DAILY SELF-WEIGHING AND HOLIDAY-ASSOCIATED WEIGHT GAIN IN ADULTS

By

SEPIDEH KAVIANI

(Under the Direction of JAMIE A. COOPER)

ABSTRACT

Obesity is a worldwide health concern and is linked to the development of several chronic diseases. The rise in obesity prevalence has remained somewhat stable in the past few years. However, almost one-third of the United States adults are classified as obese and the degree of obesity continues to increase. Although the average yearly weight gain among U.S. adults is not large (0.4-1.0kg/year), accumulation of this small, yet consistent, weight gain can lead to significant weight gain over a long period of time. Studies show that a substantial portion of annual weight gain is due to an energy surplus during short periods of time throughout the year, importantly the holiday season. To date, there are no intervention studies aimed at preventing holiday weight gain. The objective of this dissertation is to introduce daily self-weighing (DSW) using the Caloric Titration Method (CTM) as an effective intervention in preventing holiday weight gain in adults. In the manuscript, body weight and other anthropometrics, as well as lipid profile, dietary and sleep patterns, stress level, and a number of perceptions towards food were measured before (within 1 week before Thanksgiving), immediately after (within 1 week after New Year's Day) and 14-weeks after the holiday season (early April). DSW was performed by the intervention group during the holidays while the control group did not receive any type of intervention. We found that DSW does prevent holiday weight gain in both sexes while its absence is associated with a significant increase in body weight during the holidays in both sexes. Weight maintenance as a result of DSW was driven by a significant weight loss in individuals with overweight and obesity while normal weight individuals were able to achieve weight maintenance. Based on the successful implementation of DSW in the overweight and obese population, along with the risk of greatest weight gain and retention in the absence of an intervention, DSW may be an ideal target for all adults, but especially for individuals with a high body weight. This dissertation suggests a feasible, effective and innovative approach to prevent weight gain thereby possibly improving health in adults.

INDEX WORDS: HOLIDAY WEIGHT GAIN, DAILY SELF-WEIGHING, WEIGHT MAINTENANCE, CALORIC TITRATION METHOD, OBESITY, OVERWEIGHT, HOLIDAY SEASON, WEIGHT GAIN, CHRONIC DISEASE, OBESITY PREVALENCE.

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To my family for nursing me with affection and love and for believing in me and inspiring me to be who I am and to succeed in my life.

Mom, Dad, Sis!

I couldn’t have done this without you. You always picked me up on time and encouraged me to go on every adventure, especially this one!

Thank you for all of your support from thousands of miles away.

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CHAPTER 1

INTRODUCTION

With more than 35% of the U.S. population being categorized as obese and a continuing increase in the degree of obesity [1-3], battling this growing health concern has been of substantial importance in the past decade. As a chronic disease itself, obesity accompanies a cluster of conditions known as metabolic syndrome, all of which increase the risk of heart disease, stroke, certain cancers and diabetes [4]. This inseparable integration of obesity and metabolic syndrome has become a major public health challenge since the presence of several other confounding factors makes it even more complicated to solve. Further, the economic influence of obesity in the U.S. is high and anticipated to continue increasing the absence of obesity is estimated to produce a meaningful decrease in annual medical expenditures [5].

Longitudinal studies show that the average adult in the U.S. gains 0.4 to 1.0 kg per year [1], and this small, yet consistent, gain appears to begin in early adulthood and can lead to obesity over several years. "Creeping obesity" is the term used for this gradual, consistent weight gain [6]. Creeping obesity does not refer to a slight daily energy surplus. Rather, it corresponds to short periods of time throughout the year that is responsible for a considerable portion of the average yearly weight gain [6]. One of those critical short periods of time that may contribute to annual weight gain is the holiday season (mid-November to early January).

Holiday-related weight gain has been shown to result in persistent yearly weight gain in adults [6-11], with overweight/obese individuals being more vulnerable to gaining the most [7, 11, 12]. Previous studies have shown mean weight gains in adults of 0.4-1.5 kg throughout the holiday period with an average of 0.5 kg weight gain across all studies [6]. By testing the effect of energy expenditure (EE) or physical activity (PA) on holiday-related weight gain, two previous studies indicated that energy intake (EI), rather than EE, is the culprit [8, 9]. The increase in EI during the holidays could be due to increased portion sizes [13], dining with other people, longer eating sessions, and easy access to food [14]. Traditional interventions such as dieting and exercising are less likely to be beneficial during the holiday season since multiple demands, busy schedules, and frequent presence of palatable foods and drinks may overwhelm such traditional weight maintenance strategies. Therefore, it is of utmost importance to develop novel behavior modification approaches to combat holiday weight gain.

Frequent or daily self-weighing (DSW) has been shown in recent studies to be effective in weight maintenance following weight loss [15, 16]. Also, weight regain is reduced with DSW- tied interventions rather than those accompanied by weight loss drugs or medications, traditional exercise, education, or behavior therapy interventions [17-20]. A novel DSW approach was recently introduced in which a visual feedback of weight trends is provided to the individual upon weight measurement by a digital Wi-Fi scale [21]. This approach is termed Caloric Titration Method (CTM). Through CTM, individuals are encouraged to adjust their behaviors towards weight maintenance or change weight in the intended direction [21]. The flexibility and ease of this approach has been shown to more closely relate to successful dieting compared to conventional dieting approaches [22]. Since no intervention-based studies have been conducted to prevent holiday-associated weight gain, the aim of the current dissertation is to investigate the effectiveness of DSW utilizing CTM on preventing holiday weight gain in adults.

The literature review provided in Chapter 2 includes an overview of previous and current research on the obesity epidemic, weight management interventions to combat obesity, holiday weight gain, and DSW in weight management including the proposed theory for how DSW works.

Chapter 3 represents the manuscript of this dissertation, describing the impact of DSW on preventing holiday weight gain and several other markers of health during the holidays. The 4th chapter provides a summary and conclusion for this dissertation. We hypothesized that DSW with CTM would be an effective approach in preventing weight gain and body fat gain during the holiday season. We further hypothesized that overweight and obese (OW & OB) individuals would respond better to DSW compared to normal weight (NW) individuals in maintaining their weight during the holiday season.

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CHAPTER 2

REVIEW OF THE LITERATURE

I. Introduction to Obesity

Definition

Obesity is a major health concern and has been a primary area of focus by researchers and clinicians. According to the definitions provided by the World Health Organization (WHO), overweight and obesity are described as accumulation of excess fat in the body (adiposity) that poses a risk to one's health [1, 2]. Body mass index (BMI) is the most commonly used measurement to categorize individuals as underweight, normal weight, overweight or obese [3]. BMI is calculated as an individual's weight (kg) divided by the square of their height (m) [2]. Based on BMI alone, individuals with BMI≥25 kg/m^2 are classified as overweight and those with a BMI≥30 kg/m^2 are obese. Further, obesity is grouped into three different classes: Class I (low-risk), characterized by a BMI between 30-34.9kg/m^2, Class II (moderate- risk), characterized by a BMI between 35.0-39.9kg/m^2, and Class III (high-risk or severe), characterized by a BMI≥40.0 kg/m^2 [4].

Since BMI is not a biological characteristic and is simply a weight-to-height index, using BMI as an alternative for adiposity, which is the main determinant of the degree of obesity, may not be ideal for individual diagnoses or treatments [1]. Body weight, as a component of BMI calculation, consists of all organs and tissues including fat mass, muscle mass, bone mass and water. Therefore, higher or lower values of BMI do not exclusively translate into higher or lower amounts of fat mass. Additionally, no information can be derived from BMI regarding fat type (brown or white adipose tissue) or its distribution (i.e. visceral or subcutaneous), all of which are indicators of cardiovascular and metabolic health [1, 5].

Nonetheless, there is a significant positive correlation between total body fat and BMI on a population level. However, this positive correlation does not necessarily reflect the same relationship on an individual level [6]. For instance, a high BMI in an athlete with a large skeletal mass does not infer obesity or a potential obesity-related health risk. Moreover, sex, age and ethnicity are other important determinants of adiposity and fat distribution that are not considered in the simple calculation of BMI. In spite of the aforementioned limitations associated with the use of BMI as an informative marker of health, existing methods of direct measurement of adiposity (underwater weighing, whole body densitometry, imaging techniques including Dual Energy X-Ray Absorptiometry (DXA) or Magnetic Resonance Imaging (MRI)) are expensive, hence not practical for large epidemiologic or clinical studies [1, 7].

Therefore, it is important to bear in mind that the reports about obesity and overweight prevalence in large populations are solely based on BMI calculations, disregarding anthropometric characteristics.

Obesity prevalence rates and trends

Obesity is now a global epidemic and it is observed in almost one-third of the countries around the world [8]. In all efforts to combat this worldwide health concern, no country has been successful to reverse the obesity epidemic or prevent the continuing increase in the degree of obesity [8]. In the United States, the increasing rates of obesity were primarily seen in the late 1980s and continued rising drastically until 2000 [9], but have remained somewhat stable since then [10]. Based on the reports revealed by the Center for Disease Control and Prevention (CDC) in 2017, 70.7% of adults (over the age of 20) in the United States are overweight and 39.8% are obese [11, [12)]. Although the prevalence of obesity may have plateaued since the 2000s, the degree of obesity has been continuously increasing. In the year 2000 in the United States, only 2.2% of out of 30.5% obese individuals had Class III obesity [(13)]; however, in 2005- 2006, 5.9% out of the 34.6% had Class III obesity, and in 2013-2014, 7.7% out of 37.9% obese individuals were classified as Class III obese [(10)]. More alarming is the increase in the prevalence and degree of obesity in children, not only in the US [(14)], but all around the world as reported by the WHO [(11, 15)]. There was a 19.6% increase in the prevalence of overweight and obesity combined in children and adolescents (ages 2-19y) from 1980 (27.5%) to 2013 (47.1%) [(8)]. In 2014, out of 17.0% obese children, 5.8% had Class III obesity [(14)]. According to Hruby and Hu, in 2016 [(16)], the prevalence of class II obesity in children only (BMI ≥120% of the 95th percentile) increased from 3.8 to 5.9% since 2000, and class III obesity (BMI ≥140% of the 95th percentile) has doubled [(17)]. This increasing prevalence of childhood obesity, in particular, predicts an overwhelming burden of disease control on the healthcare system in the future decades.

Economic costs of obesity

Based on projections, more than half of the US population will be obese by 2030 [(18)]. It is predicted that if a small decrease in obesity prevalence could be achieved, there would be a substantial reduction in obesity-related medical expenses [(11)]. This is important giving the rising health care costs related to obesity. In 2004, Thorpe and colleagues reported that there was a 27% increase in health care costs related to obesity between 1987 and 2001 [(19)], reaching to an estimate of $78.5 billion in the 2000s [(20)]. The gross amount of these expenses increased by $40 billion per year through 2006 [(20)]. In 2012, Cawley and Meyerhoefer[(21)] predicted that the obesity-related medical costs could reach $209.7 billion, which is twice as much as the amount predicted by Finkelstein and colleagues in 2009 [(20)]. According to a systematic review by Kim and Basu [(22)] in

2016, the medical expenses for an obese individual was $1,901 ($1,239-$2,582 USD) in 2014 which accounted for the national cost of $149.4 billion for obesity.

Altogether, the magnitude of the obesity-related medical expenses along with its health risks, makes it evident that developing an effective prevention and/or treatment plan for obesity is crucial.

Physiological and psychological costs of obesity

The link between obesity and the development of several chronic diseases has been extensively studied in the past, and obesity is one of the main contributors to cardiovascular diseases (CVD), diabetes mellitus, and certain cancers [23]. The emergence and the increasing rates of chronic diseases that replaced the epidemic of infectious diseases occurred in the 1970s and 1980s which is a phase called "epidemiologic transition" [23, 24]. The concurrent worldwide rise in obesity has been the evidence for such a close relationship between these chronic conditions and obesity. A 6% increase in the number of deaths from CVD occurred between 1990 and 2013[25] which reflects the importance of studying the underlying causes for such an increasing trend. The association between obesity and cardiovascular risk is well established; however, a controversy named the "obesity paradox" has emerged since there were reports of decreased CVD risk and higher survival rates with mildly elevated BMI [26-28]. Therefore, there is a need to assess other adiposity measures to determine the degree of the risk. Factors such as the distribution of body fat, especially fat accumulation in the abdominal area measured by waist circumference (WC) and waist-to-hip ratio (WHR) has been associated with elevated risk for myocardial infarction (MI), heart failure (HF) and mortality in CVD patients [26]. In fact, fat accumulation consequent to obesity results in a number of changes in metabolism and inflammatory responses [29]. Dyslipidemia, glucose intolerance, hypertension and several unknown mechanisms are affected by obesity which in turn disturbs the cardiovascular health of an individual [30]. Progression of atherosclerosis by aging and increasing number of infiltrated macrophages in atherosclerotic lesions are also aggravated by obesity and diabetes [31]. Further, vasodilation contingent to endothelium which is an early sign of developing atherosclerosis occurs as a consequence of obesity [32, 33].

