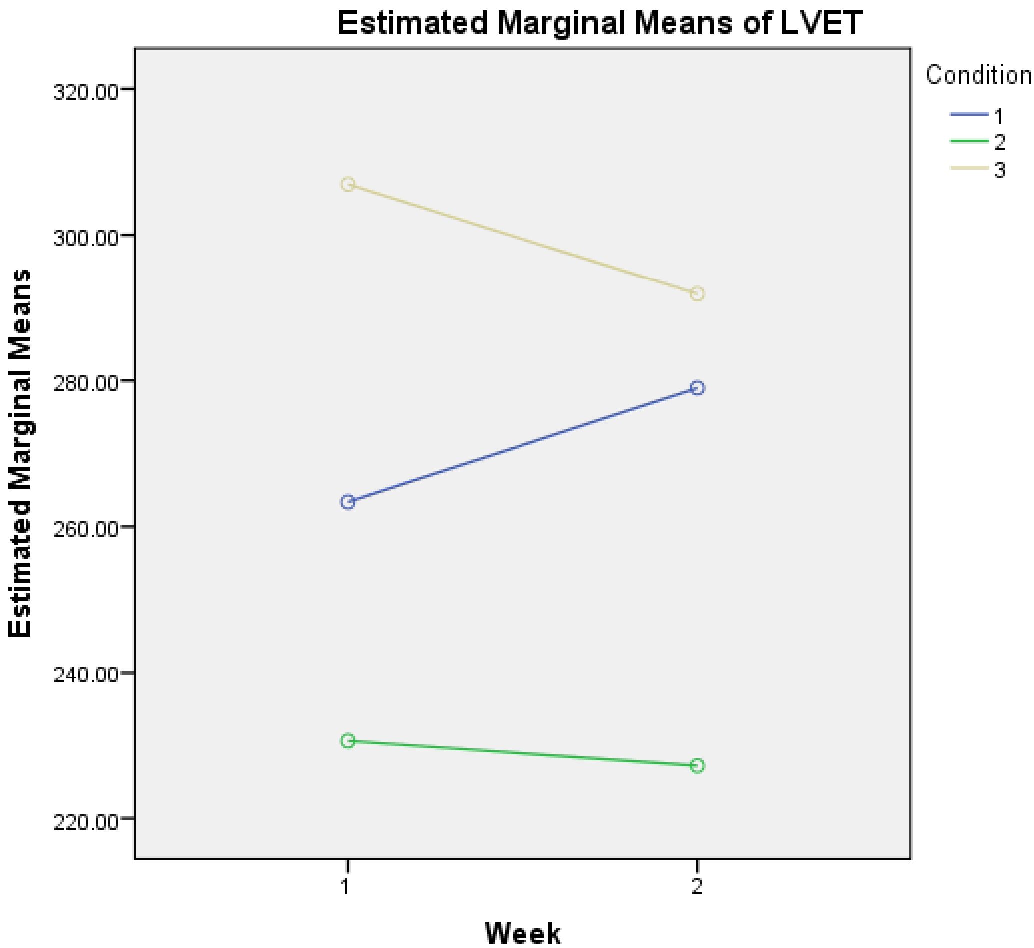


Figure 22:Estimated Marginal Means of LVET1= Level walking, 2= Incline walking, 3= Cognitive stress.



Stroke Volume (SV)

No significant main effect for Week was obtained. No significant main effect for Phase was obtained. Pairwise comparisons indicated no significant differences between phases. Review of the SV means by Phase indicates that the highest level of HR was obtained in the Incline Phase (M=123.530, SD=5.647) followed by Walking (M=94.708, SD=4.484), and Stress (M=86.276, SD=7.109). These relationships are found in Figure 22.

Cardiac Output (CO)

No significant main effect for Week was obtained. No significant main effect for Phase was obtained. . Pairwise comparisons indicated no significant differences between phases. Review of the CO means by Phase indicates that the highest level of CO was obtained in the Incline Phase (M=84.736, SD=19.954) followed by Walking (M=63.995, SD=9.706), and Stress (M=59.740, SD=10.951). These relationships are found in Figure 23.

Pre Ejection Period (PEP)

No significant main effect for Week was obtained. A significant main effect for Phase was obtained., $F(2, 4) = 8.197$, $p = .012$, $\eta p2 = .672$.. Pairwise comparisons indicated that significant difference between incline and stress phase. Review of the PEP means by Phase indicates that the highest level of PEP was obtained in the Cognitive Phase (M=129.765, SD=6.432) followed by Walking (M=121.443, SD=3.3), and Incline (M=111.070, SD=6.301). These relationships are found in Figure 24.

