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The effects of different exercise regimes on body water compartments in younger and older adults

by

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ABSTRACT

Purpose: The purpose of this study was to analyze existing data and compare the effects of an 8-week intervention of either aerobic exercise, resistance exercise, or a combination of both on changes in total body water (TBW), intracellular (ICW) and extracellular (ECW) water volumes and body composition between groups and compared with a non-exercise control group in younger and older adults.

Methods: 69 pre- or stage-1 hypertensive, overweight or obese, and sedentary adults (age 58 ± 7 y) were randomized to one of three training programs: aerobic (AT), resistance (RT), or a combination of aerobic and resistance (COMB), or a non-exercise control group (CON) for a total of 8 weeks. Body composition and body water compartments were measured with bioelectrical impedance analysis (BIA, InBody720) and a three-day diet diary was recorded at baseline and post-intervention. Statistical analyses were performed on changes between groups, all exercise (INT) vs. control (CON), between sexes, and between younger (<60 y) and older (60+ y) adults. Values are reported as mean ± standard deviation (SD).

Results: INT had larger volumes of TBW, ICW, and ECW than CON, but the differences were not significant ($P > 0.05$ for all). INT increased TBW more than CON, but the difference was not significant (0.1 ± 1.3 l and -0.3 ± 1.2 l, $P = 0.11$, for INT and CON, respectively). COMB had the greatest change in TBW compared with CON ($P = 0.05$) and had a significantly greater increase in ECW compared with CON ($P = 0.03$). There was a negative association between age and LBM, TBW, ICW, and ECW volumes (Effect size (ES) > 1.0 for all). TBW, ICW, ECW, and LBM differed between groups in younger adults ($P \leq 0.05$ for all), but did not differ between groups in older adults ($P > 0.05$ for all).

Conclusions: 8 weeks of AT, RT, COMB, or no exercise training can alter body water compartments in younger and older adults, via changes in body composition, but the changes are more variable in young adults. Body water compartment volumes are different between younger and older adults, in support of declining body water with age. Future research in this area is warranted with a larger sample, longer intervention, and more diverse population.

CHAPTER 1

INTRODUCTION

It is well documented that total body water decreases with age, even in healthy individuals (Baumgartner et al., 1995; Gallagher et al., 1995; Ritz et al., 2001). The decrease in water is due, in part, to the increase in fat mass and decrease in fat-free mass that occurs during the aging process. This is of critical importance, especially in the elderly, as a decrease in total body water may lead to diminished sweat response, renal function, and thirst response (Phillips et al., 1984; Miller et al., 1982; Fish et al., 1985; Murphy et al., 1988), as well as mild to severe dehydration. While most studies agree that dehydration by 2% body weight can diminish performance, several studies have shown that even dehydration by as little as 1% can negatively impact both mental and physical performance (Maughan, 2003; Sawka and Pandolf, 1990; Sawka, 1992; Armstrong et al., 2012) Thus, maintenance of hydration is important, as even minimal levels of dehydration can negatively affect body functioning.

Hypertension (HTN) is the number one leading risk factor for mortality (WHO 2009). HTN is associated with increased TBW and ECW volumes, primarily due to sodium retention (Kolanowski, 1999; Hall, 1994). The primary medications prescribed for HTN are diuretics, which induce fluid loss. This is of potential concern for the elderly, which are already at an increased risk for dehydration. However, it is unknown if a higher TBW volume and corresponding ECW volume in this population serves a protective mechanism against medication-induced fluid loss.

Although it is well-documented that total body water decreases as a normal part of healthy aging, it is unclear as to if this decrease can be attributed to a reduction in intracellular water (ICW), extracellular water (ECW), or a combination of both. Ritz et al. (2001) found that the proportion of water in each compartment remains fairly constant during aging, suggesting that cellular hydration preserved in healthy aging. However, further research is needed in regards to body water compartments and aging.

In addition, while it is well-documented that combination exercise leads the the most significant improvements in body composition over either aerobic or resistance training alone (Ho et al., 2012; Davidson et al., 2009; Church et al., 2010; Park and Randone, 2003), studies examining the effects of exercise on body water compartment status are sparse. Therefore, research in this area is warranted, especially in the older population, which is at increased risk of dehydration. The purpose of the present study was to examine existing data for the effects of an 8-week exercise intervention (aerobic, resistance, or a combination of both) on body water distribution, compared to a non-exercise control group in 45-74 year-old sedentary, pre- or stage 1 hypertensive, overweight or obese individuals. We hypothesized that following the intervention, all exercise subjects would have greater total body water (TBW) volume compared with control, the combination exercise group would have the largest change in TBW compared with all other groups, and TBW volume would differ between younger (<60 y) and older (60+ y) adults.

CHAPTER 2

REVIEW OF LITERATURE

Body water compartments

In the human body, approximately 50-70% of body weight is water (Sawka and Coyle, 1999). Total body water (TBW) is distributed among the intracellular and extracellular body compartments. The intracellular compartment, which contains approximately two-thirds of TBW, is related to the concept of body cell mass, which is the potassium-rich, oxygen-consuming, metabolically active body compartment (Moore et al., 1963). The extracellular compartment, which comprises one-third of TBW, is composed of the interstitial, vascular (plasma), and transcellular spaces. Interstitial fluid, which comprises more than three-fourths of extracellular fluid (ECF), is the solution in which cells are bathed, supplied with nutrients, and is the location of major cell processes. Plasma, which comprises one-fourth of ECF, provides nutrients for cells and proteins for the clotting process. The contribution of transcellular fluid to ECF is relatively small- only about 1-2 liters. Transcellular fluid includes fluids such as cerebrospinal, intraocular, pericardial, peritoneal, and synovial fluid (Grandjean and Campbell, 2004).

In its simplest form, body composition can be examined as a two-compartment model: a fat-free mass compartment and fat mass compartment. Body water is only contained in the fat-free compartment because fat is anhydrous. For the average 70 kg adult male, total body water is approximately 42 l (Maughan, 2003) of which 55% is intracellular, while the remaining 45% is extracellular. TBW fluctuates by ± 5% daily due to changes in physiological processes and fluid/food consumption (Askew, 1996). Thus, daily TBW turnover is approximately 5-10%, meaning 5-10% of TBW is replenished each day (Lentner, 1981).

Factors influencing body water

Body Composition

One of the biggest factors influencing body water is body composition. Lean body mass (LBM), which is composed of bone, muscles, tendons, ligaments, and organs, contains about 73% water (Ferry, 2005; Van Loan and Boileu, 1996). LBM differs from fat-free mass (FFM) in that LBM contains essential fat necessary for metabolic processes, while FFM contains no fat. Fat is anhydrous, and thus, fat mass only contains ~10% water (Van Loan and Boileu, 1996). Therefore, an individual with more body fat contains less body water, compared with a person of equal body size but with more muscle mass. Healthy men typically have greater TBW compared to women, primarily due to a greater body size and muscle mass (Edelman, 1962; Lesser and Markofsky, 1972).

It is well-documented that LBM decreases with age while fat mass increases. This is known as sarcopenic obesity. Sarcopenia, or the progressive decline of muscle mass with age, is the biggest factor in FFM loss, especially for men (Buffa et al., 2011). Particularly after age 60, the decline in LBM accelerates (Kyle et al., 2001; Chumlea et al., 1999; Pritchard et al., 2000). As the body loses muscle, it also loses the corresponding high water content contained within the muscle. The accumulation of fat (both visceral and subcutaneous) adds negligible water due to the hydrophobic characteristics of lipids. Thus, the loss of muscle mass through the aging process contributes to the decreased TBW and intracellular water content commonly found in the elderly. A review by Heymsfield et al. (1989) found that healthy older women (aged 65+) had greater body fat and less fat-free mass than healthy younger women aged 19-34. The authors estimated TBW is reduced by 12% in those over age 65, relative to persons aged 19-34. Thus, the combination of increased fat mass, decreased fat-free mass, and declines in bone mass and cells that come naturally with the aging process, all contribute to the decline in total body water and particularly, the intracellular water.

While it is known that total body water decreases as part of the physiological aging process, it is unknown whether exercise training can ameliorate these changes or if training can alter the water compartments (extracellular and intracellular). In addition, it is unknown what type of training (aerobic, resistance, or a combination of the two) has the greatest, if any, effect on body water. Few studies have examined the effects of different exercise regimes on body water distribution and even fewer have examined these changes with aging.

Water intake and loss

Body water is lost each day via various paths. The most common way is through urine (1400 ml), which can be affected by diabetes and kidney disease. Water is also lost by insensible perspiration from the skin (500 ml), evaporation through respiration (400 ml), and through faeces (200 ml) (Jequier and Constant, 2010; Maughan, 2003). In total, water gains and losses sum to about 2500 ml per day, but this is highly variable among individuals due to activity level, climate, and physique (Diem, 1962; Maughan, 2003). Because the regulation of water balance is so precise, body water remains relatively constant: losses of approximately 1% body water are compensated within approximately 24 h (Grandjean and Campbell, 2004;

Jequier and Constant, 2010). During water deficit, the ionic concentration of the extracellular compartment increases, causing water to move from the intracellular to extracellular compartment. Consequently, cells shrink and receptors send messages to the brain to induce drinking (Popkin et al., 2010). Following water deficit, more body water is lost than is extracellular sodium and thus, the volume of fluid replacement should be a priority over the replacement of sodium (Jequier and Constant, 2010).

Despite the different avenues for water loss, there are three major sources of water intake. In addition to water consumption, part of our water intake comes from the foods we eat and the water we produce (via oxidation of macronutrients). Up to 70% of our daily fluid needs can be met through dietary intake (Wotton et al., 2008). In the U.S., approximately 22% of our water intake comes from food, while this number is likely higher in countries where more fruits and vegetables are consumed (Popkin et al., 2010). Most fruits and vegetables contain 70-99% water, while meats and grains typically contain 60% and 35% water, respectively (Popkin et al., 2010, Davidhizar et al., 2004). As the U.S. diet continues to shift away from fruits and vegetables towards more grains and meat, the water content of the diet decreases. This is of particular importance for older individuals who are already at risk for lower water consumption. Thus, education on the water content and availability of foods is necessary.

Body Water and Composition Changes with Aging

As part of normal physiological aging, there are decreases in TBW, glomerular filtration rate (GFR), urine concentrating ability, perception of thirst, and free-water clearance, while there is an increase in antidiuretic hormone (ADH) or vasopressin (Luckey et al., 2003). In both men and women, TBW starts to decline around middle age and after age 60, TBW shows a rapid decline in women (Schoeller, 1989; Forbes, 1987; Steen, 1997), reflecting decreases in muscle mass. In men, the decline begins during middle age and continues throughout the lifespan. (Schoeller, 1989). In addition, elderly show a decreased drive to drink following water deprivation and drink less (Phillips et al., 1984; Mack et al., 1994). Dehydration in the elderly is also attributed to medications, diuretics, illnesses, and diminished kidney functions, such as decreased ability to concentrate urine, and kidney resistance to ADH. In a review by Beck (2000), between the ages of 30-85, renal mass declined by 20-25%, contributing to the 50-63% decline in GFR observed by Lindeman et al. (1985) in those 30-80 y. This decline in renal mass occurs in parallel with the declines in FFM. In addition, fear of incontinence may also limit the elderly's fluid intake. Thus, dehydration is even more prevalent in the elderly due to these natural declines in physiological processes.

Several studies have examined the effects of aging on body water compartments (Lesser et al., 1963; Lesser and Markofsky, 1979; Ritz et al., 2001; Steen et al., 1979; Steen, 1988). Most studies attribute the decline in TBW with aging to the decrease in ICW volume and increase in ECW. In a cross-sectional study by Lesser and Markofsky (1979), young and old men and women were examined for TBW, ICW, and ECW using dilution techniques. The authors found decreasing ICW and TBW volumes and increasing ECW volume with age. Therefore, declines in TBW were due to decreases in intracellular water volume and therefore, body cell mass. In addition, Ritz et al. (2001) examined changes in body water compartments between healthy adults, healthy elderly, and aged patients. Aged patients had a significantly increased ECW compared to healthy elderly. This is of potential concern as an increase in ECW could mask cellular dehydration. In addition, after adjusting for differences in TBW, ICW was significantly lower in aged patients compared to the other groups. Finally, the proportions of water spaces remained constant from adults to healthy elderly, suggesting that cell hydration is preserved in healthy aging. Therefore, the results of this cross-sectional study indicate that the changes in TBW with age are mostly due to decrease in ICW and thus, body cell mass. In a longitudinal study of men and women 18-64 y, men showed a greater decline in TBW/weight with age (Chumlea et al., 1999). In this study, mean TBW/weight declined from 58% at age 18 to 46% at age 64. In women, TBW/weight decreased as well, but less dramatically (48% to 43% for ages 18 and 64, respectively). However, in their study, TBW volume did not change in the men, so the decline in TBW/weight was due solely to increases in weight. Both the men and women increased percent body fat with age, which is important because other than disease, body fatness is considered the most important factor in describing TBW (Moore et al., 1952) because increases in total body fat are associated with less TBW. Thus, as fat mass accumulates and lean body mass declines with age, the resulting decline in TBW is mostly a consequence of the declining cell mass and potassium composing ICW.

Importance of water

Functions

Because water comprises the majority of the human body, it serves a variety of important functions. Water serves as a transporter to provide cells with nutrients via the bloodstream, as well as rids the body of wastes through urine. Water also helps with temperature regulation through sweating and respiration. In addition, it helps to maintain tissue structure and supports cell functions. Finally, water serves as a protective mechanism: it protects the brain and spinal cord by acting as a shock absorber and lubricates joints and body surfaces.

