THE ROLE OF SELF-WEIGHING IN THE CONTROL OF BODY WEIGHT

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THE ROLE OF SELF-WEIGHING IN THE CONTROL OF BODY WEIGHT

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Overweight and obesity in adults are major contributors to chronic disease and mortality. Preventing age-related weight gain, even in those already overweight or obese, can have large public health implications, as mortality and chronic disease risk increases with BMI category. Regular self-weighing is associated with weight loss and/or improved weight outcomes, particularly when performed daily or weekly. Self-weighing is often used as one component embedded in larger interventions, and it is often not possible to assess the effectiveness of self-weighing by itself. This dissertation examines the effects of self-weighing and individualized weight graphs on age-related weight gain over time. Included are objective "real world" weight data from 90,000 people using a connected smart scale to record and track their weight, an investigation into long-term weight loss maintenance three years after a self-weighing intervention, and experimental evidence testing Wi-Fi scales in preventing age-related weight gain during four years of college. Findings

BIOGRAPHICAL SKETCH

Lua Wilkinson majored in cultural anthropology and dietetics at the University of Northern Colorado, and completed her dietetic internship at UCSF medical center in 2006. Lua received a Master's of Arts in medical anthropology from the University of Colorado, Denver in 2010.

Lua has worked at Children's Hospital Colorado and New York Presbyterian Hospital as a Registered Dietitian, where she developed individual and group programming for children with obesity-related co-morbidities, eating disorders, neonatal complications and congenital heart disease.

In 2010, she was awarded a Fulbright and moved to China, where she researched infant feeding behavior among migrant women for two years. She continued work internationally with maternal and child nutrition, and has carried out research in India, China, Papua New Guinea, and the United States. She speaks Chinese fluently, and Oriya with working proficiency.

At Cornell University, she worked under Dr. David Levitsky, researching the effects of self-monitoring on weight gain prevention among adults. Her long-term research and professional interests center on developing comprehensive clinical guidelines for weight gain prevention.

After living in San Francisco, New York City, China and India, Lua has perfected the art of parallel parking. She also makes a mean lasagna.

This dissertation is dedicated to Dr. David Levitsky.

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LIST OF ABBREVIATIONS AND SYMBOLS

±	plus or minus
AHRQ	Agency for Healthcare Research and Quality
BMI	Body Mass Index
C	Control
CTM	Caloric Titration Method
kcal(s)	kilocalorie(s)
kg(s)	kilogram(s)
lb(s)	pound(s)
NHANES	National Health and Nutrition Examination Survey
NWCR	National Weight Control Registry
PI	Principal Investigator
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
US	United States
USDA	United States Department of Agriculture

INTRODUCTION

The number of overweight and obese individuals worldwide more than doubled between 1980 and 2013[1]. Age-related weight gain substantially contributes to the high rates of overweight and obesity – between the ages of 18 and 55, average weight gain is 0.5 to 1kg per year, with the steepest gains occurring between ages 18-35[2–9]. In addition to the exploitative food environment that encourages individuals to act against their own self-interest, once a person gains weight there are virtually no effective non-invasive treatments for sustained weight loss[10]. Intensive behavioral therapy is the current non-surgical gold standard; in order to produce any significant reductions in weight, however, high levels of prolonged dedication to diet and exercise regimens are required[11]. This, coupled with the need for frequent face-to-face contact with trained health professionals, leaves limited potential for dissemination at the population level[12].

Given the alarmingly low numbers of weight loss success stories, there is an urgent need to change how weight control efforts are addressed. Shifting from strategies that focus on weight loss to an emphasis on weight gain prevention would have major public health implications. According to the most updated review on weight gain prevention interventions by the Agency for Healthcare Research and Quality, the majority of weight control trials continue to disregard weight gain prevention in favor of weight loss[13]. Of the trials that do explicitly address preventing weight gain, most do not follow participants after the cessation of the intervention, and study quality is poor.

This dissertation investigates the role of frequent self-weighing on long-term weight gain prevention among adults. Included are objective "real world" weight data from 90,000 people using a connected smart scale to record and track their weight, an investigation into long-term weight loss maintenance three years after a self-weighing intervention, and experimental evidence testing Wi-Fi scales in preventing weight gain between freshman and senior year of college.

Outline of Chapters

This dissertation is divided into three parts. Part I consists of the theoretical explanation and evidence for the relationship between self-weighing and weight control. Part II consists of three independent studies, each contributing different degrees of evidence on the relationship to self-weighing and weight control. Part III summarizes future directions for self-weighing research based on these findings.

Part 1: Theoretical Considerations

This part of the dissertation discusses why frequent weighing may be used for preventing age-related weight gain. It contains Chapters 1-2.

Chapter 1. *Theoretical and Conceptual Framework*

Chapter 2. *Review of the Literature*

Part 2: Research Studies and Analysis

Part II centers on the research studies, and contains chapters 3-5.

Chapter 3. *Self-Weighing Frequency, Weight Goals and Weight Control: A Retrospective Look at Smart Scale Users*

Chapter 4. *Weight Loss Produced by Self-Weighing Endures Three Years Later*

Chapter 5. *Failure of Self-Weighing to Sustain Weight Loss*

Part 3: Summary of Findings and Recommendations for Future Research

Part III summarizes the findings from each study and contains chapter 6.

Chapter 6. *Implications of Findings and Conclusions*

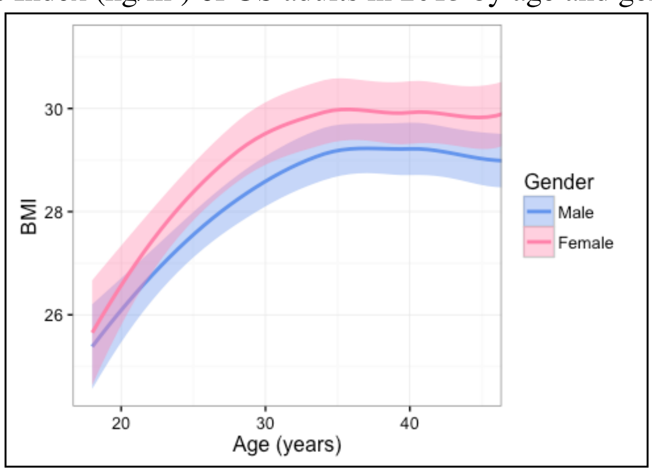
CHAPTER 1

CONCEPTUAL AND THEORETICAL FRAMEWORK

Introduction

More than two-thirds of all US adults are overweight or obese[14]. Prevalence of obesity doubles between ages 20 and 30[15], and there is no sign that this rapid increase is declining. Figure 1.1 is a cross-section from the 2013 National Health and Nutrition Examination Survey (NHANES) showing mean body mass index (BMI, kg/m^2) as a function of age and gender. US adults gain an average of one pound per year between ages 20 and 65 –a phenomenon called *age-related weight gain*[4,16]. The latest statistics from the NHANES data estimate that 60% of 20-39 year olds, 75% of 40-59 year olds, and 72% of adults over 60 are overweight or obese[14].

Figure 1.1 Body Mass Index (kg/m^2) of US adults in 2013 by age and gender



The interventions in this dissertation involve frequent (i.e. daily, weekly) weighing with visual feedback provided via smartphones or the internet as a method for assisting with weight gain prevention, also referred to here as *weight control* for simplicity. In the following chapters, *weight gain prevention* refers to a body weight change <3% of body weight, as defined in a 2006 review by Stevens et al[17]. As defined, weight gain prevention also includes those who have lost weight and maintained that weight loss with 're-gains' of no greater than 3%, a term often expressed in the literature as *weight loss maintenance*[18].

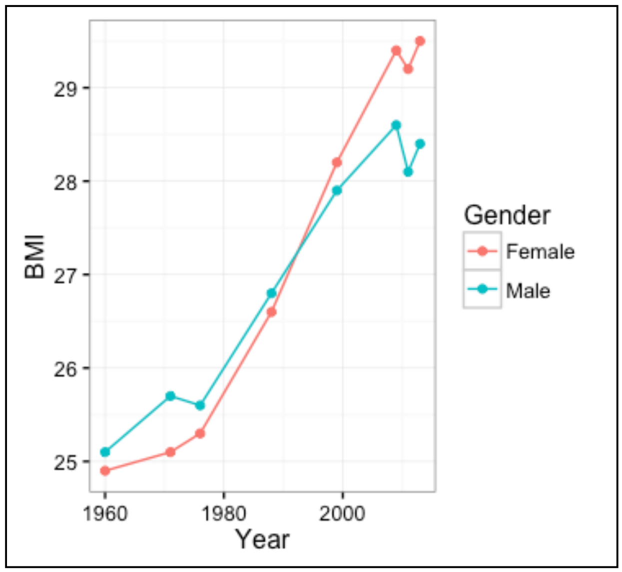
Theoretical and conceptual frameworks are helpful to guide and evaluate interventions because they provide a map to the processes of health behavior change. Social cognitive theory[19] is the theory used to design, implement, and evaluate the role of self-weighing as a weight control strategy in the studies analyzed in this dissertation. This theory provides a straightforward, linear connection between self-weighing and weight control. Yet upon further analysis of the data in this dissertation, it is clear that perhaps this linear framework is too simplistic; therefore, two additional theories are incorporated to the framework: theories of favorable self-presentation[20] and behavioral habituation[21].

This chapter briefly describes the causes of overweight and obesity, how theories of self-regulation have been used to inform self-weighing treatments for weight control, and evidence showing how and why self-weighing is superior to other forms of self-monitoring. Specific possible mechanisms that may influence self-weighing's effects on weight control are addressed, including theories of favorable self-presentation and behavioral habituation, concluding with a modified conceptual framework on how self-weighing interventions may impact weight control in adults.

Causes of Overweight and Obesity

Average American body weight increased by 28 pounds between 1960 and 2013[22] (see figure 1.2). The predominant behavioral changes that led to this increase in body weight are decreased energy expenditure and/or increased food intake[23]. Yet obtaining accurate records of physical activity and food intake changes over the last fifty years has proven difficult; much of these data comes from self-report or cross-sectional surveys, where causality cannot be determined[24]. The following sections provide an overview of the research on the causes of overweight and obesity, including the limitations of self-reported data when determining causes of the obesity epidemic.

Figure 1.2. Average BMI of American men and women, 1960-2013



<u>*Decrease in Physical Activity as Cause of Obesity*</u>

Much of the hype surrounding the rise in obesity prevalence in the last few decades centers on an assumed drop in physical activity levels – after all, technologies automate most things people used to have to do manually. The bulk of studies seeking to confirm this assumption use survey data to compare current activity levels to those in the past. For example, using data from the U.S. Bureau of Labor Statistics and NHANES, Church et al. examined the "occupational shift" – i.e. the shift from occupations requiring high levels of energy expenditure such as farming, to jobs where an individual spends most of their day behind a computer — between 1960 and 2006[25]. By observing changes in those working in occupations requiring high, medium, or low energy expenditure, Church and colleagues determined that the estimated expenditure from occupational activity has dropped by 100kcals per day in both men and women since 1960.

Archer et al. performed a related analysis using The American Heritage Time Use Study to examine 45 year trends in household management and energy expenditure in women between 1965 and 2010[26]. In this survey, household management is defined as the sum of time spent in food preparation, dish-washing, laundry, and "general housework". This study found that compared to 1965, employed women in 2010 spent 130kcal/day less on housework, and non-employed women spent 360kcal/day less. They concluded that this decrease in housework was not being substituted with other energy intensive activities, but instead women were using the time for sedentary activities such as watching television.

Yet possibly the most persuasive data on the role of physical activity in the rise of body weight was published in 2013 by Ford and Dietz of the Centers for Disease Control. Using dietary recall data from NHANES, Ford and Dietz assessed longitudinal trends in food intake between 1999 and 2004 and found that <u>total reported food intake</u> actually decreased during that time[27]. They thus concluded that if energy intake <u>decreased</u> during this time, and body weight <u>increased</u>, the most likely explanation for the rise in body weight must be from a <u>decrease in physical activity</u>.

However, none of the above analyses used direct methods of measuring energy expenditure or intake – they rely on self-reported energy expenditure and food consumption. One of the first to review the considerable inaccuracies in self-reported data was Schoeller in 1990[28], who reviewed nine studies comparing self-reported dietary intake to energy expenditure using the doubly-labeled water method. When this comparison is directly made, considerable inaccuracies are found, and underreporting is inversely related to intake. In fact, NHANES data in particular has come under scrutiny for its methodological weaknesses – a 2013 review by Archer et al. concludes that data from the majority of respondents is not even physiologically plausible; self-reported food recalls from NHANES is almost *always* lower than actual intake[29].

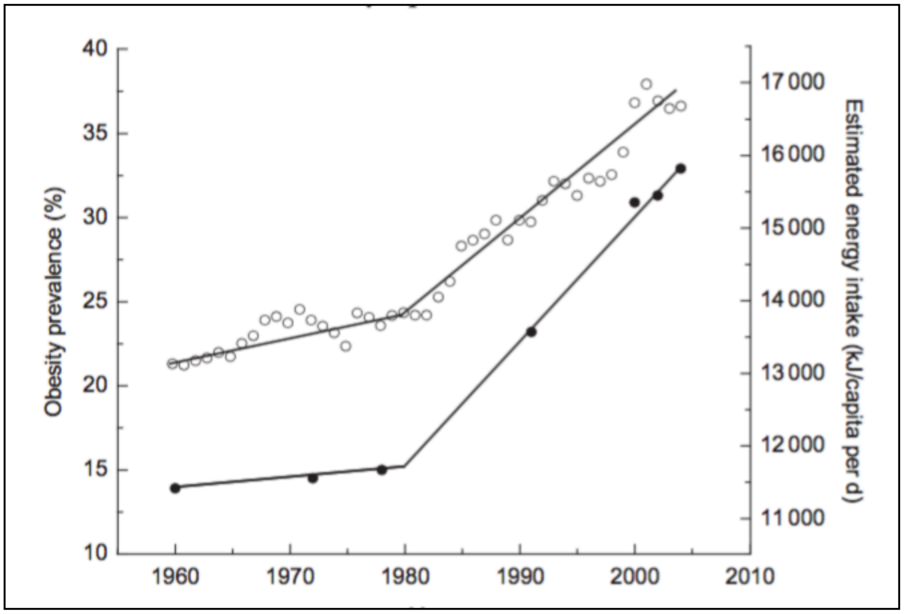
To test the hypothesis that reduced physical activity has driven the obesity epidemic without using self-reported data, Westerterp and Speakman compiled data on daily energy expenditure measured by doubly-labeled water (DLW) studies in contemporary Europe and North America[30]. They then compared this expenditure with the physical activity levels in "third world countries"—the thought was people in these areas generally mirror Western societies in the past —and showed no significant differences in physical activity between the two areas. They concluded that when energy expenditure levels are directly measured, there appears to have been very little change over the last two decades, and research concluding otherwise is likely based on biased self-report. Thus, while it seems a logical assumption that a decrease in physical activity is in part responsible for the increase in body weight over the last three decades, this conclusion has not been substantiated with the evidence available.

Increase in Energy Intake as a Cause of Obesity

If there has been very little change in energy expenditure over the last 30 years, and the increase in the weight mimics the increase in food availability, it is probable that an increase in food intake is responsible for the rise in overweight and obesity prevalence[31]. Yet as with physical activity data, epidemiological studies on diet rely on self-reported data to estimate intake. Although methodologically developed and validated, the instruments used to collect self-reported diet data are too inaccurate to determine true energy intake, as large eaters underestimate intake, and small eaters overestimate how much they eat[32].

One way in which change in population energy intake has been estimated is through food disappearance data. Food disappearance data comes from the United Stated Department of Agriculture's Economic Research Service. It is often referred to as food disappearance data because it represents the food supply after the food "disappears" into the food system[33]. While imprecise, these data can provide a rough estimation of how caloric intake is changing over time. To evaluate the relationship between body weight and food intake in the US, Levitsky and Pacanowski[31] modeled food disappearance data as a function of weight gain and found that estimated food intake strongly correlated with the timing and trajectory of obesity prevalence, illustrated in figure 1.3.

Figure 1.3. Mean daily energy intake (○), estimated from food disappearance data, and prevalence of obesity (●) (BMI ≥ 30 mg/kg^2) as a function of time. Taken from Levitsky and Pacanowski, 2011[31]



In order to examine this relationship more precisely, and to determine how many calories is responsible for the rise in body weight, Kevin Hall and collegues[34] created a mathematical simulator that incorporates how energy imbalance dynamics affect body weight change. Bodyweight response to a change in energy intake is slow; adults with greater body mass expend more energy. Because the obesity epidemic is measured at the population level, Hall and colleagues used their simulator to calculate the energy imbalance dynamics responsible for the rise in mean body weight in the US between 1978 and 2005. Figure 1.4 plots the simulated energy intake and expenditure (assuming no change in physical activity) needed to account for rising mean body weight. The two concepts discussed are the *maintenance energy gap* and the *energy imbalance gap*. The maintenance energy gap is “the increased average intake rate to maintain the final bodyweight compared to the initial bodyweight”, and is estimated at 220kcals per day total. Yet because expenditure increases with body weight, the mean US body weight has not increased linearly with this number. Instead, the energy imbalance gap is used to describe the daily average "extra" calories responsible for the slow steady increase in mean body weight in the US. This "extra" energy amounts to 7 calories per day since 1978.

Figure 1.4. A simulated increase in energy intake and expenditure underlying the observed increase in mean body weight. Taken from Hall et al. 2011[34]

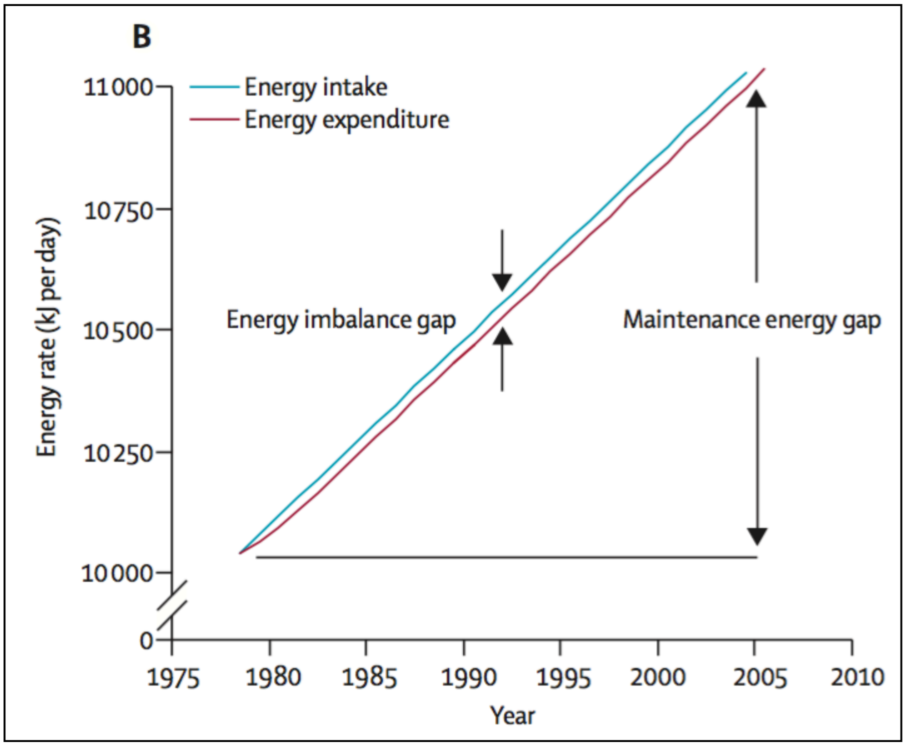


Figure 1.4 estimates the average energy imbalance that is responsible for the mean rate of weight gain over the US population. The 220 calories of estimated intake to maintain <u>average</u> excess body weight, and the 7 calories "extra" needed to <u>continue</u> the <u>rate</u> of weight gain, does not necessarily explain how many calories are responsible for the current rise in body weight. Determining this number is not quite as straightforward as calculating the energy imbalance or maintenance energy gap, as people enter adulthood at different body weights and BMIs. Yet as a rough approximation or "rule of thumb", Hall and colleagues estimate that a *permanent,*

persistent intake of only 25 kcals extra per day will lead to a weight gain of 1kg— half of this change will occur over one year, and if the 25 kcal/day change persists, the other 0.5kg will occur over 3 years.

Strategies for Weight Control

Self-monitoring is one way to create awareness of how food intake affects weight. The abundance and availability of appetizing, calorie dense foods make it more difficult for individuals to tightly regulate energy balance and weight, particularly when the amount of calories responsible for weight gain is so low at approximately 25kcals/day. Yet biological mechanisms such as hunger do not entirely inform our food choices, how much we eat, or when we eat. For example, studies show that intake does not respond with any accuracy to deprivation[35], overfeeding[36], or changes in the caloric density of food[37,38]. Day-to-day energetic compensation – that is, the relationship between the amount of energy consumed on one day and the amount consumed on subsequent days – shows no predictive, accurate pattern[39,40]. Thus, while hunger is one driver of why people eat, the amount and quality of food consumption is also determined by social norms, as well as modern food environments that play on our biological vulnerabilities.

The Obesity Society (AHA/ACC/TOS) Guidelines for the Management of Overweight and Obesity in Adults recommends comprehensive lifestyle interventions that provide a structured program including regular self-monitoring of food intake, physical activity, and weight[11]. The Academy of Nutrition and Dietetics also recommends that behavioral treatments for weight loss include self-monitoring[41]. Yet there are no such straightforward guidelines for weight gain prevention. According to the Agency for Healthcare Research and Quality's (AHRQ) systematic review on strategies for weight gain prevention among adults, individuals recruited to weight gain prevention studies are less likely to have motivation to change their behavior and adhere to a self-monitoring program due to the absence of obesity and its sequelae[13]. Despite this, AHRQ reports that of the three self-monitoring strategies mentioned, contact with an interventionist coupled with self-monitoring weight may hold particular value for those trying to lose weight. There is evidence *why* self-weighing may be a superior self-monitoring method for weight control, regardless of whether one is trying to lose weight or prevent weight gain.

Food Journals

The 2010 Dietary Guidelines Advisory Committee recommends food journaling for weight loss and maintenance– food diaries as a self-monitoring strategy appear to be effective whether the individual uses pen-and-paper or digital technologies[42]. Digital applications for self-monitoring food intake on a tablet or smart phone are common and widely available, and using paper or an app for tracking is ultimately the users decision and does not impact effectiveness[43,44]. Food journaling is partly effective because it raises awareness of the nutritional content of foods the consumer is eating. Most adults do not accurately estimate portion sizes and calorie content[45], and interventions have used web-based food journaling to improve awareness around portion size with success [46].

Yet overall adherence to food journaling is low, whether on-line or paper. In one study, only 2.58% of a sample of 189,770 people who downloaded an app ever opened it[47]. Yon and colleagues[48] compared groups using a paper diary to a PDA to self-monitor diet and found no differences in either adherence or weight change. Cordiero et al. has empirically documented specific barriers to online food journaling long-term[49], which include reliability, inability to turn journaling into a habit, difficulty with meal entry, sporadic eating patterns, negative nudges, and stigma associated with journaling in public. An extra 25 kcals/day could be accidently consumed by the most fastidious food journaler. There is some effort toward a photo-based food journal to ease these barriers, but current models are too imprecise for wide-spread use [50].

Physical Activity Tracking

Self-monitoring physical activity is also used for weight control[51]. Interest in physical activity monitoring has erupted now that accelerometers are integrated into smartphones[52]. Despite this popularity, there is very little evidence to show that these trackers are effective for weight control. Much of the research in this area has focused on ways to make physical activity tracking more enjoyable[53,54], such as goal-setting[55] or visual feedback[56]. Critical issues with current tools include design, such as wearability, appearance, display and interaction; and how the data is modeled, described, measured and presented [57]. While there have been a handful of randomized control trials, very few measured the effect of a tracker on physical activity due to poor study design and reporting[58]. There is no evidence that physical activity tracking is effective for weight gain prevention, regardless of whether or not people maintain this tracking over time[59].

Weight Tracking

Regular self-weighing is associated with weight loss[60–63], weight loss maintenance[60,64], and weight gain prevention[65–71]. Increased frequency of self-weighing is also associated with behaviors that affect weight gain, such as increases in dietary restraint and decreases in disinhibition[72]. Self-weighing is also associated with lower BMI in adults[67,73]. In behavioral interventions, regular weighing in general is associated with less weight gain, lower BMI, and weight loss[42,62,70,71,74]. Survey data shows similar associations to weight gain prevention[24,25], weight loss [26,27], and weight loss maintenance[28,29,30].

The National Weight Control Registry (NWCR) provides information about strategies used by successful maintainers of weight loss[18]. In order to join the NWCR, individuals must have lost an average of 33kg and maintained this weight for more than 5 years, and must regularly log and report techniques they use to maintain their weight. Among those enrolled in the NWCR, increased self-weighing frequency is associated with less weight re-gain[76,77].

Monitoring weight holds several advantages over monitoring food and physical activity for weight control. First, tracking weight on a graph can be done either by paper or via web app. New smart-scale Wi-Fi enabled technology allows seamless syncing with the users' smartphone through a personalized, online database. These e-scales have been used in weight control interventions and have incorporated caloric titration methods[78], mobile notifications[79], manipulating visual feedback[80], and frequency of weighing[75]. Many of these studies saw improved weight control and/or adherence.

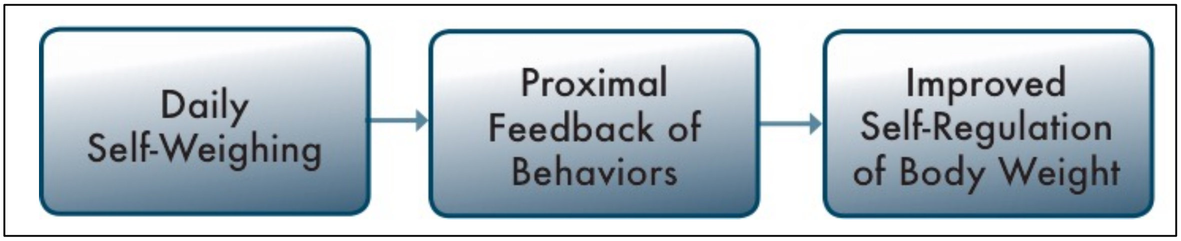
Second, small accumulations of <u>persistent energy imbalance</u> can be seen with frequent weighing. Because age-related weight gain is due to the small, persistent increase in energy intake over time, daily weighing with graphical feedback is one way to provide a greater awareness of how behaviors impact weight. In one study of 40 individuals, Helander et al. found an association with weight gain in those who took breaks from self-weighing lasting more than one month[75]. While 25 calories could easily be lost to measurement error in a food journal, graphical feedback of weight cannot be so easily misinterpreted if one is weighing frequently. Unlike food journaling, where a user is unable to pinpoint inaccuracies, daily fluctuations in weight are smoothed over time when a person weighs regularly and can see a trend develop.

