# DOES INTRA-ABDOMINAL PRESSURE EXHIBIT CHARACTERISTICS SIMILAR TO MEASURES OF PHYSICAL FITNESS?

by

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A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

in

Exercise and Sport Science

Department of Health, Kinesiology and Recreation

The University of Utah

May 2018

The University of Utah Graduate School

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# ABSTRACT

Intra-abdominal pressure (IAP) is the pressure within the abdominal cavity. IAP is routinely studied in the field of urogynecology to comprehend its relation to pelvic floor disorders. In contrast to the potential negative role of high IAP on the pelvic floor, IAP is important for various forms of human performance. Given the disparate thoughts on IAP and its impact on pelvic floor health and sport and exercise performance, better understanding the IAP response in women without pelvic floor disorders during physical activity is warranted. In brief, the purpose of the study was to describe IAP responses during a variety of exercises and physical activities in women without a history of pelvic floor disorders. Our primary aim is to calculate the percentage of maximal for a select group of the activities detailed in a previous study, using the IAP during seated ValSalva (VM) as the maximal capacity. A secondary aim is to characterize the relationship between the relative term of percent of maximal for each activity, and maximal IAP. We hypothesize that there will be an inverse relationship between percentage of maximal for each activity and maximal IAP.

In total, the data of 55 women were included in the analysis. Women were aged 20-54 (*M* 30.38±*SD* 9.43 yrs) and had BMI values between 17.7-28.9 (*M* 22.4±*SD* 2.63 kg/m$^2$). Participants completed a 1-hour exercise protocol in a human performance laboratory.

Pearson *r* correlation results indicate that all relative values (% maximal of seated

VM) were significantly and negatively correlated at ($p<0.001$) with seated VM IAP, except for seated shoulder press with 6.9 kg ($p$ 0.023) and 9.1 kg ($p$ 0.557).

Our findings support the contention that the IAP response to individual, submaximal activities exhibits a similar relationship to maximal capacity as that observed in well-established measures of fitness, such as muscular strength and oxygen consumption. It is imperative that coaches understand the relationship between IAP and higher intensity efforts during training. With this knowledge, strength and conditioning specialists may adjust training practices in order to limit the likelihood of precipitating pelvic floor symptoms in women.

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# CHAPTER 1

# INTRODUCTION

Intra-abdominal pressure (IAP) is the pressure within the abdominal cavity. The boundaries of the abdominal cavity consist of the thoracic and lumbar spine, muscles of the abdominal wall, diaphragm, and pelvic floor. Together, these muscles and structures form a cylindrical cavity allowing for regulation of IAP. The contraction and relaxation of muscles surrounding the abdominal cavity contribute to changes in volume. The inverse relationship between volume and pressure dictates that muscular contraction of muscles surrounding the abdominal cavity decreases the volume and increases the pressure. Cresswell and colleagues observed that the erector spinae, internal obliques, external obliques, and the transverse abdominus all contributed to increases in IAP during lifting tasks (Cresswell & Thorstensson, 1994). These authors found that the transverse abdominus contributed most to IAP, likely due to the circumferential orientation of the transverse abdominis muscle fibers around the trunk.

Direct or indirect methods can assess IAP, which exhibits great variability between people. The direct methods involve placing a catheter into the abdominal cavity. Indirect measurements are taken in the bladder, gastrointestinal tract, rectum, or vagina, and have been shown to accurately measure IAP (De Waele, De laet, & Malbrain, 2007). IAP is usually measured in $cmH_2O$, and high values achieved through voluntary effort are typically observed during a ValSalva maneuver (VM). The VM involves forcefully exhaling against a closed airway, accomplished through a closed glottis preventing any air from escaping the lungs. The VM increases IAP and consequently creates a rigid torso (Haff, 2016). Brandt et al. (2006) reported IAP of 7-193 cm$H_2O$ with a mean of 99.3 cm$H_2O$ in women aged 36-56 years while maximally straining measured though a rectal catheter. Shaw and colleagues (2014) indicated women utilizing a vagina pressure transducer achieved values of 16-220 cm$H_2O$ while performing a seated ValSalva. Other researchers reported IAP values of 16-137 cm$H_2O$ measured through a rectal catheter in women performing the VM (Greenland, Hosker, & Smith, 2007).

IAP is routinely studied in the field of urogynecology to comprehend its relation to pelvic floor disorders (Nygaard & Shaw, 2016). That is, exposure to high IAP is considered by many as deleterious to the pelvic floor. For example, sudden and quick increases of IAP are linked to stress incontinence, the involuntary loss of urine, in women (Nygaard & Shaw, 2016). Some clinicians and data suggest that high IAP may also contribute to the development of pelvic organ prolapse (Woodman et al., 2006). Approximately 1 in 4 women in the U.S. experience symptoms related to urinary incontinence, pelvic organ prolapse, and fecal incontinence (Nygaard & Shaw, 2016), so it is important to consider preventive measures, which may involve limiting exposure to high IAP.

It is estimated that the number of women who undergo pelvic organ prolapse surgery will increase by 47% from the year 2010-2050 (Bradley, Weidner, Siddiqui, Gandhi, & Wu, 2011). Due to the increasing prevalence of pelvic floor surgery, physicians and leading organizations recommend that women limit repeated heavy lifting and exercises requiring near maximal or maximal exertion (Nygaard & Shaw, 2016). This recommendation aimed to prevent the incidence of pelvic floor disorders and reduce complications post-pelvic-floor surgery. The American Urogynecologic Society released a statement recommending the “Do’s” and “Don’t’s” regarding prevention of pelvic floor disorder (Society, 2017). In the document, this organization recommends that women avoid repetitive strenuous exercises and heavy lifting placing strain on the pelvic floor. Specifically, the suggested median recovery period post-pelvic-floor surgery was 1-2 weeks for nonstrenuous activities and 4-5 weeks for strenuous activities (Nygaard & Shaw, 2016). Restrictions set by physicians include avoiding lifting for a mean of 5-7 weeks, carrying over 15 kg, and standing and walking for an entire workday for 4 weeks. In addition, there are other instances when these restrictions may also be warranted. In literature regarding inguinal hernias, it was reported that the ValSalva maneuver, heavy lifting, coughing, and physical activity might be the cause of herniation. Continuing these activities could increase the risk of hernia enlargement. However, when or how to restrict these activities was not reported in the literature (Ouellette & Dexter, 2006).

In contrast to the potential negative role of high IAP on the pelvic floor, IAP is important for various forms of human performance. Specifically, successful technique during many athletic movements and common exercises require spinal stability, sometimes referred to as trunk rigidity (Hodges, Eriksson, Shirley, & Gandevia, 2005; Haff, 2016). Further, a stiff trunk allows for optimal force transfer during certain movement patterns (Ulm, 2017). Athletes and recreational exercisers will achieve trunk stiffness by consciously engaging the abdominal musculature and controlling ventilation, which often results in breath holding and performing some degree of the VM, depending upon the strenuousness of the task. Increasing pressure of the abdominal cavity stabilizes the ribs, pelvis, and spine, creating a fixed point that optimizes lower and upper body movement patterns. In the task of lifting a heavy weight off the floor and then pressing it overhead, the resultant IAP generated will vary depending on how difficult the task is for a given individual. Referencing task difficulty to an individual provides an index of "relative intensity." When a task requires high force output or high relative intensity, IAP will be high. Conversely, during low relative intensity lifting, IAP will be low (Kolar et al., 2010; Ulm, 2017). What constitutes "high" or "low" IAP may relate to an individual's capacity rather than to an absolute scale for IAP in $cmH_2O$.

Weightlifters and exercise enthusiasts commonly perform the VM in order to stabilize the trunk while performing exercises near maximal capacity. Research shows that the VM alone increases IAP even higher than the IAP achieved during various resistance exercises, which may also include the VM (Hackett & Chow, 2013). For example, during a deadlift, the VM stabilizes the spine and the individual generates muscular force to overcome the load. However, the IAP generated during the deadlift reflects a lower value compared to the same individual's VM despite an increase in the biomechanical stress placed on the body during the lift. Furthermore, the author suggests that the VM is a natural reflex that is evoked during resistance exercise when near maximal or maximal efforts are required. Weightlifters also seek to further enhance spinal stability by using weightlifting belts. Lander and colleagues (1992) demonstrated a 25-40% increase in IAP for participants wearing a weightlifting belt while performing barbell back squats at a 8-repetition maximum compared to when participants did not. This is purported to offer lumbar spinal relief during the lifting of heavy objects and acts as an externally applied device to further increase IAP.

Improvements in IAP and spinal stability, even without lifting additional weight, augment lower body muscular strength and power, which could translate to improved physical performance (Tayashiki, Maeo, Usui, Miyamoto, & Kanehisa, 2016). Specifically, these authors asked young men to engage in a regular program of abdominal bracing, which was essentially isometric engagement of the abdominal muscles, over several weeks.  The participants improved their lower body muscular strength and power as well as increased their IAP during VM from this program of abdominal bracing alone. In the field of athletics, such improvement may translate to increase sport capability, which is the rationale for instituting routine strength and conditioning as an adjunct to sport specific training. For example, an American football lineman who requires lower body power to move an opposing player, or a basketball player who requires lower body power to jump higher than an opponent, both benefit from auxiliary training that is necessarily accompanied by high IAP. Consequently, exercises to increase lower body strength and power require spinal stability and are standard adjuncts in athletics.

Detailed studies describing exercise program design in professional women's athletics have not been conducted. Therefore, data on exercises utilized by strength coaches and their implication on spinal stability and IAP in women is unavailable. However, it is plausible that these training programs are similar to those conducted in men, save for the absolute intensities achieved, with males tending to achieve higher absolute intensities compared to females. In male professional sports, most athletic training programs include compound movement patterns such as the clean and jerk, squat, deadlift, overhead press, or a variation of these exercises. For example, in the

National Basketball Association, National Hockey League, and Major League Baseball, all coaches in these organizations reported using Olympic lifts and the squat exercise in order to develop the power and strength necessary to be successful in their respective sports (Ebben, Carroll, & Simenz, 2004; Ebben, Hintz, & Simenz, 2005; Simenz, Dugan, & Ebben, 2005).

Given the disparate thoughts on IAP and its impact on pelvic floor health and sport and exercise performance, better understanding the IAP response in women without pelvic floor disorders during physical activity is warranted. If athletic and fitness coaches encourage abdominal bracing to stiffen the trunk by increasing IAP, do such repeated exposures reflect the overload principle, thereby increasing the capacity to further generate IAP? Should IAP be expressed using an absolute value in $cmH_2O$, or is this best understood with reference to an individual's maximal capacity for generating IAP? If referenced to an individual's maximal capacity, then any given IAP response to an activity can be expressed in relative terms. For example, lifting a 50 lb. bag of dog food could generate 80 $cmH_2O$ in woman A, and 60 $cmH_2O$ in another woman, B. If woman A does a VM with 160 $cmH_2O$, then lifting the bag of dog food represents 50% of her maximal capacity. If woman B does a VM with 80 $cmH_2O$, then lifting the bag of dog food represents 75% of her maximal capacity. Using relative values would suggest that the lower absolute IAP in fact reflects a higher relative effort for woman B doing the same task as woman A.

Expressing IAP response to activity in relative terms with respect to an individual's maximal capacity is the manner in which measures or correlates of physical fitness are expressed. Specifically, high maximal capacity is used as an indicator of high levels of fitness and submaximal efforts are indicated in terms that are relative to the maximal capacity as a percentage. Because IAP is not routinely assessed in association with physical exercise trials, controlled, longitudinal training that would increase exposure to IAP has not been conducted to determine whether such training a) increases maximal capacity for generating IAP and b) reduces the relative strain for a given task at lower levels as explained in the example above.