Dehydration

Dehydration, both acute and chronic, is defined as the loss of body fluids in an amount greater than is taken in, usually assessed as 1% or greater loss of body weight due to fluid loss (Kleiner, 1988). There are three types of dehydration: isotonic, hypertonic, and hypotonic (EFSA, 2008). Isotonic dehydration is due to a loss of salt, and thus, only affects the extracellular compartment. Hypertonic dehydration is caused by excessive fluid loss or inadequate fluid intake (Grandjean and Campbell, 2004). Hypotonic dehydration is due to fluid replacement containing less sodium than the fluid that has been lost (Francesoni et al., 1978), causing water to move into the intracellular compartment. In order to ameliorate hypotonic dehydration, saline solutions of varying concentrations may be needed to restore osmolality and ECW volume. Dehydration can further be broken down into three levels based on severity. Mild dehydration is defined as fluid losses up to 5% body weight, moderate is between 5-10%, and severe is body weight loss by 10-15%. Most experts agree that dehydration occurs when an individual loses 3% body weight (Weinberg and Minaker, 1995), which corresponds to a mild level of dehydration. Body weight can be used to assess body water changes, such that 2.2 kg (1 lb) is equal to 470 ml (2 C) fluid (Kleiner, 1999). Although weight loss is a common assessment of fluid loss, there are other methods to assess overall hydration status. Thirst is often used as an indicator of dehydration. However, most people do not feel thirsty until they are already dehydrated. In a study by Adolf et al. (1947), even young, healthy men did not report a thirst sensation until they were already dehydrated by approximately 2% body mass. As a consequence, those normally exposed to hot climates or exercise may not be aware of their chronic dehydrated state. In addition, blood and urine markers are common indices of hydration status. Frequently used measures include, blood plasma osmolality (>302 mosmol/kgH_2O) (Valtin, 2002), plasma sodium, hematocrit, urine osmolality, or urine specific gravity. Recognizing these markers of dehydration is important as dehydration can increase the risk of renal failure, constipation, decubitus ulcers, urinary tract infections (UTIs), respiratory infections, confusion, medication toxicity, falls, and decreased muscle strength (Eaton et al., 1999; Mentes, 2006). Consequences of dehydration as related to performance are described next.

Consequences of dehydration on performance

While mild dehydration is defined as fluid loss of up to 5% body weight, even losses of 1% can significantly impact performance. One of the most well-documented effects of dehydration is on exercise performance. During exercise, water moves from the intracellular to the extracellular compartment in an attempt to maintain plasma volume. Prolonged exercise is negatively affected by dehydration due to impairments of the cardiovascular and thermoregulatory systems (Sawka and Pandolf, 1990). It has been shown that dehydration by as little as 1% body mass (BM) can negatively impair the body’s thermoregulatory responses to the exercise (Sawka and Pandolf, 1990; Maughan, 2003; Sawka, 1992). Moderate levels of dehydration (2-3% BM) can impair mental and physical performance (Maughan, 2003; Murray, 1998) and severe levels of dehydration (6-7% BM) can be life-threatening. Water loss results in increased plasma osmolality and decreased plasma volume, which could result in increased blood viscosity, potentially leading to blood clots (Vanderwalle et al., 1988). Thus, rehydration during or following dehydration is vital for fluid replacement, as well as for future performance.

Several studies have examined dehydration without fluid replacement on exercise performance, (Sawka et al., 1992; Saltin, 1964; Costill et al., 1976; Armstrong et al., 1985). Sawka et al. (1992) examined core body temperature during heat stress exercise tests in euhydrated and hypohydrated (-8% total body water) states. Although all subjects were heat-acclimated, endurance time and sweat rate were significantly reduced in the hypohydrated state compared with the euhydrated state ($P < 0.01$ for all). In addition, exhaustion occurred at a lower core temperature in the hypohydrated state compared with euhydration ($P < 0.05$). A study by Armstrong et al. (1985) also evaluated endurance performance during 1500, 5000, and 10,000 m when euhydrated and following diuretic-induced dehydration by ~2% BM. Performance was diminished significantly in the 5000 and 10000 m dehydrated trials compared with hydrated trials, with times to complete races increasing by 7.2 and 6.7%, respectively. In addition, time to voluntary exhaustion was significantly reduced in the dehydrated state. Therefore, the authors concluded that running performance in longer events (5000 and 10000 m) is affected to a greater extent than that of shorter events (1500 m). Similarly, Saltin (1964) found that subjects dehydrated by either thermal, metabolic, or a combination of the two demonstrated reduced exercise capacity after dehydration, especially when the dehydration was achieved through exercise.

Other studies have examined repeated exercise bouts following dehydration and fluid replacement. In a study by Nielsen et al. (1986) subjects exercised at 50% $VO2_{max}$ in a heated environment until 3% BM was lost. Subjects then rehydrated with either a control electrolyte, control with potassium, control with sodium, or sugar drink in a volume equal to 2700 ml over the course of two hours. Following the rehydration period, subjects repeated exercise by doing 6 min at 50% $VO2_{max}$ followed by 105% $VO2_{max}$ until exhaustion. The authors found that regardless of beverage consumed, exercise capacity was diminished during the second exercise bout.

In addition to its effect on exercise, dehydration can also impair cognitive performance. This is especially important for older individuals, who are already likely dehydrated due to a loss in lean body mass and decreased thirst sensation and kidney function. Thirst is stimulated by an increase in plasma osmolality and a decrease in plasma volume (Greenleaf, 1992). During periods of stress, such as physical exercise, increased temperature, and dehydration, the thirst stimulus lags behind fluid loss. Even mild to moderate levels of dehydration can cause alterations in alertness, concentration, and short-term memory. Armstrong et al. (2012) examined the effects of moderate exercise-induced dehydration with and without diuretic on mood and cognition in healthy young women. Even dehydration by 1.36% body mass resulted in greater perceived task difficulty (P = .04) and headache (P = .05), decreased concentration (P = .01), and worsened mood (anger-hostility) (P = .04) compared with their own euhydrated (control) trials. The authors concluded that this small (1.36%) decrement in body mass had adverse effects both during rest and during moderate exercise in healthy women. Thus, even when small fluid losses occur, which may occur even during daily activities, maintenance of hydration is important to ensure optimal mood and reduce symptoms of headache and fatigue.

While many studies have examined the effects of dehydration on performance in younger adults, few studies have examined its effects on older adults. Suhr et al. (2004) used measurements of TBW, ECW, and ICW via BIA to examine the effects of dehydration on cognitive functioning in healthy older adults (50-82 y). The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), grooved pegboard test (GPT), and Trail Making Test (TMT) were used to develop a summary score for psychomotor processing speed and attention/memory. After controlling for body mass, the authors found that individuals with lower levels of hydration had slower psychomotor processing speeds and poorer performance on memory/attention tasks.

Besides decrements in physical and cognitive performance, dehydration can also impair gastrointestinal function, leading to constipation. Constipation can be caused by a variety of things, such as medication, inadequate fiber, poor diet, and illness (Arnaud, 2003). Constipation can be alleviated by increasing fluid intake. In a study by Lindeman et al. (2000), 883 volunteers were examined and asked about their fluid intake. The authors found a correlation between prevalence of chronic constipation and low fluid intake. In addition, constipation increased with age and was more prevalent in women than in men. This may be attributed to the decrease in exercise with age and the lower fiber intake of women compared to men.

Finally, dehydration in the elderly has been linked with increased fall risk, kidney stones, urinary tract infections (Grandjean and Campbell, 2004), and is also an independent predictor of mortality (Altieri et al., 2003; Arnaud, 2003; Beetz, 2003; Boddaert and Belmin, 2003; Kalhoff, 2003; Siener and Hesse, 2003; Smith and Shaw, 2003).

Therefore, since it has been shown that minimal dehydration can negatively impact physical and cognitive performance even in young, healthy individuals, the elderly may be at an even greater disadvantage due to their susceptibility to dehydration that occurs with the aging process. This natural decline in body water with age could further contribute to the cognitive deficiencies that can be seen in the elderly. Thus, even mild to moderate dehydration in the elderly may exaggerate cognitive function impairments and is a factor that may precede acute confusion in this population (Mentes et al., 1998). Is it therefore recommended that frequent fluid intake should be heavily emphasized in the older population, who are at an even greater risks for a host of illnesses and conditions due to their diminished total body water and physiological responses.

Older Adults and dehydration

Possible reasons why the elderly are dehydrated are the loss of muscle mass, reduction in renal function (decreased glomerular filtration rate), medication and diuretic use, diminished thirst response, and hormone secretion alterations which affect water and electrolyte balance. Older adults have been shown to have a higher secretion rate of vasopressin, or antidiuretic hormone (ADH), which may lead to the elderly's inability to concentrate their urine (Leaf, 1984; Miller, 1997; Phillips et al., 1993). In addition, thirst is stimulated by an increase in plasma osmolality and a decrease in plasma volume (Greenleaf, 1972). However, as the thirst response in the elderly is diminished, fluid intake is often delayed and inadequate. A study by Phillips et al. (1984) compared responses to dehydration in older (67-75 y) and younger (20-31 y) men following 24 h of water deprivation. Following the deprivation, the older men had greater ADH levels, plasma osmolality, and sodium concentrations. Despite their higher plasma osmolality and dehydration, the older men described themselves as less thirsty and drank less than their younger counterparts. In addition, after the fluid deprivation, subjects were allowed unlimited access to water. While the younger men were able to correct plasma osmolality within the first hour following deprivation, the older subjects were unable to return to pre-deprivation levels, even after several hours of ad lib fluid intake. A similar study by Miescher and Fortney (1989) compared responses to dehydration in younger (21-27 y) and older (61-67 y) men. During heat exposure, younger men were able to maintain normal body temperature longer, as well as return to normal body temperature more quickly following heat exposure. In addition, with only 50% rehydration, older subjects took twice as long to restore their plasma osmolality than younger subjects (60 vs. 30 minutes, respectively). However, the younger subjects were able to restore plasma volume within 30 minutes, while the older subjects never fully restored their pre-exposure levels, despite losing and drinking the same volume of water. The older men again rated themselves as being less thirsty, supporting the diminished thirst response with age. Therefore, the authors concluded that control over hydration status is reduced with the aging process, which may be crucial to heat exposure tolerance.

Both of these studies lend support to the diminished thirst response and fluid homeostasis processes that occur with aging. It is therefore vital for the elderly to take in small amounts of fluid frequently, despite a lack of thirst.

Despite the necessity to more closely monitor hydration status, assessment of dehydration in older individuals is difficult due to confounding variables such as skin turgor and orthostatic hypotension, both of which often accompany the normal aging process.

Hypertension and body water

Hypertension is a chronic condition defined as an elevated systolic blood pressure of ≥140 mm Hg or a diastolic blood pressure of ≥90 mm Hg. individuals with hypertension, have increased TBW and ECW, primarily due to sodium retention (Kolanowski, 1999; Hall, 1994). In order to reduce blood pressure, diuretics, designed to induce fluid loss, are commonly prescribed. However, treatment with diuretics is counterintuitive to the aging process in which there is a natural decline in body water. In addition to hypertension, increased ECW is associated with chronic kidney disease, edema, and heart failure (Tai, et al., 2014). However, in hypertensive individuals, it is unclear if greater TBW and ECW volumes could serve as a protective mechanism against orthostatic hypotension and the natural body water declines that occur with aging. To our knowledge, no studies have examined these possibilities, and thus, research in this area is warranted.

Benefits of adequate water intake

Consuming adequate water each day has been shown to have multiple health benefits. The water requirement will vary by individual due to the effects of age, gender, body composition, activity level, and temperature. Thus, the individual water requirement is defined as the quantity necessary to maintain homeostasis in both the intracellular and extracellular body compartments (Ferry, 2005). Studies have shown that adequate water intake has been linked to prevention of various diseases, such as heart disease and some cancers. A study by Michaud et al. (1999) examined 47,909 men over a 10-year period. The authors found an inverse relationship between the increased risk of bladder cancer and decreased fluid intake.

With an additional increase of 240 ml of fluid per day (8 oz), the risk for developing bladder cancer decreased by 7%. Even those that consumed six glasses of water (1440 ml) per day showed a marked (51%) decrease in risk for developing bladder cancer, which is less than the recommended eight glasses of water per day. Therefore, the authors suggest individuals consume adequate volumes of fluid each day as it can help reduce the risk of bladder cancer.

Similarly, a study by Chan et al. (2002) examined the effects of water intake on coronary heart disease in 8220 males and 12,017 females. The authors found during a 6-year follow-up period 246 cases (128 males, 118 females) of fatal coronary heart disease. Women who drank at least five glasses of water per day reduced their risk of fatal coronary heart disease by 41% compared with women who drank two or fewer glasses per day. For men, the risk was reduced by 54% for the same water intakes. In addition, there was a positive correlation between consumption of non-water beverages and risk of fatal coronary heart disease.

Furthermore, adequate hydration has also been linked to weight loss. When water is used as a replacement beverage for sweetened beverages, juice, or whole milk, a 10-13% reduction in energy intake has been found (Popkin et al., 2010). There has also been a correlation between satiety and water intake. Dennis et al. (2010) examined overweight/obese middle-aged and older adults on either a hypocaloric diet or a hypocaloric diet with 500 ml of water before each of the three main meals of the day for 12 weeks. While both groups showed a decrease in body weight, the water group showed a 44% greater decline in body weight. The water group also showed a greater decrease in total fat mass compared with the non-water group. The authors concluded that drinking 500 ml of water before each of the three main meals of the day can lead to ~2 kg greater weight loss than a hypocaloric diet alone in middle aged and older adults over a period of 12 weeks. In addition, a study by Stookey et al. (2008) also found that overweight women who drank at least one liter of water/day increased weight loss by ~2 kg over a 12-month period compared with those who did not drink the extra water, regardless of which diet they were on (Atkins, Zone, LEARN, or Ornish). The women who drank at least 1 l water/day also had decreased weight circumference and body fat compared with women who did not drink as much.

Finally, proper fluid intake can attenuate gastrointestinal problems, such as constipation, which often comes as a result of inadequate hydration. Fluid intake promotes bowel movements, which is particularly important for older individuals who are constipated more readily. A study by Anti et al. (1998) examined the effects of extra fluid intake on constipation and laxative use in adults with chronic functional constipation. Subjects were divided into two groups: a diet with 25 g fiber per day and ad libitum fluid intake and a diet with 25 g fiber per day and 2 l mineral water/day. While a diet of 25 g of fiber per day increased stool frequency and reduced laxative use in both groups, the difference was exaggerated in the mineral water group. In addition, the mineral water group drank significantly more fluid. The authors concluded that a diet including 25 g of fiber/day with an extra 1.5-2 l fluid/day can enhance the effects of stool frequency in individuals with chronic functional constipation. This is in agreement with a study by Klausner et al. (1990), which also observed an increase in bowel movements with an increase in fluid intake in healthy adults.