Theory of Self-Weighing

Social Cognitive Theory

Self-weighing provides personal accountability and awareness about how behaviors affect weight. This is based on principles from the Social Cognitive Theory (SCT) for health behavior change, which have been recognized as essential to supporting long-term adherence to behaviors associated with weight maintenance[81]. SCT is divided into three principles that drive self-regulation: 1) self-monitoring, 2) observing proximal feedback, and 3) changing behaviors based on that feedback, which leads to improved self-regulation of body weight (see figure 1.5). The main clusters of behavior change techniques used in self-weighing studies are goals and planning, feedback and monitoring, and shaping knowledge[82]. An individual who regularly self-weighs is able to be more sensitive to what is causing changes in their weight, and this self-awareness then feeds back to alter daily behaviors that influence weight change.

Figure 1.5. Feedback can lead to improved regulation of body weight



Other Possible Mechanisms

The central process for which self-weighing affects weight control is through self-regulation; however, detaching self-weighing from other social, environmental, and personal influences on weight is not realistic. Self-weighing may interact with many of these factors to enhance or diminish its regulatory effect on weight. Two possible mechanisms explored in this dissertation are the theory of favorable self-presentation[20] and behavioral habituation[21].

Theory of Favorable Self-Presentation

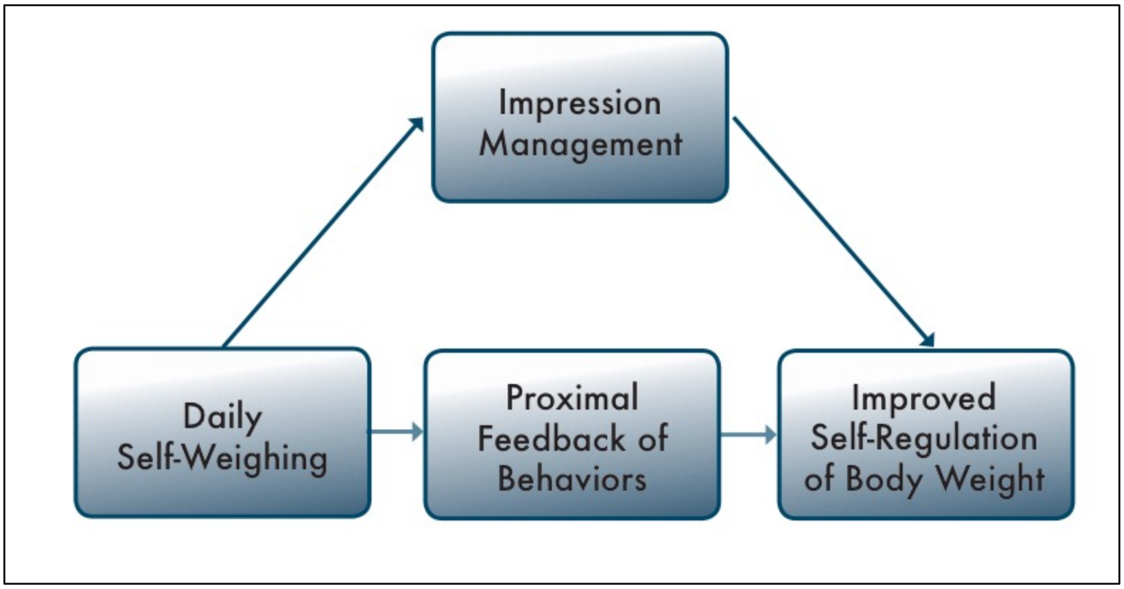
There is evidence that the effect of self-weighing on weight control is enhanced when participants know their weight is being examined[83]. For example, in a systematic review of self-weighing and weight loss, Madigan et al. reported that out of 24 trials included in the review, fourteen included interventions in which the treatment group knew their weight was being recorded by a therapist or researcher[82]. In those where the participant was 'being watched', weight loss improved by more than 1.3kg compared to those who did not have to discuss their weight with a research manager. This difference was significant, and even stronger if a participant knew the researcher or therapist would contact them if they did not weigh themselves.

The phenomenon of research participants changing their behavior when they are being watched is well documented and is known as the Hawthorn Effect[84]. Yet in a society that is increasingly critical of overweight individuals, an individual who has to report their weight to a study investigator may be motivated to lose or maintain weight as a form of *impression management*, where one presents a favorable image to others[20]. For example, Muhlheim and colleagues[85] conducted an experiment where all subjects completed food diaries for one week. Those in the experimental group were then asked to continue the food diary for two additional weeks and told that the researcher was validating their reports. The belief that the researcher could verify their food diaries improved the accuracy of the self-report somewhat, but all subjects continued to underreport intake regardless.

The Muhlheim experiment indicates that subjects may have been underreporting intake as an intentional attempt to provide a more favorable self-image to others. More recently, Johns et al.[86] analyzed weight change among people enrolled in weight loss studies who were randomized to the minimal or no intervention control group. Individuals randomized to control groups that included 'weigh-ins' in which they had to arrive in person to be weighed lost more weight than those who merely provided a pre/post weight. Furthermore, the effect of the weigh-in was intensified with each additional weight visit; the more times a participant had to show up to be weighed, the more weight they lost.

Impression management, or the desire to lose weight so a researcher thinks favorably of the participant, may mediate how self-weighing affects body weight by creating an alternative pathway between the act of self-weighing and an improved regulation of body weight (see figure 1.6). Two chapters of this dissertation, 4 and 5, explore the possibility of this mechanism as being responsible for the impact of self-weighing on weight.

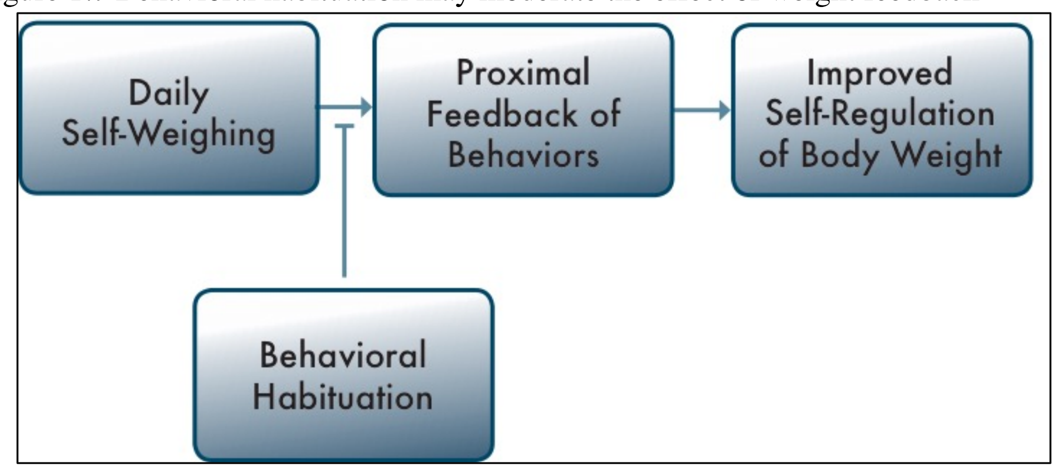
Figure 1.6. Impression management may mediate weight if paired with self-weighing



Theory of Behavioral Habituation

Data on the effects of frequent self-weighing and weight comes from trials lasting between 4 weeks to 24 months, and high levels of frequent weighing adherence followed by a gradual decrease has been reported[66]. This gradual decline in self-weighing frequency could be related to the fact that many studies use subjective, self-reported weight assessments instead of objective weight measures; that is, there is a gradual decrease in *reported* frequency of weighing versus *actual* frequency of weighing. Yet even if this gradual decrease is real, no study has reported the pattern of self-weighing and its relationship to weight for more than 12 months. This absence of longitudinal studies is a critical omission; research shows that humans habituate to a variety of behavioral and psychological responses related to weight control[21]. Declining treatment effectiveness may be related to increased habituation, or boredom, with the weight control technique. In one trial that compared standard behavioral treatment to a program that alternated different behavioral prescriptions delivered in sequence (called the Maintenance Therapy Technique), Jefferey et al.[87] discovered that varying behavioral techniques produced sustained weight loss for an unusually long period of time compared to the group receiving constant recommendations. Figure 1.7 depicts the possible moderating effect behavioral habituation has on frequent self-weighing. According to the standard SCT model, frequent self-weighing acts to improve self-regulation of body weight through the proximal feedback of how behaviors affect weight. Yet habituation may moderate this effect by 'desensitizing' the individual to the feedback from the graph. Each study in this dissertation discusses the possible effect of behavioral habituation on frequent weighing.

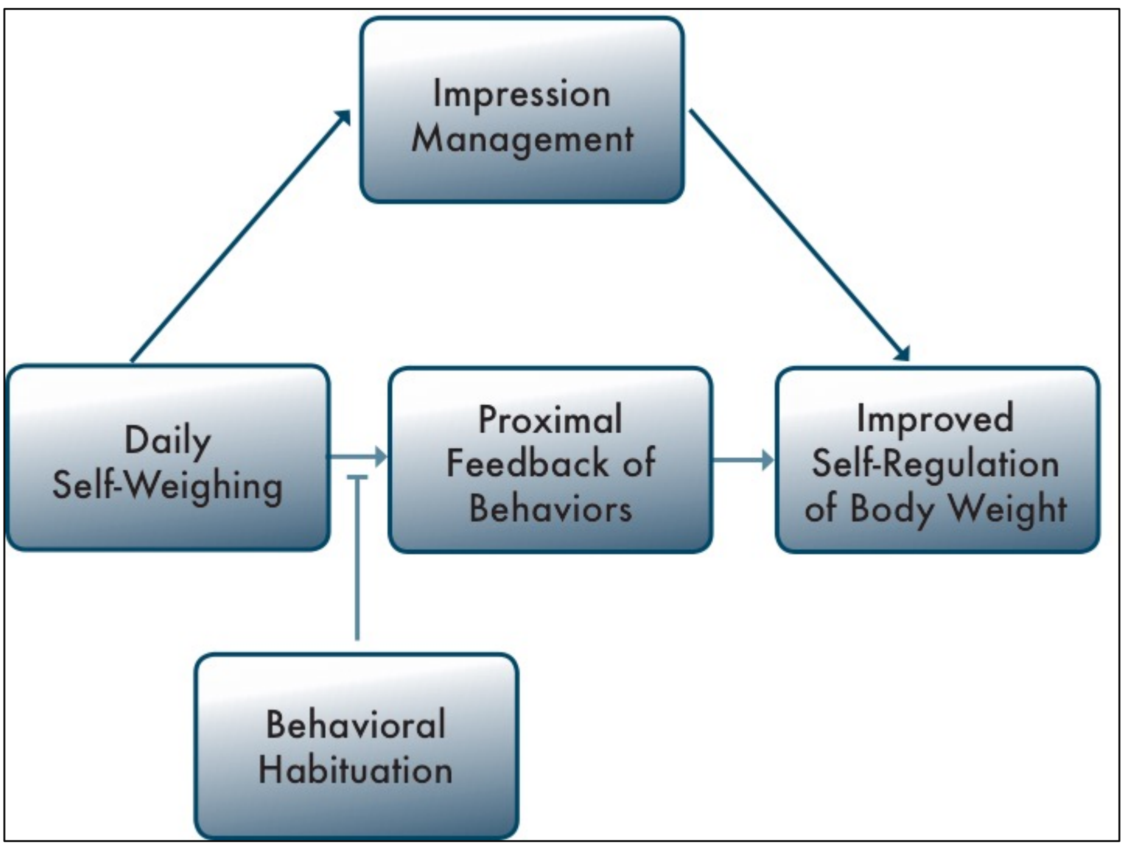
Figure 1.7 Behavioral habituation may moderate the effect of weight feedback



Revised Conceptual Model of Self-Weighing

Using the relevant constructs from self-regulation theories along with other possible mechanisms, figure 1.8 illustrates the full revised conceptual model outlining the process through which daily self-weighing may possibly impact weight. The linear framework used to design two of the studies in this dissertation (chapter 4 and 5) did not encompass the full complexity of the results. Chapters 4 and 5 both include longitudinal follow-up analysis of studies lasting well beyond twelve months; patterns of habituation and impression management emerged. Yet because these studies were not designed to study these effects directly, this model is presented as a theoretical framework for future study designs and analysis. Chapter 3 is an observational study of a dataset including over 90,000 users of a wi-fi scale. While impression management is not likely to be a mediator among these users (there is no reason to believe the users of this scale knew they were being monitored, and anonymity protocols were strictly followed), there does appear to be a decline in use over time.

Figure 1.8. Conceptual model that expands the standard self-regulation model to include accountability as a confounder and time as a mediator



CHAPTER 2

SELF-WEIGHING AS A STRATEGY FOR WEIGHT GAIN PREVENTION: A CRITICAL REVIEW OF THE LITERATURE

Approximately one-quarter of adults in the United States are actively trying to lose weight, most of whom are doing so without professional support[88]. The Obesity Society, along with the American Heart Association and The American College of Cardiology, recommends overweight and obese adults lose weight through a calorie restriction of 500-750 kcals per day and the help of an intensive, comprehensive lifestyle program[11]. Yet long-term sustained weight loss from these programs is a concern; overall, less than one out of six adults who has ever been overweight or obese has accomplished weight loss maintenance of at least 10%[89]. Up to 77% of those who participate in standard outpatient weight loss treatments drop-out within the first year[90–92] . Very few people who complete weight loss programs lose more than 10kg after the first year, and by year four, weight is only about 2kg less than what it was before the individual started dieting[93].

A different approach to managing the obesity epidemic is needed. Self-weighing is a low-intensity strategy that is associated with weight loss <u>as well as</u> weight loss maintenance. Several studies suggest that individuals who frequently self-weigh have lower BMIs and a slower rate of weight gain compared with those who do not[67]. Studies have shown an association between interventions that include daily weighing and weight gain prevention[94], and experimental data show that daily weighing with visual feedback may prevent age-related weight gain among college students[95].

This chapter expands on the previous chapter by narrowing the focus of self-weighing as a technique to control body weight by describing its effects on weight gain prevention. Two trials are introduced; one which used frequent weighing with visual feedback as a strategy for weight loss, and one where college freshman were randomized into a control or frequent weighing group and followed through their senior year. These two trials are the experimental basis for this dissertation; primary results for both have been published, and each gave the opportunity for long-term follow-up to see the effects of self-weighing over years instead of mere months.

Self-Weighing and Weight Loss Maintenance

Surveys

In 1984, Jeffrey et al.[96] examined individuals who had participated in a weight loss program two years after it had ended and found that those who reported weighing themselves were more successful at maintaining weight loss than those who did not track their weight. Self-weighing was thus hypothesized to assist in weight loss maintenance. In 1994, the National Weight Control Registry (NWCR) was established as a way to identify the characteristics of individuals who succeeded with long term weight loss maintenance. To enroll in the NWCR, individuals must have lost ≥13.6kg and have maintained this loss for ≥1 year. The first published study collected data from 629 women and 155 men, and reported that one strategy people found useful was to weigh themselves (38% weighed themselves daily and 6.5% more than once a day)[97]. More than 75% of participants weighed themselves at least once a week.

Subsequent follow-ups of those in the NWCR described a comparable pattern of those enrolled, even as the sample size grew. In 2007, Butryn et al.[76] reported an update on 3,003 members. Similar to the earliest cohort, 36% weighed themselves every day and 79% at least once a week. Weight re-gain after one year was also less for those who self-weighed (by 4.3 ± 6.3kg). The most recent data from the NWCR, a ten-year follow-up of 2,886 participants, maintained this association between frequency of self-weighing and long term weight loss maintenance[77].

Other surveys on weight loss maintenance have reported analogous results. Data from the German Weight Control Registry (*n* = 494), a similar registry to the NWCR, reports that successful weight loss maintainers tend to weigh themselves more frequently than the general population (*n*=2,129)[98]. Likewise, Kruger et al.[60] analyzed data from a 2004 Styles survey, also similar to the NWCR but with the addition of people who were <u>not successful</u> at keeping lost weight off. Respondents self-identified their weight history experience, which was not quantified (as it is in the NWCR) but subjectively assessed through the question "overall what best describes your experience with your weight?" and provides a 7 item checklist, including, "I lost weight and have been able to keep it off". From this checklist the authors categorized the individuals into "successful" or "unsuccessful" weight losers, and found that those defined as "successful" were more likely to weigh themselves daily. In another survey of 120 adolescent females who had lost weight, 43% weighed themselves frequently (those who weighed themselves weekly or more), and those who weighed themselves more often maintained lower average BMIs[99].

<u>Experimental Evidence</u>

Experimental evidence on self-weighing has been accumulating since the late 1960s, when Richard Stuart had participants chart their weight four times a day and noted losses of one pound per week over a twelve month treatment period[100]. This graphical feedback, or charting of weight, appears to be a critical component of self-weighing's influence on weight control[100–104]. In the conceptual framework outlined in Chapter 2, the feedback component (the center box) is theorized to trigger reflection and action to behavior changes that improve weight control. This component has been examined in multiple studies. For example, Oshima et al.[105] investigated the effectiveness of self-weighing twice daily with supportive feedback from a body composition monitor in overweight adults. Participants were randomly assigned to either a group that weighed themselves once per day or twice per day. While weighing twice per day appeared to be more effective than once (1.0 ± 1.4 kg vs. 2.7 ± 2.1 kg, $p < 0.05$), participants in the once daily weighing group lost <u>proportionally</u> more weight than those in the twice daily group.

Likewise, Fujimoto et al.[106] published results of participants who measured body weight four times per day and charting weight weekly, then randomized into groups with and without visual feedback. Weight loss was significant in both groups, but those <u>with</u> visual feedback saw <u>no rebound weight gain for up to 3.8 years</u>. Not only was daily weighing effective as an adjunct therapy in helping people lose weight, but they were able to maintain this weight loss over a long period of time.

Sherwood et al[107] also investigated the effectiveness of self-weighing on weight loss maintenance. Participants (n=419) who had recently lost ≥10% of their body weight were randomized to a guided or self-directed intervention. Those who were given bi-monthly weight graphs based on self-reported weight <u>regained less weight</u> than those who did not at 24 months.

Slowing the Rate of Age-Related Weight Gain by Self-Weighing

Frequent weighing is considered as a useful method to help weight gain prevention, regardless of starting weight or recent weight change. One of the few direct experimental tests of this was done by Levitsky et al.[108], who found that daily weighing decreased rate of weight gain in college females in two independent but similar studies. Female freshmen college students were given analog bathroom scales and instructed to weigh themselves daily. After 7 days, a linear function was performed on the most recent 7 days of the weight day for each participant. The untreated controls gained 3.1±0.51 kg and 2.0±0.65 kg, respectively ($p=0.01$ for both studies), whereas weight gain of the experimental groups was 0.1±0.99 kg and 0.82±0.56 kg, values that suggest weight maintenance in the frequent weighers.

Bertz et al. [109] expanded this research by randomizing first-year college students to a weighing-only group or no-treatment control, and is further explored in Chapter 5 of this dissertation. After the first year, the control group had gained 1.1 ± 4.4 kg whereas the treatment group lost 0.5 ± 3.7 kg, yielding a difference in weight change between the two groups. Further, weight change of the treatment group was not different from zero, whereas the control group's weight was, suggesting that frequent self-weighing is protective against weight gain during the first year in college.

Further extended upon in this dissertation (Chapter 4) is a study done by Pacanowski and Levitsky[110], who found that frequent self-weighing with visual feedback can assist with weight loss, weight loss maintenance, and weight gain prevention in adults. This intervention included three intervention arms over two years. During the first year, participants weighed themselves weigh an analog bathroom scale and manually input their weight into a computer program daily. Once 8 measurements had been entered, a green line appeared 1% lower on the chart. Once the individual maintained this weight, the green line was reduced in 1% increments until a 10% loss has been achieved, at which point maintenance was recommended. During the second year, participants in the intervention group were asked to continue to weigh themselves daily, but maintain their weight. There was a significant reduction in weight over the first year for those in the intervention group, and over the second year, maintained their weight. These results suggest that tailored feedback based on self-weighing is an effective approach for weight control delivered electronically.

Frequent self-weighing appears to be a useful tool for sustainable weight control; published data appear to suggest that people who weigh themselves frequently regain less weight, both in general or after weight loss, than people who do not weigh themselves frequently. Such data may suggest that self-weighing frequency may be an indicator of motivation to lose or maintain weight loss; however, several experimental studies have demonstrated that graphical feedback coupled with frequent weighing may be sufficient to prevent weight gain. The chapters laid out in this dissertation further address the relationship between self-weighing and weight control through observational, follow-up, and experimental study.

CHAPTER 3

SELF-WEIGHING FREQUENCY, WEIGHT GOALS AND WEIGHT CONTROL: A RETROSPECTIVE LOOK AT SMART SCALE USERS

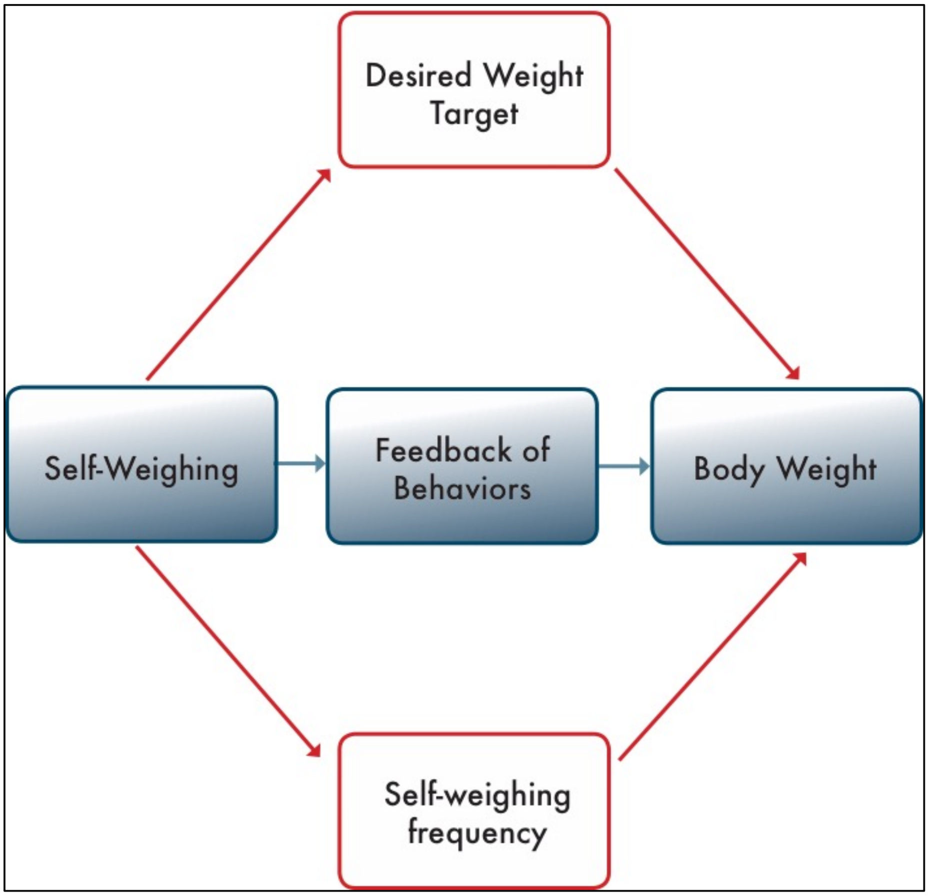
Introduction

Self-weighing is a simple and effective way to reduce the rate of weight gain in adults[66]. The relationship between frequent self-weighing and weight control is well established – many behavioral weight control interventions that include frequent self-weighing as a treatment component are effective[81]. Yet objective, real world self-weighing behavior—that is, how often people weigh themselves, what they are trying to achieve by self-weighing, and if they accomplish those goals – has not been robustly explored[111].

Internet-connected smart scales are increasingly being used to record weights; these scales automatically transmit weight recordings to a database that users can access online or via smart-phone. Users can also designate a "desired weight" goal and track their progress by looking at visual graphs of their weight trends over time. This creates a unique opportunity to study self-weighing behavior over long time periods.

This study examines the weighing behaviors and desired weight goals of over 90,000 users of an internet connected smart-scale. Figure 3.1 describes the research questions (in red) and how they relate to the conceptual framework outlined in Chapter 1. Our aim was to explore how often users normally weigh themselves, what, or if, they set as their desired weight targets, and if they achieve these goals. We also explore the relationship between self-weighing frequency and weight change over time.

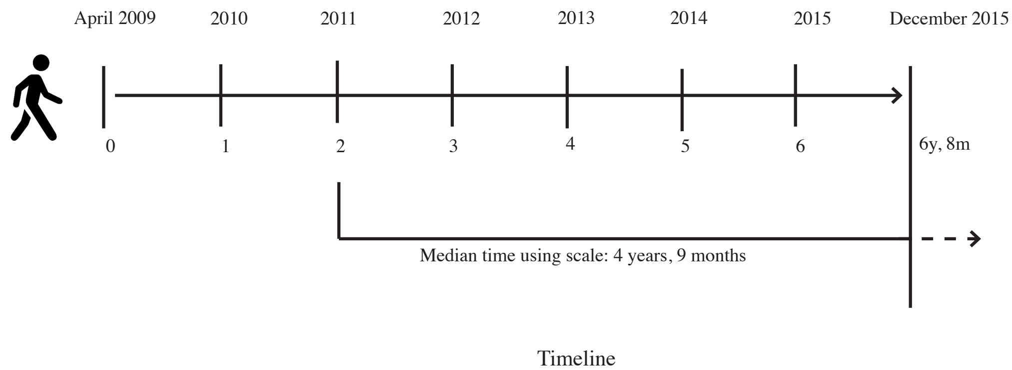
Figure 3.1. Research aims as related to the conceptual framework



Methods

All weight data are from users of the Withings Smart Scale between April 2009 and December 2015. Individuals who purchased the Withings scale from a retail store or the Withings website and completed a short profile online or through an app with self-reported height, sex, and date of birth, are included in analysis (see figure 3.2). We excluded from this analysis persons aged 18 or younger, or those with BMIs under 15. As part of the Withings Terms and Service (see Appendix 3.1), by using the scale and website, users consent to let their personal data be used for analysis purposes.