Figure 23:Estimated Marginal Means of SV. 1= Level walking, 2= Incline walking, 3= Cognitive stress.

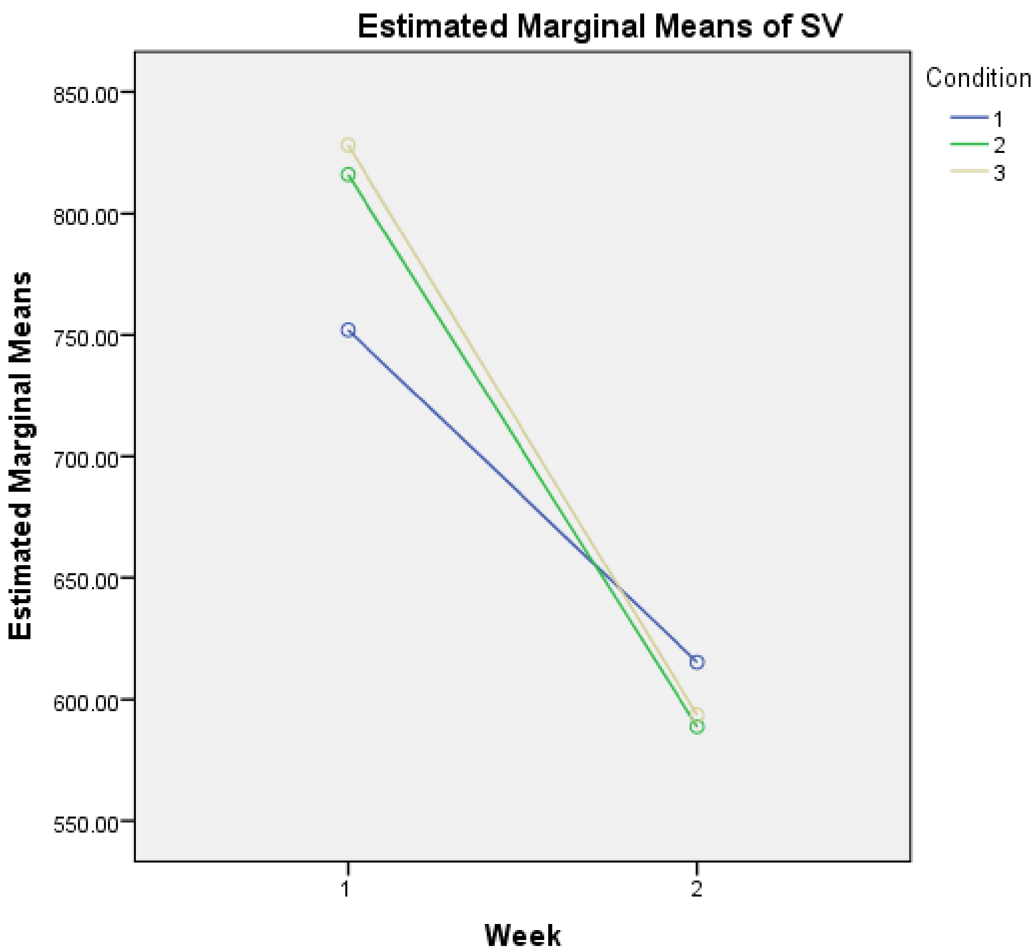


Figure 24:Estimated Marginal Means of CO. 1= Level walking, 2= Incline walking, 3= Cognitive stress.