Effects of exercise on body composition and body water

It has been shown that between aerobic, resistance, or a combination of both exercises, combination exercise leads to the greatest improvements in body composition and overall health indices (Sigal et al., 2014; AbouAssi H et al., 2015; Ho et al., 2012, Yavari et al., 2012). A study by Church et al. (2010) examined the effects of aerobic exercise, resistance exercise, or a combination of both against a non-exercise control group in 262 type II diabetic patients. Over the 9-mo intervention, the authors found that combination exercise led to cumulatively greater benefits over those of aerobic or resistance exercise alone for weight loss, fat mass, and waist circumference.

In addition to enhancements in body composition, exercise can serve as an alternative treatment for hypertension, particularly in obese individuals, by reducing blood pressure. It has been postulated that exercise can improve insulin sensitivity, which may alleviate the development of hypertension (Hsueh et al., 1994; Kolanowski, 1996; Kolanowski 1999). Further research in this area is warranted, as it is unclear which type of exercise is most beneficial for hypertensive individuals.

Although the effects of exercise on body composition has been extensively studied, few studies have examined the effects of different exercise regimes on body *water* distribution. The majority of of studies that have examined changes in body water have only used short bouts of exercise. Sawka et al. (1984) examined the effects of hydration status on fluid shifts in the heat. After heat acclimation, males and females matched for fitness and body fat performed two exercise sessions, once when euhydrated and once when hypohydrated by ~5% baseline body mass. The authors found a significant ($P < 0.05$) change in plasma volume between the conditions and a significantly higher plasma osmolality in the hypohydrated condition ($P < 0.01$). In addition, there was no change in plasma protein concentration during the hypohydration trial, suggesting protein and plasma fluid were lost at approximately the same rate from the vasculature. From their results, the authors concluded that hemoconcentration occurs during intense exercise in the heat and, when males and females are matched for fitness, gender does not alter fluid shifts during exercise in the heat.

Costill et al. (1976) also used short-duration exercise in the heat to induce dehydration in males. They found a 2.4% decrease in plasma volume for each percent decrease in body weight. In addition, sodium and chloride concentrations decreased significantly with dehydration, confirming those are the main ions lost in sweat. Although there was roughly a 125 ml loss of water from blood cells, the majority of water loss came from the extracellular compartment.

The few studies that have examined body water compartment changes over a longer duration have found increases in ICW to be positively correlated with strength and power.

Silva et al. (2010) studied 27 elite male judo athletes for about 1 month at baseline and just prior to competition. Deuterium and bromide dilution techniques were used to assess body water compartments and dual energy X-ray absorptiometry (DXA) was used to assess body composition. Between baseline and competition, the athletes lost significant body weight (1.1 kg, $P < 0.05$), but no significant differences in fat mass, FFM, TBW, ICW, ECW, or energy intake were found. However, when subjects lost >2% upper body power, there were significant reductions in TBW and ICW ($P < 0.05$). Thus, decreased TBW, and in particular, ICW, is associated with a decreased upper body power output. Similarly, a study by the same authors

(2011) also found decreased hand grip strength in this judo population when ICW declined. Thus, in elite judo athletes, upper body power and strength were adversely affected by decreased ICW.

Three years later, Silva et al., 2014 extended their previous findings to team sports. They examined body water changes over a season in competitive basketball, handball, and volleyball players using dilution and DXA techniques. Overall, athletes significantly decreased fat mass, while maintaining ICW and increasing FFM, TBW, and ECW. ICW increased from the beginning of the season (27.0 ± 6.7 kg) to the competitive period (27.2 ± 6.9 kg), but the difference was not significant. Those that increased ICW improved leg strength and jumping height. Thus, only ICW was significantly related to strength and power, even after adjusting for potential confounding variables. The results of this study indicate that ICW is the main predictor of performance, irrespective of sex, age, season length, and sport. This study also lends support for the “cell swelling theory,” which states that cellular swelling promotes anabolism and cell shrinkage promotes catabolism. However, the samples were not representative of each sport position, nor did the handball sample contain any females. Thus, caution should be taken when extrapolating these findings to the overall competitive athlete population.

Although these studies examined body water changes with exercise, the population studied only included young, healthy, competitive athletes. In addition, training was not standardized between the participants, duration of the study was relatively short (~1 mo), and the same methods (DXA and dilution techniques) were used to assess compartment changes.

Assessments of body water compartments

There is no direct way to measure intracellular water, so it is estimated from the difference of total body water and extracellular water. Total body water and extracellular water can be assessed using direct or indirect methods. Direct methods are preferred because they actually measure body water and are believed to be the most accurate. However, direct methods often require significant time, money, extensive analyses, and ingestion or intravenous administration of the tracer into the subject's body. Different methods for assessing hydration status are discussed below.

Doubly labeled water

Doubly-labeled water is a direct and preferred method to assess total body water by comparing two isotope tracers and is based on the theory that water is distributed throughout the body, with the exception of body fat. The most commonly used tracers have been tritium and deuterium. However, tritium has a radiation hazard when it is ingested, absorbed, or inhaled. Thus, the use of deuterium is safer and can be used in children, pregnant women, and other populations. In this method, water is labeled with the nonradioactive isotopes deuterium oxide (D_2O) and oxygen-18 (^{18}O) for tracing. The doubly labeled water is ingested and the disappearance rates of the isotopes are measured in the blood, breath, or urine 3-6 hours later. By determining the tracer concentration after allowing sufficient time for equilibration, the volume of the fluid (TBW) can be calculated. In addition, bromide (NaBr or KBr) can used as a tracer to determine ECW via high pressure liquid chromatography. The tracer method is preferred because it is ingested, safe, and is a direct measure of hydration status. However, it is very expensive and requires significant time and analyses of the blood or urine, as well as rapid analysis if breath is measured.

Body Mass

Changes in body mass over a short period of time are assumed to be due to water loss or gain. 1 ml of water has a mass of 1 g (Lentner, 1981), allowing the measurement of body mass to quantify changes in body water. This method is commonly used because it is a quick, simple, and easy method to directly assess changes in body water over an acute time period. While some studies factor in respiratory water loss and water exchange, other studies consider the other factors negligible (Mitchell et al., 1972).

Other direct measures

Blood, saliva, breath, and urine can also be used to directly measure body water changes because they are relatively simple, quick, and inexpensive methods. While blood (serum) typically offers the most accurate measurements, it is an invasive procedure and requires a draw from a phlebotomist. Saliva requires a rather noninvasive sample, but needs to be analyzed right away or stored in airtight containers to prevent evaporation. Similarly, breath samples need to be analyzed quickly due to the exchange of ions that occurs (Kushner and Schoeller, 1986). Finally, a urine sample is fairly noninvasive, but requires the compliance of the subject. In addition, urine takes longer to reach isotopic equilibrium, so analysis cannot be immediately performed.

Bioelectrical impedance analysis (BIA)

Bioelectrical impedance analysis (BIA) has recently gained popularity as a simple, quick, and noninvasive method to indirectly assess changes in hydration status. Bioimpedance involves small currents traveling through the body via ions in aqueous solution. Impedance to the current is measured as the current flows through the tissues. Water-containing tissues, such as blood and muscle conduct the current, while bone, fat, and air-filled spaces resist the flow of current (Baumgartner, 1996; Foster and Lukaski, 1996). Thus, lean tissue exhibits the least resistance to the current due to its high water content (Scharfetter et al., 2001). Body fat is a non-conducting material and therefore, it creates the most resistance to the current flow. Due to the conductivity of different tissues, low frequency current passes mainly through extracellular tissue, while higher frequency current (>200 kHz) passes through intra- and extracellular tissues (Thomas et al., 1999; Van Loan, et al., 1995). From the impedance, TBW and ECW can be estimated and ICW can be calculated as the difference between TBW and ECW. These measurements can then be incorporated into different formulas specific to population, age, and disease to predict body composition, especially body fat.

BIA measurements fluctuate day-to-day, in accordance with hydration status changes. In order to use BIA, several assumptions are made. It is assumed that the resistivity is known and remains constant. However, resistivity can vary depending on hydration status, electrolyte concentration, and tissue structure (Shiffman et al., 1999). Body potassium is also assumed to be in constant relation to cell mass, assuming the water content of cells is constant. In addition, it assumes body water volume is evenly distributed within a cylinder of uniform cross-sectional area (O’Brien et al., 2002; Buchholz et al., 2004). However, the distribution of TBW is not evenly distributed throughout the body, which is only approximately cylindrical. Because impedance is inversely proportional to cross-sectional area, the limbs, which have small cross-sectional areas, influence bioimpedance more than the trunk (O'Brien et al., 2002). For example, although the trunk contains approximately 50% of body mass, it only accounts for 5-12% of total body impedance (Kushner, 1992; Coppini et al., 2005; Gudivaka et al., 1994). During periods of dehydration, water and electrolyte levels are altered, which would likely decrease resistance, and thus, influence bioimpedance. Exercise effects (sweating, higher skin temp, and redistribution of blood flow) may also cause changes in resistance to current, which could also influence BIA measurements. In addition, fluid (ion) composition influences resistance, which then affects BIA. Gomez et al., 1993 found that resistance remained elevated for 90 minutes following consumption of water or hypotonic fluid, while resistance decreased following consumption of isotonic fluid. In addition, due to the inverse relationship between impedance and cross-sectional area, fluid changes in the trunk had less impact on bioimpedance than fluid shifts of similar size elsewhere in the body. In this study, a higher electrolyte concentration in the drink led to higher BIA-estimated TBW. BIA is further complicated by the fact that it needs to be correlated with body composition to develop a predictive equation in order to determine the volume of water in a specific compartment. The equation varies depending on age, population, sex, and disease status. Thus, it is critical to use a formula designed for the population being studied.

Despite these findings, BIA is still used due to its reliability when calculating TBW and has been extensively validated against other techniques (Brodie et al., 1998; DeLorenzo et al., 1997; Ellis and Wong, 1998; Foster and Lukaski, 1996; Patel et al., 1994) and found to be a highly reliable method (Shanholtzer and Patterson, 2003; Vache et al., 1998). TBW, which composes 50-70% of body weight, is fairly stable day-to-day (Sawka and Coyle, 1999). Bedogni et al. (2002) examined the reliability of the eight-polar BIA (InBody 3.0, Biospace, Seoul, Korea) in healthy individuals three times per day over five days, compared with the deuterium oxide dilution method. For all frequencies and body segments, precision of the eight-polar BIA was ≤2.8%, demonstrating the accuracy and precision of TBW estimation. Similarly, Shanholtzer et al., 2003, examined multi-frequency BIA (Multiscan 5000 Body Stat Ltd, Isle of Man, UK) test-reliability in male and female healthy subjects twice within one week. For both males and females, test-retest reliability was consistently found, demonstrating BIA is a valid method for measuring hydration status across time and within individuals.

There are two main types of BIA: single and multi-frequency. Single uses one frequency to measure impedance, resistance, and reactance, while multiple uses multiple frequencies. There are also segmental models, which divide the body into segments (two arms, two legs, and a trunk), rather than analyzing the body as one cylinder, to improve accuracy. TBW is estimated from measurements of total area, impedance, volume, length, and specific resistivity. Some studies report underestimations of FM in obese individuals while overestimating FFM in obese individuals using single-frequency BIA (Deurenberg et al., 1996; Segal et al., 1988; Gray et al., 1989). Thus, multi-frequency BIA models avoid this problem by using low and high frequency currents, which can penetrate the extracellular and intracellular compartments, respectively. Thus, the multiple frequencies allow for estimations of TBW, ICW, and ECW (Baumgartner et al., 1996). Bedogni et al. (2002) found that the eight-polar multi-frequency BIA (InBody 3.0) accurately estimated TBW, and thus, is a good tool for measuring TBW in healthy individuals. In addition, Sartori et al. (2005) examined body water compartments using the InBody 3.0 in adults ranging in body mass index (BMI) from 19.1 to 48.2 kg/m^2. While obese women (BMI > 29.9 kg/m^2) had significantly ECW:TBW compared to non-obese women, there was no difference in ECW:TBW between the different categories of obesity within the study. Thus, the eight-polar BIA accurately estimated ECW and TBW in women over a wide range of BMIs, without using population-specific formulas.

InBody720 is a segmental multi-frequency impedance plethysmograph body composition analyzer, which uses eight electrodes to measure impedance to a small current at six frequencies (1, 5, 50, 250, 500, 1000 kHz), resistance, and reactance at three frequencies (5, 50, 250 kHz). A 90 µA current is used for the 1 kHz frequency and a 400 µA current is used for all other frequencies. The body is divided into five segments (two arms, two legs, and a trunk) and impedance is measured in each section. InBody720's segmental analysis improves accuracy due to the separate evaluation of the trunk and extremities. Low frequency (5 kHz) current is used to determine ECW, while higher frequencies (>50 kHz) are used to determine TBW. The InBody720 does not use empirical estimations in its analysis, meaning it does not use variables such as age, gender, or ethnicity to improve the accuracy of the impedance measurements. This is due to the skewed results that can result if the variables are input into the equation, but the individual does not conform to the trends, such as body density. Instead, results are based solely on the impedance measurements made by InBody720. The algorithm used for measuring impedance is unpublished by the manufacturer. Therefore, the advantages of an eight-polar BIA model are: 1) the use of tactile electrodes in place of adhesive electrodes, 2) the division of the body into five cylinders for analysis, 3) the insensitivity to the subject's posture while assessment is made, and 4) the rapidity of the measurements (Sartorio et al., 2005; Malavolti et al., 2003).

Conclusion

In summary, retaining adequate levels of hydration is vital to survival, as water affects nearly every physiological process. Therefore, maintenance of total body water is of utmost importance. This is especially true for the elderly, as the changes that occur as a consequence of physiological aging put them at greater risk for dehydration. These changes include increases in ADH and fat mass, declines in thirst sensation, glomerular filtration rate (GFR), urine concentrating ability, free-water clearance, and thus, total body water. As a consequence, prevention and careful monitoring of hydration in the elderly is of particular importance and warrants further research. Studies examining the effects of exercise on body water compartments is lacking, especially in older adults. Thus, it is especially necessary to examine if any interventions, such as those favoring an increase in lean body mass and thus, greater total body water, could help ameliorate the declines of body water that naturally occur with age. Therefore, research examining the effects of different exercise regimens (aerobic, resistance, or a combination) on body water compartments, especially in the most at-risk populations for dehydration merits further research.