This project explores a secondary analysis of data collected by Shaw et al. (2014). In brief, the purpose of the study was to describe IAP responses during a variety of exercises and physical activities in women without a history of pelvic floor disorders. Conducted in a laboratory, several traditional exercises and other likely household tasks were studied, along with seated VM, which produced the highest IAP for the group. The complete protocol as described in Shaw et al. (2014) will hereafter be referred to as the "original" protocol from which this study was adapted.

The current paper, using archived data from the original protocol, will provide a preliminary investigation of whether IAP "behaves" in a similar manner to other correlates or indicators of physical fitness. The first aim of this paper is to calculate the percentage of maximal for a select group of the activities detailed in Shaw et al. (2014), using the IAP during seated VM as the maximal capacity. The second aim is to characterize the relationship between the relative term of percent of maximal for each activity, and maximal IAP. We hypothesize that there will be an inverse relationship between the percent of maximal for each activity and maximal IAP. If this hypothesis is supported, these findings will provide preliminary indication that IAP behaves as a correlate or indicator of physical fitness.

## 1.1 What Is Physical Fitness?

According to the National Institutes of Health, physical fitness is defined as a set of attributes that are either health- or skill-related. These attributes are categorized to distinguish different areas of physical fitness, including body composition, cardiorespiratory fitness (CRF), muscular strength, muscular endurance, and flexibility (Pescatello, 2014). Supplemental to health-related physical fitness are skill-related aspects of fitness, which include agility, balance, coordination, speed, and reaction time (Baechle, 2008). An important distinction must be made between physical fitness, exercise, and physical activity. Physical activity is defined as any bodily movement produced by skeletal muscles resulting in energy expenditure above resting levels. Exercise, which is a subset of physical activity, is structured and meets thresholds for duration and intensity with the objective of maintaining or improving physical fitness (Caspersen, Powell, & Christenson, 1985).

Research has demonstrated a relationship between physical fitness and health-related outcomes. The effects of physical fitness and all-cause mortality in men has been studied (Blair et al., 1995). These authors hypothesized that the highest age-adjusted all-cause mortality rate would be observed in men who had the lowest levels of CRF, and therefore were assigned as the referent.  Comparatively, the all-cause mortality rate in men who were fit was significantly lower (RR 0.33) than in the least fit. In addition, there was a 44% reduction in mortality rate for men who improved from unfit to fit during the initial and subsequent examination (RR 0.56) (Blair et al., 1995). Low CRF levels and other predictors are correlated to higher CVD mortality in men. After an average 8.4-year follow-up and adjusting for smoking, elevated systolic blood pressure, and elevated blood cholesterol, low CRF level was the highest predictor of death resulting from CVD (Farrell et al., 1998).

Some portion of physical fitness is heritable (Costa et al., 2012; Garatachea & Lucia, 2013). That is, the expression of physical fitness reflects engagement in exercise and good fitness genes. Both are needed to obtain high levels of physical fitness. Another study aimed to focus on the quantification of genetic and environmental sources of variation in physical fitness components in 105 10-year-old twin pairs and their parents. Subjects participated in performance-related tests that included static strength, explosive strength, running speed, speed of limb movement, and balance. They also participated in health-related tests: trunk strength, functional strength, maximum oxygen uptake, and flexibility. Performance-related fitness characteristics exhibited a moderate to high heritability and heritability for health-related fitness characteristics was slightly higher (Maes et al., 1996). Genetic inheritance can account for 40-70% for peak oxygen uptake, a classic measure of CRF, and cardiac mass and structure, and 30-90% for anaerobic power and capacity, depending on metabolic category (Costa et al., 2012). Although components of physical fitness display a measure of heritability, augmentations in any of the components require stimulus and sustained effort. A detailed description of each component of physical fitness will be provided to solidify the importance each plays in physical fitness and health.

### 1.1.1 Measures of Physical Fitness: Muscular Strength

Muscular strength is the maximal force that a muscle or muscle group can generate at a specific velocity to overcome external forces (Baechle, 2008). The more force the muscle or muscle group is able to produce, the heavier loads it can overcome and thus, increased muscular strength is required. Muscular strength is necessary in everyday activities such as standing from a seated position, being able to pick up objects from the floor and placing them overhead like placing a suitcase in an overhead compartment in a plane or a bus. Participating in exercises that mimic these movement patterns and that require higher loads that would be encountered in everyday life will create greater efficiency in that movement. According to the American College of Sports Medicine (ACSM), resistance training is a form of physical activity that is designed to improve muscular fitness by exercising a muscle or a muscle group against external resistance (Dunn-Lewis & Kraemer, 2016). Participating in resistance training helps decrease the loss of lean muscle mass, prevent osteoporosis, decreased blood pressure, decreased body fat percentage, and risk of heart disease (Pescatello, 2014). Resistance training can increase lean body mass and combined with aerobic training can reduce fat mass (Willis et al., 2012). In earlier research, males participating in resistance training exhibited lower systolic and diastolic blood pressures compared to less-trained and sedentary men (Fleck & Dean, 1987). Males and females aged 55-74 years old who performed resistance training displayed significant increases in bone mineral density after 40 weeks of training (Bemben & Bemben, 2011). For general health, the ACSM recommends 8-10 exercises targeting major muscle groups with at least one set of 8-12 repetitions of 2 nonconsecutive days of the week minimum (Dunn-Lewis & Kraemer, 2016). Both the ACSM and the National Strength and Conditioning Association (NSCA) recommend ranges between 2-6 sets, 1-8 repetitions with 2-5 minutes rest between each set when focusing on muscular strength (Baechle, 2008; Dunn-Lewis & Kraemer, 2016).

### 1.1.2 Measures of Physical Fitness: Muscular Endurance

The ability to produce and maintain force production over prolonged periods of time is defined as muscular endurance (ACSM, 2009; Pescatello, 2014). Benefits of increasing muscular endurance are similar to benefits obtained by increasing muscular strength through participation in regular resistance training. The ranges recommended by the ACSM and NSCA for muscular endurance are between 2-4 sets, 12-25 repetitions, and 1 minute or less of rest between each set (Baechle, 2008; Dunn-Lewis & Kraemer, 2016).

### 1.1.3 Measures of Physical Fitness: Cardiorespiratory Capacity

Cardiorespiratory fitness is the ability of the lungs and heart to supply oxygen-rich blood to working muscles within the body (Baechle, 2008; Pescatello, 2014). Higher physical fitness level is associated with better cardiovascular health and vascular function in nonexercising older individuals (Oudegeest-Sander et al., 2015). To examine this, 40 healthy older individuals aged 65 to 73 who were classified as nonexercising for the past 5-10 years were allocated to a lower physical fitness ($VO_2$max $20.7 \pm 2.4$ $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) or higher physical fitness group ($VO_2$maax $29.1 \pm 2.8$ $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). The researchers reported that the Lifetime Risk Score indicating risk for developing cardiovascular disease over a lifetime was significantly higher in the low-fitness group compared to the high-fitness group. In addition, they reported that higher physical fitness levels were associated with better cardiovascular health and vascular function. The association between low fitness and mortality across short (0 to 10 years), intermediate (10 to 20 years), and long-term (>20 years) time periods was explored (Vigen, Ayers, Willis, DeFina, & Berry, 2012). After a median 16 years follow-up, low cardiovascular fitness was associated with all-cause mortality across all periods of time in men. Further, a significant relationship exists between increased cardiovascular fitness and lower mortality risk, even while adjusting for total sedentary time and other covariates (Shuval et al., 2015).

To improve or maintain CRF, both the ACSM and the American Heart Association (AHA) recommend moderate aerobic activity (64% to 76% of maximum heart rate) for 30-60 minutes a day for 5 days a week or 20-60 minutes of vigorous aerobic activity (77% to 93% of maximal heart rate) for 3 days a week. This is accomplished through rhythmic contraction of large muscle groups such as walking, running, jogging, and cycling. Increased cardiorespiratory fitness leads to a lower risk of heart attack, stroke, reduced blood pressure, increased insulin sensitivity, and positive changes in blood lipid profile (Pescatello, 2014).

### 1.1.4 Measures of Physical Fitness: Flexibility

Flexibility is the ability for a joint to move in a specific range of motion. Since muscles are the contracting force that allows for these movements, the ability to maintain their elasticity becomes of increasing importance with increasing age. Decreased flexibility can lead to injury, decreased efficiency of activities of daily living, and overall quality of life (Pescatello, 2014; Raab, Agre, McAdam, & Smith, 1988). A loss of skeletal muscle mobility is associated with a reduction in physical performance (Schenkman, Hughes, Samsa, & Studenski, 1996). In addition, this decline may be modified through flexibility training. In a study conducted by Worrell and colleagues

(1994) on 19 subjects, flexibility increased after performing both static (+21.3%) and proprioceptive neuromuscular facilitation (+25.7%) types of stretching. As flexibility increases, there is a reduction in the incidence of muscular and skeletal injuries (Witvrouw, Mahieu, Danneels, & McNair, 2004). The guidelines established by the ACSM suggest stretching all major muscle groups at least 2-3 days a week, holding each stretch for 10-30 seconds for at least 4 repetitions per muscle group (Dunn-Lewis & Kraemer, 2016).

### 1.1.5 Measures of Physical Fitness: Body Composition

Body composition is the measured ratio of fat to fat-free mass in the body. Fat-free mass is one of two body components that includes internal organs, bone, muscle, connective tissue, and water. Fat mass is the amount of adipose tissue found in the body. Generally speaking, individuals with high levels of aerobic and muscular fitness typically have lower levels of body fat and higher levels of fat-free mass compared to their counterparts with low levels of aerobic and muscular fitness.

Body composition is routinely measured through indirect means to determine relative proportions of fat and fat-free mass. Common examples include the assessment of multiple skin fold measurements, air plethysmography using equipment such as the Bod Pod, water displacement, or hydrostatic weighing, and dual energy x-ray absorptiometry (DXA). Most research has established a positive correlation between body fat percentage and risk for coronary artery disease, type 2 diabetes, and certain cancers (Pescatello, 2014). Body fatness, in particular visceral adipose tissue accumulation, is associated with insulin resistance and incidence of type 2 diabetes

(Goedecke & Micklesfield, 2014). Britton et al. (2013) explored the relationship between body fat distribution, incident cardiovascular disease, cancer, and all-cause mortality. After multivariable adjustment, visceral adipose tissue was associated with cardiovascular disease (RR= 1.44) and cancer (RR= 1.43).

Body fat levels vary depending on the sex and age of the individual. Males typically range from 6-24% and females from 13-31% based upon population normative data (ACSM, 2009; Pescatello, 2014). Maintaining a healthy body fat percentage is key in reducing the risk of certain diseases, though practically speaking, most often this notion is supported by evidence of body mass index (BMI, $kg/m^2$), and not a true measure of body composition. Nonetheless, body composition is an important measure of physical fitness.

Enhanced measures of physical fitness lead to greater efficiency in daily tasks and decreased risk for disease and mortality. Exercise principles must be followed to observe improvements in various components of physical fitness.

## 1.2 Exercise Principles

There are many principles that guide the practice of exercise training to ensure appropriate increase in physical fitness over time. One of the most important principles is progressive overload. The principle of progressive overload states that for continual adaptation to occur, the stimulus of overload must be progressive. That is, the dose of exercise must increase over time. With progressive overload, the body adapts to the stress and stimulus placed upon it, resulting in improved physical fitness (Baechle, 2008). This is true for any of the physical fitness variables stated previously, and is best illustrated using the variable of muscular strength.