Metabolic syndrome, which is defined as a combination of hypertension, hypercholesterolemia, hyperglycemia, and visceral obesity, occurs as a result of failure to maintain homeostasis under chronic exposure to excess energy and nutrients [34]. This phenomenon overwhelms organs including pancreas, liver, and adipose tissue, all of which are in charge of metabolic balance [34]. The mitochondrial dysfunction in the skeletal muscles of obese individuals as a result of the insulin resistance secondary to high exposure to dietary glucose, predisposes the individual to developing type 2 diabetes overtime [35]. The coexistence of insulin resistance and pancreatic dysfunction progresses the disease through elevated oxidative stress in obesity [34].

Aside from CVD and diabetes, obesity is a well-recognized risk factor for certain cancers in such a way that a considerable portion of cancer deaths in both males and females is attributed to excess body weight [36, 37]. Specifically, obesity increases the risk of developing the following cancers: breast (in postmenopausal women), ovarian, liver, gallbladder, kidney (renal cell), colon, pancreatic, gastric, esophageal (adenocarcinoma), endometrial, thyroid, multiple myeloma, and meningioma. Additionally, prostate cancer progresses in association with obesity [38]. One of the mechanisms that links obesity to cancer risk is increased leptin levels and leptin resistance in obese individuals which stimulates the proliferation of cancerous cells [39]. Further, cancer cells may change their glycolytic and mitochondrial metabolic programming to adapt to alterations in the environment, and they might advance to an aggressive phase that corresponds to a more destructive disease [38]. As cancerous cells selectively force their proliferation, they stimulate the transport of metabolic intermediates out of the mitochondria in order to be used as substrates for synthetic pathways, including lipid, nucleotide, and amino acid synthesis [40, 41]. In such cells, these processes are favored over ATP production through the electron transport chain [40, 41]. Therefore, cancer cells might depend mainly on glucose to provide energy (ATP), and amino acids and fatty acids for TCA intermediates. Consequently, over-nutrition secondary to obesity increases the accessibility of glucose and fat in the cell, all of which contribute to the metabolic reprogramming that feeds cancer cell proliferation. Moreover, glycolysis has been shown to be augmented in cancer cells in the presence of obesity [42]. Finally, obesity is associated with metabolic syndrome and diabetes [43, 44], both of which are distinguished by hyperglycemia and/or hypertriglyceridemia [45]. The provision of abundant circulating nutrients in such conditions to a growing tumor, even between feeding periods [46], have been associated with an intensified risk of cancer development [47, 48].

Previous research shows that obese adults have at least 20% higher rate of dying from all-cause or CVD compared to normal weight individuals [49-52]. It is reported by Borrell and Samuel in 2014 that Class II and Class III obese individuals die 3.7 years earlier from all-cause mortality. Also, 1.6 and 5.0 years of earlier death due to CVD is expected for Class I and Class III obese individuals, respectively [49]. In addition to its biological and physiological disruptions and the higher risk of mortality [53], diminished quality of life consequent to obesity has been a point of concern for many clinicians and psychologists.

The psychological effects of both obesity and rapid cycles of weight loss and weight gain (weight cycling) have been notably studied in the past [54-60]. Researchers have identified solid links between the variability in body weight, or this weight cycling, and adverse health outcomes [58, 61]. Negative behavioral responses to weight cycling can include binge eating, life dissatisfaction and higher risk for psychopathology [61]. However, these negative responses are mostly seen in individuals who had poorer psychological functioning prior to rapid weight changes [62]. These findings highlight the need for conducting a sustainable treatment for overweight and obesity with lower chances of continuous lapses and relapses.

Risk factors for obesity

Although there is sufficient evidence on the significance of the genetic role in individuals' susceptibility to obesity, genetics alone cannot explain the obesity epidemic [63]. An obesogenic environment that fosters unhealthy behaviors is suggested to be a stronger risk factor [63]. The abundance of highly palatable, inexpensive and energy-dense foods accompanied by a sedentary lifestyle disturbs the energy balance equation (energy intake (EI) = energy expenditure (EE)) by promoting higher energy intake and lower energy expenditure [64]. Over time, all these outside forces yield to gradual weight gain and ultimately contribute to obesity [64]. The modern way of living that is closely tied to intensive use of technology facilitates the convenient completion of day-to-day tasks. However, it is not surprising that this easy accomplishment of our activities gradually leads to a daily positive energy balance as we are required to expend less energy to accomplish the same tasks. Our dependency on electronic devices, the transition from more activity-based games to sedentary video games in children, and the change from more adventurous types of hobbies (i.e. nature exploring) to music listening and watching TV shows are all examples of how technological improvements have led to our inactivity and overconsumption little by little [64]. Aside from the extensive inclusion of technology in our daily lives, the massive production of inexpensive foods and the disappearance of manual work in the industry is also intensified by technology

[65].

II. Patterns of weight gain in lifespan

The obesity epidemic emerged as a public health problem in the early 2000s when more than half of the U.S. adults were already above the healthy weight range [66]. At the time, the prevalence of overweight and obesity within certain subgroups including non-Hispanic white men aged 50–59, and non- Hispanic black women aged 50–59 was more than 70% [9, 66]. Previous researchers monitored the small daily or weekly weight gains over time to study the chronic consequences of such a consistent positive energy balance. Longitudinal studies among U.S. adults show that average weight gain over the course of one year is between 0.4 to 1.0 kg (0.88 to 2.2 pounds) [51]. Accumulation of this small, yet consistent, weight gain, which appears to begin with early adulthood, can lead to substantial weight gain over a long period of time (15-30 years) and contribute greatly to obesity [14]. This slow, consistent weight gain over time has been termed "creeping obesity" [67]. That creeping, however, does not mean that adults are in a slight energy surplus every single day of the year [67]. Rather, the evidence shows that very short periods of time throughout the year can contribute to a significant portion of the average yearly weight gain [67, 68].

Age- and sex-specified cohorts showed that most of the weight gain during adulthood occurs between the ages 20-45 y in both sexes and starts to plateau after age 45 in men but continues to rise in women until around the age of 60 before it plateaus and then begins to decline [66]. Also, the peak yearly weight gain occurs between the ages 20-35y in both sexes. In 2003, Anderson and colleagues claimed that the freshman year in college is one of the critical periods of time during which individuals might gain weight [69]. They reported a 2.3kg weight gain during the first semester of college with the proportion of overweight and obese individuals increasing significantly [69]. Further, a systematic review by Moteiro and Victora shows that rapid growth during the first years of life is associated with the prevalence of obesity later in adulthood [70]. These findings suggest that there might be certain periods of time in one's lifespan (i.e. early childhood and early adulthood) that are important determinants of developing overweight and/or obesity later in life.

Short-term weight gain

In order to further understand the aforementioned long-term patterns of weight gain, it is reasonable to investigate weight fluctuations during short periods of time. According to a randomized control trial conducted by Racette et al [71] in 48 healthy adults aged 50-60 years, there was a consistent small weight gain seen on weekend days (0.06kg), but not on the week days for a control group who followed a healthy lifestyle. Moreover, the reported weight loss during week days following a calorie restriction vs. an exercise treatment either stopped or reversed towards weight gain during the weekend days [71]. Aside from patterns of change in body weight within a week, researchers have primarily studied three time periods throughout the year to determine when weight and fat gain is occurring. Those three time periods include (1) short-term vacations in adults, (2) summer vacation in children, and (3) the holiday season in adults. All three time periods result in significant weight and/or fat gain and are discussed in more detail in the next several paragraphs.

Cooper and colleagues [72] completed the only observational study to date on the effect of a short- term vacation on weight gain. They recruited 122 adults who were going on a 1-3-week vacation.

Participants completed a baseline visit within 1 week of vacation departure, a second visit within 1 week of returning from vacation, and a third visit at 6 weeks post-vacation. They showed a significant increase in body weight (0.32 kg) and this increase persisted during the 6-week post-vacation period so the total increase in weight was 0.41 kg. Finally, this weight gain did occur despite a trend for greater physical activity as assessed by the International Physical Activity

Questionnaire. Together, this data suggests that without an intervention, significant weight gain does occur in these "high risk" environments (such as vacations) and during a relatively short period of time.

There is a considerable body of the literature on the significance of weight gain during summer vacation in children [73-77]. In 2004, Gillis et al [74] aimed to explore whether summer vacation was the culprit for the low success rate of weight control programs in children. They reported a significant weight gain (2.8% of ideal body weight) in almost 70% of the 73 overweight children they tested. Two years later, in 2006, a cohort conducted on 5380 children in 310 schools revealed that weight gain in children during summer vacation is faster and more variable compared to kindergarten and first-grade school year [77]. According to a 5-year cohort done by Moreno et al [76] in 2013, summer break was shown to result in substantial weight gain in an ethnically diverse population of children, with an average increase of 5.2 percentile points in BMI vs. a 1.5 percentile points increase during the school year. In 2014, Franckle et al [75] published a systematic review of seven previous studies, reporting that certain racial/ethnic groups (black and Hispanic) as well as overweight children and adolescents are at higher risk for summer weight gain.

The most commonly studied time period thought to contribute to yearly weight gain in adults is the holiday season. Previous studies, all of which were observational, have shown that the holiday season (mid-November to early January) can result in weight gain and fat mass gain in adults, and that overweight/obese individuals are at risk for gaining the most [67, 68, 78-80]. These previous studies on the holiday season have reported weight gains ranging from 0.4-1.5 kg, with an average weight gain of 0.5 kg across all studies [67]. In a previous review on holiday weight gain, Schoeller et al [67] reported an energy surplus of 385 kcal/wk to get an average of 0.5kg of weight gain over the holiday period. Therefore, it is a relatively small weekly surplus that leads to this measurable holiday weight gain.

The first observational study to show holiday-associated weight gain was done by Yanovski et al in the year 2000 [(68)]. This was also the only study to include a one-year follow-up period after the holiday season. Aside from the ~0.4kg holiday weight gain, their subjects maintained this weight gain until the next year along with a non-significant additional weight gain during spring or summer months (0.21kg). The authors argued that this persistence in holiday weight gain indicates its contribution towards yearly weight gain [(68)]. However, with the insufficient number of studies including a full year follow-up period after the holiday season we have lacking evidence to form any firm conclusions.

The first holiday study in 2000 was followed up by six other observational studies on holiday weight gain which are discussed here. Stevenson et al [(79)] completed an observational study looking at holiday weight gain in 148 adult men and women. Baseline measurements were obtained the week before Thanksgiving and follow-up measurements were performed within 1 week following New Year’s Day. In this study, there was a significant increase in body weight (0.78 ± 0.1 kg, $p < 0.05$) during the holidays. In contrast to what they hypothesized, results showed that regular exercise (average of 4.8 ± 0.6 hrs/wk) did not prevent holiday weight gain as weight gain was similar to their sedentary counterparts. When analyzed by initial BMI status, they observed that body fat percentage increased significantly more in those who were obese at the beginning of the study (BMI > 30 kg/m^2) compared to those that were normal weight (BMI < 24.9 kg/m^2), and there was a trend for greater body fat percentage gain in obese versus overweight (BMI = 25-29.9 kg/m^2) individuals.

While most studies examining the holiday season study Thanksgiving through New Year's Day, Hull et al [81] conducted a study on 94 college students exclusively during the Thanksgiving week holiday. They reported an average 0.5 kg weight gain among all participants, with overweight and obese subjects gaining almost twice as much (1.0 kg) of weight during Thanksgiving compared to a non-significant 0.2 kg gain in normal weight individuals. This study was carried out in a limited age range and with no body composition measures, so it is unclear if the same Thanksgiving weight gain (by BMI) would occur in adults of other ages or whether the gain was attributed to fat mass.

The same group of researchers (Hull et al [80]) performed a longer-term study on 82 healthy male and female college students. They performed anthropometric measurements at three study visits: 2 weeks prior to Thanksgiving, within 5-7 days after Thanksgiving, and within 10 days following New Year's Day. They did not find a significant weight gain from pre-Thanksgiving to post-New Year's Day; however, they found a 1.1% increase in percent body fat and a 0.8kg increase in fat mass during the study period. With a significant increase in fat mass in the absence of weight gain, the authors concluded that assessing body weight alone might undervalue the potentially harmful effects of the holiday season on health [80].

Nearly all studies examining holiday-associated weight gain have been carried out in adults. However, Branscum et al [82] evaluated holiday weight gain among elementary-school children and reported an average 0.6 kg weight gain in normal weight children (3rd, 4th and 5th grade elementary school children; 9.2y old on average) and a significantly larger weight gain in overweight and obese children (0.8 kg). This study suggested that holiday season might be a critical time for children as well as adults. The early exposure to an obesogenic environment that has been shown to have adverse effects on body weight at very young ages speaks for the need for further investigations on innovative preventive approaches during critical times of the year.

Although not intervention work, two previous studies have examined the impact of energy expenditure (EE) and/or physical activity status on holiday weight [(78, 79)]. In one study, it is reported that regular exercisers gained a similar amount of weight as non-exercisers during the holiday season, so those that continue to exercise during the holiday season were not protected against weight gain [(79)]. Similarly, Cook et al [(78)] found that lower EE did not predict weight gain in adults during the holiday season.

Therefore, based on the energy balance equation (EI = EE), if EE doesn't explain holiday weight gain, it is likely that EI is the culprit. Others have also reported greater EI during the holidays or vacations and that weight gain tends to increase with reported EI [(80, 81)]. In the following paragraphs, we explain previous findings of a few observational studies on holiday weight gain in more detail.