CHAPTER 3

METHODS

Subjects

A total of 69 adults, aged 45-74 were recruited for another study examining blood pressure and other cardiovascular markers. Consequently, subjects were included in the study if they met the following criteria: stage 1 hypertension or pre-hypertension, were overweight or obese, and were sedentary. Stage 1 hypertension and pre-hypertension were defined as having a blood pressure (systolic/diastolic) of 140-149/90-99 and 120-139/80-89 mmHg (Chobanian et al., 2003), respectively), without taking any anti-hypertensive medications. Overweight and obese individuals (class 1 or 2) had a body mass index (BMI) of 25-40 kg/m^2 (NHLBI Obesity Education Initiative Expert Panel, 1998). Sedentary was defined as not meeting the aerobic and resistance exercise guidelines of <150 minutes/week of moderate intensity aerobic exercise, <75 minutes of vigorous intensity aerobic exercise, or the combination of the two, and <2 days/week of resistance exercise over the last three months, as defined by the U.S. Department of Health and Human Services (2008).

Participants were excluded if they smoked due to the strong effect of smoking on blood pressure, cardiovascular disease risk, and other study outcomes (Go et al., 2014). In addition, subjects were excluded if they were pregnant or planning to become pregnant during the intervention period, if they planned to be gone >2 weeks during the 8-week intervention, were on blood pressure medication, or had any medical problems preventing them from exercising according to American College of Sports Medicine and American Heart Association guidelines for contraindications to exercise (American College of Sports Medicine, 2013a; Williams et al., 2007).

If subjects met the above criteria, they were randomized to one of four treatment groups: aerobic exercise training (AT), resistance exercise training (RT), combination resistance and aerobic exercise (COMB), or no exercise (CON) for eight weeks. Randomization was done according to age, sex, BMI, and baseline blood pressure.

All procedures were approved by the Iowa State University Institutional Review Board and each participant gave written informed consent prior to participation.

Study Protocol

At the beginning and end of the 8-week supervised intervention and after an overnight fast, subjects reported to the lab for the following measurements: blood chemistry analysis, anthropometry, bioelectrical impedance analysis (BIA), and a three-day diet diary. All measures were conducted in the same laboratory and with the time of day standardized after the overnight fast. Following the initial assessments, subjects involved in the exercise groups came to exercise three times per week for eight weeks.

Blood Chemistry Analysis

After an overnight fast of at least 12 hours, the blood chemistry analysis measured glucose, sodium, and blood urea nitrogen (BUN) for future plasma osmolality calculations. Approximately 5 ml of blood was drawn by a registered nurse via venipuncture from a superficial arm vein to determine these markers.

Anthropometric Measurements

Body weight and height were measured using a standard stadiometer to calculate body BMI. BMI was determined by body weight in kilograms divided by height in meters squared. Body composition was also assessed was using bioelectrical impedance analysis (BIA), as is discussed next.

Bioelectrical Impedance Analysis (BIA)

BIA measurements were performed with an InBody720 analyzer (InBody720 Biospace Co., Ltd., Seoul, South Korea) after an overnight fast. The InBody720 divides the body into 5 segments (2 arms, 2 legs, and a trunk). Subjects stood on the BIA machine with each bare foot contacting an electrode and both hands gripping the hand electrodes with arms fully extended at the sides, approximately 15 degrees away from the trunk. Weight was automatically measured by the instrument and then subject ID, height, and gender were entered prior to impedance assessments. Impedance of each body segment was measured by passing a mild electrical current of (90 µA) and (400 µA) across a range of frequencies (1 kHz - 1 MHZ) via the electrodes. Following impedance, the InBody720 automatically calculated BMI, FM, percent body fat, and LBM. TBW was estimated from area, volume, length, impedance, and specific resistivity. The entire procedure took approximately 2 min. Bedogni et al. (2002) concluded that the InBody720’s tetrapolar eight-point tactile electrode impedance method provides very accurate estimates.

Dietary Analysis

All subjects were instructed to follow the Dietary Approaches to Stop Hypertension (DASH) diet and were provided with dietary counseling. The DASH diet is rich in fruits, vegetables, and low-fat dairy, with small amounts of red meat, sugars, and total/saturated fats. At the beginning of the intervention, a registered dietician provided dietary counseling to all subjects to implement the necessary dietary changes. The goal of the counseling was not to change the quality of the diet, while not changing the energy intake. At the beginning and end of the 8-week intervention, subjects completed a 3-day diet diary, utilizing 2 weekdays and one weekend day. The 3-day diet diaries were analyzed using The Food Processor Diet and Nutrition Analysis Software (ESHA, Salem, OR).

Exercise Protocol

For the 8-week intervention, all subjects (except CON) participated in a 60-minute supervised exercise session, three times per week. The aerobic group used the treadmill or cycle ergometer, starting at 40% of their maximal heart rate max gradually increased to approximately 70% of their maximal heart rate (**Table 1**). Subjects could increase the intensity if they chose, but could not exceed 80% of their maximal heart rate, as was monitored by a heart rate monitor worn during all exercise sessions.

Table 1. Aerobic exercise (AT) progression

	Day 1		**Day 2**		**Day 3**	
Week	***Time***	***Intensity***	***Time***	***Intensity***	***Time***	***Intensity***
1	20	40	20	40	30	50
2	30	50	30	50	35	60
3	35	60	40	65	40	65
4	45	65	45	70	45	70
5	50	70	50	70	55	70
6	55	70	60	70	60	70
7	60	70	60	70	60	70
8	60	70	60	70	60	70

Intensity (% max heart rate), time (min)

The resistance exercise group performed 12 exercises each session: chest press, shoulder press, pull-down, lower back extension, abdominal crunch, torso rotation, biceps curl, triceps extension, leg press, quadriceps extension, leg curl, and hip abduction. The program progressed from three sets of 10 repetitions for the upper body and three sets of 14 repetitions for the lower body, as is shown in **Table 2**. Weight programs for each machine were estimated based on age, weight, height, and sex, determined by the Technogym Wellness System. When subjects reached the assigned weight, they were encouraged to increase the weight until exhaustion on the last repetition. This indicated the lower the repetitions, the greater the intensity of the resistance exercise.

Table 2. Resistance exercise (RT) progression

	Day 1			**Day 2**			**Day 3**		
	Reps				**Reps**			**Reps**	
Week	***Sets***	***Upper***	***Lower***	***Sets***	***Upper***	***Lower***	***Sets***	***Upper***	***Lower***
1	1	18	20	1	18	20	1	18	20
2	2	18	20	2	18	20	2	18	20
3	2	15	18	2	15	18	2	15	18
4	2	15	18	2	15	18	2	15	18
5	2	12	16	2	12	16	2	12	16
6	2	12	16	2	12	16	2	12	16
7	3	10	14	3	10	14	3	10	14
8	3	10	14	3	10	14	3	10	14

The combination exercise group completed up to 30 minutes of aerobic exercise and 30 minutes of resistance exercise each session. The combination group followed the same protocol as the aerobic group, with slight differences from the resistance protocol. For the combination group, exercises were reduced from 12 to 8 machines and from 3 to 2 sets. Thus, the combination group used eight of the same machines as the resistance group, but did not use to shoulder press, biceps curl, triceps extension, or leg extension. The progression of the combination group is shown in **Table 3**.

Table 3. Combination exercise (COMB) progression

	Day 1					Day 2					Day 3				
	Aerobic		*Resistance*			*Aerobic*		*Resistance*			*Aerobic*		*Resistance*		
Week	**T**	**I**	**S**	**U**	**L**	**T**	**I**	**S**	**U**	**L**	**T**	**I**	**S**	**U**	**L**
1	20	40	1	18	20	20	40	1	18	20	20	50	2	18	20
2	20	50	2	18	20	20	50	2	18	20	25	60	2	18	20
3	30	45	2	15	18	30	45	2	15	18	30	50	2	15	18
4	30	50	2	15	18	30	50	2	15	18	30	50	2	15	18
5	30	55	2	12	16	30	55	2	15	18	30	55	2	12	16
6	30	55	2	12	15	30	60	2	15	18	30	60	2	12	16
7	30	60	2	10	14	30	65	2	10	14	30	65	2	10	14
8	30	65	2	10	14	30	70	2	10	14	30	70	2	10	14

Abbreviations: T: Time (min), I: Intensity (% max heart rate), S: # sets, U: Upper body, L: Lower body

All subjects were asked to abstain from any moderate or vigorous physical activity outside of the intervention. In addition, all subjects, regardless of group, were asked to wear a pedometer and to record daily steps, which was reported weekly.

Statistical Analysis

For all comparison, significance was set at $P \leq .05$. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) software, version 23 (IBM SPSS Inc. for Windows, version 23.0. Armunk, NY: IBM Corp.). Multivariate ANOVAs were used to compare groups for changes in TBW, ECW, and ICW; BMI, body mass (BM), lean body mass (LBM), dry lean mass (DLM), fat mass (FM), and percent body fat (%BF); total calories, carbohydrate, protein, fat, and sodium intake. Univariate ANOVAs were used to compare changes in TBW/LBM and osmolality. For all ANOVAs, covariates of age, sex, and the baseline dependent variable were used. Data using the above variables were examined for differences between all groups, between all exercise groups (INT) and control, between sexes, and between young (<60 y) and older (60+ y) adults. Regression analyses for Cohen's D and effect size (ES) were also performed on TBW, ICW, ECW, and LBM. Unless otherwise stated, all data are reported as mean ± standard deviation (SD).

CHAPTER 4

RESULTS

Baseline characteristics

Subject characteristics at baseline are shown in **Table 4**. Of the 69 subjects at baseline, 66 (96%) completed the 8-week intervention. The reasons why the three subjects did not complete the intervention were due to physician prescribed high blood pressure medication, pneumonia, and muscle discomfort. Subjects were randomly assigned to groups and thus, were similar in BMI, sex, and age. There was a significant difference in osmolality between groups (*P* = .0.02), with the resistance group having significantly lower osmolality than the aerobic group (*P* = 0.04), but this value was not significantly different from the combination or control groups. Aside from plasma osmolality, no significant between-group differences were noted at baseline in either body composition, body water, or diet (**Table 5**).

Adherence to exercise programs

The mean exercise session adherence was 96% for all groups except resistance training, which had a 92% adherence rate. On average, participants performing aerobic exercise completed 100 ± 6% of the prescribed exercise time (in minutes) and average intensity was higher than prescribed (119 ± 13%) based on heart rate measured during exercise sessions. On average, participants performing resistance exercise completed 100 ±2% of the prescribed sets at the weight prescribed (99 ± 11%) based on weight lifted during exercise sessions (data not shown).

Table 4. Baseline Characteristics (mean ± SD)

	Total	**Aerobic**	**Resistance**	**Combination**	**Control**	p_{model}	p_{group}
n	69	17	17	18	17		
Age (y)	58 ± 7	58 ± 7	57 ± 9	58 ± 7	58 ± 6	0.94	
No. Women, % of total	42, 61%	10, 59%	10, 59%	11, 61%	11, 65%	0.98	
No. Post-menopausal, % of total	35, 83%	9, 90%	7, 70%	9, 81%	10, 91%	0.56	
Body Composition							
BMI (kg/m^2)	32.7 ± 5.2	32.7 ± 6.0	33.0 ± 5.8	32.0 ± 5.3	32.9 ± 3.8	0.93	
Body mass (kg)	94.9 ± 19.0	97.6 ± 20.7	96.3 ± 21.3	94.0 ± 18.8	91.9 ± 16.2	0.84	
LBM (kg)	56.8 ± 13.2	59.1 ± 13.4	58.1 ± 13.8	55.8 ± 14.0	54.2 ± 12.2	0.71	
DLM (kg)	15.1 ± 3.5	15.7 ± 3.5	15.4 ± 3.7	14.8 ± 3.7	14.4 ± 3.1	0.72	
Fat mass (kg)	38.2 ± 11.3	38.5 ± 13.0	38.2 ± 12.5	38.2 ± 12.4	37.9 ± 7.2	1.0	
% body fat	40.0 ± 8.1	39.1 ± 8.6	39.4 ± 7.9	40.5 ± 9.9	40.9 ± 5.9	0.91	
Body Water							
TBW (l)	40.2 ± 10.0	37.4 ± 10.7	42.7 ± 10.1	41.0 ± 10.3	39.8 ± 9.1	0.49	
ICW (l)	25.7 ± 6.0	26.8 ± 6.2	26.4 ± 6.4	25.2 ± 6.3	24.6 ± 5.5	0.71	
ECW (l)	16.0 ± 3.7	16.6 ± 3.7	16.3 ± 3.8	15.8 ± 4.0	15.2 ± 3.6	0.70	
TBW/LBM (l/kg)	0.72 ± 0.10	0.66 ± 0.20	0.74 ± 0.00	0.73 ± 0.00	0.73 ± 0.00	0.07	
Blood							
Osmolality (mOsmol/kg)	292.3 ± 3.4	293.6 ± 2.4†	290.3 ± 4.1†	293.2 ± 3.4	291.9 ± 2.8	**0.02**	**0.04**

Abbreviations: body mass index (BMI), lean body mass (LBM), dry lean mass (DLM), total body water (TBW), intracellular water (ICW), extracellular water (ECW).

Bolded values indicate significance at the α=0.05 level. P_{model} value is for overall model significance, p_{groups} represents significance between groups.

† indicates statistical significance between groups.

Table 5. Baseline diet (mean ± SD)

	Total	**Aerobic**	**Resistance**	**Combination**	**Control**	**p**
n	61	15	15	17	14	
kcal	1893.9 ± 475.8	1966.1 ± 581.8	1857.1 ± 483.9	1866.6 ± 466.7	1889.2 ± 389.3	0.93
Pro (g)	79.6 ± 21.8	77.2 ± 21.3	79.5 ± 23.6	79.7 ± 26.6	81.9 ± 14.8	0.95
Fat (g)	73.8 ± 20.7	75.5 ± 19.6	69.1 ± 20.1	72.5 ± 21.9	78.6 ± 22.3	0.42
Na (mg)	2971.1 ± 1034.2	2928.1 ± 1036.1	2820.8 ± 1072.6	3037.9 ± 1114.1	3096.8 ± 981.4	0.90

Abbreviations: kilocalorie (kcal), protein (pro), sodium (Na).