Most strength gains at the beginning of a resistance training program occur due to neural adaptations and improvements in motor control (Baechle, 2008). When performing a novel task, such as a new exercise, there must be motor adaptations and learning, which improves an individual's ability to perform that task with greater efficiency and effectiveness. This process of improvement can include beneficial adaptations in firing rate, sequence of firing, and number of motor units recruited. For example, anaerobic training, which can include resistance training, enhances firing rates of recruited motor units (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). If each motor unit within a muscle is capable of producing more force after training, this would result in fewer motor neurons needing to be recruited to produce an equivalent outcome, in this case, the expression of muscular strength (Carroll, Riek, & Carson, 2001; Ploutz, Tesch, Biro, & Dudley, 1994). Following the first 8 weeks of an exercise program, increases in muscular strength are attributed to physiological adaptations occurring in the muscle (Haff, 2016). Regardless of the mechanism, exposing individuals to increasing stress or stimulus results in muscular strength augmentation.

Muscular strength gains with training varies by initial levels of training and exercise program components. The literature is replete with resistance training studies employing different levels of stimulus. The following discussion is limited to a few examples to illustrate most important points. A review of more than 100 articles showed an approximate increase in muscular strength of 40% in untrained individuals, 20% in moderately trained, 16% in trained, 10% in advanced trained, and 2% in elite athletes during exercise program durations ranging from 4 weeks-2 years (Pescatello, 2014). This graduated response to training in varying levels of initial experience is known as diminishing returns. Muscular strength increases were observed following a 4-week program in which participants exercised 3 times a week using a heavy weight stimulus of 5 sets of 6-10 repetitions of biceps curl. Participants increased maximal dynamic and isometric muscle strength by 31% and 12.5%, respectively (Jensen, Marstrand, & Nielsen, 2005). Increases in muscular strength have been observed in individuals participating in nonspecific exercise protocols beyond 4 weeks. Participants who engaged in 5 sets of 10 repetitions of abdominal bracing for 3 times a week over 8 weeks exhibited improvements in lower body muscular strength (34.7%) and lifting power (15.6%) compared to baseline (Tayashiki et al., 2016).

Other researchers demonstrated enhancements of muscular strength in trained males ensued following a resistance training protocol. One group trained with a high load, consisting of 3 sets of 8-10 repetitions while a second utilized a low load of 3 sets of 25 to 35 repetitions. The high-load group utilized much higher relative resistance to induce fatigue in 8 to 10 repetitions. Therefore, the low-load group utilized much lower resistance, allowing for many more repetitions prior to achieving fatigue. Both groups exercised 3 times per week for 8 weeks. All groups performed exercises aimed at targeting all major muscle groups: flat barbell press, barbell military press, wide-grip lat pull-down, seated cable row, barbell back squat, machine leg press, and machine leg extension. Both groups improved muscular strength assessed through 1 repetition maximum back squat, with the high-load group demonstrating greater improvements compared to the low-load group (19.6% vs. 8.8%) (Schoenfeld, Peterson, Ogborn, Contreras, & Sonmez, 2015). In the examples listed above, observed increases in muscular strength followed a stimulus novel to the participant, and magnitude of increase in strength was associated with higher relative loads, therefore coinciding with the principle of progressive overload.

In addition to adaptations that specifically correlate to performance and physical fitness due to the principle of overload, exercise has the potential to improve indices of physical health. These include blood lipid levels, metabolic syndrome, blood pressure, and resting heart rate. High levels of cholesterol, LDL, and triglycerides have been associated with high risk for atherosclerosis and other CVD. Stefanick et al. (1998) demonstrated that there was a significant decrease in total cholesterol, LDL, and triglyceride levels in both men and women who participated in a 6-week aerobic exercise intervention 3 times a week compared to controls at 6-8-month follow-up. Johnson and colleagues (2007) demonstrated that both exercise at low amount/moderate intensity (walking 12 miles/week at 40-55% of peak oxygen consumption) and high amount/high intensity (jogging 20 miles/week at 65-80% of peak oxygen consumption) was successful in reducing metabolic syndrome compared to control group. Aerobic exercise is effective in decreasing systolic blood pressure by 4.39 mmHg and diastolic blood pressure by 2.87 mmHg (Whelton et al., 2002). With increasing aerobic training, adaptations with stroke volume, blood pressure, maximal oxygen intake, and other metabolic adaptations exhibited a dose response (Ilmarinen & Fardy, 1977). These adaptations result in an increase in maximal aerobic capacity. As maximal capacity increases, individuals attain higher levels of physical fitness. Participating in repeated aerobic exercise stresses the heart and results in adaptations leading to greater efficiency. Most noticeable is the decrease in resting heart rate and a decrease in heart rate to a given submaximal effort, indicating increased efficiency. This change in heart rate occurs largely as a function of greater stroke volume to achieve the same cardiac output. In other words, the stress placed on the heart diminishes despite the workload remaining the same (Pescatello, 2014; ACSM, 2009).

In order to determine specific exercise workloads that will cause desired physiological adaptations, exercise prescriptions indicate the intensity, or effort, expressed as a percentage of maximal capacity. In the case of aerobic fitness, maximal capacity is most commonly expressed as maximal oxygen consumption ($VO_2$ max), and the exercise stimulus to promote fitness is written as the percentage of $VO_2$ max. Because there is a strong linear association between $VO_2$ and heart rate, a percentage of maximal heart rate is used for greater feasibility of participant monitoring during exercise. In resistance training, capacity is reflected by the most weight that can be lifted in one repetition for a given lift, the “1 repetition maximum” (1 RM). Resistance exercises are then prescribed as a percentage of 1 RM. Using a percentage of maximal capacity allows for exercise programs that are individually tailored to produce a specific performance or health outcome (e.g., increases in muscular strength, power, hypertrophy, or endurance). Using a percentage of maximal capacity also allows for the ability to obtain normative data for the population. When designing an exercise program, it is important to determine if the stimulus is appropriate for the individual. The load for an exercise program will be relative to each individual depending on the 1RM. To illustrate this point, elderly populations in assisted living can participate in a resistance program at 80% of 1 RM. However, the absolute weight lifted to elicit 80% of 1RM will be considerably lower than the weight need for college-aged adults since they begin with a greater capacity, or a greater 1RM (Fiatarone et al., 1994).

The importance of establishing valid and reliable measures of physical fitness is key in determining areas of focus for each individual as it pertains to physical fitness. Although there are well-established methods of measuring the different aspects of physical fitness as mentioned previously, there are still many questions regarding physical fitness and the relation to health outcomes. Exercise intensities prescribed to a normal, healthy population may not be suitable for all individuals. Circumstances do not always allow for exercises performed at the upper limits of intensity. In certain instances, exercise may be contraindicated and be avoided due to potential harm. For example, an individual with a newly sprained ankle should avoid agility or speed movements (basketball, soccer, and football drills) that would further connective tissue damage (Järvinen et al., 2007). An individual with severe osteoporosis is not recommended to participate in activities that could result in spinal fracture (Sinaki & Mikkelsen, 1984). Someone with significant coronary blockage is counseled to refrain from participation in high-intensity activities that could lead to plague breaking off creating a clot in the smaller arteries of the heart (Maron et al., 1996). In all these cases, exercise intensity is reduced in an effort to promote safety. This is usually the case with variables that are well understood: muscular strength, muscular endurance, aerobic capacity, flexibility. However, there are physical characteristics that may behave similarly to these components of physical fitness, yet their implications on health and physical fitness are not fully understood.

## 1.3 What About IAP?

In the field of urogenycology, IAP is commonly expressed as an absolute value in $cmH_2O$. Certain absolute values are associated with negative health outcomes, most notably, pelvic floor disorders (Nygaard, Hamad, & Shaw, 2013; Shaw et al., 2014). For example, a value of 100 $cmH_2O$ is considered high, and activities causing high IAP values are not recommended. However, young nulliparous women who regularly participated in high-intensity CrossFit$^{TM}$ exercise (CrossFit, inc., Washington, DC) did not have different pelvic floor support from women who were regularly active but did not do strenuous activity (Middlekauff, Egger, Nygaard, & Shaw, 2016). Strenuous activities, like CrossFit™ and several athletic events, are known to increase IAP in a functional manner, in order to provide spinal stability (Hodges et al., 2005). When higher amounts of weight are lifted, this equates to higher increases in IAP. It seems that repeated exposure to activities increasing IAP results in improved fitness levels. Sport and exercise express stress to the body as percentages of maximal capacity. In this manner, the appropriate stimulus is assigned to obtain a specific outcome. This method is used for each variable of physical fitness. Conflicting perspectives from clinical and exercise physiology settings raise important questions concerning IAP. What is “high” IAP? Can it be defined using an absolute value in $cmH_2O$, or is this best understood with reference to an individual’s maximal capacity for generating IAP? That is, if IAP is a correlate of physical fitness, then IAP could be expressed in relative terms, as a percentage of maximal. IAP, which contributes to physical performance, has not been studied in this manner.

# CHAPTER 2

# METHODS

## 2.1 Participants

Participants were women aged 18 and 54 years and were excluded if they answered positive to any of the questions in the Physical Activity Readiness Questionnaire (Thomas, Reading, & Shephard,1992), had physical injuries or limitations preventing them from completing a 1-hour, controlled exercise protocol, were pregnant, or <=six months postpartum. The average age of participants was 30.4 (*SD* 9.3) years and mean BMI was 22.4 kg/m$^2$ (*SD* 2.68).

## 2.2 Design

This study is cross sectional and explores the relationship between the relative term of percent of maximal IAP for individual activities and maximal IAP observed during seated ValSalva.

## 2.3 Procedures

Participants completed a 1-hour exercise protocol in a Human Performance Laboratory located at the University of Utah. The laboratory was equipped with a Quinton Q-Stress TM55 treadmill (Bothell, Washington, USA), and a Monark 828E cycle ergometer (Vansbro, Sweden) used to conduct the walking, running, and cycling measurements. Participants wore light exercise clothes and voided their bladders upon arriving to the Laboratory. A wireless pressure transducer, developed for this research, was used to assess IAP during the exercise trial (Hsu et al., 2012; Hamad et al., 2012). In brief, the transducer is made of a gel-filled capsule with an electronic pressure sensor inside, a tether made of flexible polymer tubing, and an antenna. Data were communicated wirelessly through the antenna and received by a "base station" (ZLE70101BADA Applications Development Kit, Zarlink), which recorded and saved the data for later analysis. The polymer tubing allowed for device removal and provided a reference to atmospheric pressure. The antenna was taped securely near the anterior superior iliac spine. Participants were instructed to insert the device into the upper vagina like a tampon. During the exercise protocol, IAP data collected by the transducer were transmitted every 1.5 seconds to the base station at a frequency of 32 Hz. Participants completed the activity protocol on two separate occasions with the second session to assess repeatability (Egger et al., 2015). The data used for this project were selected from the first of the two trials.

The activities from the original protocol chosen for this study reflect mostly traditional exercises, in addition to some lifting tasks (Table 2.1). Tasks with progressive levels of activity, such as walking, cycling, lifting and calisthenics, were specifically chosen for these analyses, since increasing activity intensity should translate to increases in relative strain. Walking and running occurred during 30-second intervals on the treadmill, preceded by a warm up. Walking and running were divided into 3 levels of intensity (Table 2.1). Seated and standing cycling were conducted at predetermined workloads during 30-second intervals. Stand to sit involved a movement pattern resembling the squat, with the seated position closely achieving a 90 degree knee angle in most women. Lifting tasks included two levels of intensity (13.6kg, 18.2kg) in which women lifted the load from the floor onto a counter and back to starting position three times. Participants were given basic instructions and a demonstration prior to doing each task, but they were not coached to follow specific lifting mechanics. Participants performed 8 repetitions of dumbbell seated shoulder press at each intensity level (3.6kg, 5.5kg, 6.9kg, and 9.1kg). Jumping was done in place, using body weight alone, and was performed 10 times.