III. Weight loss and weight maintenance

On a national basis, the weight increases for adults for the 40 years between the 1970's to 2010; during which the obesity prevalence increased from less than 10% to more than 35%; is only 13 kg, or 0.32 kg annually [(83)]. This is not equally distributed across all, but concentrated in those with elevated BMI, indicating that annual weights of 0.5 to 1 kg are clinically significant. While prevention of these small to modest annual weight gains has not proven easy, research has shown that permanent weight loss, that requires weight maintenance following weight loss, can also be difficult [(84)]. One meta-analysis of 29 weight loss studies showed that at the 5-year follow-up, participants are only able to maintain about 21% of their initial weight loss [(85)]. Therefore, the prevention of weight gain, even with its small average yearly amount, should have important clinical implications and may be a more successful approach for combating obesity. Moreover, preventing further weight gain in already overweight and obese individuals could still have a positive impact on reducing chronic disease risk [86, 87].

In 2002, Swinburn and Egger [88] showed that the results from a 10-year weight maintenance education-based program led to a ~20% reduction in cardiovascular risk in the large community [89]. In overweight and obese individuals in particular, weight maintenance is shown to result in reducing metabolic disease risk such as type 2 diabetes [90, 91]. On the other hand, in 2001, Field and colleagues showed that overweight but not obese men and women were significantly more likely to develop hypertension, hypercholesterolemia, and heart diseases compared to their slightly leaner peers [92].

Further, in a more recent study in 2017, Zheng et al [93] found that 24% of women and 37% of men who gained a moderate amount of weight (≥2.5 kg to <10 kg) achieved the composite healthy aging outcome, whereas weight maintenance (weight loss ≤2.5 kg or gain <2.5 kg) resulted in such an outcome in 27% and 39% of women and men, respectively. These findings suggest that even slight weight gain during adulthood might be associated with meaningful increases in chronic disease risk as well as odds of unhealthy aging, and that weight maintenance or small degrees of weight loss can decrease chronic disease risk substantially.

There have been several types of weight loss interventions utilized and tested by previous researchers [94-96]. These methods include dieting, exercise, surgical approaches, self-monitored calorie tracking by the use of technology, or the combination of two or more of these methods with or without receiving professional consultation [95-99]. A comprehensive review of the literature suggests that regular physical activity complementary to energy restriction through dieting leads to greater weight loss than dieting alone in individuals with overweight and obesity [100], and that exercising has been shown to be beneficial in weight maintenance following weight loss [101]. However, previous cohorts show that exercise interventions alone are found to be less effective compared to combined behavioral weight management programs in both short- and long-term intervention programs [102, 103]. Also, exercise interventions without energy restriction pose extremely varied and individualized effects on changes in weight, ranging from weight gain to clinically meaningful weight loss [104]. A comprehensive review of the literature conducted by Swift et al [105] in 2018 showed that aerobic exercise training alone with the minimum levels of physical activity recommendations (∼150 min of moderate intensity exercise) may lead to a modest weight loss (2-3kg), but typically unlikely to lead to a clinically significant weight loss (≥5%). However, daily exercise has shown to be beneficial in losing a clinically meaningful amount of weight [106, 107].

Regardless of the relative success of each of these methods against one another, up to half of the weight loss is generally regained within a 1-year follow-up even after the most well-implemented efforts to improve weight maintenance [108]. There are several dietary recommendations which may result in either slow or rapid weight loss in different individuals. Interestingly, contrary to some previous studies [109-114], it has been reported that an initial greater weight loss can actually be harder to maintain afterwards [100]. This might be due to the fact that individuals are able tolerate intensive lifestyle modifications only for a short period of time and the chances of relapse to previous patterns are relatively high [115].

Since most studies evaluated weight loss strategies, it is challenging to determine the underlying factors for weight regain. Factors including behavioral and physiological differences are warranted to be assessed in order to determine why some individuals regain weight after weight loss while others do not. Wing and Hill [116] stated that there is uncertainty regarding how a successful treatment plan should be implemented to address obesity. For this reason, they proposed a definition for successful long-term weight loss maintenance, which is losing at least 10% of initial body weight and keeping it off for at least 1 year. According to this definition and the National Weight Control Registry [117], individuals who were successful in long-term weight loss maintenance (average weight loss of 30 kg for an average of 5.5 years) shared common behavioral strategies. These include eating a low-fat diet, frequent self-monitoring of body weight and food intake, and high levels of regular physical activity. After such successful weight loss maintenance for 2–5 years, the chances of longer-term success are shown to greatly increase [118].

Most weight loss programs involve behavioral modifications that are demanding to abide for individuals (such as dieting or exercise) [115]. Therefore, we were interested to investigate methods of promoting long-term weight loss sustainability in today's modern life. In spite of considerable genetic and environmental differences among individuals, there is a consistent trend of weight regain in overweight and obese individuals. This consistency explains the possibility of an existing vigorous biological mechanism that nearly all individuals have in common [115]. According to more conventional theories, there are several homeostatic feedback mechanisms that are designed to compensate for weight imbalances [119, 120]. Additionally, Ochner et al [115] listed a few other potential mechanisms for weight regain which include adipose cellularity (reduction in size but not the number of fat cells consequent to dieting), leptin- and neuroendocrine-dependent increase in hunger, metabolic adaptation, changes in body composition consequent to weight loss and regain, and an addiction-like neural mechanism. Metabolic adaptation, for instance, refers to significantly greater reductions in resting and total energy expenditure than would be expected for given losses in metabolic mass in response to behavioral weight loss [121-126].

Thus, the efficiency of skeletal muscle work increases as a result of the disproportionate reduction in energy expenditure relative to body mass and composition [127]. In fact, increases in metabolic efficiency occurs within hours of caloric restriction, before any reductions take place in metabolic tissue [128]. In order to overcome this metabolic adaptation, obese individuals would need to constantly reduce EI and maintain it below the levels needed for a never-obese individual at the same BMI [115]. Moreover, changes in endocrine function (e.g., decreases in leptin and increases in ghrelin), and increases in reward-related neural responsivity to high-calorie food cues all occur within 24 hours of caloric restriction [115]. Each of these mechanisms has the potential to impose a physiological influence that may adversely affect weight maintenance following weight loss. Weight loss in obese individuals leads to increased food craving [129], underestimation of amount eaten [130], decreased satiety [131] and an increased preference for energy dense foods [132]. With these additional biological influences encouraging the consumption and storage of energy, it is not surprising that weight regain following behavioral weight loss occurs at a faster rate than initial weight gain [132].

In the early 2000s, group behavioral programs that consisted of regular clinic visits were found to be the most effective weight loss intervention [133]. However, participating in face-to-face intervention programs were reported to be a burden for both the individuals and clinicians/researchers [133] and is not a sustainable model. Therefore, investigators have tested alternative remote approaches by the means of internet and technology [134-139]. Although such approaches have been shown to produce a smaller weight loss, they have been a potential successful alternative solution to keep individuals engaged in the program [136, 137, 140]. In the past two decades, computer- and cell phone-based interventions have shown promising results in a variety of behavioral modifications including, but not limited to, smoking cessation, depression, asthma education, eating disorders, weight management interventions, HIV/AIDS control, physical activity promotion, cognitive behavioral therapy, and heart disease preventive strategies. [140-142]. The easy and widespread access to technology in today’s modern life makes it a viable delivery option for public health interventions. However, there is still lacking evidence on whether these methods are useful as stand-alone weight loss treatments, or they would better serve as complementary to another conventional weight loss strategy. As innovative and appealing methods of delivering weight management programs to individuals, computer-based approaches are acceptable and could be beneficial if they are implemented in a well-organized and structured manner as in face-to-face interventions [143-145]. The literature is unclear regarding whether technology-based interventions should be continued throughout the standard treatment period if they are chosen as supplementary approaches [146]. In this dissertation, we aimed to find a standard or conventional intervention that has been or could be integrated with technology. Stated differently, our purpose was to find an already proven weight management treatment that could be improved through technology and applied in a new setting.

IV. Daily self-weighing (DSW) and weight management

Frequent or daily self-weighing (DSW) was not traditionally supported as a method of weight control in adults. It was thought that it would be discouraging, frustrating, or less motivating due to minor losses or large fluctuations in daily weight caused initially by changes in fluid balance that could disguise actual changes in body weight [147]. The risk for developing unsafe habits categorized as eating disorders or worsening an already existing eating disorder as well as developing depression were some of the potential limitations suggested by previous research [147]. Therefore, weekly self-weighing was considered the standard practice [148]. On the contrary, more recent studies indicated that frequent weighing could play an important role in weight maintenance following weight loss and in inhibiting age-related weight gain [149]. In spite of the previous perceptions about negative psychological outcomes of DSW, a clinical trial conducted on DSW in 2012 [150] revealed that DSW imposed no effects on depressive symptoms, anorectic cognitions, disinhibition, susceptibility to hunger, and binge eating. Further, in 2014, another study by LaRose et al [151] did not find any adverse effects of DSW on disordered eating behaviors.

There are a few studies conducted previously on the effects of DSW on weight loss [149]. In 1976, Fisher et al [152] were one of the first to study the effects of DSW on weight loss based on 11 case studies in which individuals were instructed on DSW and graphing their weights on a chart. They validated DSW as an effective approach to help with weight loss. A few years later, in 1979, the first experimental study was conducted by Loro et al [153], concluding that DSW facilitated weight loss as an adjunct to other behaviors. Gradually over the past 30 years, there have been other studies on single or multiple weight measurements per day on consecutive days on both normal weight and overweight and/or obese populations, and they reported various outcomes, with majority of them reporting either a beneficial or neutral effect of DSW on weight loss [154-162]. In the most recent study on college-aged women conducted in 2017, Rosenbaum et al [162] reported that DSW was associated with significant declines in BMI (- 0.35kg/m^2) and body fat percentage (-2.2%) over time. Overall, frequent weighing has even been reported to lead to weight loss with men being better respondent to DSW compared to women [149].

As previously mentioned, developing weight maintenance strategies following weight loss may be as important as the initial weight loss. According to a comprehensive review done by Pacanowski et al [154], there are numerous studies on the effects of DSW on weight loss maintenance. The findings of most, if not all, studies suggest that individuals who continued DSW following a weight loss program were less likely regain weight even though DSW did not lead to weight loss in some study subjects [151, 163, 164]. However, the success of weight maintenance in some of those studies was attributed to the parallel communication with the research personnel to receive nutritional advice [163]. Another study showed that 44% of successful dieters utilized DSW according to data from National Weight Registry [165].

Furthermore, weight regain is decreased following diet interventions that include DSW compared to other strategies that involved weight loss drugs or medications, traditional exercise, education, or behavior therapy interventions [149]. Altogether, these reports suggest that although DSW could play a beneficial role in preventing weight regain.

There are also a number of previous studies focusing on the effects of DSW on preventing age- related weight gain [166-168] although the results are inconclusive. For instance, Levitsky and colleagues [166] tested the effects of DSW on a group of college students by randomizing them into either an intervention or a control group. Participants in the intervention group weighed themselves daily, which resulted in maintenance of body weight while the control group gained weight (+3 kg). In that study, electronic graphic feedback was not utilized. Gow et al [167] aimed to prevent weight gain in overweight college students utilizing an internet intervention with 170 first-year college students. They randomized their subjects into four groups: 1) no treatment, 2) 6-week online intervention 3) 6-week weight and caloric feedback only (via email), and 4) 6-week combined feedback and online intervention. They found that combined intervention group had a decrease in BMI (-0.30 kg/m^2) while the other three groups did not have such reductions in BMI after the intervention period. Conversely, in a study by Strimas and Dionne [168] the interactive impacts of self-weighing and restrained eating status on the BMI of university students over 12 weeks was studied. They randomly assigned their subjects into a DSW group (n = 36), weekly weighing group (n = 31), or weekly heart rate monitoring control group (n = 33). They found that with restrained eating, DSW resulted in significant weight gain (+1.36 kg) relative to weekly weighing which led to weight loss (−0.77 kg). With the differential effects of frequent self-weighing on weight management in this study, authors suggested that individual differences should be considered when tailoring clinical and public health recommendations for weight management. Based on the literature to date, it appears that DSW may not be effective in restrained eaters but may be successful in other young adult populations.

The inconclusiveness of findings on the effects of DSW on age-related weight gain could be due to a lack of motivation by the individuals, the level of restrained eating already present, or perhaps maintaining weight is less motivating than providing a targeted weight loss goal to aim for. It is also possible that feedback may be a crucial component of DSW to prevent weight gain [(166)]. Therefore, some researchers investigated DSW with personalized messaging to promote weight loss. In a study conducted by VanWormer et al [(158)] individuals lost a significant amount of weight and maintained their weight loss over the next year by receiving weekly charts of weight fluctuations. Later, in 2012, Bertz et al [(169)] reported that a monitored weight loss program consisting of DSW with electronic graphic feedback resulted in better weight loss outcomes in obese postpartum women. In 2013, Steinberg et al [(155)] showed that receiving weight charts with personalized weight loss suggestions along with weekly weight control lessons through the internet led to a significantly greater weight loss compared to a control group who received no intervention. Taken all the above-mentioned findings together, the effects of DSW may be influenced by the accompanying tools such as tailored advice or feedback [(154)]. Following their previous study in 2006, Levitsky and colleagues [(169)] used the Caloric Titration Method (CTM) for a DSW intervention over a 1-year period in freshman college students. There was significant weight loss (0.5 ± 3.7 kg) at the end of one academic year while the control group had gained 1.1 ± 4.4 kg ($p<0.001$).