Comparisons between groups

Between intervention groups, there were significant differences in changes in BM (*P* = 0.02) and LBM (*P* = 0.04), with COMB gaining significantly more BM and LBM compared with AT (*P* = 0.01, 0.03, for BM, LBM, respectively) (**Table 6**). No significant group differences were found for changes in BMI, DLM, FM, % body fat, but there were large effect sizes for BMI, DLM, FM, and % body fat (ES = 0.82, 0.85, 0.58, and 0.73 for BMI, DLM, FM, and % body fat, respectively). Regarding body water compartments, there was a significant difference in TBW change between groups, but only between COMB and CON (*P* = 0.05). COMB gained the most TBW compared to all groups (0.6 ± 1.1 l) while CON lost the most TBW (-0.3 ± 1.2 l, *P* = 0.05). COMB lost significantly more ECW than CON (*P* = 0.03), but did not differ from AT or RT. There were no significant differences between groups for ICW, but a large ES was found (*P* = 0.06, ES = 0.83). In addition, no significant differences were found between groups for TBW/LBM, or osmolality (*P* = 0.32, 0.53, for ICW and TBW/LBM, respectively).

Table 6. Differences in body composition and body water as a result of exercise regimens between intervention groups (mean ± SD)

	Total	**Aerobic**	**Resistance**	**Combination**	**Control**	**p_{model}**	**p_{groups}**
n	66	16	15	18	17		
Body Composition							
BMI (kg/m^2)	-0.3 ± 1.5	-0.5 ± 0.7	-0.0 ± 0.5	-0.3 ± 2.5	-0.3 ± 1.1	0.09	
Body mass (kg)	-0.2 ± 1.9	-1.2 ± 1.8†	-0.2 ± 1.6	0.8 ± 1.2†	-0.2 ± 2.3	**0.02**	**0.01**
LBM (kg)	0.0 ± 1.5	-0.5 ± 1.2†	0.2 ± 1.7	0.8 ± 1.4†	-0.4 ± 1.6	**0.04**	**0.03**
DLM (kg)	0.0 ± 0.4	-0.1 ± 0.3	0.0 ± 0.4	0.2 ± 0.3	-0.1 ± 0.4	0.08	
Fat mass (kg)	-0.3 ± 1.4	-0.9 ± 1.6	-0.4 ± 1.4	0.0 ± 1.1	0.0 ± 1.5	0.18	
% body fat	-0.1 ± 1.4	-0.5 ± 1.3	-0.3 ± 1.4	-0.3 ± 1.1	0.6 ± 1.7	0.11	
Body Water							
TBW (l)	-0.0 ± 1.3	-0.2 ± 1.3	-0.2 ± 1.6	0.6 ± 1.1†	-0.3 ± 1.2†	**0.05**	**0.05**
ICW (l)	0.1 ± 0.7	-0.1 ± 0.7	0.1 ± 0.8	0.3 ± 0.6	-0.2 ± 0.6	0.06	
ECW (l)	0.0 ± 0.5	-0.1 ± 0.5	0.1 ± 0.5	0.2 ± 0.5†	-0.2 ± 0.6†	**0.03**	**0.03**
TBW/LBM (l/kg)	0.00 ± 0.01	-0.00 ± 0.02	0.00 ± 0.02	-0.00 ± 0.00	-0.00 ± 0.00	0.38	
Blood							
Osmolality (mOsmol/kg)	0.7 ± 3.9	-0.0 ± 4.0	1.1 ± 3.7	1.2 ± 5.0	0.7 ± 3.9	0.53	

Abbreviations: body mass index (BMI), lean body mass (LBM), dry lean mass (DLM), total body water (TBW), intracellular water (ICW), extracellular water (ECW).
Bolded values indicate significance at the α=0.05 level. P_{model} value is for overall model significance, p_{groups} represents significance between groups.
† indicates statistical significance between groups.

Absolute post-intervention body water compartment volumes are shown in **Table 7**. There were no significant differences between groups for TBW, ICW, or ECW (*P* > 0.05 for all), but medium effect sizes were found for TBW and ICW (ES = 0.49, 0.47 for TBW, ICW, respectively), and a large ES was found for ECW (ES = 0.53).

Table 7. Post-intervention body water volumes between groups (mean ± SD)

	Total	Aerobic	Resistance	Combination	Control	P
n	66	16	15	18	17	
TBW (l)	41.9 ± 9.6	43.9 ± 9.3	43.0 ± 10.9	41.5 ± 10.0	39.5 ± 8.5	0.14
ICW (l)	25.9 ± 6.0	27.1 ± 5.8	26.7 ± 7.0	25.5 ± 6.1	24.5 ± 5.2	0.13
ECW (l)	16.0 ± 3.7	16.8 ± 3.5	16.5 ± 4.2	16.0 ± 4.0	15.0 ± 3.3	0.09

Abbreviations: total body water (TBW), intracellular water (ICW), extracellular water (ECW).

Comparisons between younger and older adults

In addition, groups were separated and compared in younger (< 60 y) and older (aged 60+) adults (**Table 8**). In younger adults, there were significant differences in TBW, ICW, and ECW between COMB and CON ($P \leq 0.05$). There was also a significant difference between groups for LBM in younger adults, but the post-hoc analysis was unable to locate the difference. In older adults, there were no significant differences between groups for LBM, TBW, ICW, or ECW ($P > 0.05$ for all). However, large effect sizes for LBM, TBW, and ICW were found (ES = 1.54, 0.56, and 0.71 for LBM, TBW, and ICW, respectively) and a medium ES was found for ECW (ES = 0.42) in older adults.

Table 8. Differences in body water compartments and LBM as a result of different exercise regimes in younger and older adults (mean ± SD)

<60 y							
	Total	**AT**	**RT**	**COMB**	**CON**	p_{model}	p_{groups}
n	42	12	11	11	8		
Body composition							
LBM (kg)	-0.1 ± 1.6	-0.3 ± 1.3	0.2 ± 1.8	0.7 ± 1.2	-1.2 ± 1.7	**0.05**	
Body water							
TBW (l)	-0.2 ± 1.3	-0.3 ± 1.0	-0.2 ± 1.7	0.5 ± 0.9†	-0.9 ± 1.3†	**0.04**	**0.03**
ICW (l)	-0.0 ± 0.7	-0.1 ± 0.6	0.1 ± 0.8	0.3 ± 0.5†	-0.5 ± 0.6†	**0.03**	**0.02**
ECW (l)	-0.1 ± 0.6	-0.2 ± 0.5	0.1 ± 0.5	0.2 ± 0.4†	-0.4 ± 0.7†	**0.01**	**0.01**
60+ y							
	Total	**AT**	**RT**	**COMB**	**CON**	p_{model}	p_{groups}
n	24	4	4	7	9		
Body composition							
LBM (kg)	0.2 ± 1.5	-1.2 ± 0.7	-0.1 ± 1.6	0.9 ± 1.8	0.3 ± 1.1	0.17	
Body water							
TBW (l)	0.3 ± 1.2	0.0 ± 2.1	-0.1 ± 1.2	0.6 ± 1.3	0.2 ± 0.8	0.77	
ICW (l)	0.2 ± 0.7	-0.0 ± 1.2	-0.1 ± 0.6	0.4 ± 0.8	0.2 ± 0.7	0.78	
ECW (l)	0.1 ± 0.5	-0.0 ± 0.8	0.0 ± 0.6	0.3 ± 0.6	0.1 ± 0.4	0.77	

Abbreviations: lean body mass (LBM), total body water (TBW), intracellular water (ICW), extracellular water (ECW). Bolded values indicate significance at the α=0.05 level. P_{model} value is for overall model significance, p_{groups} represents significance between groups.

† indicates statistical significance between groups.

Comparisons between intervention (INT) and control (CON)

All exercise groups were collapsed into one intervention group (INT) and compared with control (CON) to examine the effects of exercise on body water and composition changes (**Table 9**). There were no significant differences in BMI, BM, LBM, DLM, or FM changes between INT and CON (*P* > 0.05 for all). There was a significant difference in %BF change, where INT lost body fat while CON gained body fat (-0.4 ± 1.2, 0.6 ± 1.7 kg for INT, CON respectively, *P* = 0.03). INT increased TBW and LBM while CON lost TBW and LBM, but the difference was not significant (*P* = 0.11 and 0.29 for TBW and LBM, respectively). CON lost significantly more ECW than INT (*P* = 0.05), but there was no significant difference in ICW change (*P* = 0.09, ES = 0.46).

In addition, there were no differences in TBW/LBM or osmolality between INT and CON (*P* = 0.62, 0.54, for TBW/LBM, osmolality, respectively).

Table 9. Differences in body composition, body water compartments, and osmolality between Intervention and control (mean ± SD)

	Total	**Intervention**	**Control**	**p**
n	66	49	17	
Body Composition				
BMI (kg/m^2)	-0.3 ± 1.5	-0.3 ± 1.6	-0.3 ± 1.1	0.87
Body mass (kg)	-0.2 ± 1.9	-0.2 ± 1.7	-0.2 ± 2.3	0.93
LBM (kg)	0.0 ± 1.5	0.2 ± 1.5	-0.4 ± 1.6	0.29
DLM (kg)	0.0 ± 0.4	0.1 ± 0.4	-0.1 ± 0.4	0.46
Fat mass (kg)	-0.3 ± 1.4	-0.4 ± 1.4	0.0 ± 1.5	0.17
% body fat	-0.1 ± 1.4	-0.4 ± 1.2	0.6 ± 1.7	**0.03**
Body Water				
TBW (l)	-0.0 ± 1.3	0.1 ± 1.3	-0.3 ± 1.2	0.11
ICW (l)	0.1 ± 0.7	0.1 ± 0.7	-0.2 ± 0.6	0.09
ECW (l)	0.0 ± 0.5	0.1 ± 0.5	-0.2 ± 0.6	**0.05**
TBW/LBM (l/kg)	0.00 ± 0.01	-0.00 ± 0.01	-0.00 ± 0.00	0.62
Blood				
Osmolality (mOsmol/kg)	0.7 ± 3.9	1.2 ± 5.0	0.7 ± 2.8	0.54

Abbreviations: body mass index (BMI), lean body mass (LBM), dry lean mass (DLM), total body water (TBW), intracellular water (ICW), extracellular water (ECW).
Bolded values indicate significance between intervention and control at the α=0.05 level.

Post-intervention differences in body water compartments between INT and CON are shown in **Table 10**. There were no significant differences for TBW, ICW, ECW, or TBW/LBM between INT and CON. Medium effect sizes were found for TBW, ICW, and ECW (ES = 0.35, 0.33, 0.39, for TBW, ICW, ECW, respectively).

Table 10. Post-intervention water compartment volumes between INT and CON (mean ± SD)

	Intervention	**Control**	**p**
n	49	17	
TBW (l)	42.7 ± 9.9	39.5 ± 8.5	0.23
ICW (l)	26.4 ± 6.2	24.5 ± 5.2	0.24
ECW (l)	16.4 ± 3.8	15.0 ± 3.3	0.19
TBW/LBM (l/kg)	0.73 ± 0.01	0.73 ± 0.00	0.66

Abbreviations: total body water (TBW), intracellular water (ICW), extracellular water (ECW), lean body mass (LBM).

Comparisons between sexes

Comparisons between sexes are shown in **Table A1**. Overall, males lost BM, LBM, DLM, and FM while females increased each of these variables throughout the intervention. However, no significant differences were found in BM, LBM, or DLM between sexes ($P > 0.05$ for all). In addition, no significant differences were found for BMI or %BF between sexes ($P = 0.34$, 0.99, for BMI and %BF, respectively). There were significant differences in all water compartment changes between females and males, with females demonstrating increased water volume in each compartment while males lost water (all $P = 0.02$). However, when TBW was corrected for LBM, no significant differences were found between sexes ($P = 0.28$). In addition, there was a trend for females to increase plasma osmolality over that of males, but this change was not significant ($P = 0.07$, ES = 0.12).

Differences in body water and LBM between groups for females and males are shown in **Table A2**. For females, there were no significant differences between groups for LBM, TBW, ICW, of ECW ($P > 0.05$ for all), but large effect sizes were found for LBM, TBW, and ICW (ES = 0.71, 0.76, 0.78 for LBM, TBW, and ICW, respectively). A medium ES was found for ECW (ES = 0.44). For males, there was a significant difference between groups for TBW ($P = 0.05$, ES > 1.0), but the post-hoc analysis was unable to locate the group differences. There were no significant differences between male groups for LBM, ICW, or ECW ($P > 0.05$ for all), but large effect sizes were found (ES > 1.0 for all).

Post-intervention body water compartment comparisons between males and females are shown in **Table A3**. Following the intervention, males had significantly higher volumes of TBW, ICW, and ECW compared with females (all $P < 0.001$).

Body water and LBM comparisons between age groups

TBW, ICW, ECW, and LBM differences with age are examined in **Table 11**. There was an association between lower LBM and body water in each compartment with increasing age, but no significant differences were found (*P* > 0.05 for all). Large effect sizes according to Cohen's D were found for TBW, ICW, ECW, and LBM between the youngest (45-49 y) and oldest (70-72 y) adults (ES = 1.48, 1.33, 1.16, and 1.27 for TBW, ICW, ECW, and LBM, respectively). Across groups, TBW was 1.7 l (4%) lower in adults aged 50-59 compared with aged 45-59, 2.2 l (5%) lower in adults aged 60-69 compared with those 50-59, and 8.4 l (21%) lower in adults aged 70-72 compared with those 60-69 (*P* > 0.05 for all). ICW and ECW showed identical declines between ages 45-59 and between ages 50-69 (6% and 4% for ICW and ECW, respectively). Between ages 60-72, both ICW and ECW declined by 16%, but these differences were not significant (*P* = 0.14 and 0.13 for ICW and ECW, respectively).