The order of the activity protocol remained constant and was developed to mimic a traditional exercise format for safety purposes. The laboratory session began with a warm up of easy walking on the treadmill, followed by aerobic activities of progressing intensity (walking, running, cycling), then to activities with lower intensity, including sit to stand, lifting tasks, and calisthenics. Jumping and seated ValSalva were placed at the end of the protocol in the event the pressure transducer was not retained in the upper vagina, which would have disrupted protocol flow. The exercise session concluded with stretching (data not shown).

The VM was conducted three times each in the seated and lying positions. The seated VM consistently demonstrated the highest IAP in 55 of 57 women and also had the highest mean IAP for the group. Therefore, the IAP from seated and not lying VM was used to reflect maximal IAP for the present paper.

## 2.4 Data Analysis

All IAP values were calculated using established methods from the prior study (Hamad et al., 2012). For this subanalysis of data, the data used for the original study were drawn from archived files. Descriptive statistics, means and standard deviation (*SD*), range, and minimum and maximum values were used to summarize the data (Table 2.2). Seated ValSalva represented the highest observed IAP values for most women (*M* 124.91) (*SD* 41.15). In comparison, lying ValSalva (*M* 91.82) (*SD* 31.61) yielded slightly lower mean IAP. Therefore, seated ValSalva was assumed as maximal IAP capacity, as observed in prior research (Hackett & Chow, 2013). In total, 55 out of the 57 women had data for seated VM; therefore, the two women without seated VM data were excluded from this project.

For each of the 55 participants in this study, the IAP of each activity was expressed as a percentage of maximal capacity. Therefore, the IAP for each individual activity was divided by the same participant's IAP for seated ValSalva. Pearson's *r* correlation coefficients were calculated to determine the nature of the relationship between the maximal capacity for IAP (from seated VM) and the percentage of maximal capacity for the individual activities. To confirm that the relative expression of IAP was unique from that of the absolute value, separate correlation analyses were conducted between the absolute IAP for each activity and maximal IAP during seated VM. The Statistical Package for the Social Sciences (SPSS) (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.) was used to conduct all statistical analyses.

Descriptive data were analyzed to determine whether a partial correlation analysis would be more appropriate than a bivariate analysis. For this, Pearson *r* correlation analyses were used for interval and ratio data (age and BMI) while Spearman's *rho* was used for nominal data (parity). Given the wide range of IAP for seated VM (16.48-207.73), individuals with what appeared to be "low" IAP during VM (less than 80 $cmH_2O$ or lowest ~16%) were compared to those with IAP during VM higher than 80 $cmH_2O$—as we wanted to determine whether these people with "low" IAP during VM were different by age, BMI, or parity as well. Of the individuals in the "low" group, the highest seated VM value was 69.48 $cmH_2O$, which corresponds to 1.7 *SD* from the mean (124.91).

Table 2.1 Description of activities (All activities performed for a 30-second interval unless indicated otherwise)

| Activity | Description |
|---|---|
| Seated Valsalva | The index of maximal IAP (3 maximal efforts) |
| Walking and Running Levels | Walking on treadmill at 4.8 km/hr 0% grade<br>Walking on treadmill at 5.6 km/hr 7% grade<br>Running on treadmill at 8-9.7 km/hr 0% grade |
| Cycling Levels | Seated at 600 kgm/min<br>Standing at 900 kgm/min |
| Stand to Sit | From a standing position, lower to a seated position in a chair, return to standing |
| Lifting Task | Lift 13.6 kg floor to counter and back three times<br>Lift 18.2 kg floor to counter and back three times |
| Seated Shoulder Press | Shoulder press with 3.6 kg dumbbells (8 repetitions)<br>Shoulder press with 5.5 kg dumbbells (8 repetitions)<br>Shoulder press with 6.9 kg dumbbells (8 repetitions)<br>Shoulder press with 9.1 kg dumbbells (8 repetitions) |
| Calisthenics | Abdominal Curl-Ups<br>Full Sit-Ups with feet held<br>Push Ups from Knees |
| Jumping | Jumping with counter movement 10 times |

Table 2.2 Absolute IAP values for seated ValSalva and laboratory activities.

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Seated ValSalva (Maximum IAP) | 55 | 16.49 | 207.73 | 124.91 | 41.18 |
| Walk 4.8 km/hr 0% grade | 55 | 15.27 | 36.58 | 24.72 | 3.98 |
| Walk 5.6 km/hr 7% grade | 55 | 20.13 | 56.12 | 35.67 | 6.55 |
| Run 8-9.7 km/hr 0% grade | 54 | 32.38 | 98.65 | 65.24 | 13.60 |
| Seated Cycling, 600 kgm/min | 55 | 4.05 | 16.47 | 8.24 | 2.26 |
| Standing Cycling 900 kgm/min | 54 | 14.55 | 66.86 | 42.77 | 10.35 |
| Stand to Sit | 53 | 20.59 | 99.73 | 37.15 | 15.71 |
| Lift 13.6 kg floor to counter and back | 54 | 17.14 | 62.62 | 35.00 | 9.49 |
| Lift 18.2 kg floor to counter and back | 53 | 13.60 | 119.98 | 50.81 | 19.21 |
| Seated Shoulder Press 3.6kg | 43 | 4.00 | 31.91 | 10.41 | 5.66 |
| Seated Shoulder Press 5.5 kg | 38 | 3.91 | 24.91 | 11.38 | 4.76 |
| Seated Shoulder Press 6.9kg | 11 | 8.13 | 19.30 | 12.21 | 3.63 |
| Seated Shoulder Press 9.1 kg | 8 | 10.43 | 36.52 | 21.82 | 9.82 |
| Abdominal Curl Ups | 55 | 6.49 | 82.32 | 23.17 | 15.59 |
| Full Sit Ups w/ feet held | 55 | 13.89 | 128.48 | 64.54 | 24.35 |
| Push Ups from Knees | 55 | 4.03 | 42.47 | 16.05 | 6.73 |
| Jumping | 49 | 25.70 | 153.87 | 88.50 | 24.71 |

# CHAPTER 3

# RESULTS

## 3.1 Participants

In total, the data of 55 women were included in the analysis. Women were aged 20-54 (*M* 30.38±*SD* 9.43 yrs) and had BMI values between 17.7-28.9 kg/$m^2$ (*M* 22.4) (*SD* 2.63). Of the women who had data for seated VM, 14 (~25%) were parous, having delivered 1 to 4 children, and 41 were nulliparous.

Pearson and Spearman correlation analyses showed a positive association between age and parity ($r$=.691, $p$=.000) and age and BMI ($r$=.318) ($p$=.016). However, there was no significant relationship between IAP during seated VM and age, parity, or BMI.

## 3.2 Individuals With "Low" Maximal IAP

Some participants exhibited higher IAP values for select laboratory activities than the IAP values for seated ValSalva. Those activities and corresponding numbers of participants who exhibited this phenomenon (*N*) were the following: running at 8-9.7km/hr (*N*=3), standing cycling at 900 kg/min (*N*=2), stand to sit (*N*=2), lifting 18.2 kg (*N*=2), full sit ups (*N*=4), and jumping (*N*=9). As such, differences between individuals with "low" maximal IAP and those with "high" maximal IAP were examined. Less than

16.3% (*N*=9) of the sample had maximal IAP below 80 $cmH_2O$. Of the individuals having below 80 $cmH_2O$, the highest seated VM value was 69.48 $cmH_2O$, which corresponds to 1.7 *SD* from the mean (124.91). These women were categorized as "low" and all others (83.7%, *N*=46) were categorized as "high." The differences in IAP for seated VM between these groups were statistically significant (Table 3.2). However, these two groups were of similar age, parity, and BMI (ANOVA, $p > 0.05$).

Because jumping had the largest number of observations in which IAP was greater than seated VM, the relative IAP (% of maximal) for jumping was compared between the "low" and "high" VM groups. The "low" IAP group (*N*=8) had a mean % Max IAP of 111.8% (*SD* 36.3%) compared to the "high" group (*N*=41) (*M*= 69.6%) (*SD* 19.2%); this difference in % Max IAP for jumping between groups was statistically significant ($t=4.830$, $p<0.000$).

## 3.3 Activities Analysis

The mean relative IAP for individual laboratory activities ranged from 8.41 (seated cycling at 600 kgm/min) to 75.65 (jumping) % of seated VM IAP (Table 3.3). Pearson *r* correlation results indicate that all relative values (% maximal of seated VM) were significantly and negatively correlated at ($p<0.001$) with seated VM IAP (Table 3.3), except for seated shoulder press with 6.9 kg (*p* 0.023) and 9.1 kg (*p* 0.557).

One woman in the "low" IAP group had a maximal seated VM IAP of greater than 2 *SD* below the mean (IAP = 16.49). Therefore, a sensitivity analysis of the correlations and % of maximal IAP for each activity was conducted without that one woman. All other "low" IAP women remained in the analysis. The results of the sensitivity analysis without the outlier are displayed in Table 3.4.

Figures 3.1-3.8 visually demonstrate the relationship between the % of maximal IAP with maximal IAP for the two walking and one running activity, two cycling activities, one curl up and one sit-up activity, two lifting activities, four seated shoulder press activities, one stand to sit activity, one push up activity, and the jumping activity. The outlier described above was omitted from Figures 3.1-3.8 because her inclusion significantly altered the outline of the graph and influenced the relationships among some of the variables. Activities containing multiple levels are color coded to facilitate identification. In some cases, graphs include IAP percent values that are greater than 100% due to the observation that seated VM was not the highest IAP observed for all individuals for all activities.

Lastly, as a final data check, we conducted correlation analyses between the absolute value of seated VM and the individual activities. There were few significant, positive correlations between four higher IAP activities and seated VM (lifting 13.6 kg $r = .338$, lifting 18.2 kg $r = .274$, full sits ups, $r = .281$, jumping $r = .467$), but the correlations, while significant ($p<0.001$), were of relatively low magnitude. Further, to illustrate the difference in this relationship, Figures 3.8 and 3.9 show the relationships between seated VM and the relative and absolute IAP values for jumping. Figure 3.9, which depicts an activity requiring high absolute values, illustrates that maximal and absolute IAP values are correlated. However, many of the activities requiring lower absolute IAP did not display this same relationship. Despite this, all except for seated shoulder press with 6.9 kg ($p$ 0.023) and 9.1 kg ($p$ 0.557) displayed a significant relationship between relative and maximal IAP values at the $p<0.001$ level (note: seated shoulder press with 6.9 kg significant at $p<0.05$ level). Figures 3.10 and 3.11 show the relationship between seated VM and the relative and absolute values for walking at 4.8 km/hr at 0% grade.