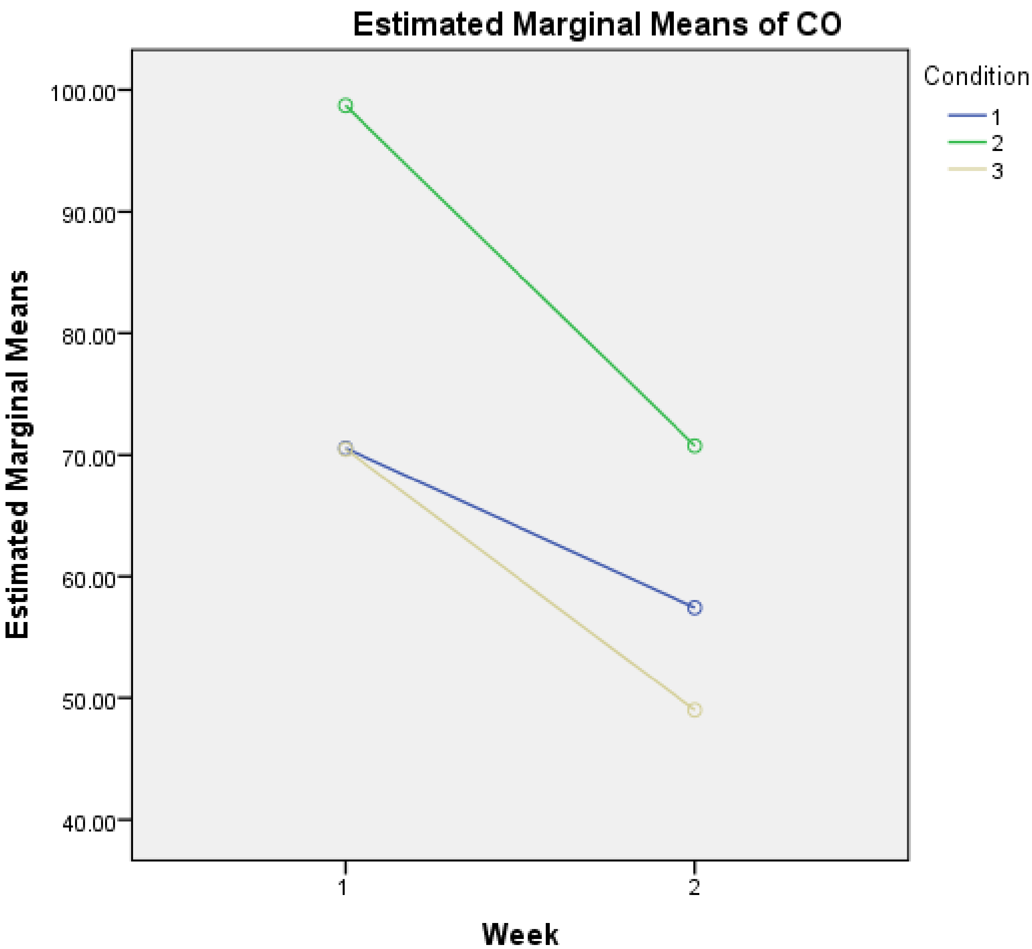
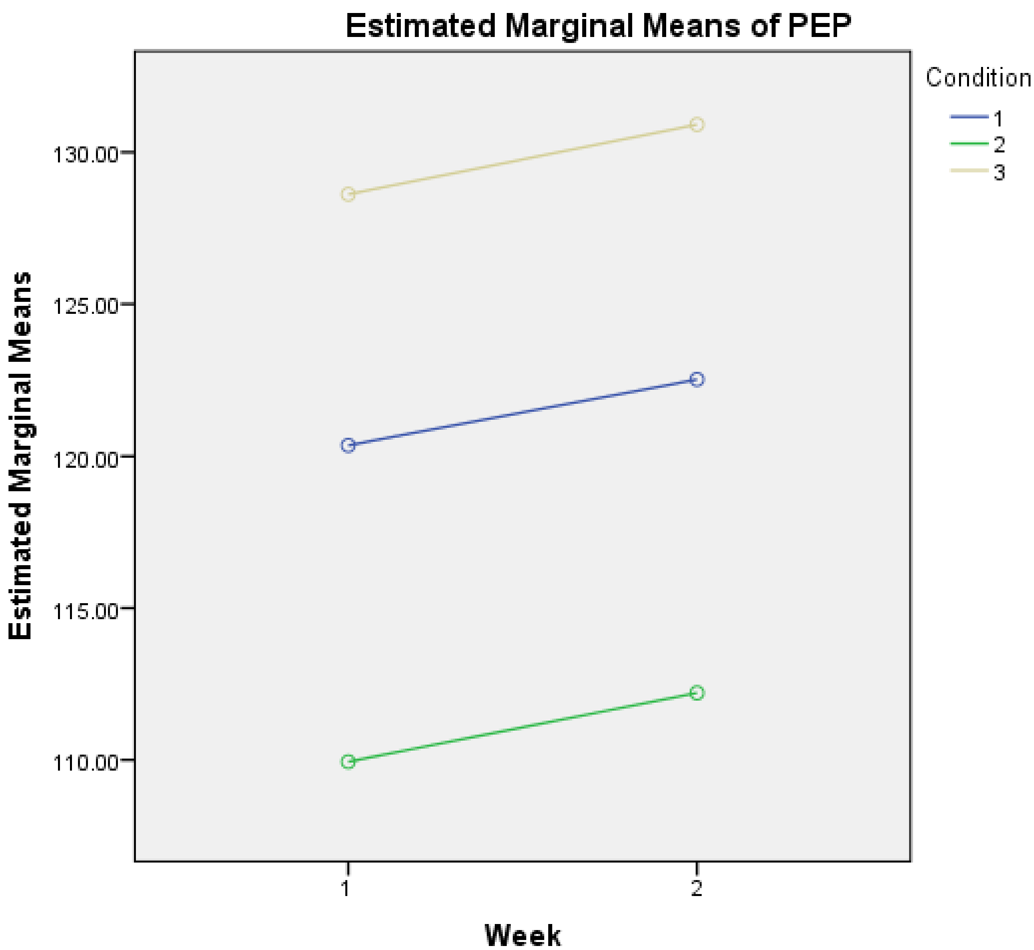