Table 11. Body water and LBM differences as a result of intervention between decades (mean ± SD)

Age (y)	Total	45-49	50-59	60-69	70-72	p
n	66	12	30	19	5	
TBW (l)	41.9 ± 9.6	44.6 ± 10.3	42.9 ± 8.6	40.7 ± 10.9	32.3 ± 5.7	0.14
ICW (l)	25.9 ± 6.0	28.0 ± 6.7	26.5 ± 5.3	25.0 ± 6.6	21.0 ± 3.3	0.14
ECW (l)	16.0 ± 3.7	17.0 ± 3.9	16.3 ± 3.3	15.7 ± 4.4	13.2 ± 2.5	0.13
LBM (kg)	57.1 ± 13.2	61.4 ± 14.5	58.4 ± 11.7	55.1 ± 14.8	46.7 ± 7.7	0.06

Abbreviations: total body water (TBW), intracellular water (ICW), extracellular water (ECW), lean body mass (LBM).

Dietary changes

Of the 66 participants that completed the study, 56 completed both the baseline and post-intervention 3-day diet diaries. Between groups, there was a significant change protein intake (**Table A4**). The resistance group increased protein intake the most of any group, while the aerobic and control groups decreased protein intake. However, the difference was not significant ($P = 0.11$ and 0.15 for aerobic and control, respectively). There were no significant differences in total caloric, carbohydrate, fat, or sodium intakes between groups.

When all exercise groups were collapsed into one intervention group and compared with the control group, there were no significant differences in dietary intake changes between INT and CON (**Table A5**).

Between sexes, there were significant differences in overall caloric, fat, and sodium intake, with males consuming more than females for each variable ($P = 0.03$, 0.04, and 0.01 for kcals, fat, and sodium, respectively) (**Table A6**). Although females and males both increased protein intake, the difference only approached significance ($P = 0.07$, ES = 0.08). Females decreased carbohydrate intake while males increased, but this difference was not significant ($P = 0.24$).

When sodium was used as a covariate in addition to baseline values, age, and sex, no significant differences were found between groups or between INT and CON for TBW or ECW ($P > 0.05$ for all) (data not shown). However, large effect sizes were found between groups for TBW and ECW (ES = 0.69 and 0.59 for TBW, ECW, respectively). Medium effect sizes were found between INT and CON for TBW and ECW (0.39 and 0.36 for TBW and ECW, respectively). Between sexes, there were significant differences for TBW and ECW ($P < 0.001$ and 0.001 for TBW, ECW, respectively) when sodium was also used as a covariate.

Regression Analysis

Linear regression analyses were performed on TBW, ICW, ECW, and LBM with age (**Table 12**). There were significant correlations between age and TBW, ICW, ECW, and LBM ($P < 0.01$ for all) and an inverse relationship was found between age, body water and LBM.

Table 12. Regression analysis for body water compartments and LBM with age.

	TBW	ICW	ECW	LBM
Significance	**<0.01**	**<0.01**	**<0.01**	**<0.01**
r	-0.35	-0.37	-0.32	-0.36

Abbreviations: total body water (TBW), intracellular water (ICW), extracellular water (ECW), lean body mass (LBM), correlation coefficient (r).
Bolded values indicate significance between groups at the α=0.05 level.

CHAPTER 5

DISCUSSION

To our knowledge, this was the first study to compare the effects of an 8-week exercise intervention of either aerobic, resistance, or a combination of aerobic and resistance training on body water compartments. In addition, this is the first study to examine the effects of different exercise regimes on older adults.

We hypothesized that all exercise (INT) subjects would have a greater total body water volume at the end of the intervention compared with control. When body water volumes were compared post-intervention, there were no significant differences between INT and CON for TBW, ICW, or ECW volumes ($P > 0.05$ for all). Although INT increased TBW over the intervention compared with CON, which lost TBW over the intervention period, the difference was not significant ($P = 0.11$)

We also hypothesized that the combination group would have the largest change in TBW compared with all other groups. There was a significant group difference in TBW volume change ($P = 0.05$), but the difference was only significant between the combination and control groups, where COMB increased TBW while CON lost TBW ($P = 0.05$). CON had the lowest TBW post-intervention and the highest percent body fat compared with all other groups. This is in agreement with previous findings due to the inverse relationship between body fat and body water. Previous studies have shown that between aerobic, resistance, or a combination of both, combination exercise leads to the greatest improvements in body composition and cardiorespiratory fitness (Ho et al., 2012; Davidson et al., 2009; Church et al., 2010; Park and Randone, 2003). Ho et al. (2012) found that combination exercise provided more favorable outcomes for fat and weight loss than aerobic or resistance training in overweight and obese individuals. Similarly, Park and Randone (2003) found combination exercise to be more effective for body composition improvements, decreasing total body fat, %BF, and visceral fat.

In addition to its beneficial effects on body composition, exercise has been shown to help reduce blood pressure, particularly in obese hypertensive individuals (Hsueh et al., 1994; Kolanowski, 1996; Kolanowski 1999). Individuals with hypertension often have increased TBW and ECW volumes due to increased sodium retention. This has important implications as increased ECW is associated with many diseases, such as chronic kidney disease, hypertension, edema, and heart failure (Tai, et al., 2014). Thus, exercise could offer an alternative treatment to diuretics, which induce fluid loss, to hypertension. This is especially important for the elderly, due to the natural declines in TBW that accompanies the aging process.

Finally, we hypothesized that TBW volume would differ between younger (<60 y) and older (60+ y) adults. When subjects were grouped and compared by decade, no significant differences were found for TBW ($P = 0.14$). However, a large effect size was found (ES = 1.48). In addition, although differences between age groups were not significant, large effect sizes were found for ICW, ECW, and LBM differences between the youngest (45-49 y) and oldest (70-72 y) participants (ES = 1.33, 1.16, and 1.27 for ICW, ECW, and LBM, respectively). Finally, the regression analysis showed significant correlations between increasing age and decreases in TBW, ICW, ECW, and LBM ($P < 0.01$ for all). Thus, TBW did differ between younger and older adults in the present study.

TBW comprises approximately 50-70% body mass (Sawka and Coyle, 1999). In the present study, average TBW was 44 ± 6% of total body mass. Our results may be lower due to the higher ratio of females to males, as well as the overweight/obese population studied. TBW/BM was lower in females than in males (41 ± 4%, 49.5 ± 5% for females and males, respectively), likely due to the higher fat percentage in females. This is consistent with findings by Malavolti et al. (2003) and Novak (1972), which also found lower TBW in females, corresponding with a higher body fat percentage compared with males.

ICW accounts for approximately two-thirds of TBW (Chumlea, et al., 1999). Our findings confirm this, with an average of 62 ± 0.0%. Females had an average ICW/TBW of 62 ± 1.0% while males had an average of 62 ± 1%. In addition, ECW accounts for roughly one-third TBW. Our findings also confirm this, with the average ECW/TBW of 38 ± 1% for the total sample, females, and males.

Our findings of decreasing TBW and LBM with age are consistent with findings from other studies (Schoeller, 1989; Ritz et al., 2001). In addition, our findings agree with Chumlea et al. (1999), Pichard et al. (2000), and Kyle et al. (2001) that there is an accelerated decline in TBW after age 60. We found that TBW declined by about 2 l (4-6%) each decade from age 45-69, but then showed a more rapid decline ~8 l (21%) from ages 60-72. ICW and ECW showed similar patterns, decreasing each decade from age 45-69 by ~4-6%, followed by an increased decline of 16% from age 60-70. However, despite these declines in each body water compartment and LBM with age, none of our values reached statistical significant.

In addition, our findings that ICW and ECW decline similarly with age are consistent with reports by Ritz et al. (2001), which found ICW and ECW to decline similarly between healthy adults (<55 y) and healthy older adults (>60 y). Although both ICW and ECW declined, the proportions of each compartment to TBW remained similar, suggesting cellular hydration is preserved during healthy aging. However, our findings are not consistent with studies by Fulop et al (1985), Steen et al. (1985), Lesser et al. (1979, or Lesser and Markofsky (1979), all of which found that during the aging process, one body water compartment declined significantly more than the other compartment.

Fulop et al. (1985), Lesser et al. (1979), and Lessser and Markofsky (1979) found that while TBW declined with age as a consequence of diminished LBM, ECW volume remained relatively unchanged. Therefore, the decline in TBW was due to ICW loss, and thus, body cell mass. However, Steen et al. (1985) found that the decrease in body water between ages 70-81 was mostly due the decrease in ECW volume. In our study, ICW and ECW declined similarly, suggesting that for this population of obese/overweight individuals, ICW and ECW decline at approximately the same rate. Thus, with varied findings, in agreement with Schoeller (1989), it is unclear if decreases in TBW with age are due to declines in the intracellular, extracellular, or a combination of both body water compartments.

Multi-frequency BIA, although relatively new, has been shown to be a valid and reliable tool for estimating body water compartments (Segal et al., 1991; Park et al.; 2010; Patil et al., 2011). A study by Aandstad et al. (2014) comparing DXA, single, and multi-frequency BIA found the test-retest reliability of the InBody720 to be 2.3 and 2.6% for males and females, respectively. However, it tended to underestimate %BF in both males and females by ~2% compared with DXA. Similarly, Tompuri et al. (2015) found underestimates of FM and %BF in boys and girls ages 6-8 y compared with DXA. Discrepancies between InBody720 and DXA were also greater in females and with increasing adiposity. Therefore, while the findings from the present study may be within the margin of error allowed by the InBody machine, it does not mean these findings are necessarily significant. In addition, it is difficult to understand discrepancies between inBody720 and other body composition assessment methods because InBody720's algorithms to compute body composition are unpublished. Thus, when a specific population is studied, the InBody formula may not be as appropriate as if used on a broader population or a different age group.

However, this study has several limitations. Although the overall sample size was fairly adequate (n=66), the distribution within each group was relatively small (n= 15-18). Small samples lack statistical power and the ability to detect significant differences. The sample was also fairly homogenous in that subjects were well-educated, obese or overweight, sedentary, and pre or stage-1 diabetic, all of which limit the generalizability of our study to older adults.

In addition, the age of the subjects could have affected the outcome. It could be that the population used was not old enough (>60 y) to show significant differences. It has been shown that after age 60, TBW declines more rapidly (Schoeller 1989; Forbes 1987; Steen 1997). The majority (n=42) of our subjects were less that 60 y, while only 24 were aged 60+. While we did find that TBW declined with age and differed between younger (<60 y) and older (60+ y) adults, we did not find significant differences between the ages of 45-72 when grouped by decade. Because our subjects ranged in age over three decades and were divided equally into groups, this may have masked any individual differences that did occur with aging. Thus, caution should be taken when extrapolating the findings of the present study to older adults.

Another limitation to our study was the failure to control for diet. It has been shown that hydration status and electrolyte content can influence BIA measurements (Deuremberg et al., 1992; Khaled et al., 1988; O'Brien et al., 1999; Roos et al., 1992). Changes in hydration typically involve accompanying changes in fluid and electrolytes between the intra- and extracellular compartments. Therefore, in order to eliminate the effects of diet and hydration status on baseline and post-intervention BIA measurements, diet should have been replicated between for the 24 h leading up to the testing. Similarly, water and fluid intakes were not monitored or recorded during the intervention. Thus, it is impossible to know if differences in body water compartment volumes may be partially attributed to individual variance in water intake.

In addition, although the evidence is inconclusive, some studies have shown that menstrual cycle can influence body water through water retention and other hormonal effects (Resener et al., 1997; Fruzzetti et al., 2007). While women in the present study reported their menstrual state, it was not specified if they were peri- or post-menopausal. Therefore, depending on the phase of the menstrual cycle, body water retention, and thus, body weight may be altered (Robinson et al., 1965; Deurenberg et al., 1988; Gleichauf et al., 1989)

It is also possible that the intervention period of eight weeks was not long enough for substantial changes in each body water compartment to occur. Future studies should examine body water compartment changes with a training regimen of longer duration, a larger and more diverse sample within a smaller age range, and control for diet and menopause.

Conclusion

In conclusion, aerobic, resistance, or combination exercise training resulted in greater body composition and body water outcomes compared to aerobic or resistance training alone in sedentary individuals with pre- or stage-1 hypertension. This has important clinical applications for individuals with hypertension, for whom diuretics are commonly prescribed, as exercise can be used as a possible treatment to lower blood pressure and improve body composition. In addition, this study supports previous findings that LBM, TBW, ICW, and ECW volumes are smaller with age, demonstrating the natural declines in body water with aging. Thus, further research is needed to see if a longer exercise intervention, as well as the type, can ameliorate these changes with healthy aging.

REFERENCES

AbouAssi H, Slentz CA, Mikus CR, et al. **The effects of aerobic, resistance, or combination training on insulin sensitivity and secretion in overweight adults from STRRIDE AT/RT: A randomized trial.** *J Appl Physiol* 1985, **118(12)**:1474-82.

Adolf EF et al. *Physiology of man in the desert*. Published: New York: Interscience 1947, pp 1-357.

Altieri A, La Vecchia C, Negri E**. Fluid intake and risk of bladder and other cancers.** *Eur J Clin Nutr* 2003, **57**:S59-S68.

American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription* (9th ed.). Philadelphia, PA, 2013a: Lippincott Williams & Wilkins.

Anti M, Pignataro G, Armuzzi A, et al. **Water supplementation enhances the effect of high-fiber diet on stool frequency and laxative consumption in adult patients with functional constipation.** *Hepato-Gastroenterology* 1998, **45(21)**:727-732.

Armstrong LE, Costill DL, and Fink WJ. **Influence of diuretic-induced dehydration on competitive running performance.** *Med Sci Sports Exerc* 1985, **17(4)**:456-461.

Armstrong LE, Lawrence E, Ganio MS, et al. **Mild dehydration affects mood in healthy young women.** *J Nutr* 2012, **142(2)**:382-388.

Arnaud MJ. **Mild dehydration: A risk factor of constipation?** *Eur J Clin Nutr* 2003, **57**:S88-S95.

Askew EW: **Water**, in Present Knowledge in Nutrition (7th ed), edited by Ziegler EE, Filer LJ, Washington D.C., International fatness indicates the large significant effect of this body Life Sciences Institute 1996, pp 98–107.

Baumgartner RN. Electrical Impedance and Total Body Electrical Conductivity. In "*Human Body Composition*" (AF Roche, SB Heymsfield and TG Lohman, eds.), pp. 79-107. Human Kinetics 1996, Champaign, IL.