Table 3.1 Sample characteristics

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Height (inches) | 55 | 60.00 | 72.80 | 64.77 | 2.84 |
| Weight (lbs) | 55 | 101.00 | 200.00 | 136.75 | 20.17 |
| BMI (kg/m2) | 55 | 17.70 | 28.90 | 22.31 | 2.63 |
| Age (yrs) | 55 | 20 | 54.00 | 30.38 | 9.43 |

Table 3.2 Maximal IAP differences between "low" and "high" participants

**Group Statistics**

| | VM Category | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Seated ValSalva (Maximum IAP) | Low | 9 | 57.01 | 17.27 | 5.76 |
| | High | 46 | 138.20 | 29.65 | 4.37 |

Table 3.3 Relative (% of maximal) IAP for laboratory activities and correlation with Maximal IAP with outlying score

| | N | Minimum | Maximum | Mean | Std. Deviation | Pearson Correlation |
|---|---|---|---|---|---|---|
| % of Max-Walk 4.8 km/hr 0% grade | 55 | 10.93 | 152.58 | 24.21 | 20.14 | -.677** |
| % of Max Walk 5.6 km/hr 7% grade | 55 | 15.92 | 210.47 | 34.92 | 28.52 | -.689** |
| % of Max- Run 8-9.7 km/hr 0% grade | 54 | 23.79 | 373.35 | 62.13 | 50.81 | -.652** |
| % of Max- Seated Cycling 600 kgm/min | 55 | 02.46 | 70.56 | 08.42 | 09.28 | -.609** |
| % of Max Standing Cycling 900 kgm/min | 54 | 17.72 | 271.48 | 41.74 | 37.13 | -.622** |
| % of Max Stand to Sit | 53 | 10.66 | 240.89 | 36.54 | 35.40 | -.584** |
| % of Max-Lift 13.6 kg floor to counter and back | 54 | 10.01 | 143.69 | 32.20 | 20.36 | -.697** |
| % of Max-Lift 18.2 kg floor to counter and back | 53 | 11.46 | 113.59 | 43.14 | 21.31 | -.571** |
| % of Max-Seated Shoulder Press 3.6kg | 43 | 02.42 | 70.64 | 11.09 | 12.17 | -.683** |
| % of Max-Seated Shoulder Press 5.5 kg | 38 | 04.36 | 30.23 | 10.31 | 05.98 | -.693** |
| % of Max-Seated Shoulder Press 6.9kg | 11 | 05.33 | 24.39 | 10.84 | 05.12 | -.673* |
| % of Max-Seated Shoulder Press 9.1 kg | 8 | 07.47 | 23.55 | 17.14 | 06.24 | -.246 |
| % of Max-Abdominal Curl Ups | 55 | 04.66 | 91.53 | 21.08 | 17.61 | -.444** |
| % of Max-Full Sit Ups w/ feet held | 55 | 21.28 | 162.39 | 56.86 | 26.94 | -.596** |
| % of Max-Push Ups from Knees | 55 | 04.79 | 56.33 | 14.62 | 09.27 | -.589** |
| % of Max- Jumping | 49 | 29.15 | 165.32 | 75.66 | 27.37 | -.645** |

*Significant at p 0.05

** Significant at p 0.001

Table 3.4 Relative (% of maximal) IAP for laboratory activities and correlation with Maximal IAP with outlying score removed

| | N | Minimum | Maximum | Mean | Std. Deviation | Pearson correlation |
|---|---|---|---|---|---|---|
| % of Max-Walk 4.8 km/hr 0% grade | 54 | 10.93 | 57.20 | 21.83 | 09.83 | -.801** |
| % of Max Walk 5.6 km/hr 7% grade | 54 | 15.92 | 90.02 | 31.67 | 15.39 | -.770** |
| % of Max- Run 8-9.7 km/hr 0% grade | 53 | 23.79 | 203.16 | 56.26 | 27.08 | -.680** |
| % of Max- Seated Cycling 600 kgm/min | 54 | 02.46 | 24.11 | 07.27 | 03.67 | -.756** |
| % of Max Standing Cycling 900 kgm/min | 53 | 17.72 | 133.19 | 37.41 | 19.27 | -.650** |
| % of Max Stand to Sit | 52 | 10.66 | 153.20 | 32.61 | 21.05 | -.682** |
| % of Max-Lift 13.6 kg floor to counter and back | 53 | 10.01 | 87.44 | 30.10 | 13.38 | -.571** |
| % of Max-Lift 18.2 kg floor to counter and back | 53 | 11.46 | 113.59 | 43.14 | 21.31 | -.531** |
| % of Max-Seated Shoulder Press 3.6kg | 42 | 02.42 | 39.65 | 09.67 | 07.94 | -.645** |
| % of Max-Seated Shoulder Press 5.5 kg | 37 | 04.36 | 30.23 | 09.95 | 05.62 | -.630** |
| % of Max-Seated Shoulder Press 6.9kg | 11 | 05.33 | 24.39 | 10.84 | 05.12 | -.673* |
| % of Max-Seated Shoulder Press 9.1 kg | 8 | 07.47 | 23.55 | 17.14 | 06.24 | -.246 |
| % of Max-Abdominal Curl Ups | 54 | 04.66 | 91.53 | 20.09 | 16.17 | -.346* |
| % of Max-Full Sit Ups w/ feet held | 54 | 21.28 | 162.39 | 56.35 | 26.93 | -.590** |
| % of Max-Push Ups from Knees | 54 | 04.79 | 56.33 | 14.39 | 09.20 | -.570** |
| % of Max- Jumping | 49 | 29.15 | 165.32 | 75.66 | 27.37 | -.645** |