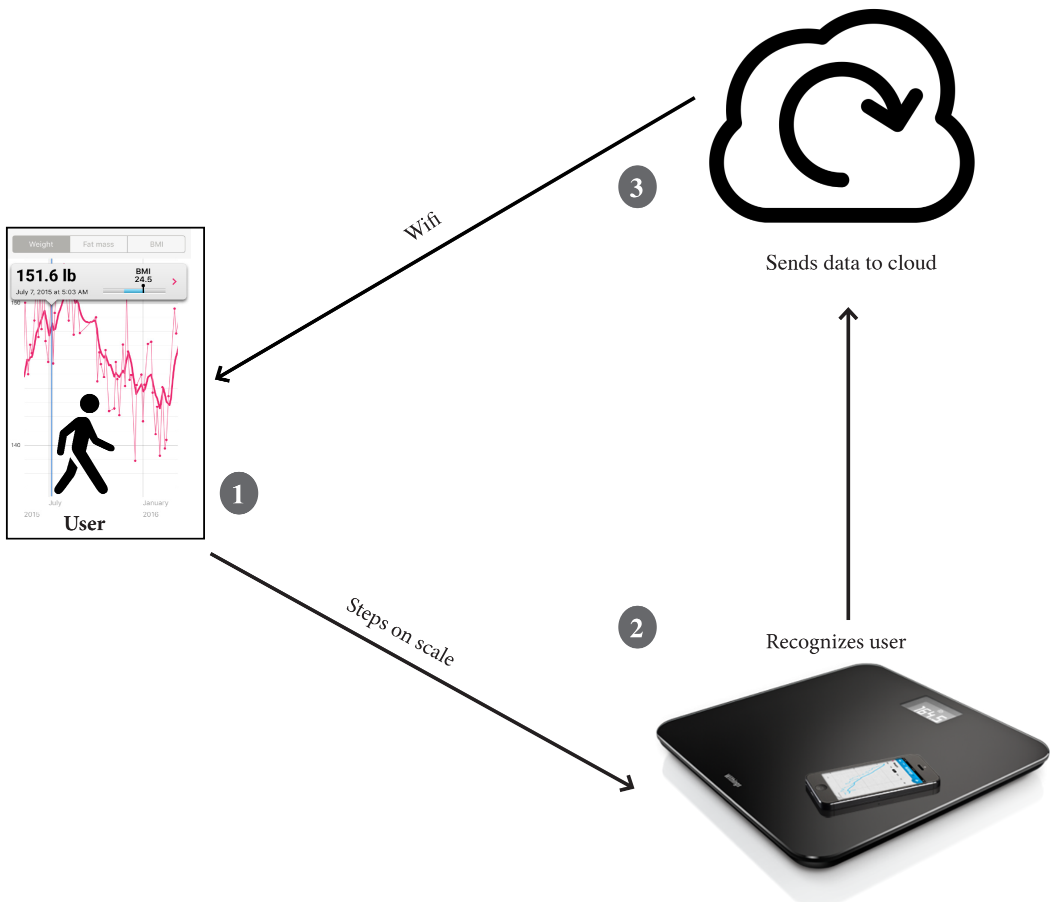
Figure 3.2. Timeline of data collection



Definitions and Data Extraction

Data extracted included 93,380 user IDs with 49,593,086 weight measurements, an average of 500 per user. Also extracted were user height in meters, gender, year of user's birthdate, and country of residence. Withings removed users with height greater than 2.05m and less than 1.44m, and those born before 1935 in order to maintain the anonymity of individuals. Withings condensed users in countries with too few users to "Other" ("too few" being defined by Withings). Weight measures included the weight in kilograms and a timestamp of the measure. Objective weight measurements were taken electronically and automatically transferred to an online database, accurate to 0.09kgs. The process of self-weighing and the data being stored is described in Figure 3.3. Withings states that up to 8 users can be registered to each scale, meaning that the scale is designed to recognize different users automatically, such that their data is independently synced to their individual user profile, even when others use it.

Figure 3.3. Description of the self-weighing and data storage process for Withings



Users have the option of including a desired weight target. Desired weight targets were extracted from all users who had made one, with the date of the target creation and target in kilograms.

Data Analysis

Data cleaning and analysis of all data presented here were performed in R version 3.3.1[112]. Descriptive statistics were assessed using standard measures with the R package tableone[113]. We summarize baseline characteristics using mean and standard deviation if the variable is continuous, and number with percentage of users for categorical variables. Paired *t* tests and chi-squared tests were used to explore differences between sexes, those who made weight loss or maintenance targets, and those who hit those targets. We used simple linear regression to examine the strength of linear relationships between weight goals, frequency of weighing and weight change variables. To further investigate the relationship between variables, we created a multiple regression model using age, gender, country, starting weight and BMI.

Derivation of Variables

Time Measurements

We defined baseline and endpoint as the first and last timestamps of when the user had weighed themselves. Time was read into R as seconds. To convert this into dates, we used the as.POSIXct command. Start date was defined as the first date and time in which a user recorded their measurement; end date was defined as last date and time. Total days used were defined as how many days had passed between the first measurement and the last.

Weight Measurements

Weight measurements were subdivided into *first measurement* and *last measurement* by taking the first and last time points measured. These were further subdivided by mean weight per user per year. BMI was calculated in the usual way, kg/m^2, and divided into standardized categories of ≤18.5 as *underweight*, 18.5-24.9 as *normal weight*, 25-29.9 as *overweight*, 30-34.9 as *obese*, and ≥35 as *morbidly obese*. Weight change was defined as the difference in kilograms between time points, as well as a percentage by taking the last weight minus first weight divided by first weight. This was subdivided into three categories: *lost, maintained,* or *gained.* We used a standard definition of weight maintenance as ±3% of starting weight[17].

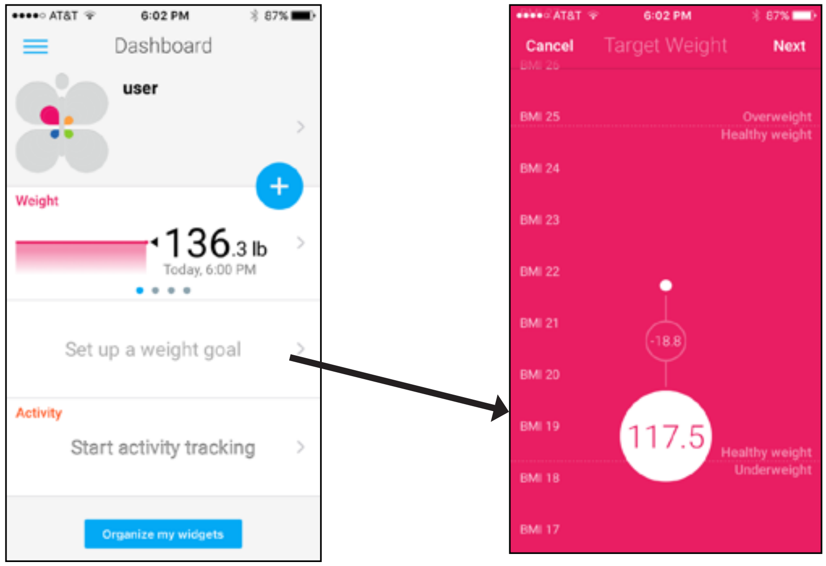
Frequency of weighing

Frequency of weighing was calculated as times per week in two ways. First, total weights divided by total weeks up until the time the data was extracted. However, this number is likely to be overinflated if a user weighed themselves multiple times per day (if, for example, they were trying out the scale) on just one day. Therefore, an additional weighing frequency variable was derived, with a maximum of one weight measurement per day. As research studies define regular self-weighing as anywhere between daily to weekly, this variable was further subdivided into more or less than once a week.

Weight Targets

Users are not required to set a "desired weight target" (see figure 3.4), but have the option of adding one at any time. Because targets can be added at any time, we used a different method of extracting and summarizing weight targets. First, targets were defined by *first* and *last* in the same way as weight measurements. This target was matched to the nearest weight measurement by date, and desired target magnitude was calculated as the difference between the users weight target from their weight at that time.

Figure 3.4. Description of how users can set up a weight goal



Setting up a weight goal

Results

Baseline Characteristics

After subtracting individuals outside the BMI and age range, 91,814 individuals with 49,349,604 self-recorded weight measurements were included in this analysis. Of these, 70,177 input 140,047 targets. Out of our sample of 91,814 users, 64% were male, 36% female, and used the scale for an average of 4.84 ± 0.59 years (see table 3.1). Users weighed themselves an average 30% of all days. Mean age in years at baseline for the users was 39.8 ±10.33 (40.05±10.23 for men, 39.25±10.49 for women). Mean baseline weight was 81.43 ± 20.05kg, with a BMI of 26.55 ± 5.26. Men were much, much more likely to create a weight target than women (86% of men made a weight target, compared to 59.7% of women). Because of the high number of users, all differences between genders were significant to the p <0.001 level (see appendix 3.2 for full table of characteristics).

Table 3.1. Baseline characteristics of users, stratified by gender.

	Entire Sample	Subgroups		
	All	Men	Women	
	n = 91814			P value
Sex, n (%)		58449 (63.7)	33365 (35.3)	<0.001
Age (years), mean (SD)	39.84 ± 10.26	40.13 ± 10.16	39.34 ± 10.41	<0.001
Height (m), mean (SD)	1.74 ± 0.10	1.79 ± 0.07	1.66 ± 0.07	<0.001
Weight (kg), mean (SD)	81.43 ± 20.05	89.97 ± 17.68	66.48 ± 14.43	<0.001
BMI (kg/m^2), mean (SD)	26.55 ± 5.26	27.91 ± 4.95	24.18 ± 4.95	<0.001
BMI Categories, n (%)				<0.001
Underweight (<18.5)	1702 (1.9)	216 (0.4)	1486 (4.5)	
Normal (18.5-24.9)	37886 (41.3)	16690 (28.6)	21196 (63.5)	
Overweight (25-29.9)	33271 (36.2)	26219 (44.9)	7052 (21.1)	
Obese (30-34.9)	12661 (13.8)	10394 (17.8)	2267 (6.8)	
Morbidly Obese (≥ 35)	6294 (6.9)	4930 (8.4)	1364 (4.1	
Years used, mean (SD)	4.82 ± 0.59	4.83 ± 0.60	4.79 ± 0.58	<0.001
Created a weight target, n (%)	70177 (76.4)	50258 (86.0)	19919 (59.7)	<0.001

Weight measurements

First measurements and last measurements were significantly different from each other by paired *t*-test (see table 3.2); however, actual difference is less than 0.1kg. BMI was also significantly different, although the difference is 0.01kg/m^2. Notably, 63.5% of women started at a normal BMI, compared to 28.6% of men. The majority of men (44.9%) started and ended in the overweight category.

Table 3.2. Weight of users, stratified by gender

	Entire Sample			Subgroups				
	First measurement	Last measurement		Men		Women		
			P value	Men $_{First}$	Men $_{Last}$	Women $_{First}$	Women $_{Last}$	P value
Weight (kg), mean (SD)	81.43 ± 20.05	81.34 ± 19.88	< 0.001	89.97 ± 17.6[illegible]	89.56 ± 17.64	66.48 ± 14.43	66.95 ± 14.72	<0.001
BMI (kg/m^2), mean (SD)	26.55 ± 5.26	26.54 ± 5.26	<0.05	27.91 ± 4.95	27.79 ± 4.96	24.18 ± 4.95	24.35 ± 5.06	<0.001
BMI Categories, n (%)			< 0.001					<0.001
Underweight (<18.5)	1702 (1.9)	1734 (1.9)		216 (0.4)	193 (0.3)	1486 (4.5)	1541 (4.6)	
Normal (18.5-24.9)	37886 (41.3)	38224 (41.6)		16690 (28.6)	17848 (30.5)	21196 (63.5)	20376 (61.1)	
Overweight (25-29.9)	33271 (36.2)	32986 (35.9)		26219 (44.9)	25496 (43.6)	7052 (21.1)	7490 (22.4)	
Obese (30-34.9)	12661 (13.8)	12660 (13.8)		10394 (17.8)	10134 (17.3)	2267 (6.8)	2526 (7.6)	
Morbidly Obese (≥ 35)	6294 (6.9)	6210 (6.8)		4930 (8.4)	4778 (8.2)	1364 (4.1	1432 (4.3)	

Weight Change

Overall weight change was -0.09 ± 7.62kg of starting body weight. Men lost an average of -0.41 ± 7.62kg; women gained 0.47 ± 6.68kg (table 3.3).

Out of the entire sample, 35.3% (n = 32,509) stayed within 3% of their starting weight, 33.4% gained weight, and 31.4% lost weight over the course of the sampled time period (figure 3.6). Table 3.3 stratifies gainers and losers by percent weight change in numbers and percent of total.

Mean weight change in those users who lost weight was -7.76 ± 6.60 kg, 6.99 ± 5.04kg for those who gained weight, and 0.03 ± 1.39kgs for maintainers (figure 3.5).

Table 3.3. Weight change of users

	Entire Sample	Subgroups		
		Gender		
	Overall	Men	Women	P value
Weight change, mean (SD)				
Kilograms	-0.09 ± 7.62	-0.41 ±8.09	0.47 ± 6.68	<0.001
Percent	0.31 ± 8.63	-0.11 ± 8.24	1.07 ± 9.22	<0.001
Weigth change category, n (%)				<0.001
Gained	30657 (33.4)	18447 (31.6)	12210 (36.6)	
Maintained	32372 (35.3)	20985 (35.9)	11387 (34.1)	
Lost	28785 (31.4)	19017 (32.5)	9768 (29.3)	

Figure 3.5. Weight change over time by cohort and subgrouped by gender. Differences significant to the p <0.001 level

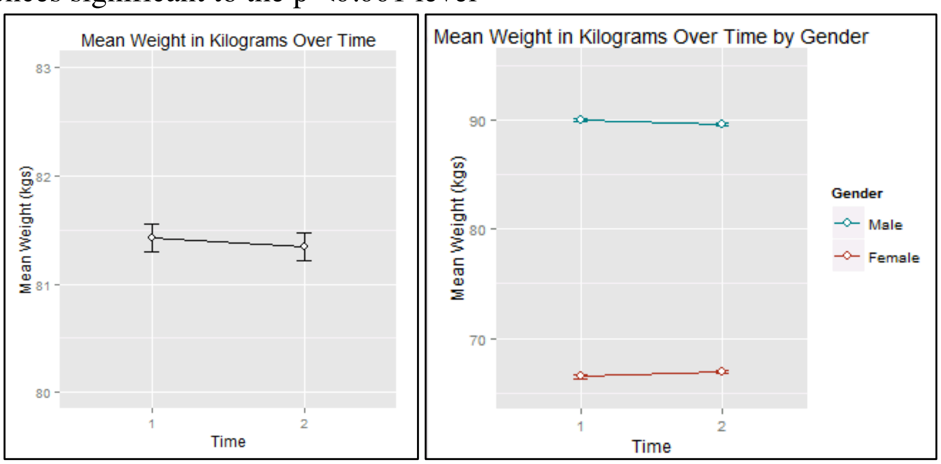


Figure 3.6. Number of users in each weight change category at last measurement

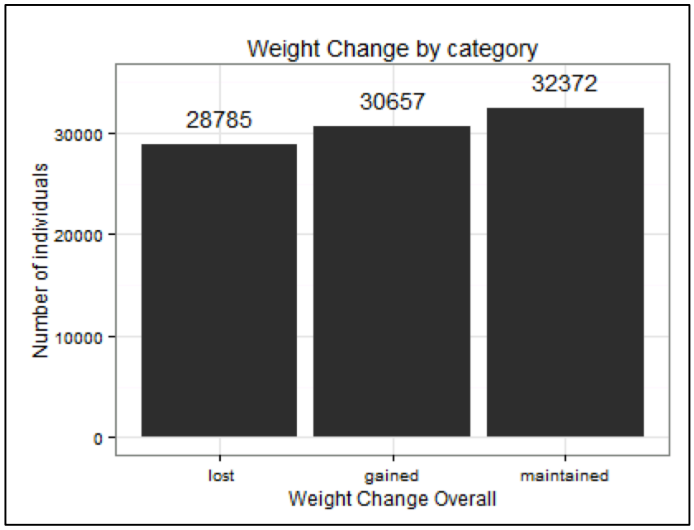
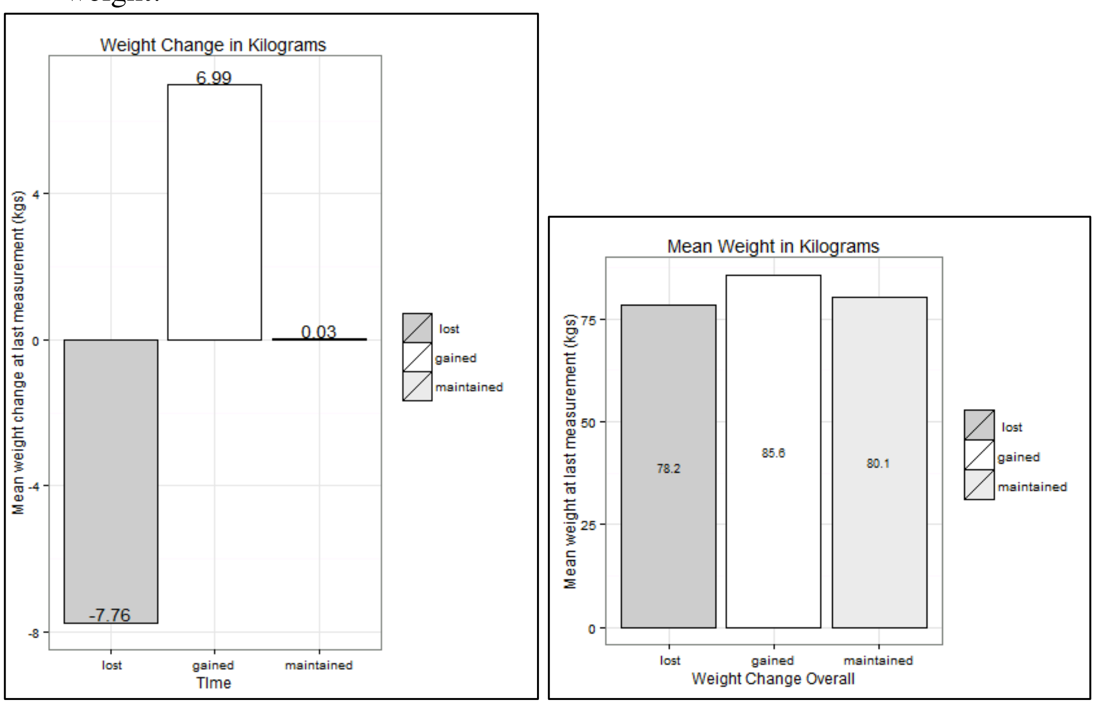


Figure 3.7. Weight change by subgroup – those who lost, gained, or maintained their weight.



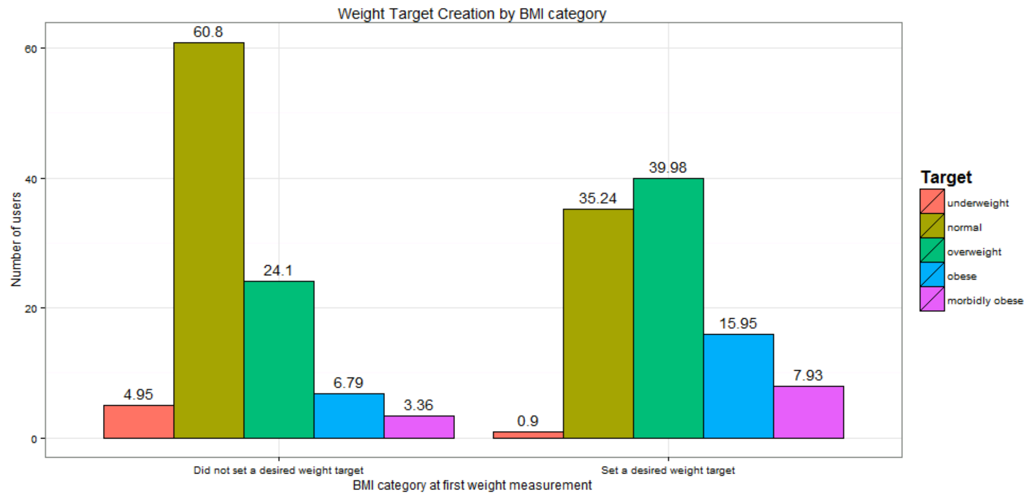
Weight Targets

Most users made a weight target (76.4%) (see table 3.4). Of those who made a target, 71.6% were male. Average starting weight for those who made a target weight was 84.67 ± 19.66kg. Most were overweight or obese (63.4%), compared to those who didn't make a target, most of whom were at a normal weight (60.8%) (see figure 3.8). However, there were few differences between those who made a target and whether or not the user gained, lost, or maintained weight (see appendix 3.3 for full table of characteristics of those making weight targets).

Table 3.4. Comparing those who made a target with those who did not

	Subgroup of those who made a weight target		
	Made a weight target	No weight target	P value
Participants (%)	70177 (76.4)	21637 (23.6)	<0.001
Male	50258 (71.6)	8191 (37.9)	<0.001
Starting Weight	84.67 ± 19.66	70.91 ± 17.60	<0.001
Starting BMI	27.29 ± 5.20	24.17 ± 4.72	<0.001
Weight change, mean (SD)			
Kilograms	-0.24 ± 7.95	0.39 ± 6.38	<0.001
Percent	0.12 ± 8.64	0.94 ± 8.57	<0.001
BMI Categories, n (%)			<0.001
Underweight (<18.5)	631 (0.9)	1071 (4.9)	
Normal (18.5-24.9)	24731 (35.2)	13155 (60.8)	
Overweight (25-29.9)	28057 (40.0)	5214 (24.1)	
Obese (30-34.9)	11191 (15.9)	1470 (6.8)	
Morbidly Obese (≥ 35)	5567 (7.9)	727 (3.4)	
Weight change category, n (%)			<0.001
Gained	7613 (35.2)	23044 (32.8)	
Maintained	7908 (36.5)	24464 (34.9)	
Lost	22669 (32.3)	6116 (28.3)	
Frequency of weighing per week	1.91 ± 1.46	1.25 ± 1.29	<0.001

Figure 3.8. Differences in who made a weight target by BMI category



Users Desiring to Lose Weight

The majority of those who made a weight target desired to lose weight (88.6%) (see figure 3.9). Seventy-two percent of those making weight targets were men. Mean desired weight goal was 75.96 ± 14.83kg, or -10.04 ± 8.75% of their starting weight (figure 3.10).