Caloric Titration Method (CTM) is a DSW method in which a visual feedback of weight trends is provided to the individual upon weight measurement by a digital Wi-Fi scale. The flexibility and ease of this approach has been shown to more closely relate to successful dieting compared to conventional dieting approaches (170).

Scientists supporting frequent self-weighing propose that it increases individuals' awareness of their weight (171). Providing individuals with a feedback of their weight fluctuations mirrors the theory of behavioral self-monitoring as a component of social cognitive theory of self-regulation. Under this theory, Albert Bandura (172) explains how important continuous self-influence is to motivate human behavior. He proposes that individuals are more likely to change or develop a certain preferred behavior by continuously having the consequences under control, which indeed triggers self-reaction and ultimately leads to a change. Cognitive-behavioral treatments have been considered as gold standard obesity treatments (173, 174). These treatments typically include behavioral tasks such as self-monitoring and stimulus control and thought restructuring as cognitive strategies (173). Studies report that standard behavioral treatments lead to weight losses of 7–10% that are associated with decreases in the development of chronic diseases secondary to excess body weight (175). However, such treatments have relatively low adherence rates compared to conventional methods. Therefore, those receiving behavioral treatment lose smaller amounts of weight (117).

V. DSW and holiday-associated weight gain

Since the holiday season is a time of significant weight gain, it has been identified as a potential target for an intervention. It may be difficult for people to try to prevent annual weight gain by focusing on it every day of the year; however, if they can monitor their weight just over the holiday season, they may prevent holiday weight gain and potentially yearly weight gain. Conversely, an intervention over the holiday season could also be considered the most challenging time to employ an intervention. The holiday season is generally associated with higher stress, busier schedules, and much greater temptation for increased food and drink consumption [176]. Therefore, traditional interventions that employ dietary or energy restriction and/or increased levels of exercise will likely be met with resistance among many adults and ultimately limited success and adherence. Therefore, novel approaches to prevent holiday weight gain is warranted. One such approach is DSW. In this dissertation, we explored the implementation of self-weighing through a self-monitored approach (CTM) in adults during the holiday season. The findings of our study would greatly benefit the efforts aimed to address the obesity epidemic, hence affecting the prevalence of obesity-related chronic diseases particularly in overweight and obese individuals.

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CHAPTER 3

DAILY SELF-WEIGHING TO PREVENT HOLIDAY-ASSOCIATED WEIGHT GAIN IN ADULTS[1]

[1] Kaviani S, VanDellen M, Cooper JA. Obesity Journal, In Review.

Abstract

Background: Previous studies report 0.4-1.5kg of weight gain during the holiday season, which may contribute to annual weight gain. **Purpose:** To test whether daily self-weighing (DSW) can prevent holiday weight gain. **Methods:** 111 adults (age 18-75y, BMI $\geq$ 18.5kg/m^2) were randomized to either a control or DSW group. There were 3 testing visits: pre-holiday (v1: within 7d before Thanksgiving), post-holiday (v2: within 7d after New Year's Day), and a follow-up (v3: 14 weeks after v2). The DSW group were given Wi-Fi scales that provide graphical feedback of daily weight. They were instructed to perform DSW during the holidays and to try not to gain weight above baseline weights. Anthropometrics were measured at each visit. **Results:** There was no change in body weight in the DSW group while the control group gained weight from v1 to v2 (change of -0.13±0.27kg vs. 2.65±0.33kg, p<0.001; respectively). In the control group, holiday weight change was similar between overweight and obese (OW&OB) vs. normal weight (NW) individuals (change of 2.71±0.48kg vs. 2.62±0.43kg, ns; respectively). In the DSW group, OW&OB lost weight while NW maintained weight during the holidays (change of -1.46±0.62kg vs 0.33±0.27kg, p=0.01; for OW&OB vs. NW, respectively).

The control group did lose weight in the follow-up period (change of -1.14±0.43kg, p=0.01; from v2 to v3), but retained 57% of their holiday weight gain, therefore weight gain from pre-holiday through follow-up was significant (1.51±0.39kg, p<0.001). **Conclusions:** DSW was a successful approach to prevent holiday-associated weight gain in adults, with OW&OB individuals responding most favorably to DSW.

Introduction

More than 35% of the U.S. adult population is categorized as obese, and there is a continuing increase in the degree of obesity [1, 2]. Longitudinal studies among adults show that average weight gain is between 0.4 to 1.0 kg per year [1]. Accumulation of this small, yet consistent, weight gain appears to begin in early adulthood and can lead to substantial weight gain over time. This creeping obesity, however, does not come from a consistent slight daily energy surplus. Rather, evidence shows that very short periods of time throughout the year could account for a considerable percentage of average yearly weight gain [3]. One of those critical times that may contribute significantly to annual weight gain is the holiday season (mid- November to early January).

The holiday season has been repeatedly shown to lead to significant weight gain in adults [3-8], with reported weight gain in studies ranging from 0.4-1.5kg and an average of 0.5kg weight gain across all studies [3]. Holiday-related weight gain also persists after the holiday season, potentially contributing to annual weight gain [4]. Additionally, overweight and obese individuals are more vulnerable to gaining the most weight or body fat during the holiday season [3, 4]. Two previous studies tested the effect of energy expenditure (EE) or physical activity (PA) on holiday-related weight gain [5, 6], and the results from both indicate that energy intake (EI), rather than EE, is the cause for weight gain. Other studies have also reported greater EI during vacations which consequently contributes to weight gain [9, 10]. Increased EI could be due to increase in portion sizes [11], dining with other people, longer eating sessions, and easy access to food [12], all of which can lead to elevated EI and are common during the holidays. Since traditional diet and/or exercise interventions are less likely to be successful during the holiday season when multiple demands, busy schedules, and frequent presence of palatable foods and drinks may overwhelm traditional attempts to prevent weight gain, it is crucial to develop novel behavior modification strategies to combat this health issue.

Recent studies have shown that frequent or daily self-weighing (DSW) could play an important role in weight maintenance following weight loss [13-22], with men being more adherent to self-monitoring behaviors including DSW compared to women [23, 24]. DSW has also been effective in preventing age-related weight gain during critical times in the lifespan, such as the freshman year of college [16, 24]. Furthermore, weight regain is decreased following diet interventions that include DSW [24-27]. Previous research on weight management introduced a novel approach accompanying DSW, termed the Caloric Titration Method (CTM)[28], in which a visual feedback of weight trends is provided to the individual upon weight measurement by a digital Wi-Fi scale. Research suggests that by receiving visual feedback of weight change or pattern, individuals are encouraged to adjust their behaviors towards weight maintenance or change in the intended direction [28]. The flexibility and ease of this approach has been shown to more closely relate to successful weight management compared to conventional dieting approaches [29].

Although DSW+CTM has been shown to be effective in preventing age-related weight gain in young adults (college students) [28, 30, 31], DSW, with or without CTM, has never been tested during the holiday season. Furthermore, no other interventions have been tested to prevent holiday-associated weight gain. The purpose of this study was to determine the impact of DSW during the holiday season on holiday-associated weight gain in adults. Our hypothesis was that DSW with CTM would be an effective approach in preventing weight gain and body fat gain during the holiday season. We further hypothesized that overweight and obese (OW & OB) individuals would respond better to DSW compared to normal weight (NW) individuals in maintaining their weight during the holiday season.

Materials and Methods

Study Design

A single-blinded, randomized control trial (RCT) was conducted with two participant groups: a control group and an intervention group. Digital Wi-Fi scales were provided to the intervention group for the purpose of DSW. It was critical that participants in both study groups were blinded as to the main purpose of the study in order to prevent intentional behavior modifications (outside of DSW in the intervention group) that could influence body weight due to simply being a participant in a weight management study. Therefore, we employed a cover story in which participants were told that the project aimed to examine "how the holidays affect markers of health". All participants completed a total of three testing visits over a 6-month period (mid-November to early May) which included a pre-holiday visit (before Thanksgiving), post-holiday visit (immediately after New Year's Day), and a 14-week follow-up (early May) to assess sustainability after the end of the holiday season.

Participants

111 adult men and women, ages 18-65y and a BMI of at least 18.5kg/m^2 were recruited for the study. Anyone with an eating disorder or history of an eating disorder, anyone currently on, or planning to begin, a weight loss and/or an exercise program, pregnant or lactating women, and anyone using medications or having chronic diseases known to affect metabolic rate (such as thyroid conditions) were excluded from the study. This study was approved by the Institutional Review Board, and written informed consent was obtained prior to beginning study procedures.

Procedures

Screening Visit

Participants came in to the human nutrition lab (HNL) for the screening visit which took place in late September to early November, and informed written consent was obtained. A Likert item was then administered to measure habits of self-weighing frequency. This Likert consisted of a multiple-choice question about self-weighing frequency in the past month. The choices for responding were “Daily, 2-3x a week, 1x a week, 1x a month, or Never”. Weight and height were also measured to calculate BMI. The Drive for Objective Thinness Questionnaire [32] was also used to determine existing eating disorders or history of eating disorders, and a score of >45 on this questionnaire resulted in exclusion from the study. Qualified subjects were randomized into either the intervention group or control group (balanced blocks by age, sex, and BMI).

Pre-Holiday Visit (v1)

If eligible after the screening visit, participants were scheduled for v1. This pre-holiday visit occurred within one week prior to the Thanksgiving holiday. Participants reported to the HNL after an overnight fast (no food or drink for 8-12h) and at least 12h without any vigorous exercise. Height, body weight, waist and hip circumference, seated blood pressure, and body composition using Dual Energy X-Ray Absorptiometry (DXA™; Hologic Inc., Discovery A, Bedford, MA) were measured. A fasting blood draw was also taken for blood lipids. Questionnaires administered at this visit included the Perceived Stress Scale (PSS) [33, 34], Three factor Eating Questionnaire (TFEQ) [35], Power of Food Scale [36], National Insomnia Screening Questionnaire [37], self-weighing frequency Likert item, Mindful Eating Factors Questionnaire [38] and Fat Preference Questionnaire [39]. To assess participants’ perceptions of healthy and unhealthy foods, participants categorized a series of 60 images of different foods accompanied by their names (e.g., pizza, pancake, cheese, and broccoli). Participants selected ‘healthy’ or ‘unhealthy’ for each food item.

<u>*Intervention Period (Holiday Season)*</u>

Intervention group: At the conclusion of v1, each participant in the intervention group received the Wi-Fi scale (Body Composition Wi-Fi scale, Nokia (Withings®), Paris, France). They were asked to keep the scale in their bathroom and to weigh themselves once a day starting from the day after v1 until their post-holiday visit (v2) in early January. They were instructed to weigh themselves first thing in the morning after voiding (and defecating if that is their normal pattern). Once they stepped on the scale, their data would automatically transfer to their individual Withings® account as well as their Withings® mobile app (Nokia Health Mate app). Immediately after a weight measurement, participants saw electronic graphical feedback of their weight fluctuations on the scale’s screen as well as in their mobile app. The average of the first 4 days of body weights was determined to be the participants’ “baseline” weight. This baseline weight was then set as their “target” weight in their Withings® account which showed up as a straight line on their graph of daily weight fluctuations. Participants were instructed to try not to gain weight above this “target weight” line. They did not receive any additional instructions on how to achieve that goal. Each participant had an account with exclusive login credentials that were available to the researchers to ensure data reporting and compliance with DSW instructions.

Participants’ body weight was monitored by research personnel. If three consecutive days of DSW were missed during the intervention period, individuals were sent a reminder email to continue DSW. Any weight fluctuations greater than 5% of prior week’s average weight in a 1-week period was considered rapid weight change. If this occurred, the participant would be asked to come to the HNL and explain about general health and lifestyle practices that could be causing rapid weight change. Additionally, if a participant felt like the DSW was affecting them negatively in any way, they would be advised to meet with research personnel. For either of the above instances, the participant was to be withdrawn from the study and advised to seek counsel through a professional health care provider if there appeared to be a potential medical condition or if the participant was engaging in unhealthy behaviors such as following a severe energy deficient diet, excessive exercise, or experiencing adverse psychological effects.

Control group: Participants in this group were not given the scales and did not receive any instruction about weighing themselves or any other type of intervention. However, participants in the control group completed the same study visits, and the same measurements associated with those study visits, as the intervention group. We chose not to measure physical activity and/or food intake during the holiday season in both study groups in order to eliminate any influence of conducting such measurements on participants' behaviors, especially in the control group.

Post-Holiday Visit (v2)

All participants returned to HNL within 7-10 days after New Year's Day under the same unexercised and fasted conditions as v1. All study procedures that occurred during v1 were repeated. This included anthropometric measurements, fasting blood draw, and questionnaire completion. Participants in the intervention group were told they could discontinue DSW; however, they were allowed to keep the scale until the follow-up visit and were told to use it as they saw fit. They did not receive any additional instructions from research personnel regarding scale usage, and participants in either group were not given any information or data about their health measures at either visit (v1 or v2). This was done to avoid influencing behavior during the 14-week follow-up period.

Follow-up Visit (v3)

Fourteen weeks after v2, all participants once again reported to the HNL under the same unexercised and fasted conditions as v1. All study procedures that occurred at visits 1 and 2 were repeated exactly as stated above. The scales were collected from participants in the DSW group at this visit and weighing frequency data throughout the 14-week follow-up period was obtained from their online Withings® accounts.