*Significant at p 0.05

** Significant at p 0.001

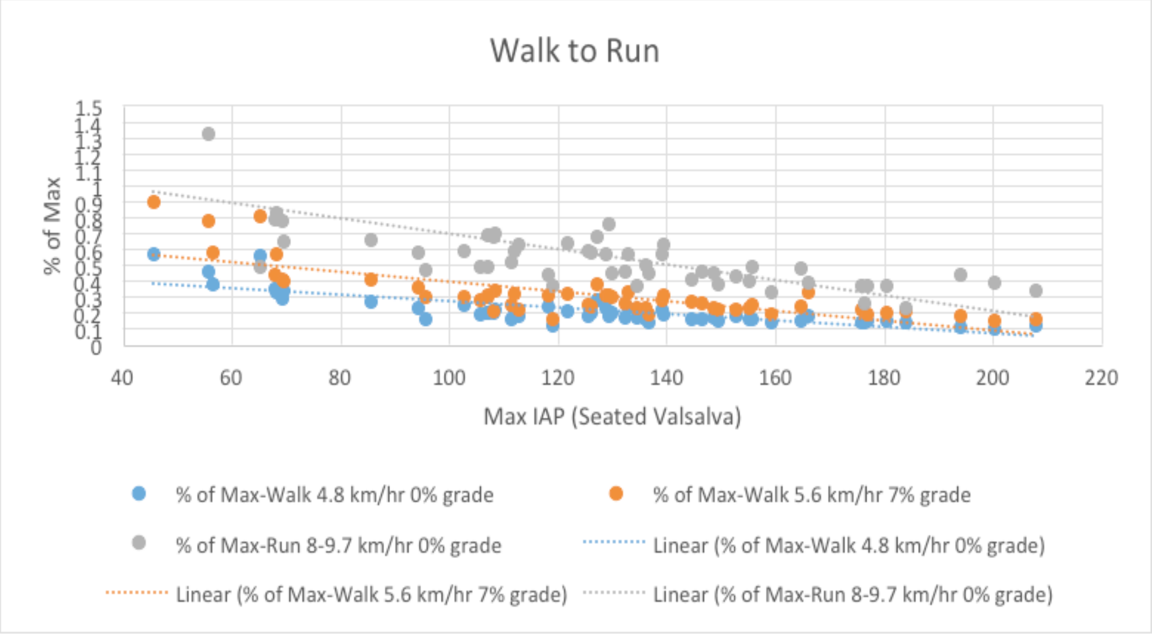

Figure 3.1 Walk to Run

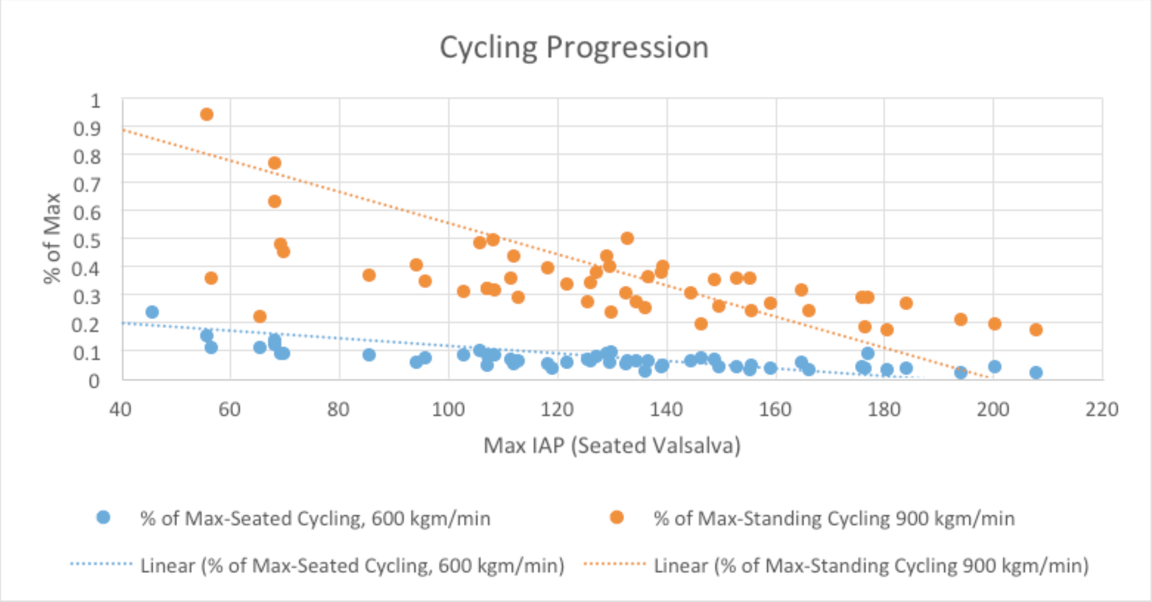

Figure 3.2 Cycling

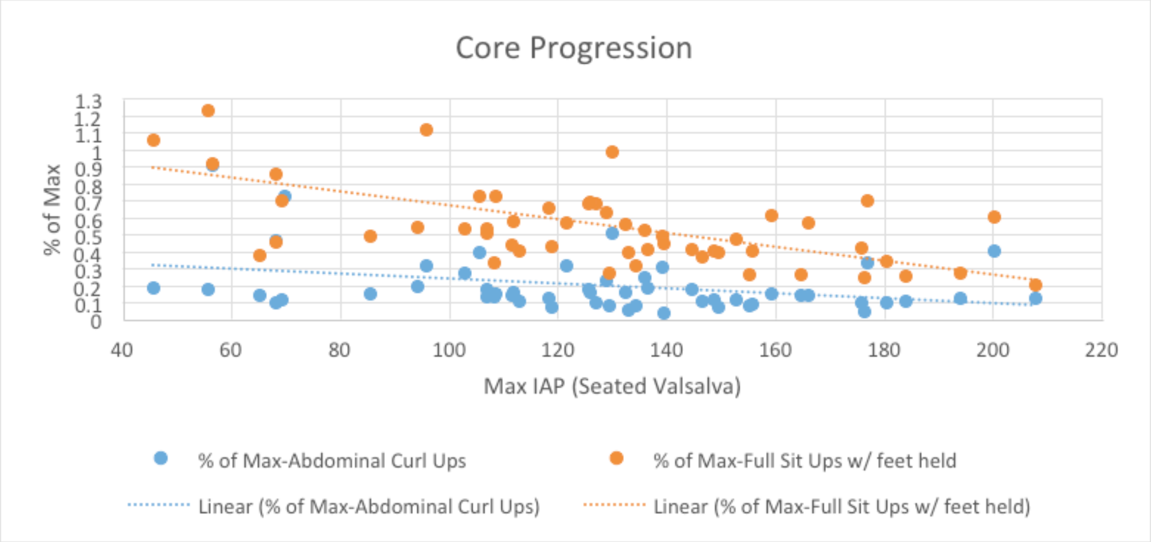

Figure 3.3 Abdominal Curl ups and Full Sit ups

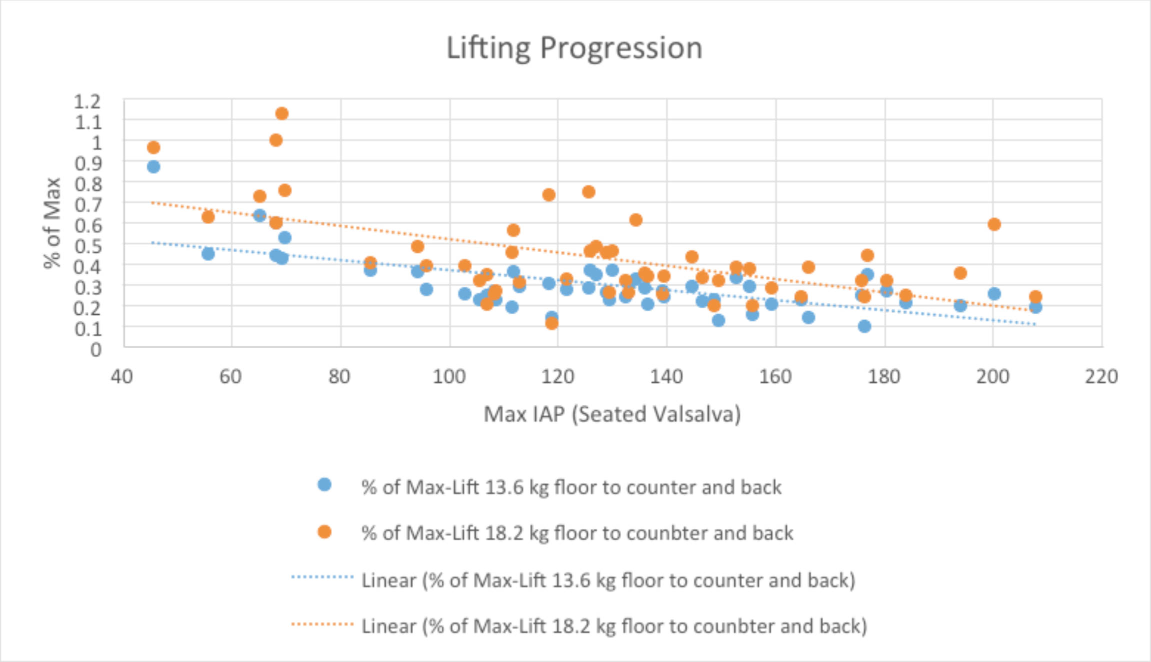

Figure 3.4 Lifting

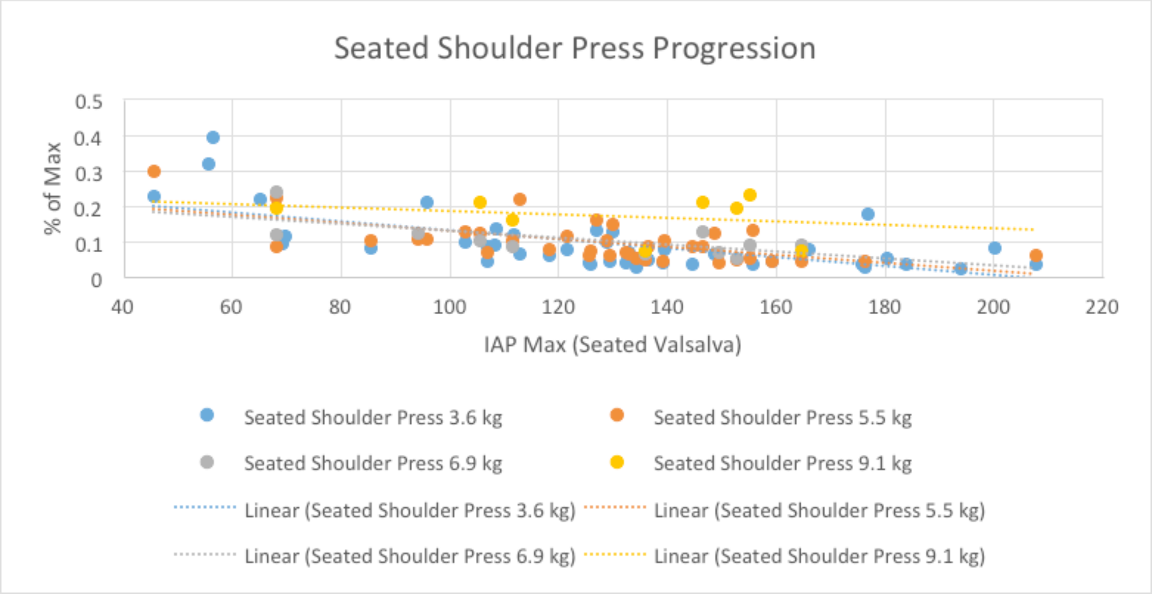

Figure 3.5 Seated Shoulder Press

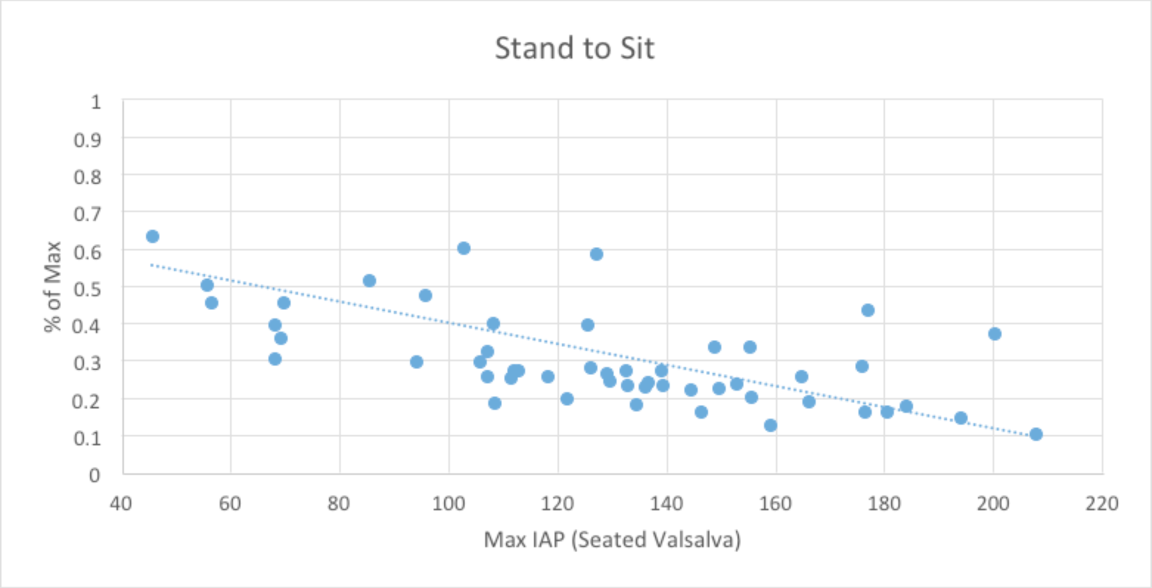

Figure 3.6 Sit to Stand

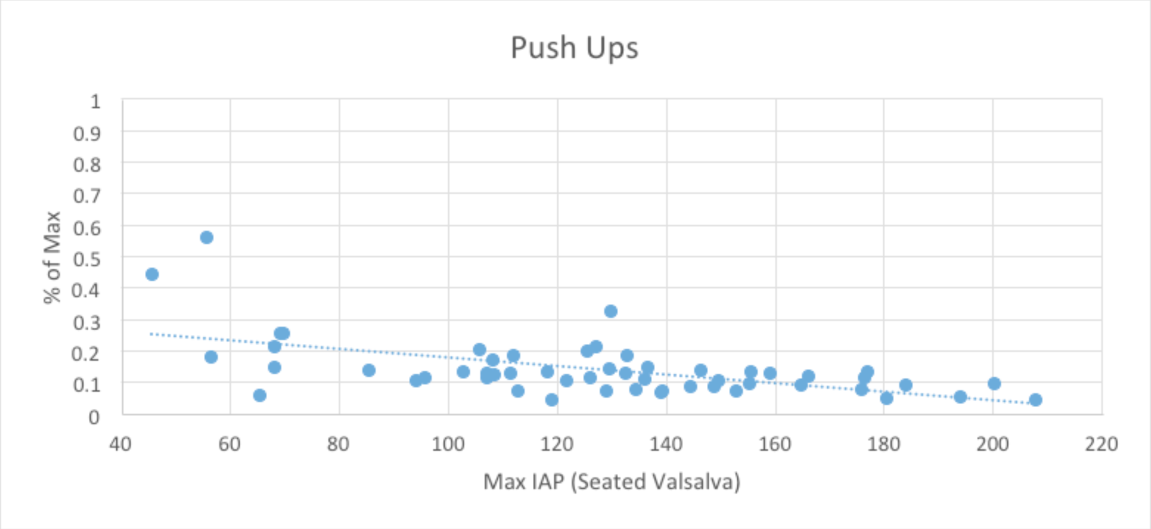

Figure 3.7 Push Ups

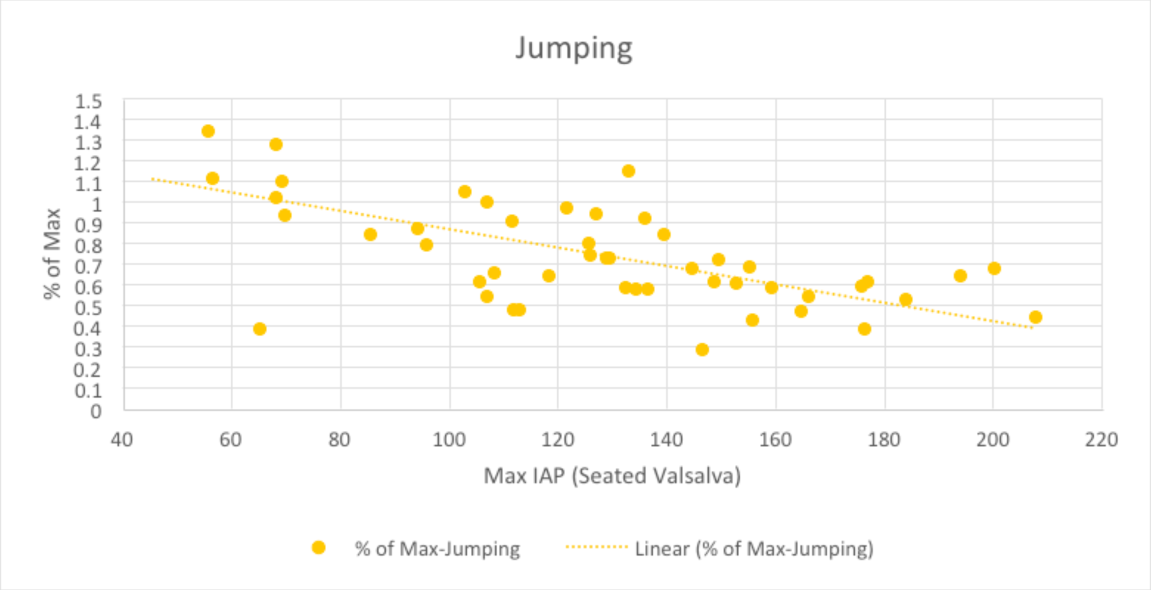

Figure 3.8 Jumping

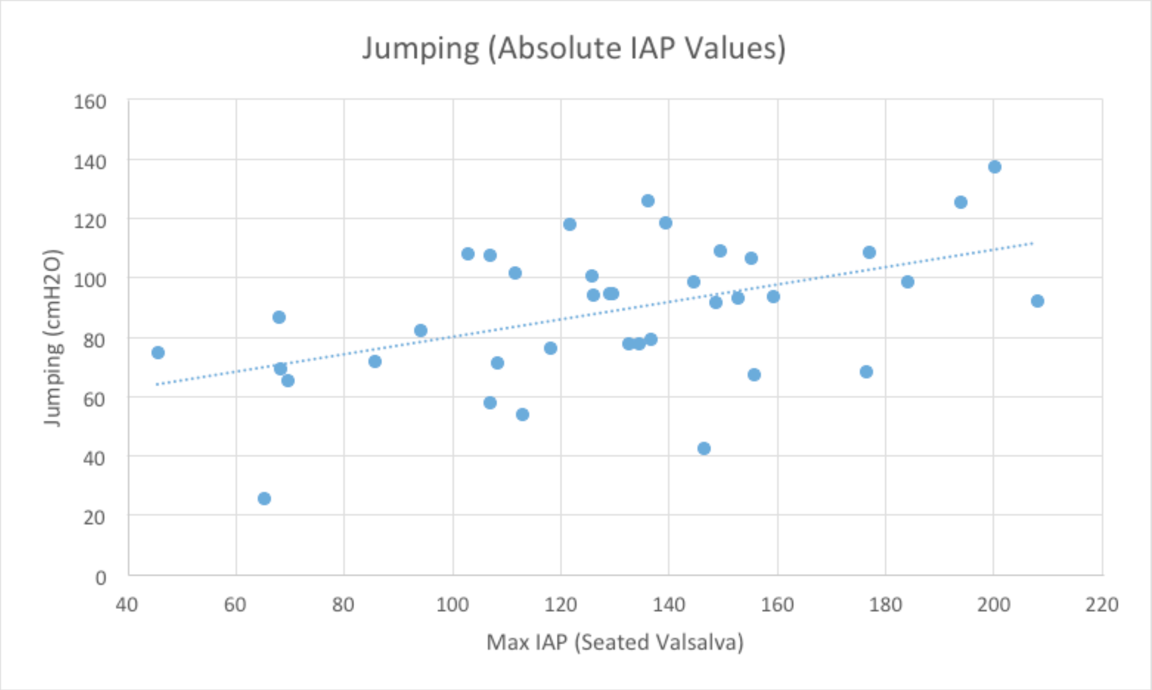

Figure 3.9 Jumping Absolute Values

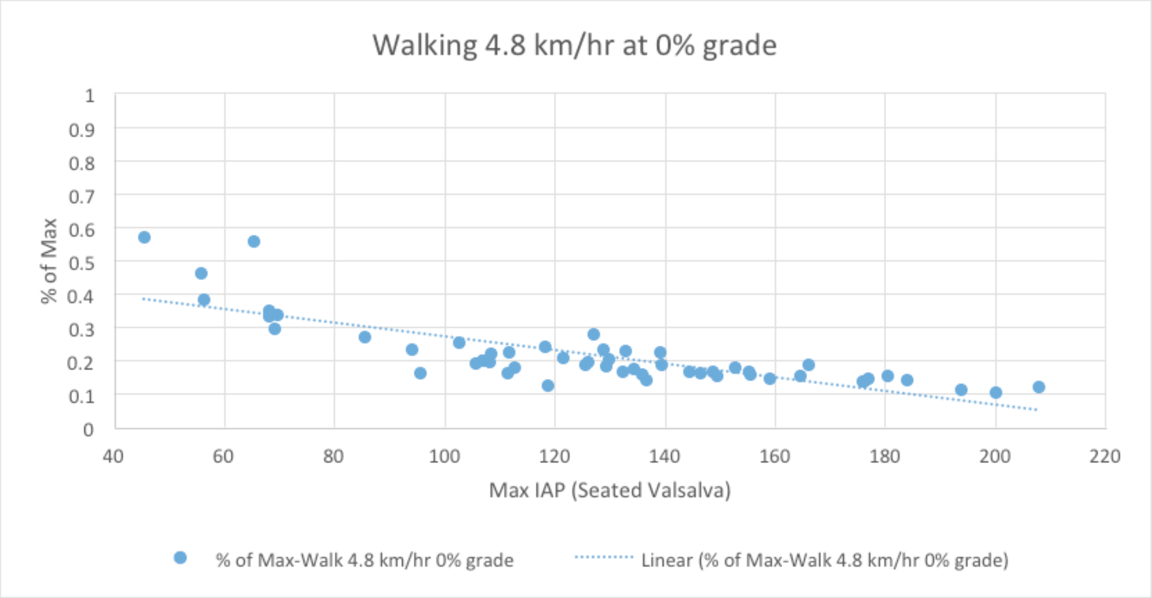

Figure 3.10 Walking 4.8km/hr 0% Grade

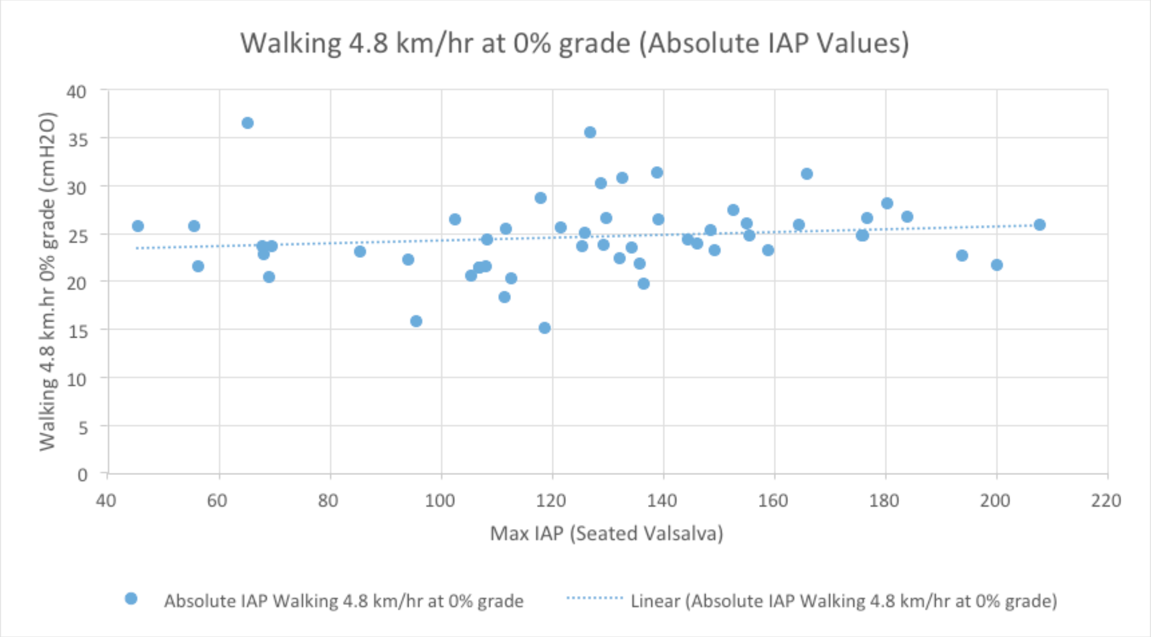

Figure 3.11 Walking 4.8 km/hr 0% Grade Absolute Values

# CHAPTER 4

# DISCUSSION

In this secondary analysis of previously reported descriptive data of IAP measured during a laboratory exercise protocol, we found that the relative expression of IAP had a negative association with maximal capacity for generating IAP. In most cases, this negative association was of moderate to strong magnitude and statistically significant ($p<.001$). The two exceptions to this overall finding occurred in seated overhead press of 6.9 and 9.1 kg, which fewer women could do ($N=11$ and $N=9$, respectively). Taken together, these findings support the contention that the IAP response to individual, submaximal activities exhibits a similar relationship to maximal capacity as that observed in well-established measures of fitness, such as muscular strength or maximal oxygen consumption.

In prior clinical and exercise studies, IAP has been reported as an absolute value in units of $cmH_2O$ or mmHg. Because there is concern that repeated exposure to "high" IAP may contribute to pelvic floor symptoms and disorders (Middlekauff et al., 2016; Nygaard et al., 2013), there is a need to define either a threshold value for high IAP or values for IAP that constitute limits of safety. In exercise settings, IAP rises in response to increases in activity intensity, as we have seen with increasing walking speeds and others have observed with lifting weights (Coleman et al., 2012; Tayashiki et al., 2016).

However, the maximal limits for doing any exercise activity will vary by individual, which helps define physical fitness. Therefore, understanding whether IAP is “high” may depend upon individual capacity, as our data demonstrate. To illustrate, in one woman with absolute IAP during seated VM of 45 $cmH_2O$ and absolute IAP during jumping of 75 $cmH_2O$, jumping was 165% of volitional maximal capacity. On the other end of the spectrum, another woman generated absolute IAP of 208 $cmH_2O$ during seated VM and 92 $cmH_2O$ during jumping, which was only 45% of maximal. Despite having a higher absolute value of IAP during jumping, the woman with the higher maximal capacity may have experienced lower relative strain from the jumping activity compared to the woman with lower maximal capacity. Using the method of calculating relative intensity, as is commonly done in exercise science, for IAP may therefore be useful in studying whether IAP is high or within limits of safety for individuals. Further, given that jumping is an activity reported to induce stress urinary incontinence, relative intensity for IAP may also help signal when pelvic floor symptoms are likely to occur.