Figure 3.9. Number of users (%) who set a desired weight target, and whether they wanted to lose or gain weight

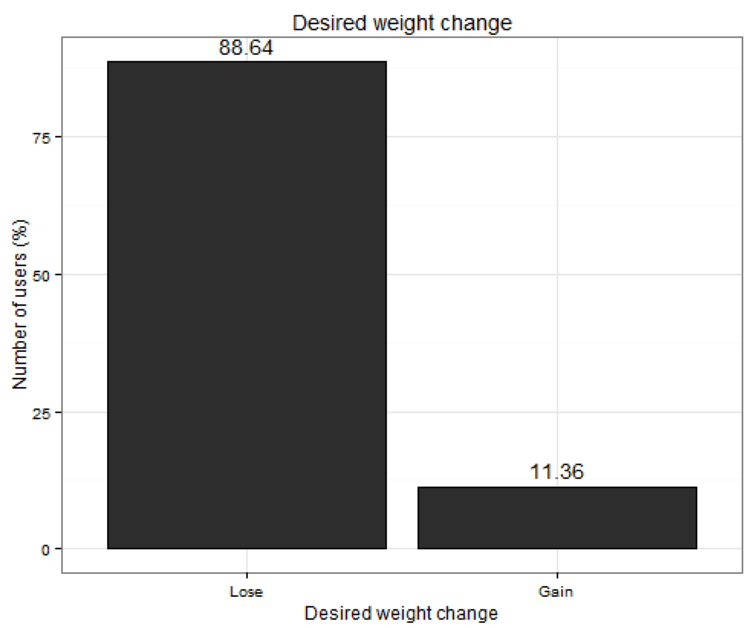
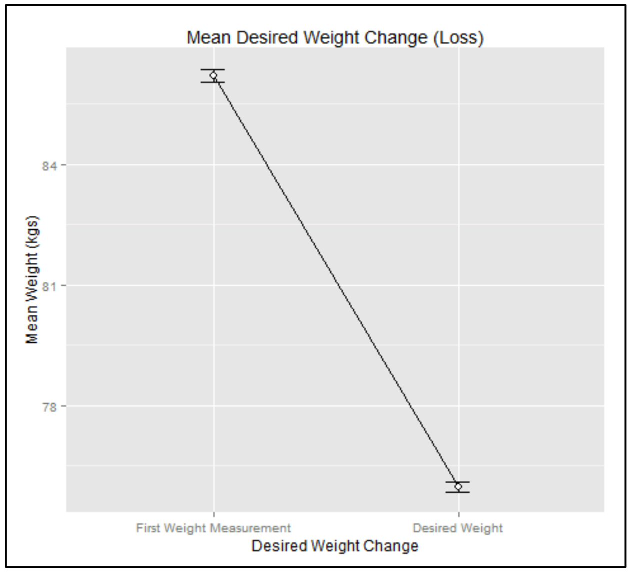
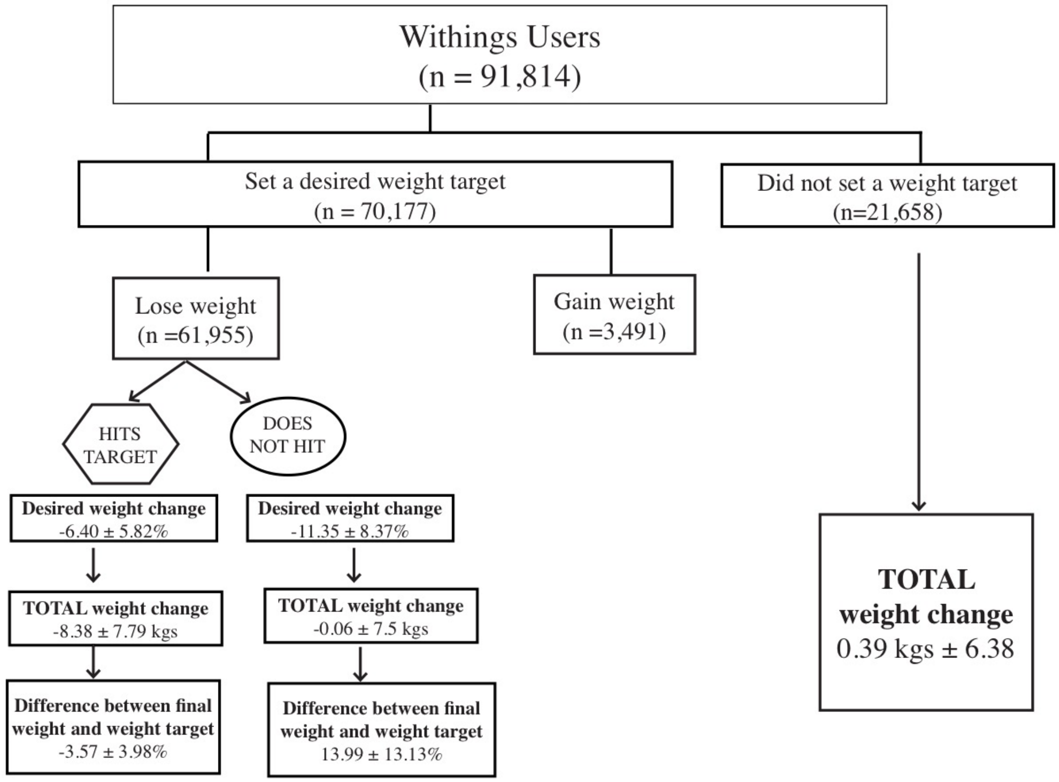


Figure 3.10. Difference between actual and desired weight



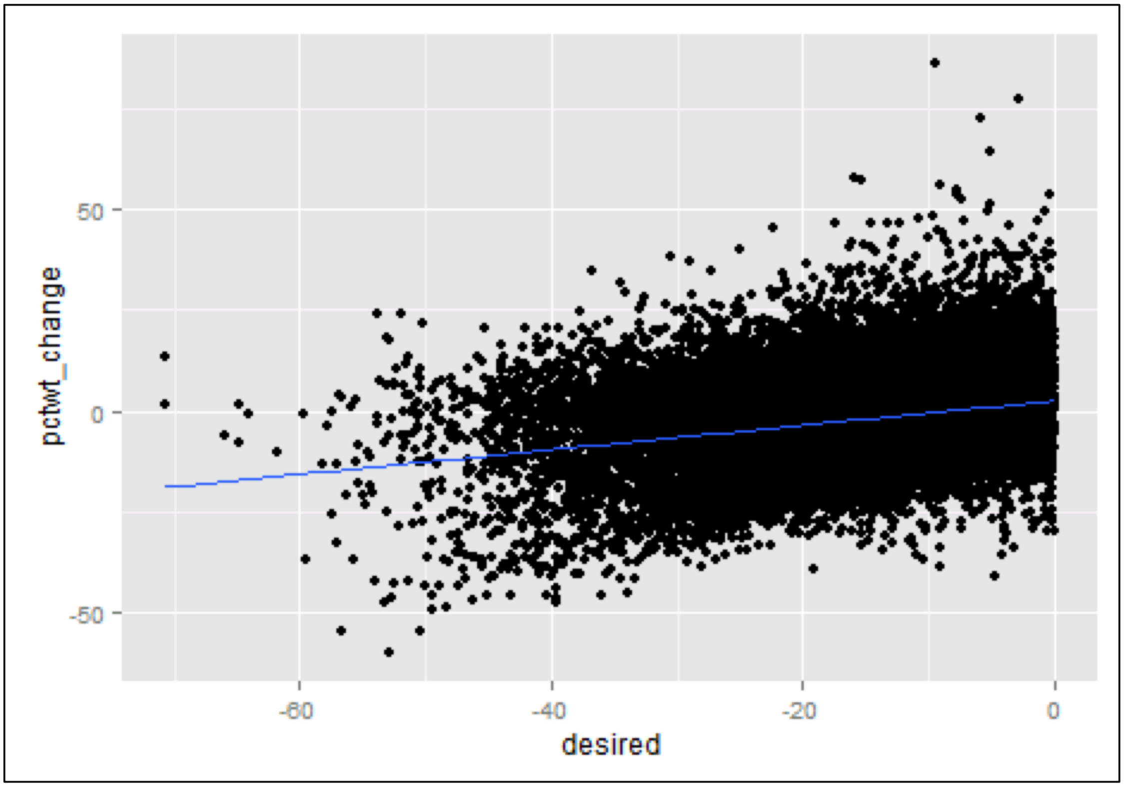
Of those wanting to lose weight, 9.3% met their desired weight target. The average desired weight change of those who met their target was -6.40 ± 5.82%; those who did not hit their target had a desired weight change of -11.35 ± 8.37% ($p < 0.001$). Actual weight loss for those who hit their target was -8.38 ±7.79kgs (-9.73±6.78%), compared to a weight loss of -0.06 ±7.5kgs (0.28 ±7.88%) for those who did not hit their target ($p < 0.001$). Figure 3.10 is a flowchart comparing those who hit their target to those who did not.

Figure 3.10. Flowchart of who made weight loss targets, who hit those targets and the change in weight.



While the above flowchart shows sizeable differences between the distance to target weight of those who hit their targets compared to the goals of those who didn't, figure 3.11 is a scatterplot of the users percent weight change between first and last weight by percent *desired* weight change. The scatterplot shows a slightly positive slope, meaning the further away a users weight target was from their actual weight, the more weight they lost. The statistical model for this graph, [lm(percent weight ~ percent desired target change)], also suggests that the further ones goal is from their current weight, the more weight they lost (see Appendix 3.4 for coefficients).

Figure 11. Percent weight change by percent target change.



Weighing Frequency

On average, users weighed themselves 1.75±1.45 times per week (see table 3.5). Over 60% of users weighed themselves more than once a week; women weighed themselves 1.48 ± 1.35 times a week, men 1.91 ± 1.47 times a week on average.

Table 3.5. Average times weighed per week

	Entire Sample	Subgroups	
		Gender	
	Overall	Men	Women
Average times weighed per week, mean (SD) *max one time per day*	1.75 ± 1.45	1.91 ± 1.47	1.48 ± 1.35
Weighing Frequency, *more than once a week, n(%)*	55310 (60.2)	38396 (65.4)	16914 (50.7)

Weight change is correlated with weighing frequency; if an individual weighs themselves weekly or more, the more weight they lose [final weight = frequency of weighing + male + first weight + having a lose target] (see figure 3.16 and 3.17;

appendix 3.5 for coefficients). Those who lost weight consistently weigh themselves more than those who maintain weight. Those who gained weight weighed themselves least of all (figure 3.18).

Figure 3.16. Weighing frequency by weight change (kgs)

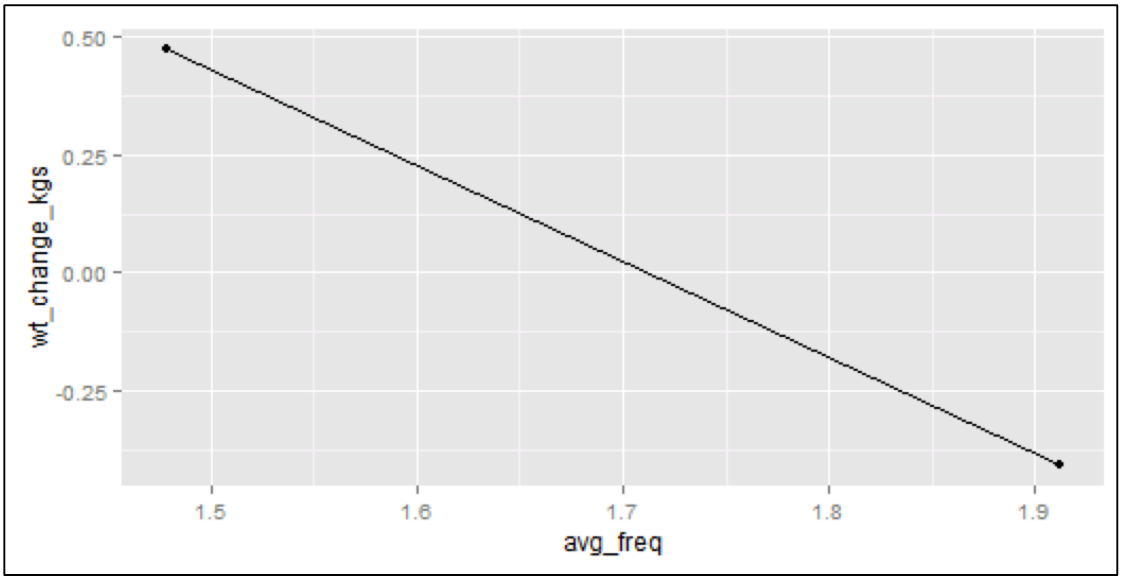


Figure 3.17. Weighing frequency by weight change category

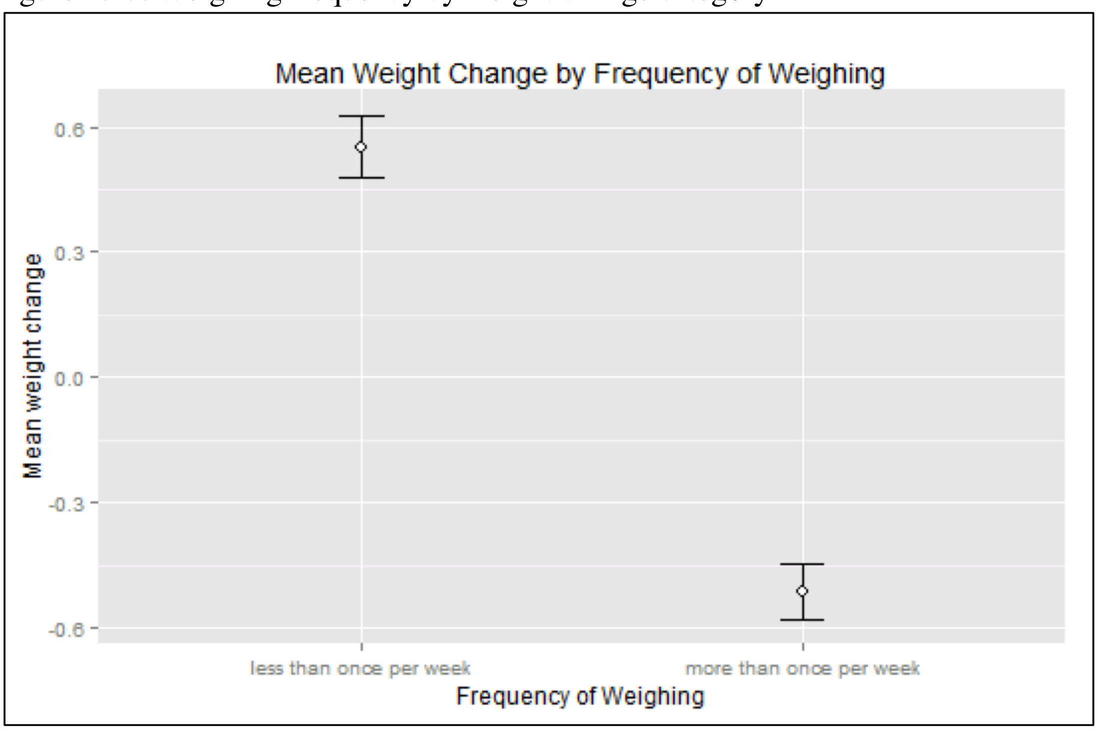
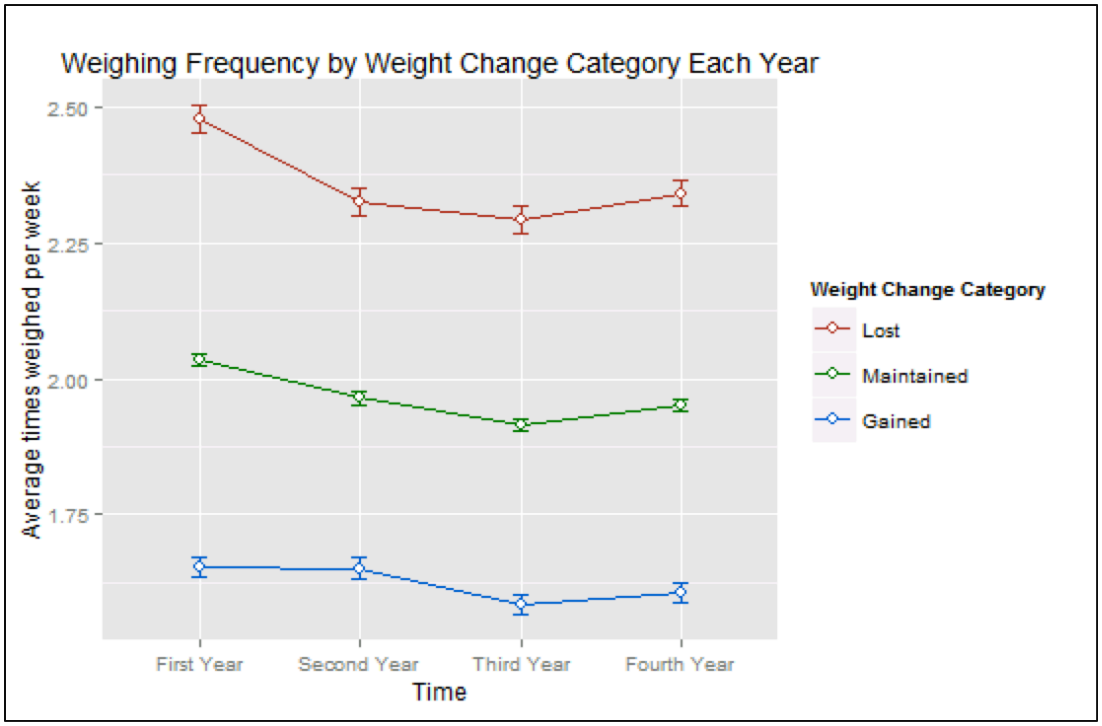


Figure 3.18. Weighing frequency by weight change category



Discussion

Although the users of this smart scale are a select group, the data from this study are important in documenting the overall patterns and variables associated with weighing frequency and weight change over a 4-6 year period. This is the first analysis that serially follows the weights of such a large group of people over such a long period. Although one-third of users gained weighed during this time, on average, this population maintained their weight. While worldwide estimates of weight gain are not known due to difficulties with data collection and analysis[1], it *is* clear that the prevalence of overweight and obesity are rising worldwide, particularly age-related weight gain. Also of note is that this population weighs themselves two times a week or more – this is the first time such an observation of such a large group of individuals in the 'real world' has been made. This study is also unique in its inclusion of a general sample in a nonclinical setting – most of the previous research in this area has focused on individuals in clinical or university settings.

Desired weight and weight outcomes

Our results suggest that individuals who buy this particular smart scale are likely to have a desired weight in mind – most often they desire to lose weight. Our results also suggest that having a goal further from one's current weight is associated with greater weight losses. However, these results also suggest that those who *hit* their weight target had much smaller goals than those who did not hit their goal (those who hit their goal desired to lose -4.90 ± 6.03% of starting body weight, those who did not hit their goals desired to lose -10.66 ± 8.62%). Yet this may suggest more about the likelihood of hitting achievable targets versus which magnitude of desired weight change is more beneficial for weight loss. It is not clear how much of the effect is just that the smaller target is more likely to be reached versus differences in how it might affect motivation.

Current guidelines recommend weight losses of 3-10% of body weight for at least one year to improve clinical parameters[11,41,114]. In addition to clinical benefits of modest weight loss, primary care providers and researchers often recommend small, incremental goals based on the assumption that more realistic goals lead to better compliance and motivation for continuing with the dietary intervention, thus improving the overall weight outcome. Yet despite the popularity of this assumption, there is very little evidence that encouraging small, "realistic" weight loss goals has any influence at all on the outcome[115].

Some studies suggests that having more unreasonable goals may be beneficial in 'jumpstarting' a weight loss program[116,117]. Yet these studies were all short term (≤6 months). When Crawford and colleagues did a systematic review on the impact of weight loss expectations and weight loss outcomes, they found that pre-treatment goals had an impact on the short and midterm (≤12 months), but no impact on outcomes over a year[118]. Durant and colleagues also performed a meta-analysis on the relationship between pre-treatment weight loss goals and treatment outcomes and found no relationship[119]. No study in either of these reviews went longer than 18 months.

However, these results *are* consistent with research that shows that individuals are likely to have goals that differ significantly from those recommended by health care professionals. Multiple studies have noted the discrepancy between weight loss expectations of patients compared to recommendations from providers[120–124]. Current guidelines advise weight losses of 3-5% to be clinically meaningful and reasonable[11]. This recommendation is not based on evidence of how motivating a weight loss goal can be[38]; rather, it is based on the amount of weight one might consider losing if they desire clinical impact in terms of co-morbidity risk decrease. However, a 3-5% reduction is often unsatisfactory to most adults trying to lose weight, which is also consistent with the population sampled here. Participants enrolling in weight loss programs report wanting to lose between 20 and 30% of their weight at baseline[120], results which are also largely consistent with the Withings scale users. This illustrates a striking discrepancy between clinical and personal expectations of weight loss goals or targets. It further strengthens the question about reasons people want to lose weight, and that above all, it may be motivations that make a bigger impact than how far away ones target weight is from their current weight.

Frequency of weighing

This study also suggests that individuals who purchase a smart scale are likely to weigh themselves two times a week or more. While some clinical guidelines recommend self-weighing to assist in weight loss and weight loss maintenance, they do not specify at what frequency other than “regular self-weighing”[11,41]. How individuals or clinicians translate “regular” is unknown (every week, every day, etc). Mainstream websites such as livestrong.com or prevention.com, as well as many weight loss programs such as Jenny Craig recommend that weighing this often is detrimental to one’s mental health and weight loss journey, regardless of the evidence to the contrary. While it was not surprising that individuals who weigh themselves more frequently are more likely to lose weight (probably due to enthusiasm and motivation), this analysis provides more evidence of the associations between frequent weighing and weight change, particularly over long periods of time.

Strengths and Limitations

One major limitation must be noted. The information about these users cannot necessarily be extended to the larger global population. A much more in depth analysis of weight variation, seasonality, serial weighing frequency, or how the desired weight interacts would be necessary to make any broader conclusions. Withings users are a select group of individuals, who pay upwards of $130 to have this smart scale in their home. We do not have information about why they bought this scale, although there are likely a number of reasons someone would buy such a scale that separates them from the population as a whole (ie health issues, pregnancy status, athletic competition, etc.).

Conclusion

This work provides novel insights into how smart scale buyers self-weigh in a "real-world" setting. It is one of the few studies to demonstrate a positive relationship between how "far" away ones desired weight is from their current weight and overall weight loss in those wishing to lose weight. Finally, it is the first longitudinal look of weight change over a period longer than 2 years, and is the first study to look at such a large group of individuals at once.

CHAPTER 4

WEIGHT LOSS PRODUCED BY SELF-WEIGHING ENDURES THREE YEARS LATER

Introduction

The dramatic increase in weight gain globally presents an urgent need for interventions that reverse this trajectory. Thousands of diet and exercise programs have been introduced in the scientific and lay literature that successfully reduce body weight of adults, yet none of these have been translated to large-scale public health improvements[31,125,126]. The max 'peak' of weight loss from most behavioral modification interventions is obtained at 6 months; after this, the individual regains the lost weight over time even if the intervention continues[127–129]. While data on how much weight is gained continues to accumulate, a longitudinal analysis by Black and colleagues estimate that after dieting, subjects regain lost weight approximately 2.25 times as long as it takes to lose it[130].

Frequent self-weighing may be effective for longer-term weight loss maintenance. In one meta-analysis on the effectiveness of self-weighing for weight loss, Madigan et al.[82] identified three trials[106,131,132] that followed up participants beyond the end of the intervention (for 6-18 months), and found a total mean loss of -5.5kg (95% CI 11.4 to 4.7). Since these studies were conducted, evidence has been accumulating that self-weighing may be particularly effective over the long-term when coupled with strategies that produce slow, steady weight loss[133]. Although it is generally believed that an initial rapid decrease in weight can be highly motivating and "jump-start" a diet, smaller behavior changes may be more sustainable[74]. Pacanowski[78] used a system called the *Caloric Titration Method,* or *CTM,* to produce a slow rate of weight loss of 1% body weight using daily weighing with graphic feedback and weight target lines over a 2 year study. In year 1, the intervention group lost 2.6±5.9kg while controls lost 0.5 ±4.4kg (p=0.019). In the second year, the intervention group continued using the CTM for maintenance while the control was provided the intervention and lost a comparable amount to the intervention group in year 1.

This chapter is a three-year follow-up of weight loss achieved by participants in the Pacanowski78 study on the effects using the CTM as a means of producing a slow weight loss. Because of the very low-intensity nature of self-weighing interventions, we were interested to see the long-term effects of participating in a self-weighing intervention on weight change.

Research Methods and Procedures

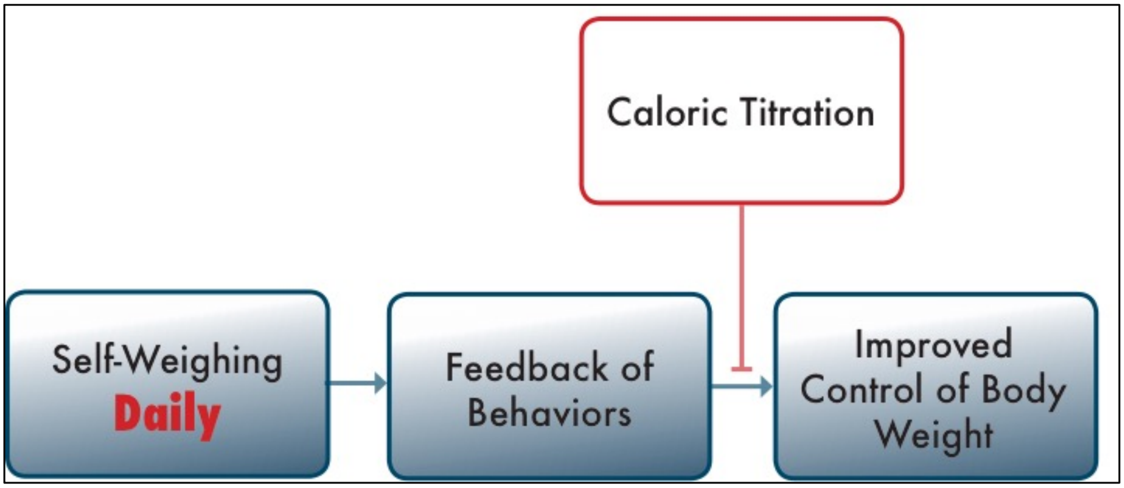
Conceptual Development

The *Caloric Titration Method* (CTM) consists of visual feedback of daily weight trends and goals as seen in figure 1. Individuals weigh themselves every morning immediately after rising from bed, and enter the weight into a web site. Once a user enters a minimum of eight weights, a green line appears 1% lower than their current weight representing their target weight. Once the weight stabilizes at the 1% goal, the line moves down again by 1% until a total of 10% maximum weight loss is achieved, at which time the individuals are asked to maintain this weight loss.

Figure 4.1**.** Sample view of the CTM graph. Green line is target weight.

Key concepts of the CTM are derived from standard behavioral treatment[134]. Participants using the CTM are encouraged to explore various ways to produce the 1% decrement in weight such as reduce portion size, desert eating, snack eating or increase exercise. This self-examination, when coupled with visual feedback, promotes problem-solving skills which are used to identify strategies to overcome barriers. According to self-regulation theory[19], individuals form beliefs based on what they can do, and are able to anticipate the likely consequences of whatever actions they choose. Figure 4.2 illustrates the CTM's function in the self-regulation paradigm for weight control. By using the CTM's emphasis on slow rate of weight loss, participants can plan courses of action that are likely to produce desired results, and feel confident to permanently sustain these changes over the long-term.

Figure 4.2**.** The Caloric Titration Method emphasizes a slow rate of weight loss and daily weighing



Intervention Components

A detailed description of the study design and procedures can be found in Pacanowski[78]. This was a 2-year delayed-control study that ran between Fall of 2010 - 2012. One hundred and sixty-two adults were randomly assigned to a 12-month daily self-weighing intervention (n=88) or a delayed intervention control group (n=74) that received the intervention 12 months after the treatment group (see appendix 4.1 for flowchart of randomization procedures). Inclusion criteria was adults over the age of 18 interested in losing weight and with body mass index (BMI) > 27.0 kg/m^2. Excluded were those who were pregnant or planning on becoming pregnant, diabetics, or those with a history of an eating disorder. Adults who were interested in participating but did not meet the BMI cutoff were invited to participate in a weight *maintenance* cohort (n=15). This cohort was not randomized into further groups, but instead was provided with an intervention designed to promote weight maintenance.

All participants in the weight loss intervention were invited to an initial session in November 2010. Evidence-based weight loss strategies were presented, and individuals in the experimental group were given a typical bathroom scale (American

Weight Scales Model 330 LPW) and asked to weigh themselves early in the morning with light clothing. They were shown how to enroll in the study's website (http://weightloss.human.cornell.edu/), and were asked to log their weight daily by manually inputting their weights into the database. Because wifi scales hadn't gained in popularity at the time this study had started, participants were asked to provide weights in person once every six months for validation. Participants were also provided with an informational handout.