Sample Analysis

The fasting blood samples from visits 1-3 were used to measure and complete lipid panel including total cholesterol (TC), High Density Lipoprotein cholesterol (HDL-c), Low Density Lipoprotein cholesterol (LDL-c), and triglycerides (TG) (Athens Regional Hospital, Athens, GA).

Statistical Analysis

Statistical analyses were performed using the JMP Pro 13 statistical software package (Statistical Discovery™, From SAS Institute Inc., Cary, NC). To test the effects of treatment conditions (DSW vs control) on the outcome variable (body weight) across the 3 testing visits, as well as on the change from one visit to another (pre- to post-holiday, post-holiday to follow-up, and pre-holiday to follow-up), a full factorial repeated measures ANOVA was conducted based on sex and weight status (normal weight (NW), overweight and obese (OW & OB)). A Pearson's correlation was conducted to find the relationship between holiday weight changes and age. A two-way repeated measures ANOVA was used to test the effects of treatment conditions (DSW vs control) on other anthropometric measurements (body fat, waist circumference, hip circumference, and waist-to-hip ratio), systolic and diastolic blood pressure, and blood markers (TC, TG, HDL-cholesterol, LDL cholesterol, and TC/HDL) across the 3 study visits. Post hoc analyses were performed using a Tukey's test where applicable. Statistical significance was set at $p < 0.05$, and data are presented as mean ± SEM, unless otherwise specified.

Daily weights over the holiday period (v1-v2) for the DSW group was analyzed using Auto-Regressive Integrated Moving-Average (ARIMA) model as a component of Box-Jenkins time series methodology [40] to analyze and forecast trends of change in body weight throughout the holiday season. This forecasting technique projected the future values of the daily body weights based entirely on the inertia of this time-series data. Additionally, data collected from all questionnaires (except for the self-weighing frequency Likert item), was analyzed using a parallel multiple mediator model [41] to test whether any component of participants' perceptions about food, as well as their dietary preferences and sleep behavior, was a significant mediator for the impact of DSW vs control on changes in body weight during the holiday season.

Finally, to analyze self-weighing frequency measured by the aforementioned Likert item, we quantified the percentage of individuals in control vs DSW, in NW vs OW&OB, and in males (vs. females) based on their self-reported, self-weighing frequency during the past month. Pearson's Chi-Squared test was used to conduct multiple comparisons within all pairs of groups at baseline (control vs DSW, NW vs OW&OB, or male vs female) as well as across two visits (pre- vs post-holiday or pre-holiday vs follow-up) within each group. A similar analysis was utilized to compare self-reported, self-weighing frequency (Likert item) with the data collected from the digital scales throughout the follow-up period in the DSW group.

Results

Feasibility: 111 participants were enrolled in the study (n=55 in the control group, n=56 in the DSW group) and 104 participants (n=53 in the control group, n=51 in the DSW group) completed all three testing visits (94% retention rate) (**Figure 1S**). **Table 1** presents participants' characteristics at baseline, grouped by sex. Two participants in the control group and five in the DSW group withdrew from the study due to personal reasons (trips, relocation, and pregnancy) after completion of the post-holiday visit. Therefore, there was no follow-up visit data for these 7 individuals. On average, participants in the DSW group missed 1.8 days of DSW out of an average of 51.5 days (96.4% of compliance rate). Further, none of the participants in the DSW group were excluded by the research personnel either as a result of rapid weight fluctuations or due to missing 20% or more of DSW during the holiday season.

Whole Group Body Weight Changes

There was a significant main effect of treatment ($p=0.001$), sex ($p<0.001$), and initial weight status ($p<0.001$), as well as a treatment*weight status interaction ($p=0.01$) on body weight across the three testing visits. The post-hoc analysis revealed a significant weight gain in the control group from pre- to post-holiday (67.02±1.78 vs 70.17±1.83kg, respectively; $p<0.001$) but significant weight loss from post-holiday to follow-up (70.17±1.83 vs 67.78±1.89kg, respectively; $p=0.01$) (**Table 2**). Despite this post-holiday weight loss, however, the control group overall still showed significant weight gain throughout the entire study period (66.65±1.60 vs 67.78±1.89kg for pre-holiday vs follow-up visit, respectively; $p<0.001$). On the contrary, the DSW group maintained body weight from pre- to post-holiday (66.65±1.60 vs 66.79±1.63kg, respectively; p=ns), as well as during the follow-up (66.79±1.63 vs 66.55±1.64kg for post- holiday vs follow-up visit, respectively; p=ns) and throughout the entire study period (66.65±1.60 vs 66.55±1.64kg for pre-holiday vs follow-up visit, respectively; p=ns) (**Table 2**).When comparing changes in weight over the study period between DSW vs. control, not surprisingly, change in weight during the holidays was greater for control vs DSW (2.65±0.33 vs -0.13±0.27kg, respectively; $p<0.001$). Weight loss during the follow-up period was greater in control vs DSW (-1.14±0.42 vs -

0.12±0.19kg, respectively; p=0.03). However, over the entire study period (from pre-holiday to follow-up visit), change in weight was greater in control vs DSW (1.51±0.39 vs -0.15±0.35kg, respectively; p=0.002) **(Figure 1).**

Body Weight Changes by Sex and BMI

In the control group, both males and females significantly gained weight during the holidays (**Table 2 and Figure 2A**). In the follow-up period, however, males but not females lost weight (**Table 2**) although the difference between the two sexes for change in weight was not significant (**Figure 2A**). Consequently, significant weight gain was only observed in females throughout the entire study period (2.09±0.48kg vs. 0.10±0.63kg; p=0.02 for females vs males, respectively; p=0.02) (**Table 2, Figure 2A**). Conversely, in the DSW group, there was no change in weight for either sex during the holidays, the follow-up period, or throughout the entire study (**Table 2**). Also, there was no difference between the sexes for change in weight at any time period or throughout the entire study (-0.02±0.40 vs 0.01±0.48kg for females vs males, respectively; p=ns) (**Figures 2B**). Further, there was no significant correlation between holiday weight changes and age.

When analyzed by BMI, NW individuals in the control group gained the same amount of weight compared to OW&OB individuals during the holiday season (2.62±0.43 vs 2.71±0.47kg, for pre- vs. post-holiday, respectively; p=ns) (**Table 2 and Figure 2C**). Although both NW and OW&OB significantly gained weight throughout the entire study period (from pre-holiday to follow-up visit) (**Table 2**), weight gain in OW&OB was greater compared to NW (2.99±0.80 vs 0.87±0.41kg, respectively; p=0.02). This was due to the weight loss in NW, but not OW&OB, in the follow-up period (**Table 2**) which was significantly greater for NW vs. OW&OB (-1.72±0.50

vs 0.25±0.75kg, respectively; p=0.04) (**Figure 2C**). Conversely, in the DSW group, OW&OB, but not NW individuals, significantly lost weight during the holiday season as well as throughout the study period (**Table 2**). These changes in weight were different between OW&OB vs. NW both during the holidays (-1.46±0.62 vs 0.33±0.27kg, respectively; p=0.001) and over the entire study period (-1.49±0.73 vs 0.47±0.34kg, respectively; p=0.03) (**Figure 2D**).

Other anthropometric measures and blood markers

There was a significant treatment*visit interaction for total body fat percentage (TBF%) (p=0.001). Post-hoc analysis showed that the decrease in TBF% was greater in DSW vs control during the holiday season (-1.08±0.19 vs 0.95±0.19%, respectively; p<0.001) and also throughout the entire study period (-0.87±0.37 vs. 0.45±0.26% vs. for DSW vs control, respectively; p=0.01) (**Table 2**). There was no main effect of treatment, visit, and interaction effects on measures of waist circumference (WC), hip circumference (HC), waist/hip ratio (WHR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and TG, HDL, or TC/HDL ratio. For TC and LDL, there was a significant visit effect (p=0.02 and p=0.04 for TC and LDL, respectively), both of which decreased across the three testing visits (**Table 2**). This decrease was driven primarily by changes in the DSW group.

Holiday daily weights

Because we could access daily weight data, we could explore the pattern of weight change (or not) in the DSW group. The graphical illustration of average daily weights from all participants in the DSW group during the holiday season can be found in **Figure 3**. Five specific time frames were chosen (pre-Thanksgiving week, Thanksgiving week, late November-mid December, pre-Christmas week, and Christmas & New' Year's Day Holidays) to look for patterns of change in weight. Box-Jenkins analysis showed $p>0.05$ for all time frames. This indicated that the patterns did not occur randomly or by chance. Therefore, the forecasts generated by this analysis were significantly adequate in predicting future patterns. These forecast lines (**Figure 3)** show a decreasing trajectory in body weight during the pre- Thanksgiving week, which then began to increase during the Thanksgiving week. This elevation was preserved throughout the Thanksgiving week and started to decrease after Thanksgiving until mid-December. There was a returning increase in body weight during the pre-Christmas week which escalated until the end of the holiday season. However, these increases did not exceed the baseline/target weight prior to the beginning of the holiday season.

Questionnaire results

None of the questionnaire scores at the pre-holiday visit were determined to be significant mediators for the effect of the study interventions (DSW vs control) on changes in body weight during the holiday season. The questionnaire scores at all study visits can be found in **Table 3**.

Self-Weighing Frequency Likert Item

There was no change in the one-month frequency of self-weighing from pre- to post-holiday visit in the control group (p=ns), **Figure 2S**. Also, when grouped by BMI, there were no differences in reported weighing frequency between NW vs OW&OB at the pre-holiday visit in the control group (p=ns), **Figure 3S**. There was a significant increase in self-weighing frequency from pre-holiday to follow-up visits in the DSW group (50.0% of individuals at the pre-holiday visit vs 78.6% at the follow-up visit weighed themselves more frequently than once a week; $p=0.03$) (**Figure 4S-A**), while no change was observed in the control group (50.9% of individuals at the pre-holiday visit vs 43.4% at the follow-up visit weighed themselves more frequently than once a week, p=ns) (**Figure 4S-B**). When analyzed by BMI in the DSW group, an increase in self-weighing frequency was seen in NW individuals (**Figure 5S-A**), but not in OW&OB (**Figure 5S-B**) (NW: 41.6% at pre-holiday vs 76.2% at follow-up; p=0.03 vs. OW&OB: 41.6% at pre-holiday vs 50.0% at follow-up (p=ns) for weighing more frequently than once a week). Finally, no significant difference was observed between the self-reported, self-weighing frequency (Likert item) vs Wi-Fi scale data during the follow-up period in the DSW group (p=ns).

Discussion

The aim of this study was to determine whether DSW was an effective approach to prevent holiday-associated weight gain in adults. For the first time, we show that DSW does prevent holiday weight gain in both males and females while its absence is associated with a significant increase in body weight during the holiday season in both sexes. When examining the effectiveness of DSW based on initial BMI status, we found that the weight maintenance of the whole group was driven by a significant weight loss in OW&OB individuals (average loss of -1.46±0.62 kg) while NW subjects were able to achieve weight maintenance with a non- significant slight increase in weight (average change of 0.33±0.27kg). There was also a corresponding decrease in TBF% following DSW suggesting efficacy of DSW on improvements in body composition as well.

Adults in the control group gained a substantial amount of holiday weight (average gain of 2.65±0.33 kg), which can largely be attributed to the significant increase in TBF% (average increase of 0.95±0.19% or 0.75±0.19kg fat mass; and an average increase of 1.0±0.2% or 0.47±0.15kg of fat mass particularly in the trunk area). Individuals in the control group did lose some of their holiday weight gain by the end of the 14-week follow-up period; however, as a group, they retained almost 57% of the weight gain so that their overall weight gain from pre-holiday (November) to April was still significant. Interestingly, males in the control group lost

~95% of the holiday weight gain within 14-weeks after the holidays, while females maintained ~77% of their holiday weight gain within this follow-up window. This pattern suggests that although holiday weight gain may be similar between men and women in the absence of an intervention, men may be more likely to lose some or most of that weight after the holiday season while women may retain more of that weight. We are unsure as to why men compensated for their holiday weight gain while women did not. However, based on a previous review on sex differences in behavior modifications, men tend to be more responsive to the adverse effects of a specific behavior or situation [42]. Therefore, we speculate that men were more motivated to compensate for the adverse effects of the holiday season on their body weight. When considering individuals' initial weight status (NW vs. OW&OB), weight loss during the follow-up period was only seen in the NW subjects, whereas OW&OB individuals maintained their holiday weight gain. This extends previous findings that overweight and obese individuals are more susceptible to weight or fat mass gain during the holiday season [4, 8, 43] and may be more likely to retain that additional weight. Based on the successful implementation of DSW in the OW&OB population, along with the risk of greatest weight gain and retention in the absence of an intervention, DSW may be an ideal target for all adults, but especially for individuals with a BMI >25 kg/m^2.

Compared to previous observational studies on holiday-associated weight gain, the large increase in body weight observed in the control participants in this study (average of 2.65kg) was somewhat surprising. Several prior observational studies have reported average holiday weight gains ranging from 0.4-1.5kg [3-5, 7, 8, 43]. We are unsure of the reasons behind the large magnitude of weight gain in the current study in control participants. This could be due to a number of factors, including geographic differences where our study sample is accustomed to a southern lifestyle, which may be different than other regions of the country. This larger than expected increase in weight over the holiday season may also explain why we observed weight loss in the control group post-holiday; if they had not gained as much weight, we may not have seen weight loss in this group.