While all of the correlations between the relative IAP and maximal IAP were negative, there was variability in correlation strength. The strongest correlations were observed for walking and seated cycling activities, likely because these activities do not allow for much variability in performing the tasks. Other activities such as lifting and jumping are subject to greater task variability between individuals, which may explain slightly lower correlations. Higher task variability is likely explained, in part, by differences in biomechanics, muscle recruitment patterns used by the individuals, and previous experience with the task. Interestingly, the relative IAP for abdominal curl ups had a much weaker correlation with maximal IAP than full sit-ups. This may be due to individuals utilizing head and shoulder momentum during a curl up to assist in the movement or simply the low amounts of IAP needed to accomplish the movement compared to full sit-ups.

We and others have demonstrated previously that IAP increases with increased activity intensity (Hodges et al., 2005; Tayashiki et al., 2016). In the present study, this occurred with participants that performed the walking/running activity, the trunk exercises activity, cycling activity, and lifting activity. This supports findings by Hodges and colleges who found that IAP increased in response to higher loads during back squat (Hodges et al., 2005). Increases in IAP have also been reported due to higher walking speeds (de Gennaro et al., 2017). This may be due to several factors, primarily impact forces and the role IAP plays in spinal stability. For example, the greatest IAP mean percent of maximal (75.66%) occurred during jumping, an activity requiring spinal stability and producing high ground reaction forces (McNair & Prapavessis, 1999). Seated cycling had the lowest mean IAP percent of maximum (8.42%). The seated posture supports spinal stability and cycling does not involve impact forces. Our study supports previously published literature that demonstrates IAP increases in response to greater demands placed on the body. This mirrors other measures of fitness formerly mentioned such as muscular strength or oxygen consumption. As the intensity of the activity increases, the system stressed increases the output to accomplish the activity. Consequently, our findings support the notion that IAP responds similar to measures of fitness.

Distinguishing between individuals with “low” and “high” maximal IAP presented a unique problem. What absolute value would be established as the threshold to be considered high? To our knowledge, there was no previously published literature on an established value to be considered "high" IAP for seated VM. Upon further review of literature, maximal IAP achieved during VM or abdominal bracing was consistently around 90 $cmH_2O$ (Brandt et al., 2006; Tayashiki et al., 2016). In experienced exercisers, this mean can be even higher (170 $cmH_2O$) (Cresswell, Blake, & Thorstensson, 1994). As such, we felt it appropriate to set the threshold conservatively at 80 $cmH_2O$. Moreover, is there an IAP value to be considered to reflect maximal capacity? Research previously published supports the notion of substantial variability when performing VM (Brandt et al., 2006; Greenland et al., 2007). In sensitivity analyses, removal of one extreme outlier (>2 *SD* from the mean for seated VM) altered the relationships we observed, and for some, removal of this score increased the strength of the relationship.