Under the experimental condition, after the first 8 days of entries, a green line was displayed representing a 1% decrease in the participant's mean weight up to that point, representing the *weight target*. For those enrolled in the maintenance condition, after the first 8 days of entries, a green line was placed representing the weight the participants should try and maintain. After one year, participants randomized to the delayed control group were given access to the experimental condition, and provided the same bathroom scales, informational handout, and instructions on how to enroll in the website. Those in the experimental condition were asked to continue weighing themselves, but the green weight target line was shifted to the mean body weight of the 8 days leading up to the 12-month time-point and asked to maintain their weight at the green line. Participants were weighed by researchers at baseline, 6, 12, and 24 months.

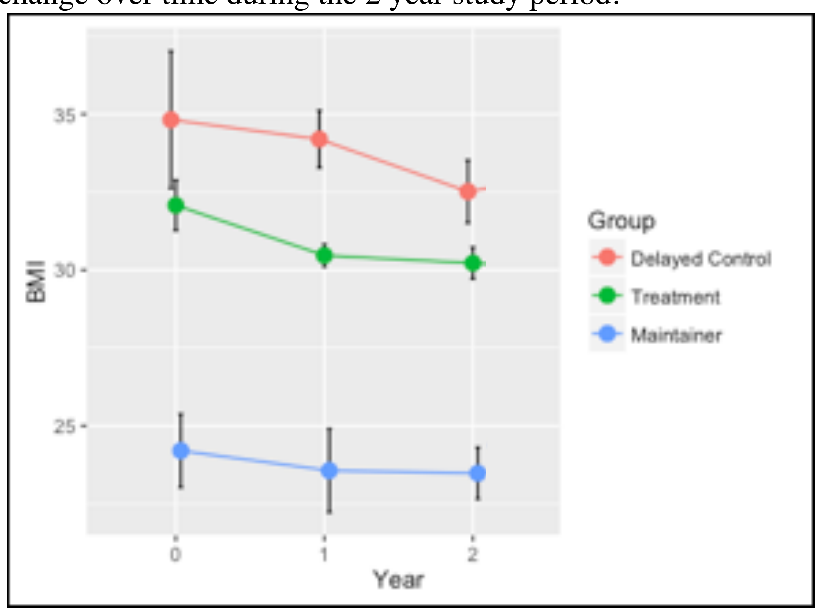
Those offered to participate in the weight maintenance study were invited to a separate initial meeting where evidence-based strategies for preventing weight gain were presented. They were given a scale and asked to enroll in the study's website. The website produced graphs of the participant's weight and time as described above, with a green line appearing after 8 days representing the mean weights of those entries. However, instead of the line decreasing, the line stayed at that point and participants were asked to maintain that weight.

All study procedures were approved by the Cornell University Institutional Review Board, and all participants provided written consent.

Intervention Outcomes

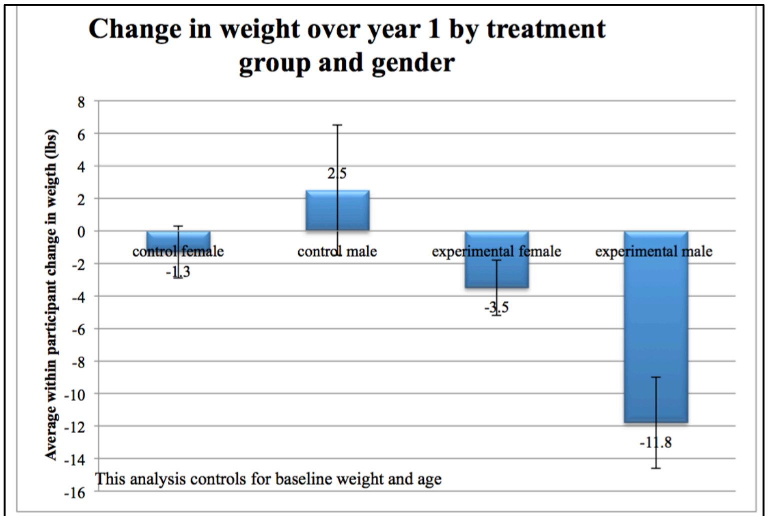
Figure 4.2 is a graphical representation of BMI change during the study. At the end of the first year, participants who were given access to the CTM lost a significant amount of weight (2.6±5.9kg) compared to the delayed control group (0.5±4.4kg), whose weight did not change (*p*=0.019). When given access to the CTM during year 2, the control group lost a similar amount of weight as the experimental group in the first year (1.9 ±5.7kg). The CTM group maintained their weight loss throughout the second year of the study (0.1±4.8kg).

Figure 2. BMI change over time during the 2 year study period.



In an exploratory, post-hoc analysis, Pacanowski found a significant group by gender by time effect, where males lost more weight than females at both timepoints (see figure 3, taken from Pacanowski's publication).

Figure 4.3. Change in weight over year 1 by treatment group and gender, taken from Pacanowski.



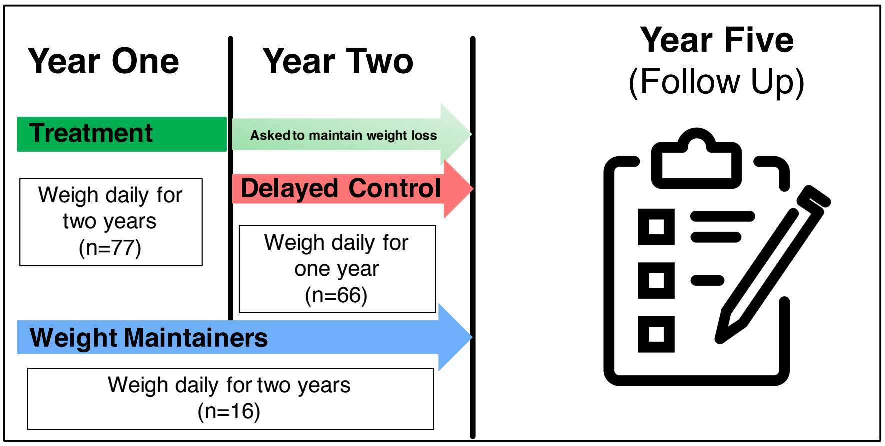
Change in weight (lbs) over the first year of the study by treatment group and gender, controlling for baseline weight and age. Error bars are +/- 1 standard error.

Only women were asked to participate in the weight maintenance arm (n=15). Weight change over two years was -0.9 ±4.9kg, which was not significantly different from a control group in a comparable study[71].

Follow-up Procedures

Of the 178 original participants (n=162 in the weight loss study and n=16 in the maintenance study), 114 were contacted for follow-up. Sixty-four of the original participants were not contacted due to loss to follow-up or request for removal from the study during the original 2-year study. Those who were contacted were told that researchers were interested in dong a follow-up study to see how their involvement in the CTM program had impacted them in the long-term, and that if interested they would be asked to asked to log their current weight in the website, as they had done during the study period. They would also be asked to fill out an online questionnaire similar to the intervention questionnaires (see appendix 4.2 for questionnaire). Figure 3 describes treatment groups and follow-up procedures.

Figure 4.4. Visual representation of study and follow-up procedures



Statistical Analysis

Anthropometric and Demographic

Analysis were performed in R 3.2.5[112] using multiple packages, notably the lme4 package[135] lmer () and lsmeans[136] functions for linear mixed model regression. Data cleaning and restructuring was done using SPSS, Chicago, IL. For descriptive statistics, values are presented in proportions and means ± standard deviation.

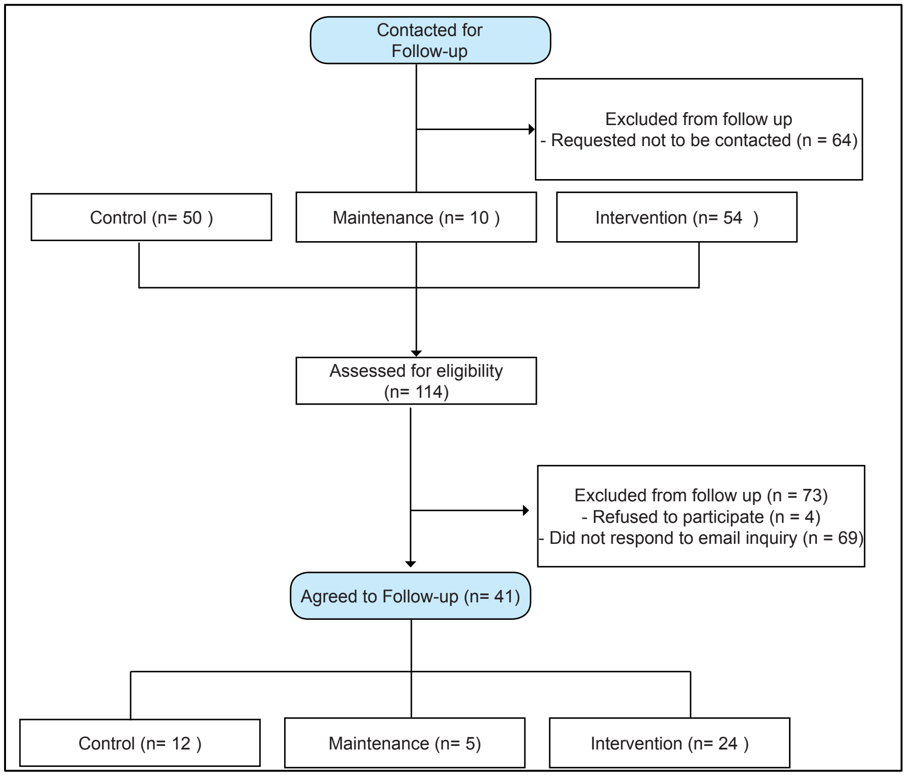
Characteristics for the follow-up cohort are described by treatment group, gender, age, BMI (kilograms per meter squared), BMI category, initial body weight, weight loss during the study period, and frequency of weighing during the study period. Answers to the follow-up questionnaire is also aggregated and described. Paired and unpaired student's *t* tests were used to compare characteristics of those who followed up to those who did not, including relevant anthropometrics and demographics. χ^2 tests were used to compare gender, group, reported ethnicity, or BMI category. Bonferroni and Tukey's tests were used to adjust for multiple comparisons when needed.

ANOVA and t-tests were used to compare body weight and BMI during the study to follow up. The basic linear mixed model used includes main effects of time, group, age, gender, baseline BMI, and an interaction between group and time. We included group by time as an interaction to answer whether weight or BMI change differed by group (since the maintenance group did not lose weight during the 2-year study period, and the treatment/delayed control groups had different weight loss trajectories).

Follow-Up Results

Of those contacted, 73 either refused to participate in the follow-up survey or did not respond to our e-mail inquiry. We obtained follow-up data from 41 subjects, of which 24 came from the treatment group (58%), 12 from the delayed control (29%), and 5 from the maintenance group (12%) (see figure 4.5).

Figure 4.5. Flowchart of follow-up procedures



Participant Characteristics

Of those who responded to our follow-up request, ten (24%) were male and 31 (76%) female (table 4.1). The mean age was 53.5 ±9.54 years, an average weight of 191.37 lbs with a BMI of 30.28 ± 5.14. Participants had an average of 16 ± 2 years of education. The majority self-identified as white (n=39). Based on BMI category, 17 individuals were overweight (42%), 12 obese (29%), 6 morbidly obese (15%), and 6 as normal weight (15%). The full list of characteristics by treatment group can be found in appendix 4.3 for these and other characteristics.

Table 4.1. Follow-up characteristics by group at the time of follow-up

Follow-Up by Treatment Group					
	Total	Control	CTM	Maintenance	p-value diff
Female (n, %)	31 (75.6)	10 (83.3)	16 (66.7)	5 (100)	0.219
Age, years (mean, SD)	53.46 (9.54)	53.75 (10.58)	52.73 (9.56)	56.00 (8.15)	0.79
BMI (kg/m^2)	30.28 (5.14)	33.31 (4.31)	29.99 (4.90)	24.37 (1.71)	0.002**
Body Weight (lbs)	191.37 (41.08)	211.14 (44.03)	190.81 (35.78)	146.62 (22.39)	0.009**
Education (years) *Highest level of education completed: 1st grade (1), 2nd grade (2), 3rd grade (3), 4th grade (4), 5th grade (5), 6th grade (6), 7th grade (7), 8th grade (8), 9th grade (9), 10th grade (10), 11th grade (11), 12 grade (finished high school (12), one yr college (13), two yrs college (14), three yrs college (15), college degree (17), masters degree (18), doctorate degree (19)*	16.34 (2.03)	15.75 (2.30)	16.43 (1.83)	17.40 (2.07)	0.307
Ethnicity (number of participants)					NA
American Indian	1	-	1	-	
White	39	12	22	5	
Other	1	-	1	-	

Table 4.2 describes self-reported weighing behaviors and satisfaction with the CTM study. Most individuals stopped using the CTM website (n=32; 78%) to record their weight after the end of the study. Of those who continued to use the website, 2 report that they continue to use it every day. Two people continue to use it several times per week, 2 less than once a week, and 3 individuals use the website to record their weight less than once per month.

The majority continued to report weighing themselves several times a week or more (n = 24; 58%). Of the individuals weighing themselves less frequently, 7 (17%) report weighing themselves once a week, 8 report weighing themselves less than once a week (20%), and 2 (5%) individuals report weighing themselves less than once per month.

Participants overall reported finding the CTM program slightly or moderately helpful in helping them reach their goal weight in the long-term (n = 28; 68%). Twelve individuals (29%) found the program extremely helpful, and one participant (2%) did not find the program helpful at all. Along with this trend, 32 participants

(77%) report that they would be moderately or extremely likely to recommend the CTM program to a friend. Five individuals (12%) would be slightly likely to recommend it to a friend, while 4 (10%) would be unlikely to recommend the CTM program.

Table 4.2. Satisfaction and impact of the survey on weighing behaviors and weight

	Follow-Up by Treatment Group				
	Total	Control	CTM	Maintenance	p-value diff
How often do you weigh yourself? N (%)					0.529
Several times per day (1)	-				
1 time/ day (2)	9 (22)	2 (16.7)	6 (25)	1 (20	
Several times/ week (3)	15 (36.6)	4 (33)	8 (33.3)	3 (60)	
Once a week (4)	7 (17.1)	2 (16.7)	5 (20.8)	-	
Less than once a week (5)	8 (19.5)	2 (16.7)	5 (20.8)	1 (20)	
Less than once per month (6)	2 (4.9)	2 (16.7)	-	-	
Have you continued to record your weight in the CTM program website since the study's end (December 2012)? *YES (1), NO (2)*	32 (78)	11 (91.7)	19 (79.2)	2 (40)	0.063
How often do you use the CTM on-line program to track your weight?					0.003**
Several times per day (1)	-				
1 time/ day (2)	2 (4.9)	-	2 (8.3)	-	
Several times/ week (3)	2 (4.9)	1 (8.3)	-	1 (20)	
Once a week (4)		-	-	-	
Less than once a week (5)	2 (4.9)	-	-	2 (40)	
Less than once per month (6)	3(7.3)	-	3 (12.5)	-	
Overall, how helpful did you find the CTM program in reaching your weight goal for the long term? *Not at all helpful (1), Slightly helpful (2), Moderately helpful (3), Extremely helpful (4)*	2.90 (0.86)	2.92 (1.00)	2.83 (0.82)	3.20 (0.84)	0.696
At this moment, how much do you feel in control of your weight (1 being not in control at all, 10 being in full control)?	5.76 (2.78)	5.42 (3.18)	6.08 (2.64)	5.00 (2.83)	0.655
A close friend wishes to lose weight. How likely would you be to recommend the CTM program to your friend? *Unlikely (1), Slightly Likely (2), Moderately Likely (3), Very Likely (4)*	3 (0.92)	2.67 (0.98)	3.17 (0.82)	3.00 (1.22)	0.316

Compared to the larger sample of 178 individuals, there were no systematic differences in gender, age, reported ethnicity, education level, starting weight, BMI, or group randomization among those who agreed to follow up (see table 4.3). There were differences between weight loss during the study; those who agreed lost significantly more weight during the study than those who did not respond (follow up -5.32 ±8.18% compared to -1.75 ±6.54% for those who did not respond, p=0.008). Those who agreed to follow-up also weighed themselves more often during the study (follow-up = 6.13 ±0.79 times per week vs 4.77 ±1.76 for those who did not, p = <0.001) and thought the program was helpful in the sense that they were willing to recommend it to a friend.

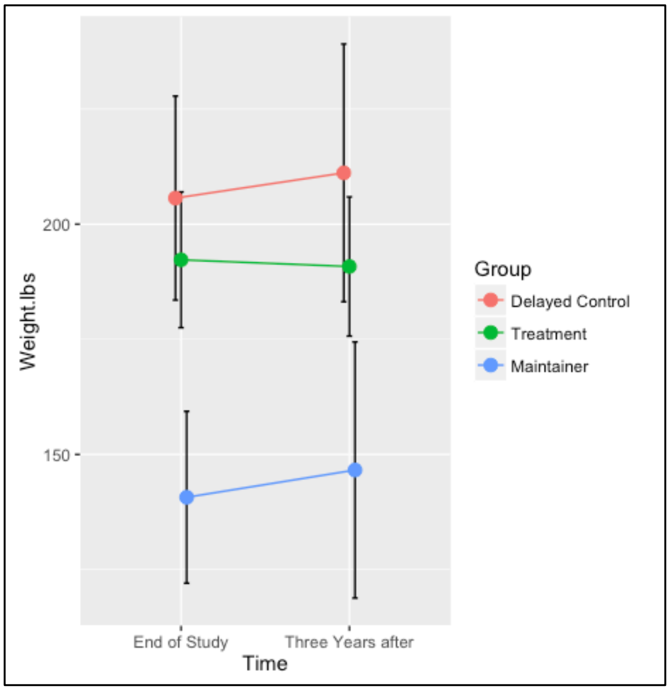
Table 4.3. Individuals who agreed to follow up compared to those who did not

Follow-Up Characteristics Compared to Original Sample			
	Agree to Follow-up	Refused Follow-Up	p-value diff
Baseline weight (lbs) (mean (sd))	201.56 (41.30)	200.49 (43.5)	0.89
Baseline BMI (mean (sd))	31.92 (5.21)	33.05 (5.48)	0.248
Age (mean (sd))	53.46 (9.54)	51.35 (9.49)	0.23
Gender (male), n(%)	10 (24.4)	20 (14.6)	0.218
Education (years) *Highest level of education completed: 1st grade (1), 2nd grade (2), 3rd grade (3), 4th grade (4), 5th grade (5), 6th grade (6), 7th grade (7), 8th grade (8), 9th grade (9), 10th grade (10), 11th grade (11), 12 grade (finished high school (12), one yr college (13), two yrs college (14), three yrs college (15), college degree (17), masters degree (18), doctorate degree (19)*	16.34 (2.03)	15.84 (2.19)	0.207
Group (%)			0.179
Control	12 (29.3)	62 (45.3)	
CTM	24 (58.5)	64 (46.7)	
Maintenance	5 (12.2)	11 (8)	
Total weight change during the study (mean (sd))	-5.32 (8.18)	-1.75 (6.54)	0.008
Frequency of weighing after 12 months of treatment (compliance indicator)	6.13 (0.79)	4.77 (1.76)	<0.001
A close friend wishes to lose weight. How likely would you be to recommend the CTM program to your friend? *Unlikely (1), Slightly Likely (2), Moderately Likely (3), Very Likely (4)*	3.21 (0.98	2.69 (1.06)	0.011

Anthropometric and Weight Change at Follow Up

Mean weight and BMI change for all subjects at follow-up after 30 months was not significantly different from zero, regardless of whether they were given the full CTM intervention or maintenance intervention (see figure 4.5). Because those enrolled in the maintenance groups had lower BMIs by design, we present results on weight change separating the maintenance study group from those in the weight loss CTM study.

Figure 4.5. Weight change after involvement in daily weighing intervention



Change in body weight between the end of the study (year 2) and follow up (Year 5) was calculated by subtracting weight measured weight at year 2 from self-reported weight at year 5. Weights appeared to be normally distributed; Shapiro-Wilk statistic yielded 0.968 with a p-value of 0.74. A similar trend was found with BMI (W =0.97 with a p-value of 0.4).

CTM and Delayed Control Groups

Average self-reported weight at follow-up was 197.59±39.91lbs, with a BMI of 31.1±4.91 (see figure 4.6). Mean weight change *during* the study was -5.67 ± 8.48 percent of starting body weight (pictured above in figure 4.2). Mean weight change between the end of the study and the follow up was 0.46 ± 7.92%. Analysis of variance was used to assess if there were any statistical differences in weight and BMI between the end and follow up (p = 0.922 for weight change, p = 0.916 for BMI change). This non-significant difference indicates weight loss maintenance; that is, a non-significant result means we cannot conclude that there is any difference in body weight or BMI between the end of the study and the follow-up period.

In the follow-up period, the BMI of those who participated in the CTM weight loss trial was essentially unchanged (see figure 4.6).

Figure 4.6. Average BMI change of 36 participants from end of the study to the follow up survey

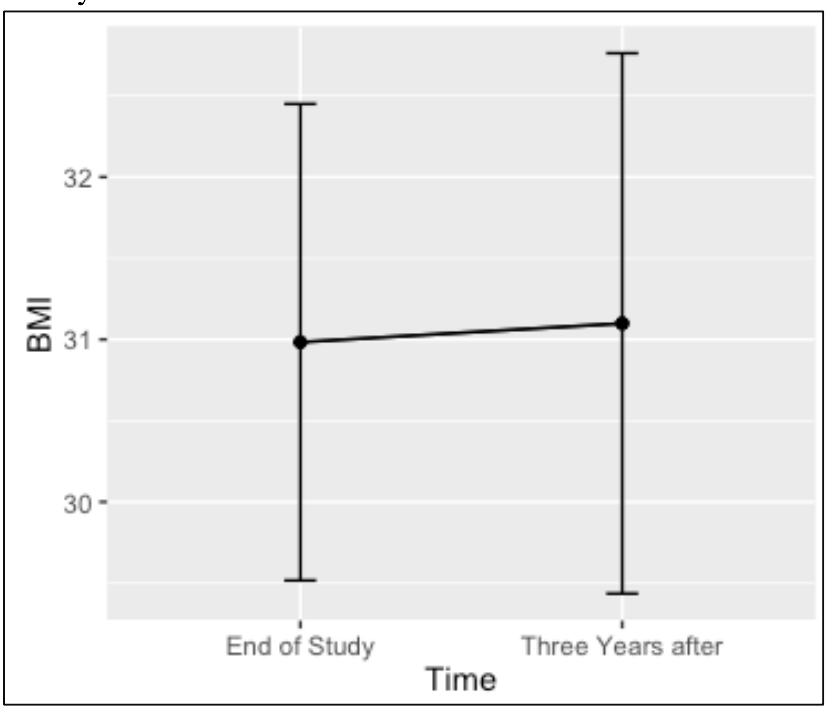
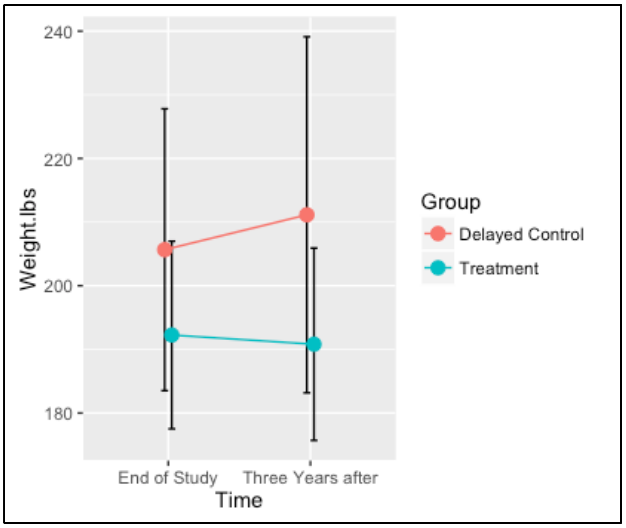
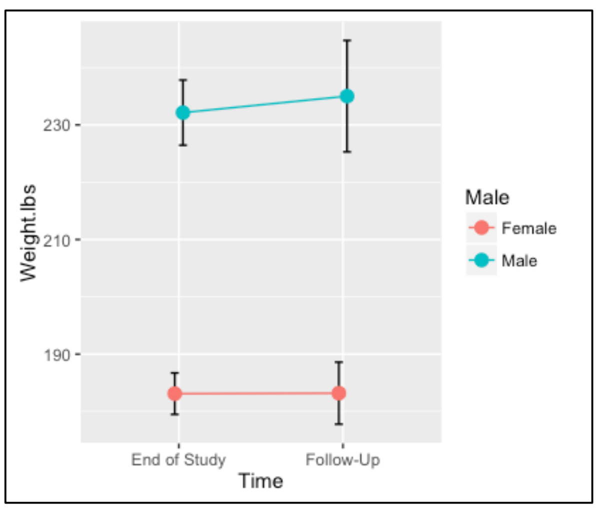


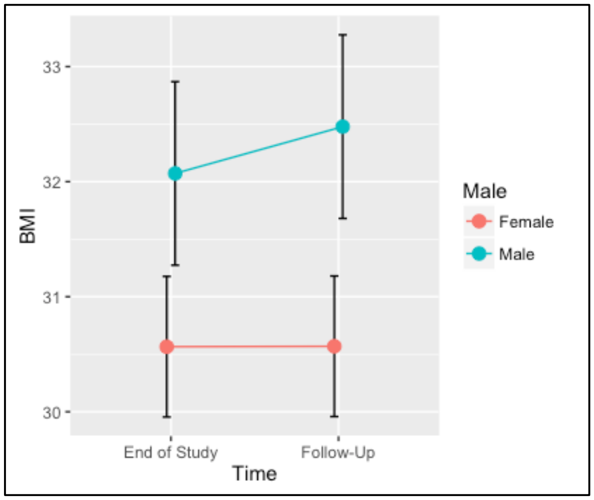
Figure 4.7. CTM weight loss participants weight change between the end of the study and 30 months' after



Unlike in Pacanowski's study, we did not find a significant gender by time interaction (figure 4.8). Analysis of variance testing [mean weight in lbs = Time*Male) of this interaction is significant to the *p*= <0.001 level for weight, but not BMI (*p*=0.166). This is likely due to the males having higher overall weights than females (*p* = <0.001).