In an attempt to understand the patterns of change in body weight during the holiday season while engaging in DSW, we performed a more in-depth exploration of the daily recorded weights obtained from our participants' online Withings® accounts. The graph of daily weight fluctuations shows that the initiation of DSW resulted in a noticeable decreasing trend in body weight for the first week. Although our participants started to gain weight during the Thanksgiving week, the increase was not yet enough to reach their initial body weight. More remarkably, this increase was compensated over the next 3-week period after Thanksgiving.

Although weight gain resumed a week before the Christmas holidays and continued through New Year's Day, the participants were successful in maintaining their weight at or below their baseline weights until the end of the holiday season, likely because of the initial loss with DSW and the compensation after gaining some weight during Thanksgiving. These findings indicate that DSW does not completely protect individuals from holiday weight gain, rather it prompts them to compensate for increases in weight and to keep their weight at or below their initial weight. We believe this may be attributed to the theory of behavioral self-monitoring as a component of social cognitive theory of self-regulation since the participants were able to get immediate feedback of weight fluctuations in reference to the target weight through the use of CTM. Under this theory, Albert Bandura (44) explained how important continuous self-monitoring is to motivate human behavior. He proposed that individuals are more likely to change or develop a certain preferred behavior by continuously monitoring the consequences, which indeed triggers self-management of the behavior. The fact that almost 80% the participants kept weighing themselves at least once a week even after the intervention ended suggests that DSW is a feasible and easy behavior to implement in one's lifestyle. Also, 96.4% of compliance to DSW during the holiday season confirms the ease of implementation of DSW. Subjective data from our participants suggest the involvement of technology through smart phones was intriguing, encouraging and practical to our participants.

We first postulated that weight loss subsequent to initiating DSW in OW&OB individuals could be due to lack of knowledge about their initial weight. However, their self-weighing frequency (self-reported) was equal to that of NW subjects prior to the beginning of the intervention. It is also possible that the OW&OB individuals were more motivated to change their behaviors since they knew research personnel would be accessing their daily weights, whereas NW subjects may not have felt this similar motivation and were able to simply comply with weight maintenance as instructed. This is speculation, however, as we did not have an additional group that recorded weight but did not have research personnel view those weights online. Therefore, we can conclude that DSW was successful in this setting. It remains to be seen if the same degree of success would occur in the absence of accountability or other individuals viewing a person's weight patterns.

Complementary to social cognitive theory of self-regulation, we used the questionnaire data to search for a mechanistic explanation for how DSW prevented holiday weight gain. Although none of those questionnaires showed significant mediators of DSW, the decrease in uncontrolled eating score (subscale of TFEQ) after the 14-week follow-up in the DSW group (**Table 3)** suggests that DSW might have resulted in better control over how often and in what quantities one eats. Conversely, in the absence of DSW, the increase in external cues score (subscale of mindful eating factors questionnaire) verifies the appetizing components of the holiday season including larger portion sizes, dining with other people, longer eating sessions and easier access to food.

Although there are several strengths to this novel behavior modification study, there were also some limitations. Since this was primarily a convenience sample, we did not have an equal number of NW to OW&OB participants. However, they were balanced between the two groups. Also, more than 70% of our participants were females which somewhat limits the generalizability of our conclusions about the comparisons between the two sexes. Since we did see differences between men and women in the control group during the follow-up period, this potential sex effect should be examined more closely in future work. Importantly, in this study population, DSW was equally effective in both men and women. Another limitation was the length of the follow-up period. We are uncertain about the effectiveness of DSW beyond 14- weeks post-holiday, and the long-term effectiveness of DSW on weight maintenance should be examined further.

Conclusions

Altogether, the results of this study indicate that DSW is an effective approach in preventing holiday-associated weight gain in adult males and females with a greater success in overweight and obese individuals. Particularly, Caloric Titration Method (CTM) is an innovative approach to implement DSW in an individual’s daily life since it increases awareness about their body weight through accessible technology. Since holiday weight gain may be a major contributor to annual weight gain, and therefore the increasing prevalence of obesity, the feasibility and effectiveness of this intervention may have significant clinical implications. Future research including a larger number of individuals with overweight and obesity and more male participants would provide valuable information on weight gain during such a critical period of time throughout the year.

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Table 1. Baseline Participant Characteristics.
Values are presented as Mean ± SD.

BMI: Body Mass Index

TBF%: Total Body Fat Percentage

WC: Waist Circumference; HC: Hip Circumference; WHR: Waist to Hip Ratio; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; HDL: High Density Lipoprotein; LDL: Low Density Lipoprotein

	Control Group (n=55)			**Daily Self-Weighing Group (n=56)**		
	Females (n=41)	*Males (n=14)*	*Total*	*Females (n=41)*	*Males (n=15)*	*Total*
Age (year)	28.3±11.8	28.2±6.0	28.3±10.6	29.6±12.6	32.6±10.9	30.5±12.1
Height (cm)	162.9±6.8	178.4±6.7	166.9±9.5	164.7±7.2	173.7±7.1	167.5±8.4
Weight (kg)	63.9±13.0	76.0±7.7	67.0±13.1	63.2±9.0	75.3±14.0	66.6±11.9
BMI (kg/m^2)	23.9±3.9	23.9±2.2	23.9±3.5	23.3±2.6	25.0±3.9	23.6±2.9
TBF%	29.2±6.1	16.3±6.1	25.9±8.3	29.0±5.4	19.6±4.7	26.4±6.7
WC (cm)	79.9±12.0	86.4±6.5	81.6±11.2	76.9±7.7	86.3±10.5	79.3±9.4
HC (cm)	101.7±9.5	102.8±5.6	102.0±8.6	99.9±6.9	105.0±8.7	101.4±7.7
WHR	0.8±0.1	0.8±0.1	0.8±0.1	0.8±0.1	0.8±0.1	0.8±0.1
SBP (mmHg)	112.0±12.9	124.6±11.0	115.2±13.5	111.9±11.6	119.9±9.1	114.2±11.4
DBP (mmHg)	74.6±9.2	78.5±9.0	75.6±9.2	73.4±8.3	73.2±8.6	73.3±8.3
Total Cholesterol (mg/dL)	175.4±52.0	163.5±25.8	172.4±46.9	164.3±33.6	167.8±28.5	165.3±32.0
Triglyceride (mg/dL)	76.1±28.1	90.9±40.8	79.8±32.0	97.4±53.8	92.2±46.8	95.0±51.5
HDL-cholesterol (mg/dL)	56.1±10.1	47.0±13.8	53.8±11.7	53.1±13.6	45.4±7.9	50.9±12.6
LDL cholesterol (mg/dL)	104.2±52.6	98.4±26.1	102.7±47.2	93.4±25.2	103.9±22.0	96.4±24.6
Total Cholesterol/HDL Ratio	3.2±1.1	3.7±1.1	3.3±1.1	3.2±0.8	3.8±1.0	3.4±0.9

Table 2. Health markers at all study visits
Values are presented as Mean ± SD.
* indicates a within-group difference from pre- to post-holiday (p<0.05).
# indicates a within-group difference from post-holiday to follow-up visit (p<0.05).
^ indicates a within-group difference from pre-holiday to follow-up visit (p<0.05).
TBF%: Total Body Fat Percentage; WC: Waist Circumference; HC: Hip Circumference; WHR: Waist to Hip Ratio; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; HDL: High Density Lipoprotein; LDL: Low Density Lipoprotein.

	Control Group			**DSW Group**		
	Pre-Holiday Visit	*Post-Holiday Visit*	*Follow-up visit*	*Pre-Holiday Visit*	*Post-Holiday Visit*	*Follow-up visit*
Body Weight (kg) (all subjects)	67.0±13.1*	70.2±13.2#	67.8±13.7^	66.6±11.9	66.8±11.8	66.5±12.0
Males *n=14 (control); n=15 (DSW)*	76.0±7.7*	78.3±8.3#	74.4±7.3	75.3±14.0	74.9±14.3	76.3±14.7
Females *n=41 (control); n=41 (DSW)*	63.9±13.0*	67.2±13.3	65.9±14.3^	63.2±9.0	63.4±8.8	63.2±8.8
NW *n=38 (control); n=42 (DSW)*	61.3±9.3*	64.2±9.3#	61.5±8.0^	62.3±8.1	62.8±8.3	62.8±8.6
OW&OB *n=17 (control); n=14 (DSW)*	79.8±11.2*	84.0±10.0	82.4±12.9^	79.7±12.0*	78.2±13.2	77.4±14.1^
TBF%	25.9±8.3*	26.7±8.5	26.7±8.3	26.4±6.7*	25.3±6.6	26.1±6.6
WC (cm)	81.6±11.2	81.4±10.8	79.5±10.5	79.3±9.4	80.6±9.3	79.1±9.4
HC (cm)	102.0±8.6	102.2±10.0	100.9±9.9	101.4±7.7	102.2±12.0	100.1±8.1
WHR	0.8±0.1	0.8±0.1	0.8±0.1	0.8±0.1	0.8±0.1	0.8±0.1
SBP (mmHg)	115.2±13.5	113.9±14.7	115.0±13.53	114.2±11.4	114.9±11.3	113.4±10.8
DBP (mmHg)	75.6±9.2	75.9±8.7	75.8±9.5	73.3±8.3	74.7±8.6	72.3±8.4
Total Cholesterol (mg/dL)	172.4±46.9	169.6±52.9	168.6±51.8	165.3±32.0	159.6±34.6	158.8±39.7
Triglyceride (mg/dL)	79.8±32.0	81.6±34.0	80.3±34.4	95.0±51.5	90.5±54.3	85.7±39.7
HDL-cholesterol (mg/dL)	53.8±11.7	52.1±11.9	53.0±11.6	50.9±12.6	51.5±15.3	51.7±13.2
LDL cholesterol (mg/dL)	102.7±47.2	101.2±49.6	99.5±50.0	96.4±24.6	91.3±26.8	90.0±25.5
Total Cholesterol/HDL Ratio	3.3±1.1	3.4±1.2	3.3±1.2	3.4±0.9	3.3±1.0	3.2±0.9

Table 3. Questionnaire scores at all study visits.

Values are presented as Mean ± SD.

TFEQ, Three Factor Eating Questionnaire.

* indicates a within-group difference from pre- to post-holiday ($p<0.05$). # indicates a within-group difference from post-holiday to follow-up visit ($p<0.05$).

^ indicates a within-group difference from pre-holiday to follow-up visit ($p<0.05$). § Overall score for Mindful Eating Factors Questionnaire is the mean of scores on the five subscales. ¶ Difference scores in Fat Preference Questionnaire are created by subtracting the "Frequency" score from the "Taste" score.

	Control Group			**DSW Group**		
	Pre-Holiday Visit	*Post-Holiday Visit*	*Follow-up visit*	*Pre-Holiday Visit*	*Post-Holiday Visit*	*Follow-up visit*
•TFEQ						
Cognitive Restraint score	15 ± 3	15 ± 2#	18 ± 3^	16 ± 2	16 ± 2#	17 ± 2^
Uncontrolled Eating score	23 ± 3	24 ± 4	24 ± 4	24 ± 3	24 ± 3#	23 ± 4
Emotional Eating score	8 ± 2	9 ± 2	9 ± 2	8 ± 2*	9 ± 2	8 ± 2
•Power of Food Scale	44 ± 16	47 ± 15	49 ± 14	48 ± 14	50 ± 15	51 ± 17
•Mindful Eating factors (Overall Score)§	3.1 ± 0.8	3.1 ± 0.5	3.0 ± 0.5	3.1 ± 0.4	3.1 ± 0.4	3.2 ± 0.4
Disinhibition	3.0 ± 0.5	3.1 ± 0.4	3.0 ± 0.5	3.0 ± 0.5	3.0 ± 0.5	3.0 ± 0.5
Awareness	3.2 ± 1.0	3.3 ± 0.9	3.3 ± 0.9	3.4 ± 0.8	3.5 ± 0.7	3.5 ± 0.6
External Cues	3.4 ± 0.9*	3.8 ± 0.9	3.7 ± 0.9^	3.8 ± 0.7	3.8 ± 0.7	3.9 ± 0.6
Emotional Response	2.5 ± 1.0	2.4 ± 0.9	2.5 ± 0.9	2.5 ± 0.9	2.4 ± 0.9	2.5 ± 0.9
Distraction	3.2 ± 2.7	2.7 ± 0.8	2.7 ± 0.8	2.9 ± 0.9	2.9 ± 0.8	3.1 ± 0.8
•Fat Preference Questionnaire						
Taste score (%)	57.5 ± 20.8	59.8 ± 19.9	60.5 ± 22.5	56.9 ± 20.5	60.5 ± 24.5	58.5 ± 27.8
Frequency score (%)	36.7 ± 22.8	38.6 ± 22.3	35.6 ± 20.4	35.8 ± 21.1	32.9 ± 23.3	35.9 ± 23.4
Difference score (%) ¶	20.7 ± 19.3	21.3 ± 17.3	24.7 ± 20.2	21.2 ± 18.2*	27.9 ± 20.4	23.8 ± 21.7
•Perceived Stress Scale	32 ± 3*	30 ± 4	31 ± 3^	31 ± 5	31 ± 4	31 ± 3
•National Insomnia Screening	30 ± 9	30 ± 8	29 ± 8	28 ± 7	28 ± 7	29 ± 10
•Perceptions of foods						
Unhealthy foods	13.4 ± 1.2	13.1 ± 1.0	13.4 ± 1.0	12.9 ± 2.4	14.2 ± 1.2	14.0 ± 2.6
Healthy foods	0.1 ± 0.2	0.1 ± 0.3	0.1 ± 0.4	0.1 ± 0.3	0.1 ± 0.4	0.1 ± 0.4
Ambiguous foods	11.5 ± 4.3	12.0 ± 5.0	11.2 ± 4.4	10.8 ± 4.3	10.5 ± 5.0	11.2 ± 5.0