Figure 25:Estimated Marginal Means of PEP. 1= Level walking, 2= Incline walking, 3= Cognitive stress.



Discussion

The current study was conducted in order to establish the test-retest reliability of ambulatory impedance cardiography (ICG) during aerobic exercise and cognitive stress across a 2 week period. For the purpose of this study Heart Rate (HR), Left Ventricular Ejection Time (LVET) Stroke Volume (SV), Cardiac Output (CO), and Pre-Ejection Period (PEP) were acquired and analyzed during three phases. The phases were, walking on a level treadmill, walking at incline, and an at rest cognitive stress test.

Test-Retest Reliability

A number of factors render the determination of the test-retest reliability of the ICG measures difficult. First, only five subjects had complete data. Second, four averages for the physiological measures were obtained during each phase. Physiological data taken in time series is subject to autocorrelation and this can inflate the estimates of reliability. Therefore, three different approaches to estimating test-retest reliability were used.

In the first approach, a structural equation modeling technique was applied using Lisrel. Each observation of each phase from week 1 was treated as an indicator for a latent variable. Likewise each observation of each phase from week 2 was treated as an indicator for a latent variable. Then a correlation was computed between the two latent variables representing the measure at week 1 and week 2. This analysis is more appropriately labeled invariance across time, which is analogous to test-retest reliability. Review of Table 19 indicates that 12 of the 15 measures were correlated at a 0.6 level or higher. A 0.6 cutoff is generally considered adequate. The exceptions for adequate consistency using this approach were HR during walking, LVET during incline, and PEP during walking.

A more traditional approach to computing test-retest reliability was also used. Intraclass correlations (ICC) are similar to Pearson Moment correlations but they are computed slightly different and tend to work better with small sample sizes compared to Pearson correlations, which inflates the correlation in these situations. An ICC was calculated by measure and subject, using week 1 and week 2. Then the average ICC was computed to represent the test-retest reliability. A review of Table 19 indicates the 7 of the 15 measures were correlated at a .6 or better. Needless to say this approach did not produce as robust findings as the structural equation modeling approach with none of the LVET reliabilities reaching .6 and only one of the SV and PEP reliabilities reaching that level. The most consistent phase in which satisfactory test-retest reliability was attained across measures using ICC was during the Cognitive Stress.

A third approach was used to establish the consistency of the measures over time. This was the Bland-Altman Plot. This method compares standardized difference scores and illustrates the number of paired observations more than +/- 1.96 standard deviations from zero (which should only occur by chance 5 times out of 100 or 5%). The Bland-Altman Plots indicated there were only 19 out of 300 (6.3%) paired observations falling outside of +/-1.96 standard deviations.

Comparisons of ICG Indices Across Weeks and Phases

The RMANOVAs conducted on the cardiovascular indices show no significant difference from the subjects initial testing (week 1) to the subjects follow up testing (week 2) on any ICG index. This finding is consistent with the test-retest reliability findings. Furthermore there were significant differences on HR, LVET, and PEP between conditions, consistent with what would be expected given the demands of the task. That is, measures of cardiac functioning increased parametrically from siting and completing a mental arithmetic task, to walking on a treadmill, to walking on a treatment at an incline. There were no significant differences on SV or CO which is difficult to interpret as those measures should be sensitive to the differences in cardiac demand between phases.

Implications

ICG has been routinely recorded in controlled laboratory setting for some time. Richard et al. (2001) demonstrated the test-retest reliability of ICG observations over a three day interval. This study extends this conclusion to ambulatory ICG. Furthermore, it demonstrates that ambulatory ICG recording can be a reliable instrument for the acquisition of cardiac function during exercise and manipulations of cognitive stress. This study indicates that observations will perform consistently from one testing period to another, opening up the possibility of frequent testing in the natural environment.