Figure 4.8. Difference in weight (lbs) and BMI between men and women in the CTM at follow-up





Maintenance Group

Average self-reported weight at follow-up for the maintenance group was 146.62 ± 22.39 lbs, with a BMI of 24.37 ±1.71. Overall weight change during the study was -2.85 ±5.58 % of starting body weight. Between the end of the study and follow-up, average weight change was 3.83% ± 6.33 (see figure 4.9). Figure 4.10 shows the distribution of individual differences by ID between the end of the study and follow up. Analysis of variance was used to assess if there were any statistical differences in weight and BMI between the end and follow up (*p*=0.637 for weight and *p*=0.344 for BMI). This non-significance indicates weight maintenance; we cannot conclude that there is any difference in body weight or BMI between the end of the study and the follow-up period.

Figure 4.9**.** Participants in the maintenance group change between the end of the study and 30 months later

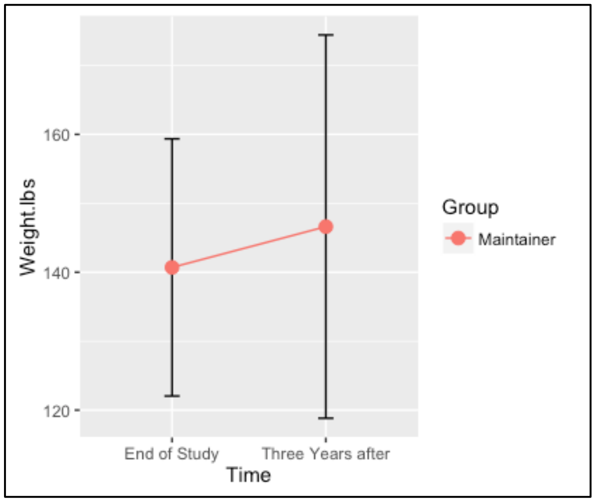
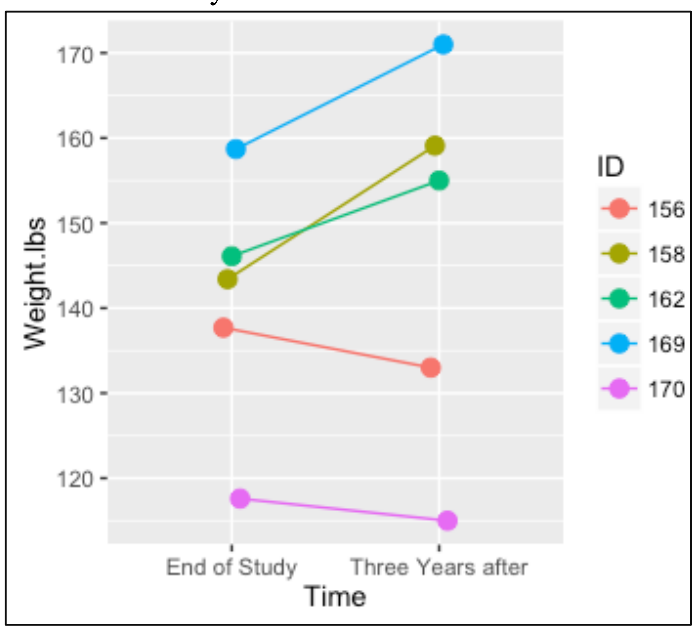


Figure 4.10**.** Participants in the maintenance group change between the end of the study and 30 months later by ID



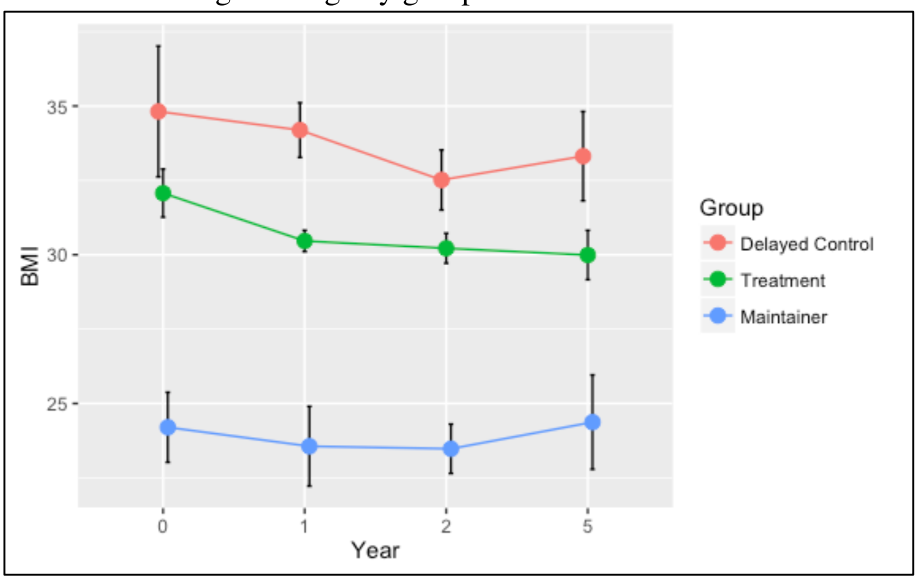
Overall Weight Change

Regardless of group assignment or gender, participants were successfully able to maintain their weight in the thirty months that passed since the end of the intervention. On average, subjects had a mean weight change of 0.87% ± 7.76 between the end of the study and follow-up. There were no differences in the slope of weight change between gender or the three cohorts.

Mixed Models

Using only ANOVA to analyze these data has limitations, particularly the inability to control for covariates of gender, group, age, or baseline BMI. We chose a mixed model to analyze the two time points because this could easily be expanded the model to include more than two time points—for example, we could easily add baseline data to the model to assess differences between or within time-points and groups. Figure 4.11 shows the entire sample, including baseline, year 1, year 2, and follow-up results by group.

Figure 4.11. Overall weight change by group over time



Our mixed model [BMI = Time + Group + Group*Time + age + Male + baseline BMI], where individuals are fixed through time) results indicate no effect of group assignment, time, age, or gender on BMI at follow up (see appendix 3.4 for coefficients and full model descriptions). We were only interested in the difference between timepoint 2 and 5 (as times 0-2 have been analyzed by Pacanowski), so performed a lsmeans analysis of our model and found no differences between this and our ANOVA (see appendix 4.4).

Discussion

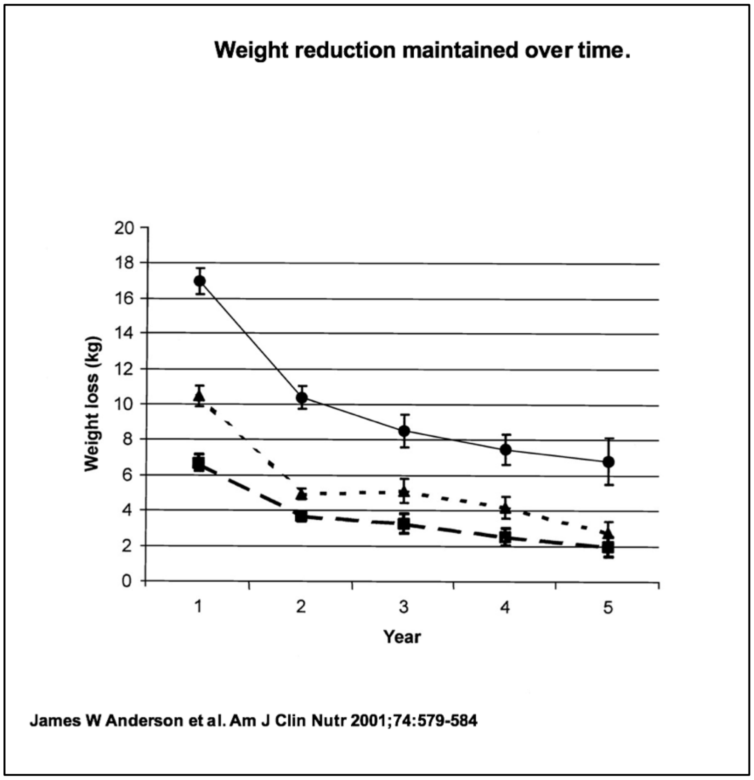
The major finding of this study is all groups that used the CTM to lose weight, maintained that weight loss three years after completing the study. In addition, those participants who used the CTM only to maintain their weight successfully maintained that weight loss through the same period. Mean weight loss after self-weighing treatment was 2.7 ± 5.9 percent of body weight in the first year intervention group, and 1.9 ± 5.4 percent lost in the delayed control group in the second year. The maintenance group lost an average of -2 ± 10.7 lbs over the 2-year intervention period. While the original sample was divided into 2 studies (weight loss and maintenance), we analyzed their anthropometric follow-up values together as our question was whether frequent self-weighing with visual feedback was enough to produce weight maintenance, both with or without weight loss. The amount of weight change between the studies end to 30 months later was not significantly different from zero, with a mean of 0.46% ±7.92% change in body weight. Using a threshold of ±3% of body weight to define weight maintenance, participants were able to maintain the weight they lost during the CTM intervention.

Comparison with published studies

Our statistical analysis all show that weight between the end of the study and the follow-up was not different from zero, meaning weight did not change between these two time points. The public health importance of these results rests on the assumption that these individuals would have slowly regained their lost weight over time. Since all of the individuals in our follow-up sample had been given the intervention, we are denied a comparable group of individuals to compare the significance of this number -- we cannot know what the weight change *would have been* over 3 years without the intervention.

Since no daily weighing studies have reported follow-up results up to 30 months out[66], we compare these results to other studies that followed individuals after losing weight from weight loss intervention. In order to quantify the rate of weight regain after diet, Anderson et al. performed a meta-analysis of US adults after completing a structured weight loss program[137]. Figure 4.12, taken from their publication, presents total weight regain as a function of time. Initial weight losses of ~10kg were maintained at one year; however, after 4-5 years overall weight increases as individuals, unable to maintain a reduced calorie diet, regain much of the weight they had lost.

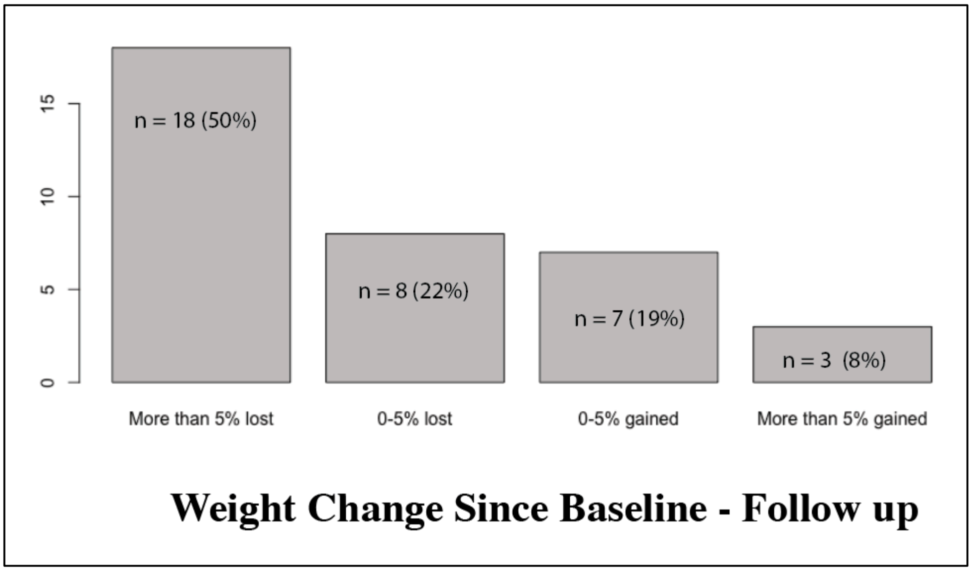
Figure 4.12. Weight reduction over time in 29 studies. (▲) = all subjects. (●) = subjects consuming very-low-energy diets. (■) = subjects consuming hypoenergetic diets. Graph from Anderson et al.[138]



If we place the participants who used the CTM intervention to lose weight on the above timeline, they would have regained between 2.5 – 4.5kg by the time we followed-up with them.

Other studies have shown similar weight rebounds – according to the AHA/ACC/TOS Guidelines for the Management of Overweight and Obesity, less than 35% of adults who participate in intensive, comprehensive lifestyle interventions for weight loss are able to maintain a loss of *at least* 5% of starting body weight after 2 years[11]. However, overall the CTM weight loss cohort was -5.3% ± 10.76% lower at follow up than baseline, exceeding this figure. In fact, 50% (n=18) maintained a weight loss of over 5% of their starting body weight. If using the ±3% of starting body weight as a threshold for weight maintenance, 20 individuals (56%) had a net loss, 12 (33%) maintained their weight, and only four individuals (10%) gained weight over the five-year period (see Figure 4.13).

Figure 4.13. Weight change since start of the intervention-follow-up in weight loss participants (n=36)



Those in the weight maintenance cohort fared similarly well, although we face the same difficulties with *compared to* what. Of the five women in the maintenance group who followed up, one lost weight, two maintained, and two gained weight, with a total mean change of 0.81% ± 7.47% starting body weight. Weight change comparisons of this group is not straightforward. First, the five women in the maintenance cohort were 48, 50, 53, 62 and 67 years old. According to the 2009, 2011, and 2013 NHANES data, women between the ages of 48 and 67 have a mean BMI of 30.7, 30.5, and 30.6. Because rates of weight change over time are dependent on BMI category and starting weight[4], we cannot compare this to our sample, who had an overall BMI of 24.37 at follow up.

The closest to finding a comparison group for our maintainers are individuals followed over time, matched to BMI, age, and gender. We identified three studies[2,16,139] that tracked either cross-sectional or longitudinal weight change of women in these age groups over a similar time period. Mozaffarian et al.[16] examined prospective investigations involving three separate cohorts of US women and men, of which one (Nurses Health Study) matched our criteria for sex and age. Women gained 2.33 lb on average over four years in this cohort. Stenholm and collegues[2] performed a cross-sectional analysis to examine longitudinal differences of rate of weight change between BMI categories from 2004-2010, and found the average increase for women ages 40-69 was 0.08kg/m^2 per year. Rates of BMI increase were greatest among those who were initially normal weight or overweight.

Table 4.4. Rates of weight gain per year of normal weight individuals, matched by age to the weight maintenance cohort.

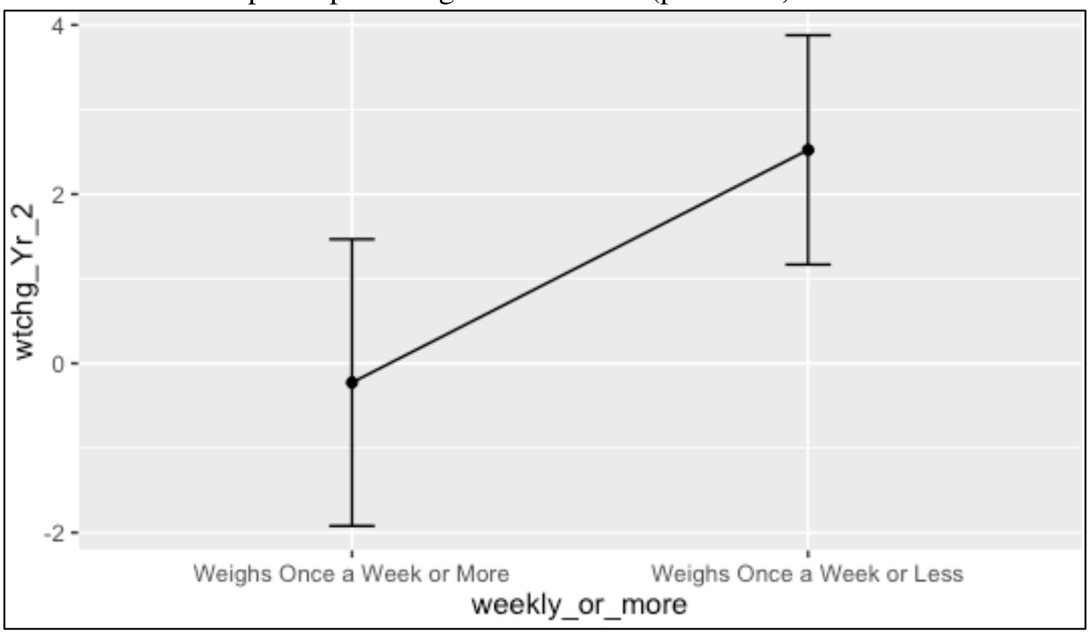
Author	Year	N	Age	Time period	Weight change among normal weight adults	BMI change among normal weight adults	Mean change per year
Present Sample *(maintenance group ONLY)*	2010-2015	10	48-67	5 years	0.8lbs ± 5.13	0.17 [-1.5 to 1.69]	0.264 lbs / 0.06 BMI
Mozaffarian[28]	2011	120,877	52.2±7.2	4 years	2.33 lb (CI −5.5 to 10.7)		0.58 lbs
Stenholm[26]	2004-2010	8891	40-69	6 years	—	0.5 [CL 0.37 to 0.63]	0.08 BMI

Compared to the weight maintenance group in our study, it is unclear what effect the CTM had compared to *what might have happened*. These results may be due to the small number of follow-up participants.

Frequency of weighing

We are not able to definitively identify what specific aspect of the CTM had the largest effect on weight 30 months after the studies end. Only 22% of those who followed-up reported that they continued to weigh themselves daily, and only two individuals continued to use the website regularly. While most continued to weigh themselves once a week or more (31; over 75% of those surveyed), the primary aim of the original intervention was to see if frequent weighing with feedback affected weight. So while the majority of individuals using this program maintained their weight and weight loss 30 months after the interventions end, very few continued to weigh themselves every day. Those who continue to weigh themselves once a week or more maintained a weight slightly below their weight at the end of the study (see figure 4.14. This warrants further investigation, as it could possibly be that weekly weighing is as effective as other intervals for weight loss -- other studies on frequent weighing have shown improvements in weight loss with weekly weighing[140–143].

Figure 4.14. Weight change from the end of the study to follow up as a function of how often the participant weighs themselves. (p = 0.214).



Nonetheless, the majority of respondents continue to weigh themselves several times a week or more (58%), and most reported finding the CTM program helpful (68%). Most would be willing to recommend the program to a friend (77%). This has important implications for long-term acceptability of the program. Between the end of this study and the follow-up, multiple computer applications were introduced to the market that allowed recording and uploading weight data automatic and seamless. Many reported that they continued to weigh themselves using automated scales which uploaded their data for them and they were able to visualize it without having to manually record their weight into an online database.

Why those engaged in the CTM maintained their weight

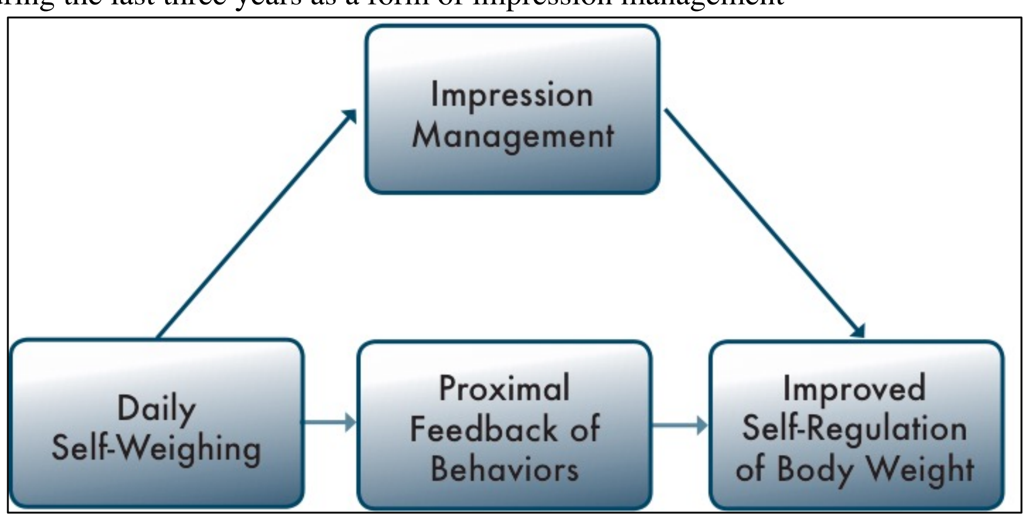
Five years after the start of the CTM intervention, and three years after the end, all participants, regardless of which group, maintained weight at the same level as the study's end. All those in the trial maintained the weight they lost. The general idea of the CTM is not to provide individuals with specific instructions, diets, or manuals on how to lose weight. The CTM gives individuals autonomy to choose which method works right for them. They are free to change their diet one week, and increase physical activity the next. They maintain their autonomy. The CTM merely encourages self-regulation through proximal feedback of behaviors, which gives an individual interested in weight control better, more precise information about how their behaviors are affecting their weight over the long-term. In the same way a control group might maintain or lose weight through being accountable to a research therapist, so does the person using the CTM become accountable to themselves. As one individual in the delayed control group put it, *"I state I am in full control of my weight because, I know when and why it is going up and the same for when it is going down. Weighing in daily does put it in front of you daily so you are less likely to let it get too far out of control."*

Limitations

This study has a number of limitations. First, participants who responded to our call for follow-up weighed themselves more often during the study period and lost more weight during the study period, which may have led to underreporting of some measurements, although we have no evidence of this. In order to maximize follow-up responses, we did not ask the participants to come in to be weighed.

In returning to the conceptual framework from Chapter 1, however, another constraint are the differences between those who responded to the follow-up survey request. Those who responded lost significantly more weight during the trial than those who did not. There are many possibilities for this difference. It is possible that those who responded are engaging in impression management -- matching on demographics and baselines isn't capturing key differences between people who agree to follow up and don't. Figure 4.15 revisits this framework to explore this possibility. Even in terms of the original study, it's hard to part out to what extent the self-weighing, visual feedback, or titration goals that led to success of those who lost weight; in the follow-up period, it is clear visually that those who weigh weekly or more maintained their weight three years after the end of the study, but this effect was not significant.

Figure 4.15. Individuals who responded to the follow-up survey may be more likely to report they daily self-weigh and that they have maintained their weight loss during the last three years as a form of impression management



Conclusion

Data from the 5-year follow-up shows that participants were able to successfully maintain their weight thirty months after the end of the study period. This analyses suggest that for some individuals, this frequent self-weighing appears to be an effective self-guided strategy for long term weight loss maintenance and age-related weight gain prevention. The self-weighing CTM program used here appears feasible and acceptable to its users. Future research and weight maintenance programs may consider the addition of this strategy for long term weight re-gain prevention.

CHAPTER 5

FAILURE OF SELF-WEIGHING TO SUSTAIN WEIGHT LOSS

Introduction

Young American adults gain approximately one pound per year[4,6]. Between the ages of 20 and 30, prevalence of obesity doubles[3,144], and rapid weight gain in those aged 18-35 is associated with greater risk for obesity-related conditions later in life[145,146]. Data from more than 10,000 young adults (aged 14 to 22 in 1979) followed for the National Longitudinal Survey of Youth 1979 demonstrate that more than 98% of men and 92% of women remain on upward sloping weight trajectories[4]. Those who experienced early and rapid weight gain were most likely to continue on this steep trajectory and end up on a higher BMI category by middle age as well as suffer from weight-related complications such as hypertension and diabetes later in life.

Developing effective weight gain prevention strategies for young adults is particularly vital – reducing weight gain during this time would potentially decrease the overall proportion of adults who are obese, consistent with U.S. Healthy People 2020 national objectives[15]. There is ample evidence that the transition to college is a time of rapid weight gain[147–149], but weight gain prevention efforts aimed at young adults have had limited success[150,151]. While positive results are often observed initially, few interventions continue for more than two years, and long-term effects between the treatment and control groups are rarely significant[152].

Early experimental data by Levitsky et al. provides evidence that frequent weighing with visual feedback is protective against weight gain for up to twelve weeks in two separate cohorts of incoming female freshman during the fall of 2002 and 2003

(≤0.1kg change in treatment group and 2-3kg weight gain in controls)[108]. Yet since the publication of this seminal work, numerous studies have been published with mixed results. Three studies in particular found conflicting results between frequent self-weighing and weight[143,153,154], but may have been underpowered or not long enough to detect differences in weight.

To further explore the effects of self-weighing on weight gain among young adults, Bertz, Pacanowski, and Levitsky[95] extended Levitsky et al.'s early intervention to three years of college. Preliminary published findings[95] show that, as before, frequent self-weighing is effective in preventing weight gain for the first year of college (-0.5 ± 3.7kg for intervention and 1.1 ± 4.4kg for control, p=0.035). The present paper is a full analysis of three years of data from the Bertz, Pacanowski, and Levitsky study, and aims to test the hypothesis that self-weighing prevents weight gain in young adults by (a) using males and females, (b) increasing the time span to three years, (c) testing the effectiveness of Wi-Fi scales with visual feedback to prevent age-related weight gain.

Research Methods and Procedures

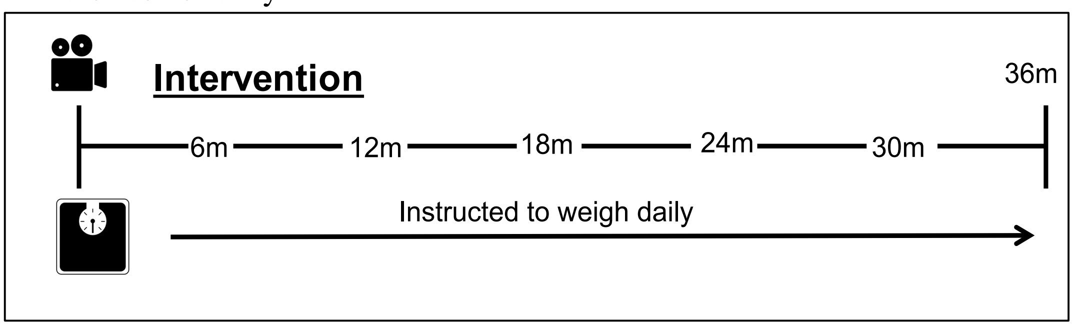
In December 2012, 167 college freshman were randomized to either an experimental (n=78) or control (n=81) condition. Eligibility criteria included being a first year college student age 18-25; BMI ≥ 18.5, and no history of disordered eating (defined as having a score >45 on the Drive for Objective Thinness Questionnaire[155].

After randomization, all attended a study orientation, where they viewed a short 22-minute lecture in which the principal investigator, David Levitsky, explained that the objective of the study was to evaluate body weight change over the college experience. They were provided with various evidence-based techniques on how to prevent weight gain during college, and what to do if they found themselves gaining unwanted weight[156]. All participants were then given a digital Wi-Fi scale (Wi-Fi body scale, Withings, Paris, France), and instructed on how to set-up and connect the scale.