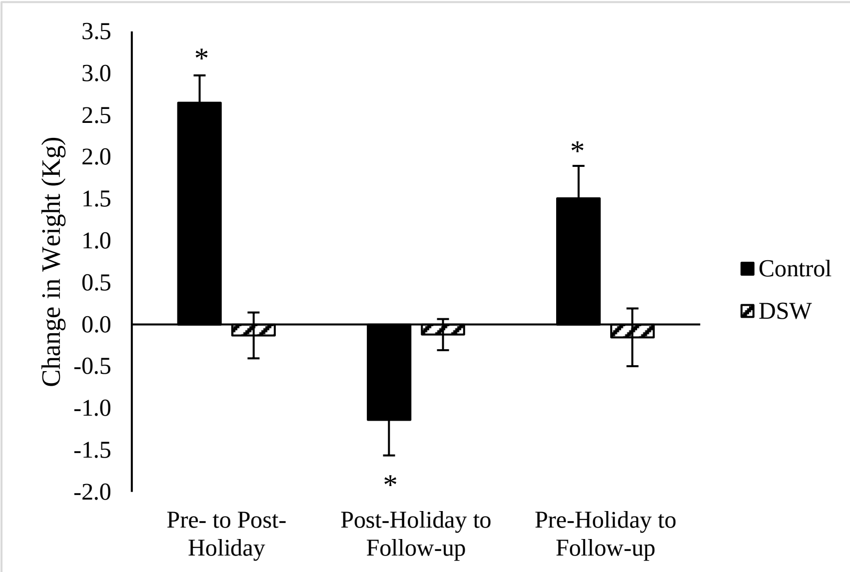


Figure 1. Within-subject change in body weight in DSW vs the control group.
* indicates a difference between Control vs. DSW at each time period ($p<0.05$).
"Pre- holiday visit" occurred within 7 days before Thanksgiving.
"Post-holiday visit" occurred within 7 days after New Year's Day.
"Follow-up visit" occurred 14 weeks after the post-holiday visit (early to mid-April).
DSW; Daily Self Weighing.

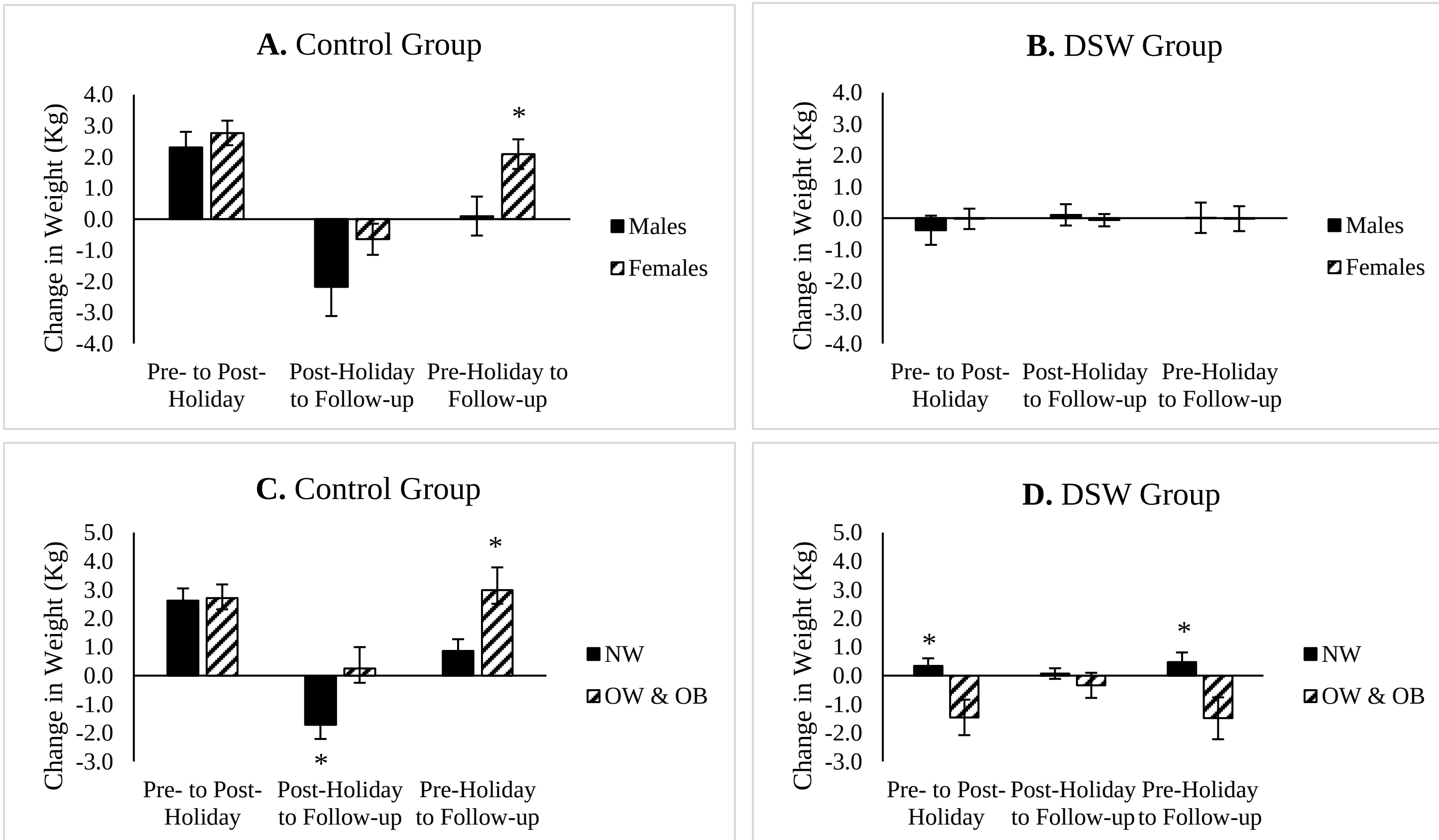


Figure 2. Change in body weight grouped by sex or BMI category.

Within-subject change in body weight grouped by sex in the control group (n=14 males vs n=41 females) (**A**), and the DSW group (n=15 males vs n=41 females) (**B**), and grouped by initial weight status in the control group (n=38 NW vs n=17 OW&OB) (**C**), and the DSW group (n=42 NW vs n=14 OW&OB) (**D**).

* indicates a difference between males vs. females (**A** and **B**) and between NW vs. OW&OB (**C** and **D**) at that time period ($p<0.05$).

"Pre- holiday visit" occurred within 7 days before Thanksgiving.

"Post-holiday visit" occurred within 7 days after New Year's Day.

"Follow-up visit" occurred 14 weeks after the post-holiday visit (early to mid-April).

DSW; Daily Self Weighing, NW; Normal Weight, OW & OB; Overweight and Obese.

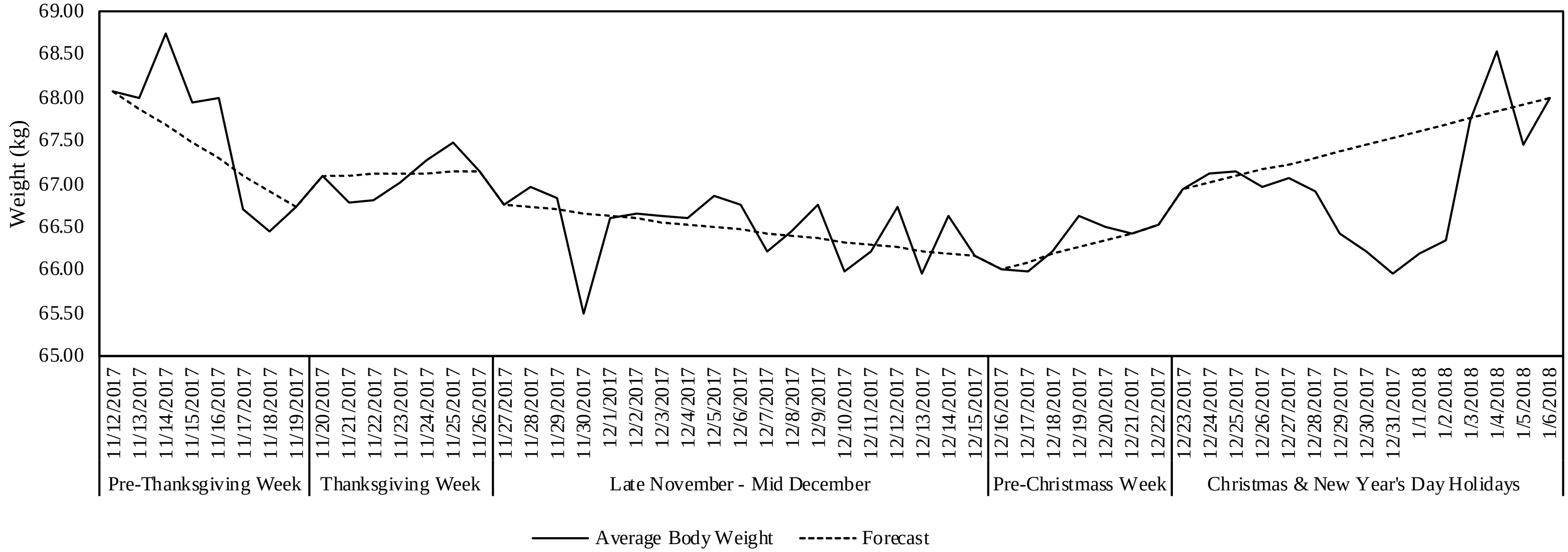


Figure 3. Changes in daily body weight during the holiday season in the DSW group.
Straight line represents the average body weights for the DSW group, and the dashed line represents the forecast of changes in weight during each time period based on the results from Box-Jenkins time series analysis.
DSW; Daily Self Weighing

Supplemental Figures

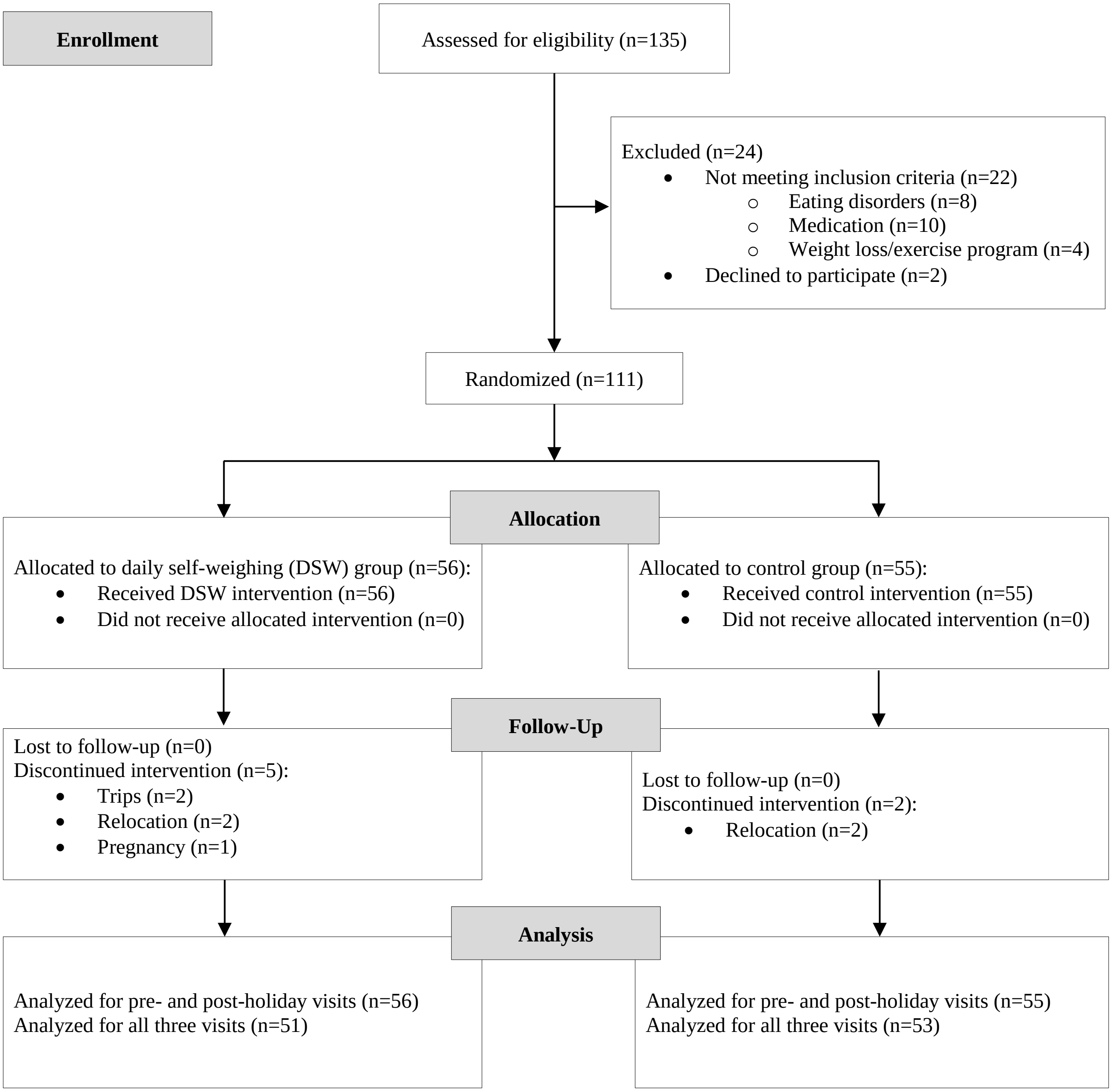


Figure 1S. CONSORT Flow Diagram of participants.
Progress of enrolment, intervention allocation, follow-up, and data analysis through the phases of our study on a control and an intervention (DSW) group.