Baumgartner RN, Stauber PM, Koehler KM, Romero L, Garry PJ. **Associations of fat and muscle masses with bone mineral in elderly men and women.** *Am J Clin Nutr* 1996, **63**:365-372.

Baumgartner RN, Stauber PM, McHugh D, Koehler KM, and Garry PJ. **Cross-sectional age differences in body composition in persons 60+ years of age.** *J Gerontol* 1995, **50A**:M307-M316.

Beck LH. **The aging kidney: defending a delicate balance of fluid and electrolytes**. *Geriatrics* 2000, **55**:26-28, 31.

Bedogni S, Malavolti M, Severi S, et al. **Accuracy of an eight-point tactile-electrode impedance method in the assessment of total body water.** *Eur J Clin Nutr* 2002, **56**:1143-1148.

Beetz R. Mild dehydration: **A risk factor of urinary tract infection?** *Eur J Clin Nutr* 2003, **57**:S52-S58.

Boddaert J and Belmin J. **Orthostatic hypotension and its treatment in the elderly.** *Presse Med* 2003, **32**:1707-1715.

Brodie D, Moscrop V, Hutcheon R. **Body composition measurement: a review of hydrodensitometry, anthropometry, and impedance methods.** *Nutrition* 1998, **14**:296-310.

Buchholoz AC, Bartij C, Schoeller DA**. The validity of bioelectrical impedance models in clinical population.** *Nutr Clin Practice* 2004, **19**:433-446.

Carson C. **The effective use of effect size indices in institutional research.** http://rlrw.bnu.edu.cn/uploads/2011420132315861.pdff. Accessed April 14, 2016.

Chan J, Knutsen SF, Blix GG, Lee JW, and Fraser GE. **Water, other fluids, and fatal coronary heart disease. The Adventist Health Study.** *Am J Epidemiol* 2002, **155**:827-833.

Chobanian AV, Bakris, GL, Black, HR, et al. **The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure: the JNC 7 report.** *JAMA* 2003, 289(19), 2560–2572. doi:10.1001/jama.289.19.2560

Chumlea WC, Guo SS, Zeller CM, et al. **Total body water data for white adults 18 to 64 years of age: The Fels Longitudinal Study.** *Kidney Int* 1999, **56**:244-252.

Church TS, Blair SN, Cocreham S, et al. **Effects of aerobic and resistance training on hemoglobin A1c levels in patients with type 2 diabetes: a randomized control trial.** *JAMA* 2010, **304(20)**:2253-2262.

Costill DL, Cote R, and Fink W. **Muscle water and electrolytes following varied levels of dehydration in man.** *J Appl Physiol* 1976, **40(1)**:6-11.

Davidhizar R, Dunn LC, and Hart AN. **A review of the literature on how important water is to the world's elderly population.** *Int Nursing Review* 2004, **51**:159-166.

Davidson LE, Hudson R, Kilpatrick K, et al. **Effects of exercise modality on insulin resistance and functional limitation in older adults: a randomized control trial.** *Arch Intern Med* 2009, **169(2)**:122-131.

DeLorenzo A, Andreoili A, Matthie J, et al. **Predicting body cell mass with bioimpedance by using theoretical methods: a technological review.** J *Appl Physiol* 1997, **82**:1542-1558.

Dennis EA, Dengo AL, Comber DL, Flack KD, Savla J, Davy KP, Davy BM. **Water consumption increases weight loss during a hypocaloric diet intervention in middle-aged and older adults.** *Obesity* 2010, **18(2)**:300-307.

Deurenberg P. **Limitations of the bioelectrical impedance method for the assessment of body fat in severe obesity**. *Am J Clin Nutr* 1996, **64**:449S-452S.

Deuremberg P, Schouten FJM. **Loss of total body water and extracellular water assessed by multifrequency impedance.** *Eur J Clin Nutr* 1992, **46**:247-255.

Deurenberg P, Westrate JA, Paymans I, et al. **Factors affecting bioelectrical impedance measurements in humans.** *Eur J Clin Nutr* 1988, **42**:1017-1022.

Diem K. *Documenta Geigy Scientific Tables*. Manchester: Geigy Pharmaceutical Company Limited, 1962, pp 538-539.

Eaton D, Bannister P, Mulley GP, et al. **Axillary sweating in clinical assessment of dehydration in ill elderly patients.** *British Med J* 1999, **309**:1271.

Edelman IS. **Organization of body water and electrolytes, in Biological Aspects of Aging**, edited by Shock NW, New York, Columbia University Press, 1962, pp 46-57.

EFSA (2008). *Draft dietary reference values for water. Scientific Opinion of the Panel on Dietetic Products, Nutrition and Allergies,* (agreed on 11 April 2008 for release for public consultation).

Ellis KJ and Wong WW. **Human hydrometry: Comparison of multifrequency bioelectrical impedance with $2H_2O$ and bromine dilution**. *J Appl Physiol* 1998, **85**:1056-1062.

Ferry M. Strategies for ensuring good hydration in the elderly. *Nutr Rev* 2005, **63(6)**:S22-S29.

Fishchback FT, Dunning MB. A manual of laboratory and diagnostic tests 7th edition. Philadelphia, PA: Lippincott Williams and Wilkins; 2004. pp. 964-969.

Forbes GB. *Human body composition: Growth, aging, nutrition, and activity.* New York, Springer-Verlag, 1987.

Foster KR and Lukaski HC. Whole-body impedance what does it measure? Am J Clin Nutr 1996, 64(Suppl):388S-396S.

Fruzzetti F, Lazzarini V, Ricci C, et al. **Effect of an oral contraceptive containing 30 mu g ethinylestradiol plug 3 mg drospirenone on body composition of young women affected by premenstrual syndrome with symptoms of water retention.** *Contraception* 2007, **76(3)**:190-194.

Fulop T Jr, Worum I, Csongor J, et al. **Body composition in elderly people. I. Determination of body composition by multiisotope methods and the elimination and the elimination kinetics of these isotopes in healthy elderly subjects.** *J Gerontol* 1985, **31**:6-14.

Gallagher D, Visser M, De Meersman RE, Sepulveda D, Baumgartner RN, Pierson RN, et al. **Appendicular skeletal muscle mass: Effects of age, gender, and ethnicity.** *J Appl Physiol* 1995, **83**:229-239.

Gleichauf CN and Roe DA. **The menstrual cycle's effect on the reliability of bioimpedance measurements for assessing body composition.** *Am J Clin Nutr* 1989, **50**:903-907.

Go AS, Mozaffarian D, Roger VL, et al. **Executive summary: heart disease and stroke statistics – 2014 update: A report from the American Heart Association.** *Circulation* 2014, 129(3):399-410.

Gomez TD, Mole PA, Collins A. **Dilution of body fluid electrolytes affects bioelectrical impedance measurements.** *Sports Med Training Rehab* 1993, **4**:291-298.

Gray DS, Bray GA, Gemayel N, Kaplan K. **Effect of obesity on bioelectrical impedance.** *Am J Clin Nutr* 1989, **50**:255-260.

Gudivaka R, Schoeller DA, Ho T, et al. **Effect of body position, electrode placement, and time on prediction of total body water by multifrequency bioelectrical impedance analysis.** *Age Nutr* 1994, **5**:111-117.

Hall JE. **Renal and cardiovascular mechanisms of hypertension in obesity.** *Hypertension* 1994, **23**:381-394.

Heymsfield SB, Wang J, Lichtman S, et al. **Body composition in elderly subjects: a critical appraisal of clinical methodology**. *Am J Clin Nutr* 1989, **50(5)**:1167-1175.

Ho SS, Dhaliwal SS, Hills AP, et al. **The effect of 12 weeks of aerobic, resistance or combination exercise training on cardiovascular risk factors in the overweight and obese in a randomized trial.** *BMI Public Health 2012*, **12**:704.

Hsueh WA, Buchanan TA. **Obesity and hypertension.** *Endocr Metab Clin North Am* 1994, **23**:405-427.

Khaled MA, McCutcheon MJ, Reddy S, et al. **Electrical impedance in assessing human body composition: the BIA method.** *Am J Clin Nutr* 1988, **47**:789-792.

Klausner AG, Beck A, Schindlbeck NE, Muller-Lissner SA. **Low fluid intake lowers stool output in healthy male volunteers.** *J Gastroenterol* 1990, **28**:606-609.

Kleiner SM. **Water: an essential but overlooked nutrient.** *J Am Diet Assoc* 1999, **99**:200–206.

Kolanowski J. **Obesity and hypertension: from pathophysiology to treatment.** *Int J Obes* 1999, **23(Suppl 1)**:42-46.

Kolanowski J. **Particularites de l'hypertension arterielle associiee a l'obesite: de la physiologie a l'approche therapeutique.** *Rev Franc Endocrinol Clin* 1996, **37**:219-224.

Kushner RF. **Bioelectrical impedance analysis: A review of principles and applications***.* *J Am Coll Nutr* 1992, **11**:199-209.

Kyle UG, Genton L, Hans D, et al. **Age-related differences in fat-free mass, skeletal muscle, body cell mass and fat mass between 18 and 94 years.** *Eur J Clin Nutr* 2001, **55(8)**:663-672.

Lesser GT, Markofsky J. **Body water compartments with human aging using fat-free mass as the reference standard.** *Am J Physiol* 1979, **236**:R215-R220.

Lentner C. *Geigy Scientific Tables*. 8th edition, 1981. Basle: Ciba-Geigy.

Lindeman RD, Romero LJ, Liang HC, Baumgartner RN, Koelher KM, Garry PJ. **Do elderly persons need to be encouraged to drink more fluid?** *J Gerontol A Biol Sci Med Sci* 2000, **55(7)**:M361-365.

Lindeman RD, Tobin J, Shock NW**. Longitudinal studies on the rate of decline in renal function with age.** *J Am Geriatr Soc* 1985, **33:**278-285.

Luckey A and Parsa C**. Fluid and electrolytes in the aged.** *Archives of Surgery* 2003, **138**:1055-1060.

Mack GW, Weseman CA, Langhans GW, Scherzer H, Gillen CM, Nadel ER. **Body fluid balance in dehydrated healthy older men: thirst and renal osmoregulation.** *J Appl Physiol* 1994, **76**:1615–1623.

Malavolti M, Mussi C, Poli M, et al. **Cross-calibration of eight-polar bioelectrical impedance analysis versus dual-energy X-ray absorptiometry for the assessment of total and appendicular body composition in healthy subjects aged 21-82 years.** *Ann Hum Biol* 2003, **30**:380-391.

Maughan RL. **Impact of mild dehydration on wellness and on exercise performance.** Eur J Clin Nutr 2003, **57(Suppl 2):**519-523..

Mentes JC. **A typology of oral hydration: Problems exhibited by frail nursing home residents.** *J Gerontological Nursing* 2006, **32**:13-19.

Mentes J, Culp K, Wakefield B, et al. *Dehydration as a precipitating factor in the development of acute confusion in the frail elderly. In Hydration and Aging*. ed. MJ Arnaud, R Baumgartner, JE Morley, I Rosenberg & S Toshikazu, 1998, pp 83-110. New York: Springer.

Michaud DS, Spiegelman D, Clinton SK, et al. **Fluid intake and the risk of bladder cancer in men.** *New England J Med* 1999, **340(18)**:1390-97.

Moore FD, Haley HB, Bering EA, Brooks L, Edelman I. **Further observations on total body water. II. Changes on body composition in disease.** *Surg Gynecol Obstet* 1952, **95**:155-180.

Moore FD, Olsen KO, McMurrey JD, Parker HV, Ball MR, Boyden CM. T**he body cell mass and its supporting environment.** Philadelphia: WB Saunders, 1963.

Murray R. **Rehydration strategies- balancing substrate, fluid, and electrolyte provision.** *Int J Sports Med* 1998, **19(Suppl 2)**:S133-S135.

NHLBI Obesity Education Initiative Expert Panel. *Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults*, 1998.

Nielsen B, Sjogaard G, Ugelvig J, Knudsen B, Dohlmann B. **Fluid balance in exercise dehydration and rehydration with different glucose-electrolyte drinks.** *Eur J Appl Physiol* 1986, **55(3)**:318-325.

Novak LP. **Aging, total body potassium, fat-free mass, and cell mass in males and females aged between ages 18 and 85 years.** *J Gerontol* 1972, **27(4)**:438-443.

O'Brien C, Baker-Fulco CJ, Young AJ, et al. **Bioimpedance assessment of hypohydration.** *Med Sci Sports Exerc* 1999, **31**:1466-1471.

O'Brien C, Young AJ, Sawka MN. **Bioelectrical impedance to estimate changes in hydration status.** ***Int*** *J Sports Med* 2002, **23(5):**361-366.

Park DH and Ransone JW. **Effects of submaximal exercise on high-density lipoprotein-cholesterol subfractions.** *Int J Sports Med* 2003, **24(4)**:245-251.

Park B, Yang JJ, Yang JH, et al. **Reliability and data integration of duplicated test results using two bioelectrical impedance analysis machines in the Korean Genome and Epidemiology Study.** *J Prev Med Public Health* 2010, **43(6):**479-485.

Patel RV, Matthie JR, Withers PO, et al. **Estimation of total body water and extracellular water using single- and multiple-frequency bioimpedance.** *Am Pharmacother* 1994, **28**:565-569.

Patil BR, Patkar DP, Mandlik SA, et al. **Single prediction equation for bioelectrical impedance analysis in adults aged 22-59 years.** *J Med Engin Tech* 2011, **35(2)**:109-114.

Phillips PA, Rolls BJ, Ledingham JG, et al. **Reduced thirst after water deprivation in healthy elderly men.** *N Engl J Med* 1984, **311**:753–759.

Pichard C, Kyle UG, Bracco D, et al. **Reference values of fat-free and fat masses by bioelectrical impedance analysis in 3393 healthy subjects.** *Nutrition* 2000, **16**:245-254.

Popkin BM, D'Anci KE, Rosenberg IH. **Water, hydration, and health.** *Nutr Rev* 2010, **68(8)**:439-458.