Intervention Condition

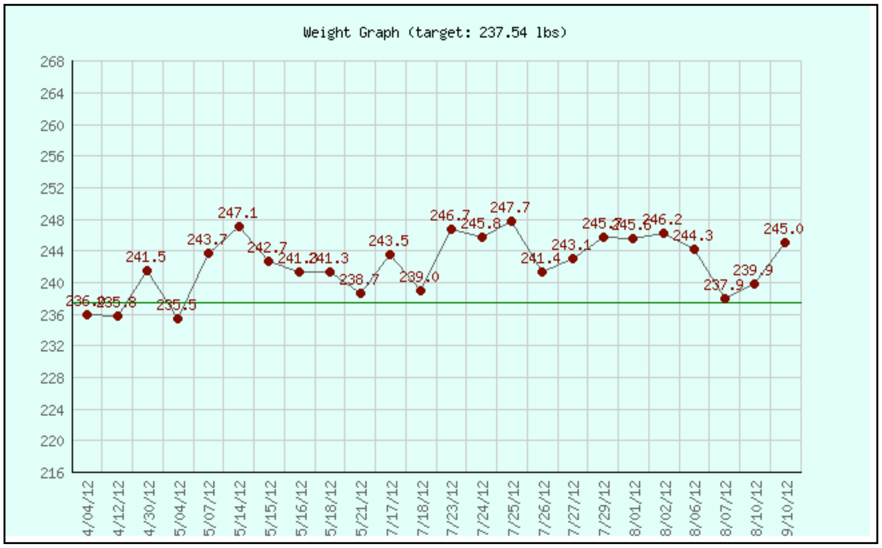
Those randomized to the intervention condition (n=78) were asked to weigh themselves daily for the duration of their time in college (see figure 5.1).

Figure 5.1. Those in the intervention group were given a scale and asked to weigh themselves daily



Each time they weighed themselves, an e-mailed graph of their weight was sent to them via an automated system, which included a “target weight” reference line (see figure 5.2). This “target weight” was based on the average of the subject’s first eight weights. Participants were asked to try not to gain weight above this line. This visual feedback with a reference line is known as the Caloric Titration Method (CTM; see Chapter 4)[78]. Throughout this paper we refer to the experimental group as CTM; control group as C.

Figure 5.2. An example of the email feedback intervention participants received.

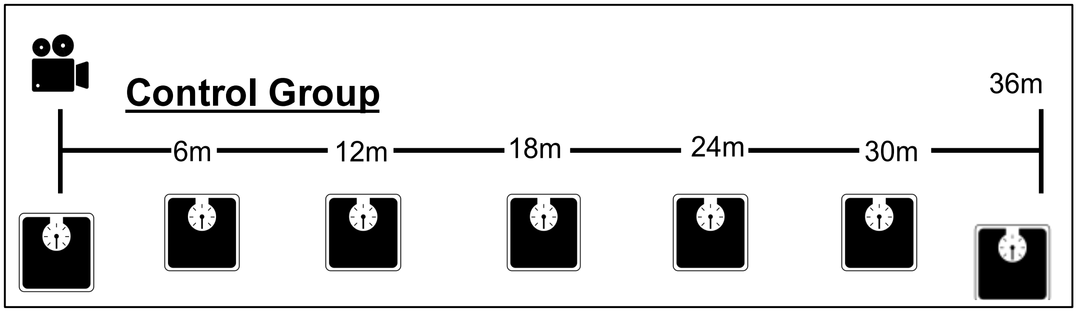


Those in the CTM group were asked to place their scale close to their bed and weigh themselves first thing in the morning. They were not asked to take their scales with them while traveling unless they were going to be gone for a prolonged period of time (summer vacation, study abroad, etc.).

Control Condition

Those in the control group (C) were also given scales, and were told to weigh themselves as they would normally, and were otherwise given no instructions (see figure 5.3). They were asked to use the study scale to weigh themselves on 3 days during a specified time period at baseline, 6 months, 12 months, 18 months, 24 months, 30 months, and 40 months. For these measurements, they were contacted via e-mail at the designated timepoint and asked to provide measurements by stepping on their Wi-Fi scale.

Figure 5.3. Those in the control group were given a scale and asked to only weigh themselves at certain times



Administration of Intervention

The Wi-Fi enabled scale provided to the study participants (Withings Wi-Fi body scale, Withings, Paris, France) automatically records and uploads subjects' weight and BMI to a central database maintained by Withings. In order to maintain control of the data collected by the scale, and to ensure that the participants did not have access to the Withings visual feedback or any other possible 'contaminants' to the study, the data collection and feedback dissemination procedures were as follows (see appendix 5.1):

1. Every subject was issued a Withings scale.
2. A subject's weights are only recorded by the Withings scale and cannot be set or altered manually by the subject.
3. A selected group of subjects (CTM) ***were*** able to view their weight records, weight graph, and target weight.
4. A selected group of subjects (C) ***were not*** be able to view their weight records, weight graph, or target weight.
5. The target (maintenance) weight for each subject is the average of the subject's first eight weights. This is a calculated value and could *not* be altered by the subject.

Study administrators created a gmail account (email address and password) for every subject in the study. Subjects were given 48 hours from the time they received their scale to create a Withings account, at which time the study administrator logged into each participant account and changed the password, thus disabling the subject's access to the Withings account. The correct account configurations were each verified by a study administrator.

Data from each subject's Withings account was shared to a secure database that only study administrators had access to. This allowed the study administrators control over which group saw what information. For example, the CTM group had complete access to their weight records, weight graph, and target weight via secure study web site, whereas the C group did not have such access. To streamline any password or technical issues the students may have and prevent the need to reaching out to Withings for help, those in the CTM group were issued a unique URL for viewing their weight records and could only view their weight through this site.

An automated email monitoring service was developed that automatically notified the CTM subjects if they have not recorded their weight for more than three days. All procedures were tested and validated prior to study deployment.

Data Extraction

Taken together, there were 6 time periods in which data was collected (total of 40 months). However, due to lag time in the first period, the duration of time within each period was not evenly spaced. Between the baseline measurement and the first time the C's were asked to weigh themselves, 300 days had passed. From that time point to the next, there were 161 days, then 177, 181, 185, and 189 days (see Table 1).

Table 5.1. Time between data collection points, from which mean weight data was collected

Time period	Beginning date	End date	Days within this time period
10m (1)	12/2/12	9/28/13	300
15m (2)	9/29/13	3/9/14	161
21m (3)	3/10/14	9/3/14	177
27m (4)	9/4/14	3/4/15	181
33m (5)	3/5/15	9/6/15	185
39m (6)	9/7/15	3/14/16	189

Each C was asked to provide 3 weights during a one-week period at a specified time in each time point. To obtain the correct data, we extracted the last three weights from each time period, along with the number of times the individual weighed themselves total during that time period. Both total times weighed as well as total days weighed were used. Some individual scales recorded very high numbers of times weighed. In order to obtain accurate frequency of weighing per week counts, we decided to analyze <u>both</u> total times a weight was recorded <u>and</u> total days weights were recorded.

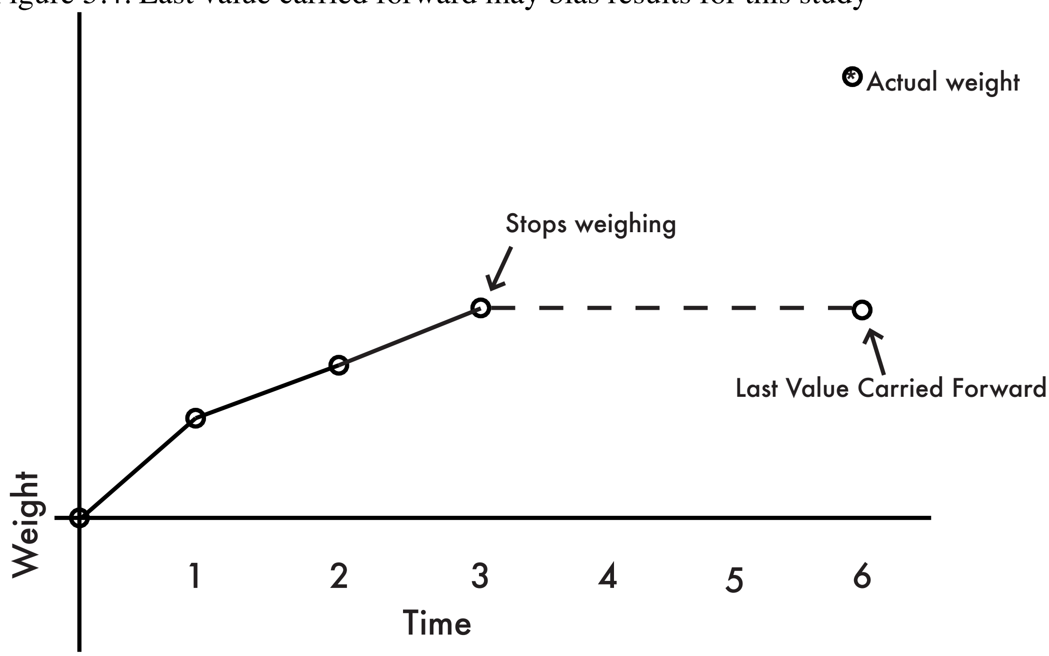
Statistical Analysis

For the study population, sample size was calculated based on a predicted difference in body weight change between groups of 0.0 ± 1.4kg for CTM vs. 0.7 ± 1.4kg for control per year corresponding to expected weight gain from previous studies[147,157–161]. Assuming a dropout rate of 25%, 79 participants per group were necessary in order to detect a significant difference between the two groups with 80% power.

First year statistical analysis and results have been reported elsewhere[109]. Briefly, a Bonferroni adjusted repeated measures linear mixed model was used, adjusting for baseline weight, BMI, and gender. Missing data was handled using restricted maximum likelihood estimations, with data analyzed using baseline value carried forward. Student's *t-tests* were used to compare baseline carried forward values to data that included only participants providing baseline, 6-month, and/or 12-month data, and no significant differences were found.

For 12-40 months, characteristics of participants were evaluated in two ways: 1) differences between intervention and control groups and 2) differences between those who continued weighing and those who stopped at any time point. Because our primary outcome was the absence of body weight change, intention to treat analysis was not used -- any value carried forward for 40 months would influence the final trajectory of that individual (see figure 4). For example, if an individual stopped weighing themselves at 18 months due to weight increase, a last value carried forward analysis would show them as maintaining weight, which would be incorrect. Since we do not know what happened to individuals who stopped weighing themselves, we instead completed a subset analysis of those in each group who dropped out and compared this to those who remained active.

Figure 5.4. Last value carried forward may bias results for this study



For the 12-40 month sample analysis, we included any individual who had weight data during the time point being assessed. A Bonferroni adjusted repeated measures linear mixed model was used, adjusting for baseline weight, BMI, time, gender, and how often an individual weighed themselves per week, accounting for correlation between repeated measures within subjects. These data were analyzed to account for measures between each timepoint as well as between beginning and end. Change in outcome variables was calculated as the value obtained from the Wi-Fi scale at time period 2 minus time period 1. Statistical significance was indicated by p-values <0.05. Analysis were performed in R 3.2.5[112] using multiple packages, notably the lme4 package[135] lmer () and lsmeans[136] functions for linear mixed model regression. Data cleaning and restructuring was done using SPSS (version 23, IBM, Chicago, IL).

Results

Study Participants

A total of 159 individuals were eligible and randomized to the C (n=78) or CTM (n=81) groups (see appendix 5.2 for timepoint breakdown). Of these, 103 individuals (64% of original sample) completed the study to the end; i.e. they continued to weigh themselves as instructed (see Table 5.1 for end characteristics). There were no differences in gender between groups at the end of the study.

Table 5.1. End characteristics of study participants

Variable	Control Group n = 57	CTM Group n = 46	P value
Age (years)	22 ± 0.53	22 ± 0.49	0.126
Female, n (%)	39 (50)	47 (58)	0.162
Body mass index (baseline)	23 ± 2.91	23 ± 3.27	0.643
Body mass index (end)	23 ± 3.68	24 ± 4.12	0.447
Body weight (baseline), lbs	146.89 ± 27.49	1490.05 ± 27.53	0.621
Body weight (end)	151 ± 32	155 ± 32.77	0.516
Body mass index categories (end)			0.358
18.5-24.9 kg/m2, n (%)	36 (63.2)	26 (56.5)	
25-29.9 kg/m2, n (%)	14 (24.6)	11 (23.9)	
≥30 kg/m2, n (%)	2 (3.5)	6 (13.0)	
Frequency of weighing per week (on average since baseline)	1.28 ± 3.24	4.21 ± 1.55	<0.001

Of those who stopped weighing themselves, 35 (62.5%) were from the CTM group ($p = 0.047$) (see table 5.1). Twenty-nine females (51.8%) stopped weighing themselves, which was not significantly different from males ($p = 0.79$). Baseline BMI was not different between those who stopped and those who continued, nor was body weight or BMI category.

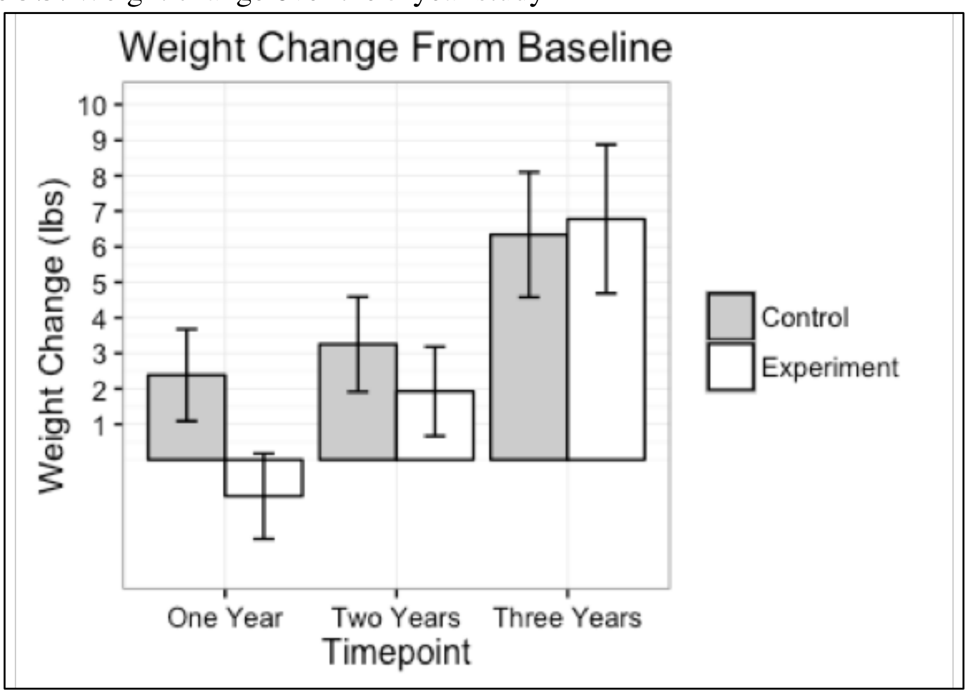
Table 5.2. Characteristics of those who continued weighing themselves

Variable	Continued n = 103	Stopped n = 56	P value
CTM, n (%)	46 (44.7)	35 (62.5)	0.047**
Female, n (%)	57 (55.3)	29 (51.8)	0.793
Body mass index (baseline)	23 ± 3.07	23 ± 3..12	0.475
Body weight (baseline), lbs	147 ± 27.33	150 ± 27.81	0.549
Body mass index categories (end)			0.461
18.5-24.9 kg/m2, n (%)	76 (73.8)	38 (80.9)	
25-29.9 kg/m2, n (%)	20 (19.4)	7 (14.9)	
≥30 kg/m2, n (%)	3 (2.9)	2 (4.3)	

Effect of the CTM self-weighing intervention

Over the course of the three-year study, the CTM group gained 6.19 ±12.95 pounds, whereas the C group gained 4.8 ±13.3 pounds (see figure 5.5). Average BMI change was 0.95±1.96 for CTM, 0.73 ± 2 for C.

Figure 5.5. Weight change over the 3-year study



Of those in the CTM group, 8 (17.4%) lost weight, compared to 11 (19.3%) in the C group. More in the C group maintained their weight, and more in the CTM group gained weight, although there were no statistically significant differences between weight change categories between groups (see table 3) and gender (table 4).

Table 5.3. Weight change categories between groups

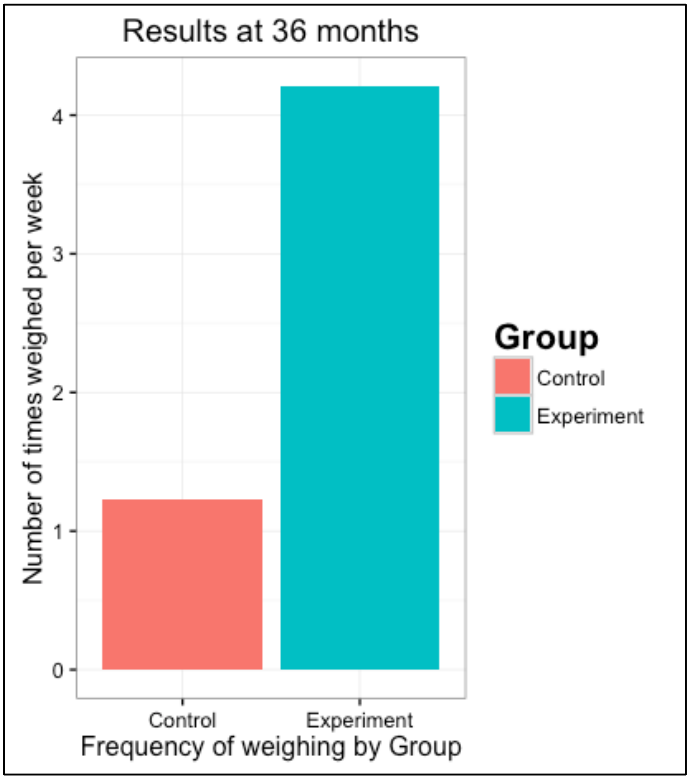
Variable	Control Group n = 57	CTM Group n = 46	P value
Weight change category			0.608
Lost	11 (19.3)	8 (17.4)	
Maintained	23 (40.4)	15 (32.6)	
Gained	23 (40.4)	23 (50.0)	

Table 5.4. Weight change categories between gender

Variable	Male n = 73	Female n = 86	P value
Weight change category			0.845
Lost	8 (17.4)	11 (19.3)	
Maintained	16 (34.8)	22 (38.6)	
Gained	22 (47.8)	24 (42.1)	

The median frequency of weighing for those who continued weighing in the CTM group throughout the study was 4.21 ± 3.24 times per week. The C group was 1.28 ± 1.55 times per week, with a significant difference in frequency of weighing between groups (p <0.001) (see figure 5.5).

Figure 5.5. Frequency of weighing per week throughout the study by group



In order to gauge the effect of frequency of weighing on weight outcome by group, we ran a linear regression model [final weight = starting weight + group + gender + frequency of weighing total per week] and found that weighing frequency had no effect on weight change throughout the study's duration (p=0.64). (see appendix 5.3 for coefficients and models). However, this was only taking in the first and last values into account; it excluded any and all participants who did not complete their final weight.

We ran an analysis of variance test using the model [mean weight ~ gender + beginning weight + group*time + frequency of weighing] and found that gender ($p < 0.001$), beginning weight ($p < 0.001$), time ($p > 0.001$), and frequency of weighing ($p = 0.047$) had a significant effect on mean weight (see appendix 5.3 for coefficients). Since the ANOVA does not tell us precisely *which* mean of *which* variable affects weight, we used a mixed linear model with Bonferonni corrections as described above. For this model, we used [mean weight ~ gender+ beginning weight + group*time + frequency of weighing], using subject as a random effect. We found no evidence of an effect of frequency of weighing on weight change in any time period. Figure 5.6 represents the change in weight throughout the study as a function of how often an individual weighed themselves per week. In both groups, there is a slight trend of gaining less weight with more frequent weighing, but this trend is neither statistically nor clinically significant, as the change in weighing frequency is minimal.

Figure 5.6. Percent weight change as a function of weighing frequency for the duration of the study by randomized group

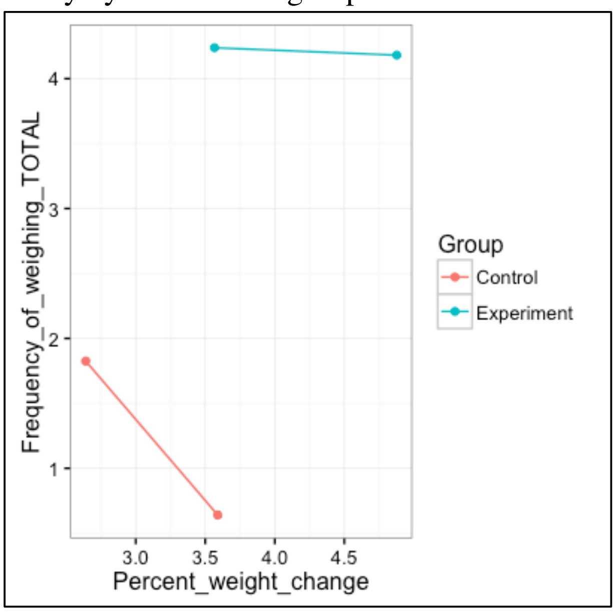
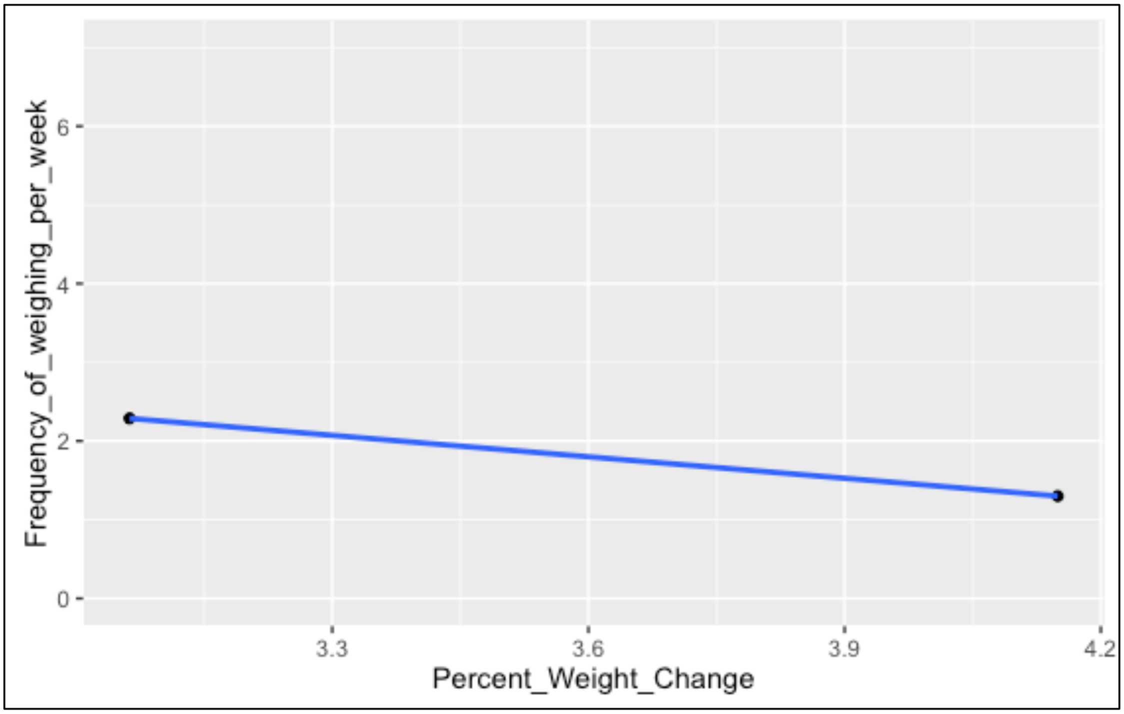
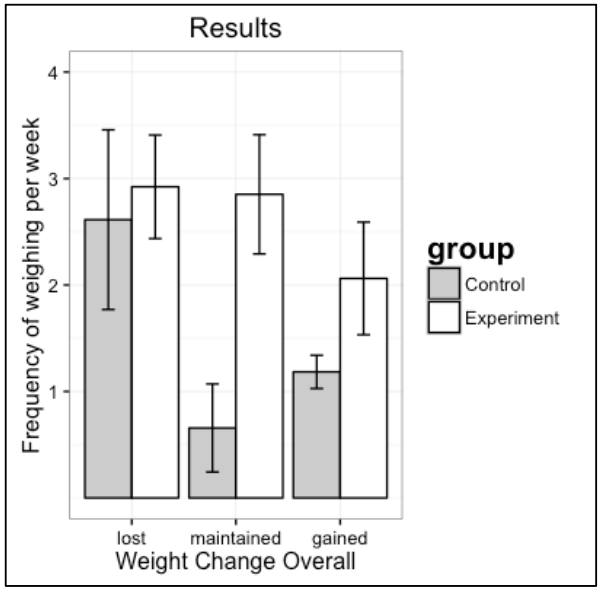


Figure 5.7. Percent weight change as a function of weighing frequency for the duration of the study



While there appears to be an inverse relationship between how often an individual weighs themselves and percent weight loss, this effect was not significant ($p = 0.314$). There was no significant difference between how often a person weighed themselves and whether they lost, gained, or maintained their weight (see figure 5.7). Nineteen individuals lost weight, 38 maintained, and 46 gained. Those who gained weight weighed themselves 2.10 ± 2.07 times per week, those who maintained weighed themselves 3.05 ± 4.15, and those who gained weight weighed themselves 2.42 ± 2.03 times per week ($p = 0.465$). A linear regression using the model [Frequency of weighing per week = gender + beginning weight + weight change category*group] revealed no significant differences between weight change category and frequency of weighing, although it did reveal that those in the experimental group weighed themselves more often ($p = 0.004$).