Our study has limitations. We assume that VM elicits maximal IAP response. Although this is supported by the literature (Hackett & Chow, 2013; Hodges et al., 2005), levels of IAP achieved are subject to voluntary maximal exertion, familiarity with the VM, and ability to recruit musculature necessary to perform VM correctly. Proper VM necessitates strain against a closed glottis; this ensures that air is not lost though expiration and enables IAP to rise in the abdominal cavity. Individuals unable to close the airway would diminish the maximal IAP they are able to achieve. Indeed, the range of IAP by VM reported herein was extremely wide (16.49 to 207.73 $cmH_2O$), which is not unique to our study (Brandt et al., 2006; Greenland et al., 2007). Some correlation results changed with sensitivity analyses with the lowest VM value removed. Further, some activities such as jumping resulted in higher IAP than VM in some but not most women. However, there are examples of supra-maximal exertion, such as the Wingate anaerobic power test, in which workloads exceed 100% of that achieved in a test of maximal oxygen consumption (Medbø & Tabata, 1989). Physical fitness was not assessed in the original study, so a direct comparison of IAP among higher and lower fit women could not be done. Lastly, our findings are limited to women within the age (18 to 54 yrs) and BMI (18.5 and 29.9 kg/m$^2$) ranges of our participants.

Our findings suggest that it may be helpful to express IAP in terms relative to maximal, rather than as absolute values. For clinicians, this may mean a change in perspective such that an absolute value that may appear to be high instead be considered in light of an individual's capacity before determining whether that exposure is potentially harmful. Such a change in focus may help clinicians and coaches understand the unique IAP stress a woman experiences with a given task. Although IAP is not routinely assessed in strength and conditioning settings, coaches may observe women with pelvic floor symptoms such as urinary incontinence during heavy lifting and impact activities. Despite not having access to the means of measuring IAP associated with these activities, it is imperative that coaches understand the relationship between IAP and higher intensity efforts during training. With this knowledge, strength and conditioning specialists may adjust training practices in order to limit the likelihood of precipitating pelvic floor symptoms in women.

In conclusion, additional data are needed to confirm the present findings. Documenting changes in IAP associated with motor learning, such as in acquiring sound lifting techniques, could reduce the influence of varying biomechanics in IAP observed during exercise tasks. Further, a prospective longitudinal design constructed to improve physical fitness, using activities known to elevate IAP, is indicated. Lastly, documented improvements in physical fitness that correspond to increases in capacity to generate IAP through VM, and result in lower relative IAP with submaximal efforts would solidify our findings.

# APPENDIX

Table A1. Lifting

## Descriptive Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| Seated ValSalva | 124.914909090909090 | 41.175446080145754 | 55 |
| % of Max-Lift 13.6 kg floor to counter and back | .321999023480450 | .203612535950577 | 54 |
| % of Max-Lift 18.2 kg floor to counter and back | .431403164915427 | .213074462210275 | 53 |

## Correlations

| | | Seated ValSalva | % of Max-Lift 13.6 kg floor to counter and back | % of Max-Lift 18.2 kg floor to counter and back |
|---|---|---|---|---|
| Seated ValSalva | Pearson Correlation | 1 | -.697$^{**}$ | -.571$^{**}$ |
| | Sig. (2-tailed) | | .000 | .000 |
| | N | 55 | 54 | 53 |
| % of Max-Lift 13.6 kg floor to counter and back | Pearson Correlation | -.697$^{**}$ | 1 | .773$^{**}$ |
| | Sig. (2-tailed) | .000 | | .000 |
| | N | 54 | 54 | 53 |
| % of Max-Lift 18.2 kg floor to counter and back | Pearson Correlation | -.571$^{**}$ | .773$^{**}$ | 1 |
| | Sig. (2-tailed) | .000 | .000 | |
| | N | 53 | 53 | 53 |

Table A2. Core Progression

## Descriptive Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| Seated ValSalva | 124.914909090909090 | 41.175446080145754 | 55 |
| % of Max-Abdominal Curl Ups | .210764114070781 | .176108873081959 | 55 |
| % of Max-Full Sit Ups w/ feet held | .568566977633299 | .269418883573485 | 55 |

## Correlations

| | | Seated ValSalva | % of Max-Abdominal Curl Ups | % of Max-Full Sit Ups w/ feet held |
|---|---|---|---|---|
| Seated ValSalva | Pearson Correlation | 1 | -.444** | -.596** |
| | Sig. (2-tailed) | | .001 | .000 |
| | N | 55 | 55 | 55 |
| % of Max-Abdominal Curl Ups | Pearson Correlation | -.444** | 1 | .658** |
| | Sig. (2-tailed) | .001 | | .000 |
| | N | 55 | 55 | 55 |
| % of Max-Full Sit Ups w/ feet held | Pearson Correlation | -.596** | .658** | 1 |
| | Sig. (2-tailed) | .000 | .000 | |
| | N | 55 | 55 | 55 |

**. Correlation is significant at the 0.01 level (2-tailed).

Table A3. Cycling

### Descriptive Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| Seated ValSalva | 124.914909090909090 | 41.175446080145754 | 55 |
| % of Max-Seated Cycling, 600 kgm/min | .084110668305061 | .092054245721982 | 55 |
| % of Max-Standing Cycling 900 kgm/min | .417428276704738 | .371228912546713 | 54 |

### Correlations

| | | Seated ValSalva | % of Max-Seated Cycling, 600 kgm/min | % of Max-Standing Cycling 900 kgm/min |
|---|---|---|---|---|
| Seated ValSalva | Pearson Correlation | 1 | -.610** | -.622** |
| | Sig. (2-tailed) | | .000 | .000 |
| | N | 55 | 55 | 54 |
| % of Max-Seated Cycling, 600 kgm/min | Pearson Correlation | -.610** | 1 | .956** |
| | Sig. (2-tailed) | .000 | | .000 |
| | N | 55 | 55 | 54 |
| % of Max-Standing Cycling 900 kgm/min | Pearson Correlation | -.622** | .956** | 1 |
| | Sig. (2-tailed) | .000 | .000 | |
| | N | 54 | 54 | 54 |

**. Correlation is significant at the 0.01 level (2-tailed).

Table A4. Push Ups

## Descriptive Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| Seated ValSalva | 124.914909090909090 | 41.175446080145754 | 55 |
| Push Ups | .146171342917058 | .092710941463181 | 55 |

## Correlations

| | | Seated ValSalva | Push Ups |
|---|---|---|---|
| Seated ValSalva | Pearson Correlation | 1 | -.589** |
| | Sig. (2-tailed) | | .000 |
| | N | 55 | 55 |
| Push Ups | Pearson Correlation | -.589** | 1 |
| | Sig. (2-tailed) | .000 | |
| | N | 55 | 55 |

**. Correlation is significant at the 0.01 level (2-tailed).

Table A5. Running and Jumping

## Descriptive Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| Max IAP | 124.914909090909090 | 41.175446080145754 | 55 |
| % of Max-Run 8-9.7 km/hr 0% grade | .621272471063730 | .508065977243440 | 54 |
| % of Max-Jumping | .756586943699249 | .273705027189660 | 49 |

## Correlations

| | | Max IAP | % of Max-Run 8-9.7 km/hr 0% grade | % of Max-Jumping |
|---|---|---|---|---|
| Max IAP | Pearson Correlation | 1 | -.652** | -.645** |
| | Sig. (2-tailed) | | .000 | .000 |
| | N | 55 | 54 | 49 |
| % of Max-Run 8-9.7 km/hr 0% grade | Pearson Correlation | -.652** | 1 | .776** |
| | Sig. (2-tailed) | .000 | | .000 |
| | N | 54 | 54 | 48 |
| % of Max-Jumping | Pearson Correlation | -.645** | .776** | 1 |
| | Sig. (2-tailed) | .000 | .000 | |
| | N | 49 | 48 | 49 |

**. Correlation is significant at the 0.01 level (2-tailed).

Table A6. Walking

## Descriptive Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| Max IAP | 124.914909090909090 | 41.175446080145754 | 55 |
| % of Max-Walk 4.8 km/hr 0% grade | .242089919182521 | .201410742430113 | 55 |
| % of Max-Walk 5.6 km/hr 7% grade | .349161277221454 | .285248024693646 | 55 |

## Correlations

| | | Max IAP | % of Max-Walk 4.8 km/hr 0% grade | % of Max-Walk 5.6 km/hr 7% grade |
|---|---|---|---|---|
| Max IAP | Pearson Correlation | 1 | -.677** | -.689** |
| | Sig. (2-tailed) | | .000 | .000 |
| | N | 55 | 55 | 55 |
| % of Max-Walk 4.8 km/hr 0% grade | Pearson Correlation | -.677** | 1 | .990** |
| | Sig. (2-tailed) | .000 | | .000 |
| | N | 55 | 55 | 55 |
| % of Max-Walk 5.6 km/hr 7% grade | Pearson Correlation | -.689** | .990** | 1 |
| | Sig. (2-tailed) | .000 | .000 | |
| | N | 55 | 55 | 55 |

**. Correlation is significant at the 0.01 level (2-tailed).

Table A7. Seated Shoulder Press

## Descriptive Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| Seated ValSalva | 124.914909090909090 | 41.175446080145754 | 55 |
| Seated Shoulder Press 3.6 kg | .110903953817434 | .121618333820486 | 43 |
| Seated Shoulder Press 5.5 kg | .102963436502740 | .059379082793179 | 38 |
| Seated Shoulder Press 6.9 kg | .108427863205368 | .051249880647434 | 11 |
| Seated Shoulder Press 9.1 kg | .171399389547948 | .062412722941027 | 8 |

## Correlations

| | | Seated ValSalva | Seated Shoulder Press 3.6 kg | Seated Shoulder Press 5.5 kg | Seated Shoulder Press 6.9 kg | Seated Shoulder Press 9.1 kg |
|---|---|---|---|---|---|---|
| Seated Valsalva | Pearson Correlation | 1 | -.683** | -.688** | -.673* | -.246 |
| | Sig. (2-tailed) | | .000 | .000 | .023 | .557 |
| | N | 55 | 43 | 38 | 11 | 8 |
| Seated Shoulder Press 3.6 kg | Pearson Correlation | -.683** | 1 | .614** | .c | .c |
| | Sig. (2-tailed) | .000 | | .001 | . | . |
| | N | 43 | 43 | 27 | 0 | 0 |
| Seated Shoulder Press 5.5 kg | Pearson Correlation | -.688** | .614** | 1 | .907** | .470 |
| | Sig. (2-tailed) | .000 | .001 | | .000 | .240 |
| | N | 38 | 27 | 38 | 11 | 8 |
| Seated Shoulder Press 6.9 kg | Pearson Correlation | -.673* | .c | .907** | 1 | .384 |
| | Sig. (2-tailed) | .023 | . | .000 | | .347 |
| | N | 11 | 0 | 11 | 11 | 8 |
| Seated Shoulder Press 9.1 kg | Pearson Correlation | -.246 | .c | .470 | .384 | 1 |
| | Sig. (2-tailed) | .557 | . | .240 | .347 | |
| | N | 8 | 0 | 8 | 8 | 8 |

**. Correlation is significant at the 0.01 level (2-tailed).

Table A8. Sit to Stand

## Descriptive Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| Seated ValSalva | 124.914909090909090 | 41.175446080145754 | 55 |
| Sit to Stand | .365390529918874 | .353961527503773 | 53 |

## Correlations

| | | Seated ValSalva | Sit to Stand |
|---|---|---|---|
| Seated ValSalva | Pearson Correlation | 1 | -.584** |
| | Sig. (2-tailed) | | .000 |
| | N | 55 | 53 |
| Sit to Stand | Pearson Correlation | -.584** | 1 |
| | Sig. (2-tailed) | .000 | |
| | N | 53 | 53 |

**. Correlation is significant at the 0.01 level (2-tailed).

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