Resener EV, dosSantos JE, Ferriani RA, et al. **Variation in body weight and water during the menstrual cycle in patients with premenstrual syndrome.** *Endocrin Metab* 1997, **4(2)**:135-140.

Ritz P, Investigators of the Source Study and of the Human Nutrition Research Centre-Auvergne. **Chronic cellular dehydration and the aged patient.** *J Gerontol A Biol Sci Med Sci* 2001, **56**:M349–M352.

Robinson MF and Watson PE. **Day-to-day variations in body-weight of young women.** *Bri J Nutr* 1965, 19:225-235.

Roos AN, Westendorp RGJ, Frolich M, et al. **Tetrapolar bioimpedance is influenced by body posture and plasma sodium concentration.** *J Clin Nutr* 1992, **46**:53-60.

Saltin B. **Aerobic and Anaerobic work capacity after dehydration.** *J Appl Physiol* 1964, **19**:1114-1118.

Sartorio A, Malavolti M, Agosti F, et al. **Body water distribution in severe obesity and its assessment from eight-polar bioelectrical impedance analysis.** *Eur J Clin Nutr* 2005, **59**:155-160.

Sawka MN. **Physiological Consequences of hypohydration: exercise performance and thermoregulation.** *Med Sci Sports Exerc* 1992, **24**:657-670.

Sawka MN and Coyle EF. **Influence of body water and blood volume on thermoregulation and exercise performance in the heat.** *Exerc Sport Sci Rev* 1999, **27**:167-218.

Sawka MN and Pandolf KB. **Effects of body water loss on physiological function and exercise performance.** In: *Perspectives in Exercise Science and Sports Medicine: Volume 3. Fluid Homeostasis During Exercise,* CV Gisolfi and DR Lamb, (Eds.) Indianapolis: Benchmark Press, 1990:1-38.

Sawka MN, Young AJ, Latzka WA, et al. **Human tolerance to heat strain during exercise: influence of hydration.** *J Appl Physiol* 1992, **73(1):**368-375.

Scharfetter H, Schlager T, Stollberger R, Felsberger R, Hutten H, Hinghoferszalkay H. **Assessing abdominal fatness with local bioimpedance analysis: Basics and experimental findings.** *Int J Obes Relat Metab Disord* 2001, **25**:502-511.

Schoeller DA. **Changes in total body water with age.** *Am J Clin Nutr* 1989, **50**:1178-1182.

Segal KR, Burastero S, Chun A, Coronel P, Pierson Jr RN, Wang J. **Estimation of extracellular and total body water by multiple-frequency bioelectrical-impedance measurement.** *Am J Clin Nutr* 1991, **54**:26-29.

Segal K, Van Loan M, Fitzgerald P, Hodgdon J, Van Itallie T. **Lean body mass estimation by bioelectrical impedance analysis: a four-site cross-validation study.** *Am J Clin Nutr* 1988, **46**:7-14.

Shanholtzer BA and Patterson SM**. Use of bioelectrical impedance in hydration status assessment: reliability of a new tool in psychophysiology research***.* *Int J Psychophysiol* 2003, **41**:163-167.

Shiffman CA, Aaron R, Amos V, Therrien J, Coomler K. **Resistivity and phase in localized BIA.** *Phys Med Biol* 1999, **44**:2409-2429.
Sigal RJ, Alberga AS, Goldfield GS, et al. **Effects of aerobic training, resistance training, or both on percentage body fat and cardiometabolic risk markers in obese adolescents: the healthy eating aerobic and resistance training in youth randomized clinical trial.** *JAMA Pediatr* 2014, **168(11)**:1006-1014.

Siener R, Hesse A. **Fluid intake and epidemiology of urolithiasis.** *Eur J Clin Nutr* 2003, **57**:S47-S51.

Silva AM, Fields DA, Heymsfield SB, et al. **Body composition and power changes in elite judo athletes.** *Int J Sports Med* 2010, **31(10)**:737-741.

Silva AM, Matias CN, Santos DA, et al. **Increases in intracellular water explain strength and power improvements over a season.** *Int J Sports Med 2014*, **35(13)**:1101-1105.

Smith AJ and Shaw L. **Mild dehydration: A risk factor for dental disease?** *Eur J Clin Nutr* 2003, **57**:S75-S80.

Steen B. **Body water in the elderly: A review.** *J Nutr Health Aging* 1997, **1**:142-145.

Steen B, Lundgren BK, Isaksson B. In: Chandra RK, ed. **Nutrition, immunity, and illness in the elderly.** New York: Pergamon Press, 1985:49-52.

Stookey JD, Constant F, Popkin BM, Gardner CD. **Drinking water is associated with weight loss in overweight dieting women independent of diet and activity.** *Obesity* 2008, **16(11)**:2481-88.

Suhr JA, Hall J, Patterson SM, Tong Niinisto R. **The relation of hydration status to cognitive performance in healthy older adults.** *Int J Psychophysiol* 2004, **53**:121-125.

Thomas BJ, Cornish BH, Ward LC, Jacobs A. **Bioimpedance: Is it a predictor of true water volume?** *Ann N Y Acad Sci* 1999, **873**:89-93.

Tompuri TT, Lakka TA, Hakulinen M, et al**. Assessment of body composition by dual energy X-ray absorptiometry, bioimpedance analysis and anthropometrics in children: the physical activity and nutrition in children study.** *Clin Physiol Funct Imaging* 2015, **35**:21-33.

U.S. Department of Health and Human Services. 2008 Physical Activity Guidelines for Americans. Be Active, Healthy, and Happy! 2008. Retrieved from http://www.health.gov/paguidelines/pdf/paguide.pdf

Vanderwalle H, Lacombe C, Lelievre JC, Poirot C. **Blood viscosity after a 1-h submaximal exercise with and without drinking.** *Int J Sports Med* 1988, **9**:104-107.

Van Loan M, Boileu R. **Age, gender, and fluid balance.** In: Buskirk E, Puhl S, eds. *Body Fluid Balance: Exercise and Sport.* Boca Raton, FL: CRC Press; 1996:215-230.

Van Loan MD, Kopp LE, King JC, Wong WW, Mayclin PL. **Fluid changes during pregnancy: use of bioimpedance spectroscopy**. *J Appl Physiol* 1995, **78**:1037-1042.

Williams, M. a, Haskell, W. L., Ades, P. a, Amsterdam, E. a, Bittner, V., Franklin, B. a, ... Stewart, K. J. **Resistance exercise in individuals with and without cardiovascular disease: 2007 update: a scientific statement from the American Heart Association Council on Clinical Cardiology and Council on Nutrition, Physical Activity, and Metabolism.** *Circulation*, 2007, *116*(5), 572–84. doi:10.1161/CIRCULATIONAHA.107.185214

World Health Organization. (2009*). Global health risks: mortality and burden of disease attributable to selected major risks.* World Health Organization (Vol. 2011). Doi:10.2471/BLT.09.070565.

Wotton K, Crannitch K, Munt R. **Prevalence, risk factors and strategies to prevent dehydration in older adults.** *Contemp Nurs* 2008, **31**:44-56.

Yavari A, Najafipoor F, Aliasgarzadeh A, et al. **Effect of aerobic exercise, resistance training or combined training on glycemic control in patients with type 2 diabetes.** *Biol Sport* 2012, **29(2)**:135-143.

APPENDIX: ADDITIONAL TABLES

Table A1. Differences between sexes in body composition, body water, and osmolality as a result of intervention (mean ± SD)

	Total	Females	Males	p
n	66	39	27	
Body Composition				
BMI (kg/m^2)	-0.3 ± 1.5	-0.1 ± 0.8	-0.5 ± 2.1	0.34
Body mass (kg)	-0.2 ± 1.9	0.1 ± 1.4	-0.5 ± 2.4	0.47
LBM (kg)	0.0 ± 1.5	0.4 ± 1.1	-0.5 ± 1.9	0.43
DLM (kg)	0.0 ± 0.4	0.1 ± 0.3	-0.1 ± 0.4	0.27
Fat mass (kg)	-0.3 ± 1.4	-0.5 ± 1.3	-0.0 ± 1.5	0.93
% body fat	-0.1 ± 1.4	-0.4 ± 1.5	0.2 ± 1.1	0.99
Body Water				
TBW (l)	-0.0 ± 1.3	0.4 ± 1.0	-0.6 ± 1.5	**0.02**
ICW (l)	0.1 ± 0.7	0.2 ± 0.6	-0.2 ± 0.8	**0.02**
ECW (l)	0.0 ± 0.5	0.1 ± 0.5	-0.2 ± 0.6	**0.02**
TBW/LBM (l/kg)	0.00 ± 0.01	0.00 ± 0.01	-0.00 ± 0.01	0.28
Blood				
Osmolality (mOsmol/kg)	0.7 ± 3.9	1.2 ± 5.0	0.7 ± 2.8	0.07

Abbreviations: body mass index (BMI), lean body mass (LBM), dry lean mass (DLM), total body water (TBW), intracellular water (ICW), extracellular water (ECW).
Bolded values indicate significance between sexes at the α=0.05 level.

Table A2. Differences in body water compartments and LBM between groups for females and males as a result of intervention (mean ± SD)

Females						
	Total	**AT**	**RT**	**COMB**	**CON**	**p**
n	39	9	8	11	11	
Body composition						
LBM (kg)	0.4 ± 1.2	-0.0 ± 1.0	-0.0 ± 0.9	0.9 ± 1.5	0.4 ± 1.1	0.22
Body water						
TBW (l)	0.4 ± 1.0	0.4 ± 1.2	0.0 ± 0.7	0.7 ± 1.1	0.3 ± 0.8	0.55
ICW (l)	0.2 ± 0.6	0.3 ± 0.8	0.0 ± 0.4	0.4 ± 0.6	0.2 ± 0.4	0.44
ECW (l)	0.1 ± 0.4	0.1 ± 0.5	0.0 ± 0.4	0.2 ± 0.5	0.1 ± 0.4	0.70
Males						
	Total	**AT**	**RT**	**COMB**	**CON**	**p**
n	27	7	7	7	6	
Body composition						
LBM (kg)	-0.5 ± 1.9	-1.2 ± 1.2	0.4 ± 2.4	0.5 ± 1.4	-1.8 ± 1.4	0.08
Body water						
TBW (l)	-0.6 ± 1.5	-1.0 ± 0.9	-0.4 ± 2.2	0.4 ± 1.1	-1.4 ± 1.1	**0.05**
ICW (l)	-0.2 ± 0.8	-0.5 ± 0.5	0.2 ± 1.1	0.2 ± 0.7	-0.7 ± 0.5	0.06
ECW (l)	-0.2 ± 0.6	-0.4 ± 0.5	0.1 ± 0.7	0.2 ± 0.4	-0.7 ± 0.6	0.08

Abbreviations: lean body mass (LBM), total body water (TBW), intracellular water (ICW), extracellular water (ECW).
Bolded values indicate significance between sexes at the α=0.05 level.

Table A3. Post-intervention body water volumes between sexes (means ± SD)

	Total	Females	Males	p
n	66	39	27	
TBW (l)	41.9 ± 9.6	35.5 ± 4.9	51.2 ± 6.7	**< 0.001**
ICW (l)	25.9 ± 6.0	21.9 ± 3.0	31.8 ± 4.1	**< 0.001**
ECW (l)	16.1 ± 3.7	13.6 ± 9.4	19.6 ± 2.7	**< 0.001**

Abbreviations: total body water (TBW), intracellular water (ICW), extracellular water (ECW).

Bolded values indicate significance between groups at the α=0.05 level.

Table A4. Dietary differences between groups as a result of intervention (mean ± SD)

	Total	Aerobic	Resistance	Combination	Control	p
n	56	15	14	14	13	
kcal	3.5 ± 439.7	-12.3 ± 435.1	7.4 ± 384.8	122.2 ± 462.4	-110.3 ± 492.3	0.58
CHO (g)	0.5 ± 62.7	-0.4 ± 67.0	-14.3 ± 66.8	18.9 ± 70.0	-2.5 ± 44.4	0.43
Pro (g)	2.9 ± 21.9	-5.0 ± 21.6	14.6 ± 22.7	8.5 ± 19.3	-6.4 ± 18.0	**0.03**
Fat (g)	-2.1 ± 23.1	1.5 ± 16.6	-0.2 ± 18.8	-0.9 ± 23.1	-9.5 ± 32.9	0.85
Na (mg)	119.3 ± 1073.0	126.9 ± 1129.4	204.0 ± 1134.5	-19.1 ± 1199.2	168.5 ± 896.5	0.75

Abbreviations: kilocalorie (kcal), carbohydrate (CHO), protein (pro), sodium (Na).

Bolded values indicate significance between groups at the α=0.05 level.

Table A5. Dietary differences between intervention and control as a result of intervention (mean ± SD)

	Total	Intervention	Control	p
n	56	44	12	
kcal	3.5 ± 439.7	32.4 ± 419.4	-102.5 ± 513.3	0.42
CHO (g)	0.5 ± 62.7	1.2 ± 66.9	-2.2 ± 46.4	0.46
Pro (g)	2.9 ± 21.9	5.2 ± 22.4	-5.3 ± 18.3	0.17
Fat (g)	-2.1 ± 23.1	-0.1 ± 19.0	-9.4 ± 34.4	0.62
Na (mg)	119.3 ± 1073.0	100.5 ± 1117.2	188.6 ± 933.3	0.39

Abbreviations: kilocalorie (kcal), carbohydrate (CHO), protein (pro), sodium (Na).

Table A6. Dietary differences between sexes as a result of intervention (mean ± SD)

	Total	Female	Male	p
n	56	32	24	
kcal	3.5 ± 439.7	-61.2 ± 373.3	89.8 ± 510.9	**0.03**
CHO (g)	0.5 ± 62.7	-5.6 ± 54.8	8.6 ± 72.4	0.24
Pro (g)	2.9 ± 21.9	2.2 ± 22.1	4.0 ± 22.1	0.07
Fat (g)	-2.1 ± 23.1	-5.8 ± 18.1	2.9 ± 28.1	**0.04**
Na (mg)	119.3 ± 1073.0	96.7 ± 838.9	149.6 ± 1342.8	**0.01**

Abbreviations: kilocalorie (kcal), carbohydrate (CHO), protein (pro), sodium (Na).

Bolded values indicate significance between groups at the α=0.05 level.