Future Applications

This study was initially designed as a pilot study to examine the feasibility of using ambulatory ICG while hazard workers are dressed in full Level A HAZMAT suits with a self-contained breathing apparatus. Level A HAZMAT suits, are necessary to protect against external irritants, but are known to cause rapid exhaustion. There might be potential to use ambulatory psychophysiological recordings while workers are wearing a HAZMAT suit. Then hemodynamic status can be monitored continually, and the worker pulled from the field and out of their suit before they suffer any injury.

To summarize, testing conducted here with a small number of subjects has shown that the MW1000A device can provide accurate ambulatory impedance cardiography with no significant difference between testing intervals. The simple application of electrodes makes this device easy to use and requires little training. Its non-invasive properties render employing ICG both a simple and effective means of determining the hemodynamic properties of a subject.

References

American Psychiatric Association, 1994. Diagnostic and Statistical Manual of Mental Disorders, 4th ed. American Psychiatric Association, Washington, D.C.

Gregg , M., James , J., Matyas , T., & Thorsteinsson , E. (1999). Hemodynamic profile of stress-induced anticipation and recovery. *International Journal of Psychophysiology*, *34*, 147-162.

Hand, D. J., & Taylor, C. C. (1987). *Multivariate analysis of repeated measures a practical approach for behavioral neuroscientist.* . London, UK: Chapman and Hail.

Jones, J. (2011). A new frontier for cardiac monitoring. NASA Spinoff, Retrieved from http://www.sti.nasa.gov/tto/spinoff2001/hm1.html

Lozano, D., Norman, G., Knox, D., Wood, B., & Miller, (2007). Where to b in dz/dt. Psychophysiology, 44, 113–11.

McFetridge-Durdle, J., Routledge, F., Parry, M., Dean, C., & Tucker, B. (2008). Ambulatory impedance cardiography in hypertension: A validation study. *European Journal of Cardiovascular Nursing*, *7*, 204-214.

Moreno, L. (2010). Noninvasive real-time continuous hemodynamic monitoring with ambulatory impedance cardiography within remote, austere environments. In Florida Space Research Program. Orlando

Moreno, L. (2011). Noninvasive Continuous Hemodynamic Monitoring with Ambulatory Impedance Cardiography During a Submaximal Exercise Protocol: Ensemble Window

Modification Determines LVET during Mild-to-Moderate Physical Exertion. *Florida space grant consortium*.

Myrtek, M. and Spital, S. (1986) Psychophysiological response patterns to single, double, and triple stressors. *Psychophysiology*, 23: 663-671

Richard, R., Lonsdorfer-Wolf, E., Charloux, A., & Doutreleau, S. (2001). Non-invasive cardiac output evaluation during a maxima progressive exercise test, using a new impedance cardiograph device . *European Journal of Applied Physiology, 85*, 202-207.

Roth, D.L., Bachtler, S.D. and Fillingim, R.B. (1990) Acute emotional and cardiovascular effects of stressful mental work during aerobic exercise. Psychophysiology, 27: 694-701.

Rousselle, J., Blascovich, J., & Kelsey, R. (1995). Cardiorespiratory response under combine psychological and exercise stress . *International Journal of Psychophysiology , 20*, 49-58.

Saab, P., Llabre, M., Hurwitz, B., Schneiderman, N., Wohlgemuth, Q., Durel, L., Massie, C., & Nagel, J. (1993). The cold pressor test: vascular and myocardial response patterns and their stability. *Psychophysiology, 30*, 366-373.

Selye, H., 1993. Goldberger, L., Breznitz, S. Eds., History of the stress concept In: Handbook of Stress, *Theoretical and Clinical Aspects Free Press*, New York, pp. 717

Shrout , P. E., & Fleiss , J. L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin , 86*(2), 420–428. doi: 10.1037//0033-2909.86.2.420

Siconolfi, S.F., Garber, C.E., Baptist, G.D., Cooper, F.S. and Carleton, R.A. (1984) Circulatory effects of mental stress during exercise in coronary artery disease patients. *Clinical Cardiology*, 7: 441-444

Van De Wate, J., Miller, T., Vogel, R. & Mount, B., (2003). impedance cardiograph : the next vital sign technology?. *Chest*, 123, ;2028-203.
DOI: 10.1378/chest.123.6.202

Ziegele, S., Grundmann, U., Fuers, O., Raddat, A., & Kreue, S. (2006). Hemodynamic response to exercise as measured by the solar ikg impedance cardiography module and correlation with metabolic variables. *Journal of Clinical Monitoring and Computing*, *21*, 13-20. doi: 10.1007/s10877-006-9053-