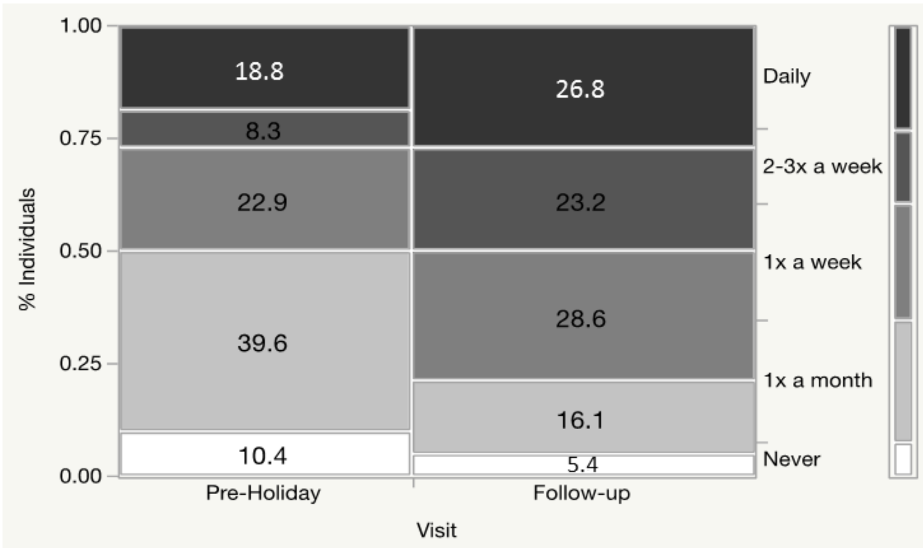
Figure 2S. Self-weighing frequency at pre- vs. post-holiday visit in the control group.
Percentage of individuals in the control group for all five categories of self-weighing frequency (daily, 2-3x a week, 1x a week, 1x a month, and never) from pre- (v1) to post-holiday visit (v2). There were no differences in self-weighing frequency from v1 to v2 (ns).

Figure 3S. Self-weighing frequency in NW vs. OW&OB individuals in the control group at pre-holiday visit.

Percentage of individuals in the control group at the pre-holiday visit (v1) for all five categories of self-weighing frequency (daily, 2-3x a week, 1x a week, 1x a month, and never) between NW vs OW&OB individuals. There were no differences in self-weighing frequency between NW vs OW&OB (ns).

NW; Normal weight, OW&OB; Overweight and obese.

A. DSW Group



B. Control Group

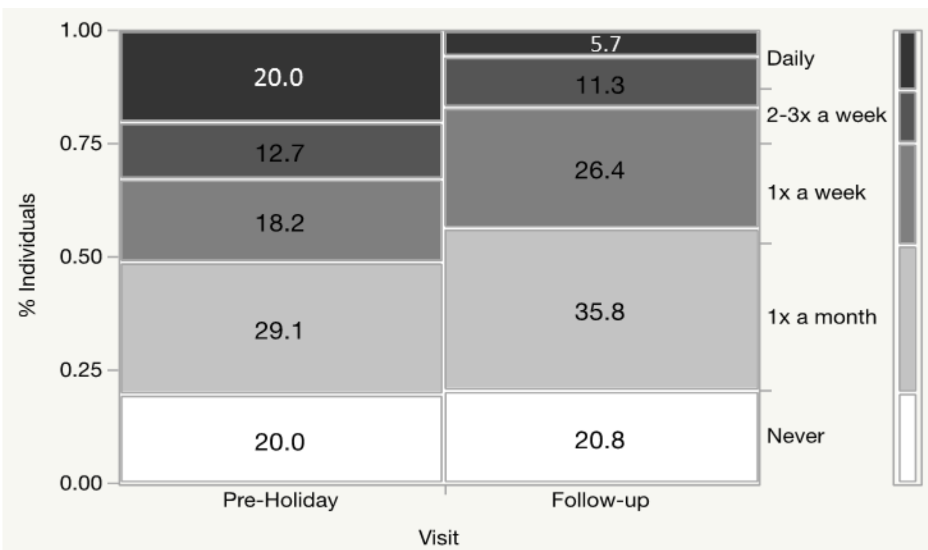
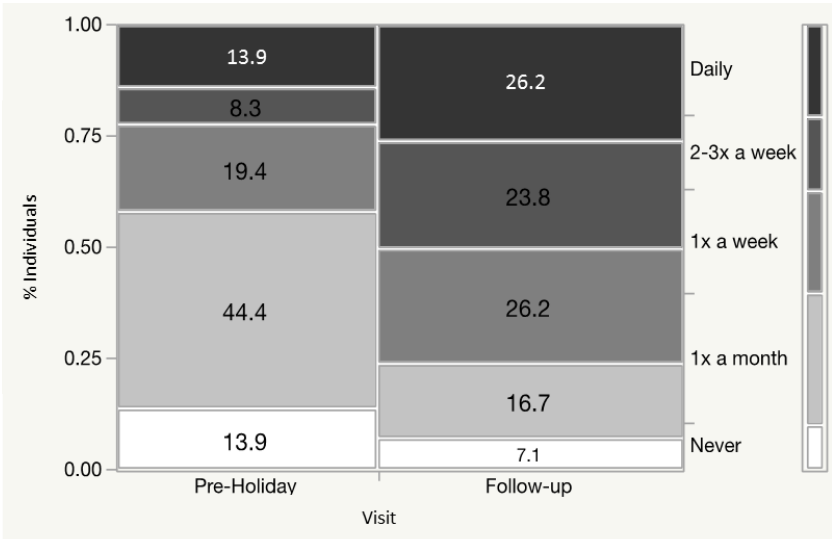


Figure 4S. Self-weighing frequency at pre-holiday vs. follow-up visit in the (**A**) DSW and (**B**) control group.

Percentage of individuals in the DSW group for all five categories of self-weighing frequency (daily, 2-3x a week, 1x a week, 1x a month, and never) for pre-holiday (v1) to follow-up visit (v3) in (**A**) DSW group and (**B**) control group. There was a significant increase in self-weighing frequency from v1 to v3 (p=0.03) in the DSW group but no change in the control group.

DSW; Daily Self-Weighing.

A. Normal Weight



B. Overweight and Obese

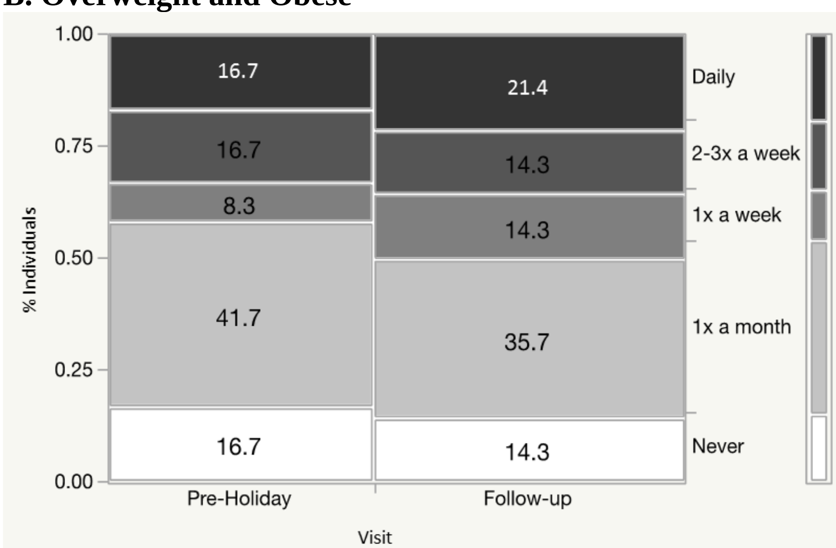


Figure 5S. Self-weighing frequency at pre-holiday vs. follow-up visit in the DSW group for (**A**) normal weight (NW) and (**B**) overweight and obese (OW&OB) individuals.

Percentage of individuals in the DSW group for all five categories of self-weighing frequency (daily, 2-3x a week, 1x a week, 1x a month, and never) from pre-holiday (v1) to follow-up visit (v3) for (**A**) NW individuals, and (**B**) OW&OB individuals. There was a significant increase in self-weighing frequency from v1 to v3 (p=0.02) for the NW group but no change in the OW&OB group (ns).

DSW; Daily-Self-Weighing, NW; Normal weight.

CHAPTER 4

SUMMARY AND CONCLUSIONS

The purpose of this dissertation was to investigate the effectiveness of DSW on preventing holiday-associated weight gain in adults. Holiday weight gain possibly occurs as a result of exposure to the obesogenic environment subsequent to the presence of several appetizing stimuli during this period of time. Those stimuli are difficult to overcome through traditional interventions such as dieting and exercising. Since holiday weight gain may be contributing a substantial portion of yearly weight gain, developing a strategy to encourage behavior modification with the purpose of weight maintenance during the holidays is crucial. The success of frequent or DSW has been reported in previous weight loss or weight maintenance studies. In this dissertation, for the first time, we showed that DSW using CTM effectively prevents weight and body fat gain in both sexes specifically during the holiday season. In particular, we showed that DSW is more successful in individuals who are OW&OB. Conversely, in the absence of DSW, significant weight gain was observed in both males and females, with OW&OB individuals gaining the most.

While participants in the control group gained a significant amount of weight, we did observe some weight loss within 14 weeks after the holiday season. However, overall change in body weight was still positive as more than 50% of the total weight gain was retained 14 weeks post-holiday. Men in the control group lost most of their holiday weight gain within 14 weeks after the holidays, while women maintained a large portion of their holiday weight gain (about 75%) within this follow-up period. This suggests that although holiday weight gain may be similar between men and women in the absence of DSW, men may be more likely to appropriately compensate for the holiday weight gain afterwards.

The patterns of change in body weight during the holiday season shows that DSW resulted in a noticeable decreasing trend in body weight for the first week of the intervention. Furthermore, the increasing trend in weight during Thanksgiving week was compensated for over the subsequent 3-week period after Thanksgiving. The returning weight gain 1 week before the Christmas holiday and its continuation until New Year's Day, however, did not exceed the individuals' initial weight. These findings suggest that DSW does not completely protect individuals from holiday weight gain, rather it encourages them to adjust or compensate for this weight gain which was evident by the overall weight maintenance from pre- to post-holiday. We believe this effect of DSW with CTM could be explained by the theory of behavioral self- monitoring as a component of social cognitive theory of self-regulation. This theory suggests that continuous self-influence is important in motivating human behavior. Based on this theory, individuals are more likely to change or develop a certain behavior by constantly monitoring the outcomes, which then stimulates self-reaction and ultimately leads to change.

In this current study, more than half of the participants continued weighing themselves at least once a week even after the intervention ended. Therefore, we suggest that DSW is a feasible and easy behavior to employ in daily life. Also, the high compliance rate to DSW during the holiday season (96%) confirms the ease of implementation of this method. Further, given the existing technology-filled environment, the involvement of smart phones in our intervention was intriguing, encouraging and practical to individuals.

Although not quantitative data, based on the in-person interactions with our subjects, we presumed that the initial weight loss with DSW in OW&OB individuals was likely attributed to their lack of knowledge about their initial weight. However, this hypothesis was not supported by the self-weighing frequency questionnaire which showed equal self-weighing frequency between OW&OB individuals vs. NW at the beginning of the study. Even so, the initial self-weighing frequency followed by DSW might have adequately motivated OW&OB individuals, but not NW, to modify their dietary and physical activity habits. We believe that NW subjects may not have been motivated to lose weight due to their success at maintaining their body weight at or below their baseline weight and were compliant to follow intervention instructions (weight maintenance). Therefore, they might have found it unnecessary to make any changes prior to the first holiday.

Altogether, the results of our research indicate the efficacy of DSW in preventing holiday associated weight gain in adults with weight loss actually occurring in OW&OB individuals. Further, CTM adds an innovative angle to the implementation of DSW and it attracts individuals' attention to body weight through easy-access technological devices and software. Since holiday weight gain could be a contributor to the increasing prevalence of obesity, this brief period of time each year needs to be addressed through the development of a feasible and effective intervention. Therefore, DSW with CTM is a promising new era of further research on preventing holiday-associated weight gain.