Figure 5.8. Frequency of weighing per week and weight change overall



Discussion

This study demonstrates, in a randomized controlled trial spanning three years, that frequent self-weighing with electronic feedback is associated with a significant reduction of age-related weight gain for the first year of college, but this is not maintained throughout the duration of the student's time in school. Frequency of weighing after almost four years has no significant effect on whether a student gains, maintains, or loses weight. The most significant predictor of weight gain is starting weight.

Frequency of weighing and weight

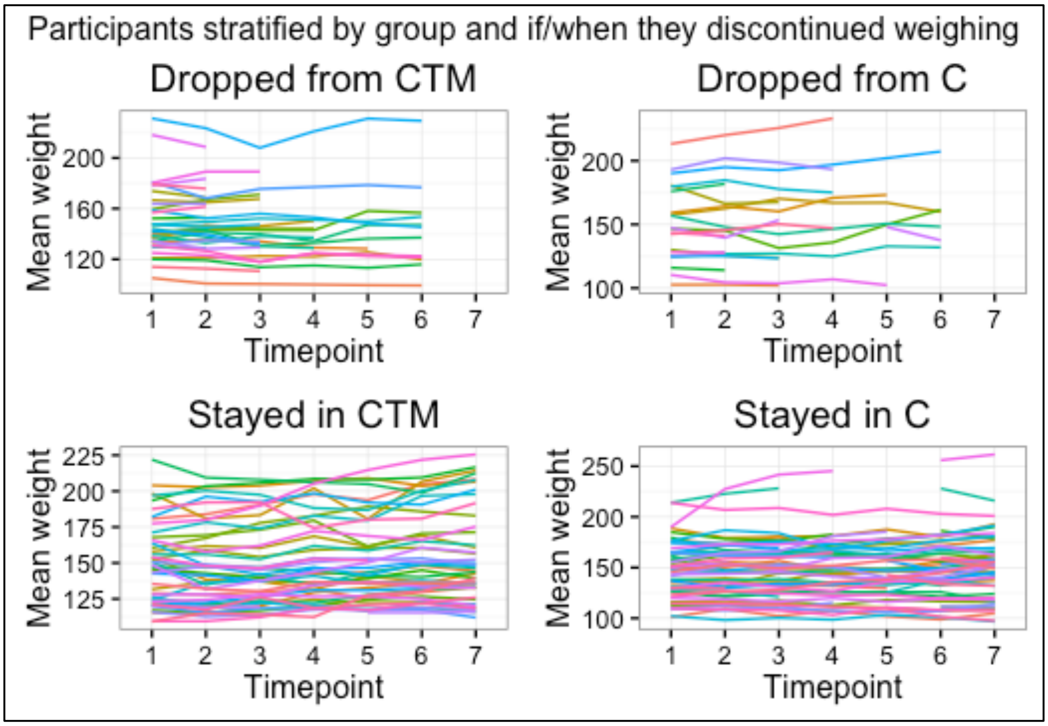
Overall, there was an observed interaction between weight change and time; the students involved in this study gained weight over time. There were also observed differences between how often individuals in each group weighed themselves; of those who remained active in their participation in the study through their senior year, those in the CTM group consistently weighed themselves more often than those in the C group. However, while there was a visual *trend* of an inverse relationship between weight and weighing frequency, this was not statistically significant after the first year, and we cannot conclude with the current study that frequency of weighing is related to weight maintenance in college students over the full three years, regardless of group assignment. This remained the case whether frequency of weighing was tested as a categorical variable of more than or less than once a week. While figure 5.8 appears to have significant differences between those who maintained weight and frequency of weighing, statistically these showed no effect.

It should be noted that those in the C group weighed themselves once a week. If habituation does in fact play a role in how effective self-weighing is over the long-term (as discussed in the conceptual framework in Chapter 1), it could be hypothesized that weighing oneself everyday may be a likelier way to cause habituation than weighing oneself once or twice a week.

Attrition

Since we do not have data on those who stopped weighing themselves, we cannot know for certain why those in the C group were more likely to continue weighing than those in the CTM. We developed a simple visual model comparing weight over time among those who dropped out, to see if visual comparisons could be made (figure 5.9). While it is not clear from the visual comparison, there still may be a tendency for impression management. There are a few reasons to believe this may have been the case. First, the research assistants in charge of monitoring the data were often the same age and in the same class as some of the participants. The principal investigators in charge of the study were well-known to some of the participants, as teachers or teaching assistants.

Figure 5.9. Those who continued weighing compared to those who did not by group



Other reasons those in the CTM group may have dropped out of the study in a more systematic fashion was that they were emailed a graph every time they weighed themselves. This may have caused email fatigue; unfortunately, it is not known what the participants did with these emails. Daily self-weighing is itself a cost – it may have just been too mild of an annoyance for some to keep the habit. Another possibility is that since those in the CTM group *were* weighing themselves more frequently, they may have habituated to the scale. The effect of weight loss, then gain after the first year hints that the scale may have lost its effect on self-regulation. This may have caused those in the CTM group to drop out at a higher rate, yet this remains unclear.

Counterfactual

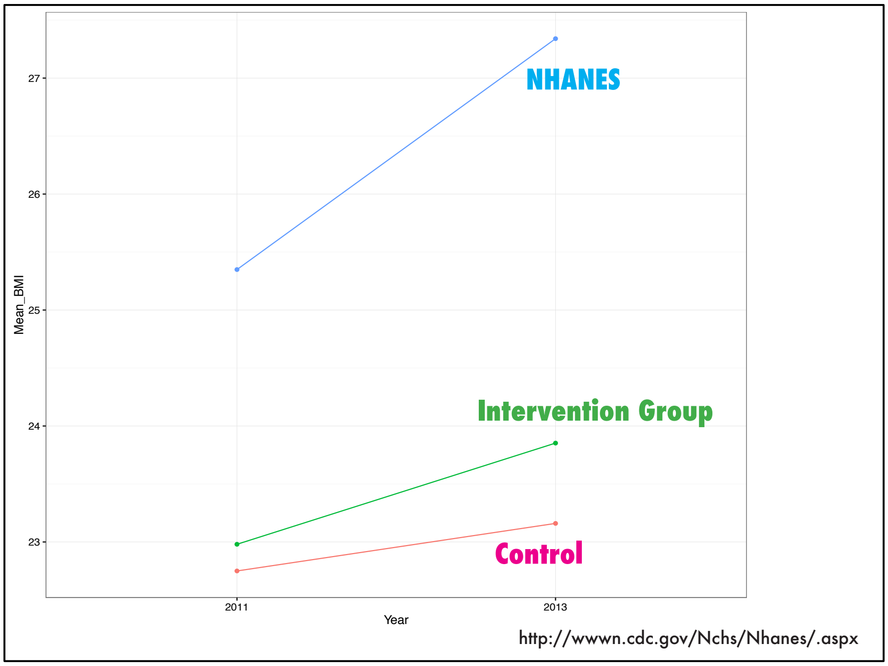
Our analysis showed that overall, the individuals in this study weighed themselves an average of 1.8 ± 3.3 days per week. While those in the CTM group weighed themselves significantly more than those in the C group, those in the C group still weighed themselves an average of ~1.28 days per week. It is possible that weighing once a week is sufficient to reduce the average weight gain of college students. If this were the case it would be important to know how much weight the students would have gained if they did not have a scale available. Racette et al.[160] followed 138 females and 66 males from a private university in St. Louis, Missouri. Females gained 3.74 ± 9.9 lbs from freshman to senior year, while males gained 9.24 ± 14.08 lbs, for a total of 5.51 lbs ± 11.68, a number very close to those in our study (see table 5). Gropper et al.[147] collected data on 131 college students at Auburn University and reported a total gain of 6.7 ±10 lbs. While this number may or may not be significantly different than those in our study, 70% of those followed by Gropper et al. gained weight, compared to 44% in the current study.

Table 5.5. Weight change at two other universities

Study	Setting	Weight in pounds				Total
		Men	Women	Control	CTM	
Current	4-year college	6.99 ± 15.88	4.19 ± 10.37	4.8 ± 13.3	6.1 ± 12.95	**5.44 ± 13.12**
Racette	4 year college in St. Louis, MI	9.24 ± 14.08	3.74 ± 9.9			**5.51 ± 11.68**
Gropper	4-year college, Auburn	12.98 ± 11	3.74 ± 9.68			**6.7 ± 10**

Another comparison that could be made is using weight gain of individuals sampled in the NHANES data, matched for both age and time period of the survey (see figure 5.10). While the slope of those in the NHANES survey is visually steeper, the average American 19-year-old also starts off at a higher BMI. As discussed previously, those with higher BMIs tend to have steeper weight gain trajectories in early adulthood. Moreover, the NHANES data is cross-sectional, while ours is longitudinal making the direct comparison inappropriate

Figure 5.10. Those in the current study compared to NHANES national survey data



Conclusion

Younger generations are likely to accumulate greater exposure to overweight and obesity throughout their lives[3]. The observed trend of developing overweight or obesity at a younger age is particularly concerning as the rate of weight gain does not decrease until middle age. Those who experience early and rapid weight gain are more likely to remain on a steeper trajectory and have a greater risk for obesity-related conditions throughout their lifetime[4]. This study was effective in preventing freshman weight gain for one year. But by the student's senior year, all students, regardless of randomization, showed similar overall means in weight change. Frequency of weighing, while always showing an inverse relationship with weight, failed to show significant effects. This is regardless of whether frequency of weighing was analyzed as a binary (“more than once a week”, “less than once a week”) or continuous variable. Future trials are needed to examine total participant weight change against a matched population.

CHAPTER 6

CONCLUSIONS

This dissertation provides further experimental evidence on the effects of self-weighing on long-term weight control. While none of the studies showed a statistically significant interaction between frequency of self-weighing and weight control, the analysis that are included here each show an effect in the same *direction*. This effect may not be statistically significant, but it appears that there is some relationship.

For example, in the Chapter 3 analysis of WiFi scales, frequency of weighing increased with each ‘level’ of weight change – those who lost weight weighed themselves most often, followed by those who maintained weight. Those who gained weight weighed themselves least frequently of all. In the follow up of those involved in the CTM weight loss study (Chapter 4), this same *signal* was seen; those who weighed themselves once a week or more maintained their weight with almost zero change compared to three years ago. Yet again, these effects were not statistically significant. Perhaps most head-scratching of all was the data in Chapter 5, where freshman who were randomized to a daily weighing intervention maintained their weight for the first year of college compared to those in the control group, an effect that all but disappeared, even appears to have *reversed*, by the time they were seniors. And still a third time, there was a negative slope when frequency of weighing was plotted against weight change; those who weighed themselves more often gained less over time.

Taken each on its own, the studies included in Part II of this dissertation may not be enough to persuade critics that frequent self-weighing is effective for weight gain prevention, Nonetheless, taken together, this research shows that there seems to be indication of frequent weighing's relationship to weight maintenance. Theoretically and conceptually, the linear framework based on social cognitive theory is a logical model of why frequent weighing might work. Chapter 1 describes the causes of age-related weight gain and how theories of self-regulation have informed self-weighing treatments for weight control. The amount of calories responsible for the current weight gain epidemic appear to be negligible; twenty-five extra calories a day could easily be ingested without the individual noticing. Observing individual weight trends over long periods of time allows a person to better visualize the effects of energy balance on their body weight, theoretically making it easier to maintain their weight.

However, the studies in Part II of this dissertation paint a slightly more complex picture. Self-weighing was fairly effective in both preventing weight gain among college students and in helping overweight and obese adults lose weight – and maintain that weight loss for up to a year. Yet in the first case, this effect was washed out during the senior year, and in the latter, response bias makes interpreting survey results dubious.

Therefore, a revised conceptual model is suggested, one that includes possible habituation and the role of impression management on self-weighing studies. The research in this dissertation was not powered or designed to answer such questions, but this conceptual framework can be used to design future, longer-term studies on the use of self-weighing as a strategy to prevent weight gain.

In conclusion, this dissertation illustrates the complexities in self-weighing research. Chapter 2 reviewed the evidence supporting self-weighing for weight loss maintenance and preventing age-related weight gain. While several experimental studies have demonstrated that graphical feedback coupled with self-weighing may be sufficient to prevent weight gain, these studies were mainly of short duration and come to similar conclusions as the studies in Chapters 4 and 5 did before longer follow up was analyzed.

Chapter 3 provides insights into self-weighing behaviors in the real-world, as well as further evidence of the associations between self-weighing and weight control, particularly over long periods of time. A large number of users included in this analysis have been weighing themselves weekly or more for almost seven years. And while no definitive relationship between self-weighing frequency and weight control can be concluded from these data, the results do suggest novel insights into weight targets and weight control. There appears to be a strong relationship between the magnitude of the desired weight and whether or not someone hits their weight target; but this effect disappears if weight change is plotted against percent target *ignoring* whether a user hit their goal or not. This suggests that the magnitude of a weight target – that is, whether the weight goal is reasonable or unreasonable – may in fact have little relationship to what actually happens. Those who hit their target because their weight loss goal was more "reasonable" may have simply had an easier time making their goal because it was less work. This relationship does not prove that the weight goal itself is what matters, but perhaps it is how much motivation the individual making that target has.

Chapter 4 describes follow up results from a study that used the Caloric Titration Method (CTM) to reduce weight in overweight and obese adults, and prevent weight gain among normal weight women. Our results suggest that participants who respond to a request for a follow-up survey are those who successfully maintain their weight thirty months after the end of the intervention. However, these must be interpreted with extreme caution as this might have more to do with impression management or motivation than the effect of the intervention.

Chapter 5 followed college freshman who were exposed to a weight-gain prevention trial for three years, and found that self-weighing failed to sustain weight loss after the first year. This non-significant result brings about further questions, however, as individuals in the control group weighed themselves an average of 1.3 times a week. While there were no differences between groups at the end of the study, frequency of weighing appeared to have a small effect on whether an individual lost, maintained, or gained weight. This study brings out many questions regarding habituation and impression management. Along with these developments, other limitations include blindly believing 'objective' measurements that come from a wifi scale and whether or not the participants actually received the intervention as given. While digging deeper into the feedback from the scale, it appears that some users may have in fact had their scale in a public area, where others were using it besides them. There is no way to know whether this was the case other than to ask each participant. Similarly, it is unclear whether the intervention of daily weighing with visual feedback actually reached the participants, as we do not know how often participants opened and looked at the email feedback from the research monitors.

In summary, the current conceptual model that frames how research on self-weighing is put forth appears to be too linear and myopic to explain the long-term effects of frequent weighing and weight control. Clearly, more research is needed to test the effects of self-weighing on weight loss maintenance and weight gain prevention over periods of more than twelve months. Yet until these longer-term studies are undertaken, it is likely that the short term effects of frequent weighing undoubtedly are useful for weight control for many people.

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It is understood between the parties that Withings keeps the right, in any case, to modify all or part of the Withings Services Terms and Conditions, to reflect changes to the law or any applicable regulation, changes to our Services or any event which is deemed sufficient by Withings to command such revisions. Any new version of the Withings Services Terms and Conditions will not apply retroactively but replaces and supersedes the previous Withings Services Terms and Conditions. We advise you to frequently consult the Withings Services Terms and Conditions and to save the latter version on durable media.

3. General provisions

a. Severability

If any provision of Withings Services Terms and Conditions is held invalid or unenforceable by a court of competent jurisdiction, the invalid or unenforceable part or provision will be deemed as unwritten.

b. Waiver

Any failure to exercise or delay in exercising any right, power or privilege under the Withings Services Terms and Conditions shall not operate as a waiver; nor shall any single or partial exercise of any right, power or privilege preclude any other or further exercise thereof.

c. Evidence – Electronic communication

Any notification and communication between Withings and you can be realised by any electronic means of communication such as emails. You hereby grant us your express consent for sending you by electronic means of communication any notification through your Withings Account.

d. Governing law – Dispute resolution

In the event of any controversy or dispute between Withings and You arising out of or in connection with your use of any Products and Services (such as our Website, API, Application etc.) provided by Withings, the parties shall attempt, promptly, in good faith and before any judicial action, to resolve the dispute though alternative dispute resolution.

Unless otherwise required by applicable law, this Withings API Terms of Use and any matters relating to them, including all disputes, will be governed by the laws of France and be settled in the courts of Paris (France).

The Parties may agree to resolve their dispute in accordance with Directive 2013/11/UE of the European parliament and of the council of the 21 may 2013 on alternative dispute resolution for Consumer disputes and the Regulation (EU) No 524/2013 of the European Parliament and of the council of 21 May 2013 online dispute resolution for Consumer disputes.

Reference: eu-en/withings-services-terms-and-conditions/20150426

Updated on 26 Apr 2015.

Versions: 26 Apr 2015 , 27 Jan 2015 .

APPENDIX 3.2

	Entire Sample			Subgroups			
				Men		Women	
	All	Baseline	Endpoint	Men $_{\text{Baseline}}$	Men $_{\text{Endpoint}}$	Women $_{\text{Baseline}}$	Women $_{\text{Endpoint}}$
Participants, n (%)	92143			58645 (64%)		33498 (36%)	
Sex, n (%)							
Male	58645 (63.7)						
Female	33498 (35.3)						
Age (years), mean (SD)		39.84 ± 10.26		40.13 ± 10.16		39.34 ± 10.41	
Height (m), mean (SD)	1.74 ± 0.10			1.79 ± 0.07		1.66 ± 0.07	
Weight (kg), mean (SD)		81.43 ± 20.05	81.34 ± 19.88	89.97 ± 17.68	89.56 ± 17.64	66.48 ± 14.43	66.95 ± 14.72
BMI (kg/m^2), mean (SD)		26.55 ± 5.26	26.54 ± 5.26	27.91 ± 4.95	27.79 ± 4.96	24.18 ± 4.95	24.35 ± 5.06
BMI Categories, n (%)							
Underweight (<18.5)		1702 (1.9)	1734 (1.9)	216 (0.4)	193 (0.3)	1486 (4.5)	1541 (4.6)
Normal (18.5-24.9)		37886 (41.3)	38224 (41.6)	16690 (28.6)	17848 (30.5)	21196 (63.5)	20376 (61.1)
Overweight (25-29.9)		33271 (36.2)	32986 (35.9)	26219 (44.9)	25496 (43.6)	7052 (21.1)	7490 (22.4)
Obese (30-34.9)		12661 (13.8)	12660 (13.8)	10394 (17.8)	10134 (17.3)	2267 (6.8)	2526 (7.6)
Morbidly Obese (≥ 35)		6294 (6.9)	6210 (6.8)	4930 (8.4)	4778 (8.2)	1364 (4.1	1432 (4.3)
Years used, mean (SD)	4.82 ± 0.59			4.83 ± 0.60		4.79 ± 0.58	
Created a weight target, n (%)	70177 (76.4)			50258 (86.0)		19919 (59.7)	
Desired to maintain or lose weight	66686 (95.0)			48011 (95.5)		18675 (93.8)	
Desired to gain weight	3491 (5.0)			2247 (4.5)		1244 (6.2)	
Met their weight target, (n) %							
Maintained or lost weight	7206 (10.8)			4924 (10.3)		2282 (12.2)	
Gained	1685 (48.3)			1160 (51.6)		525 (42.2)	
Weighing Frequency, mean (SD)							
Percent of days weighed	30 ± 28			33% ± 28		26 ± 28	
Per week	2.14 ± 1.97			2.3 ± 1.87		1.54 ± 1.95	
Weight change (kg), mean (SD)	- 0.09 ± 7.62			-0.41 ± 8.09		0.47 ± 6.68	

APPENDIX 3.3

	Subgroup of those wanting to lose or maintain weight		
	Overall	Made their target	Did not make their target
	66686 (95.0)	7206 (10.8)	59480 (89.2)
Gender (male)	48011 (72%)	4924 (68.3%)	43087 (72.4)
Weight change, mean (SD)			
Kilograms	-0.55 ± 7.85	-7.22 ± 7.59	0.26 ± 7.49
Percent	-0.29 ± 8.35	-8.42 ± 6.92	0.69 ± 7.97
Weight change category, n (%)			
Gained	20589 (30.9)	–	20589 (34.6)
Maintained	23730 (35.6)	1515 (21)	22215 (37.3)
Lost	22367 (33.5)	5691 (79)	16676 (28.0)
Desired weight (kgs), mean (SD)	75.96 ± 14.83	75.48 ± 16.43	76.01 ± 14.63
Desired weight change, mean % (SD)	-10.04 ± 8.57	-4.90 ± 6.03	-10.66 ± 8.62
Desired weight change, n (%)			
Maintain (± 3%)	13197 (19.8)	3907 (54.2)	49582 (83.4)
Lose	53489 (80.2)	3299 (45.8)	9898 (16.6)
Frequency of weighing per week	2.33 ±1.96	2.46 ± 2.12	2.32 ± 1.94
Desired weight change, n (%)			
Lose more than 10%	27551 (41.3)	1136 (15.8)	26415 (44.4)
Lose 5-10%	18711 (28.1)	1727 (24.0)	16984 (28.6)
Lose 3-5%	7227 (10.8)	1044 (14.5)	6183 (10.4)
Lose 0-3%	8718 (13.1)	1929 (26.8)	6789 (11.4)
Difference between final weight and weight target (%), mean (SD)	11.70 ±13.42	-3.71 ±4.08	13.57 ±12.95
Gained more than their target n (%)	51853 (77.8)	—	51853 (87.2)
Maintained weight at their target n (%)	11756 (17.6)	4129 (57.3)	7627 (12.8)
Lost more than their target n (%)	3077 (4.6)	3077 (42.7)	—
Weight change compared to target, n (%)			
≥10% less than target	558 (0.8)	558 (7.7)	
5-10% less than target	1244 (1.9)	1244 (17.3)	
3-5% less than target	1275 (1.9)	1275 (17.7)	
0-3% less than target	4129 (6.2)	4129 (57.3)	
0-3% more than target	7627 (11.4)		7627 (12.8)
3-5% more than target	6542 (9.8)		6542 (11.0)
5-10% more than target	15648 (23.5)		15648 (26.3)
≥10% more than target	29595 (44.4)		29595 (49.8)
Weight change, n (%)			
More than 10% lost	6582 (9.9)	2553 (32.7)	4229 (7.1)
5-10% lost	9576 (14.4)	2305 (32.0)	7271 (12.2)
3-5% lost	6209 (9.3)	1033 (14.3)	5176 (8.7)
0-3% lost	11869 (17.8)	1187 (16.5)	10682 (18.0)
0-3% gained	11861 (17.8)	328 (4.6)	11533 (19.4)
3-5% gained	6158 (9.2)	–	6158 (10.4)
5-10% gained	8787 (13.2)	–	8787 (14.8)
More than 10% gained	5644 (1.6)	–	5644 (9.5)

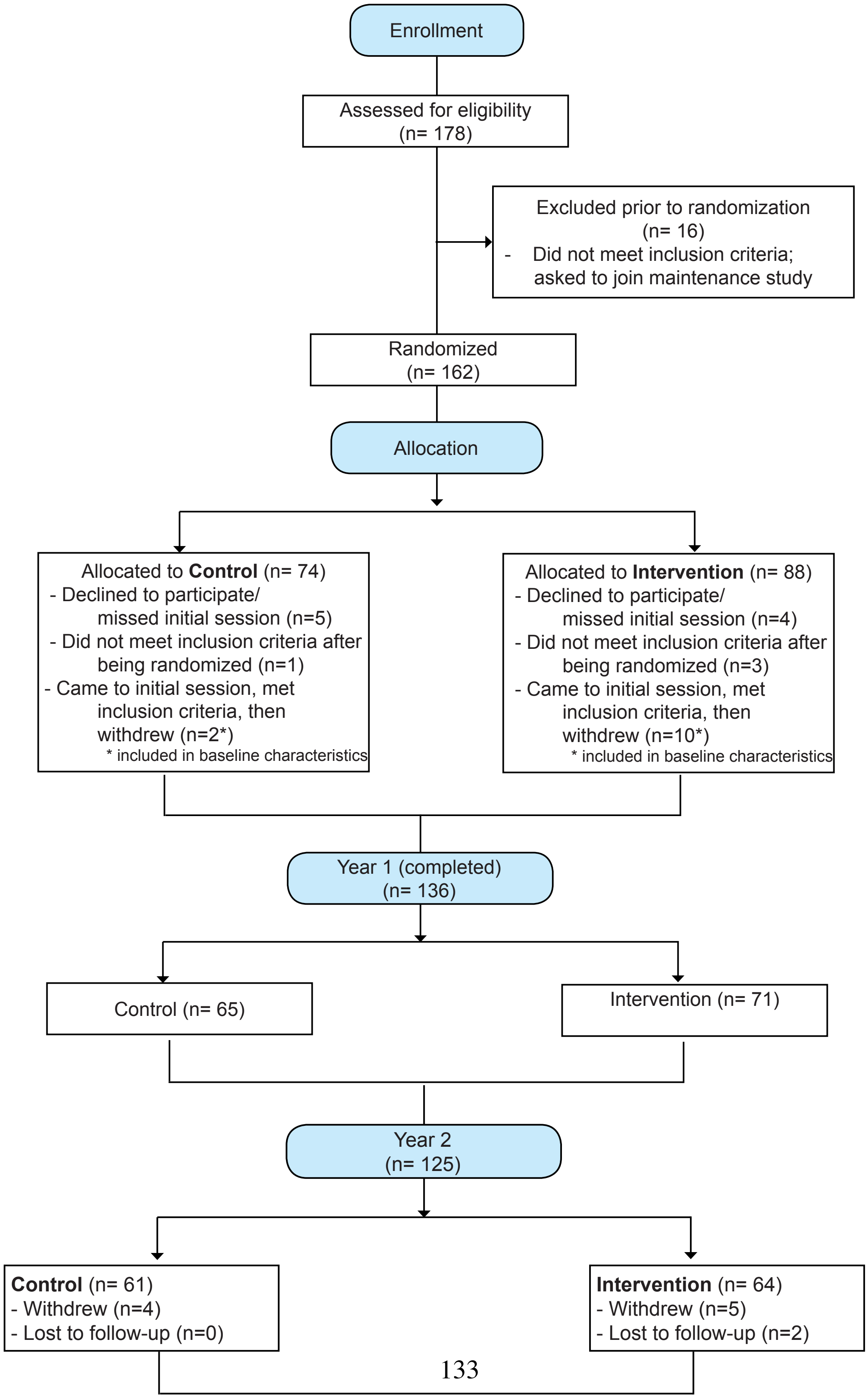
APPENDIX 3.4

```
Call:
lm(formula = actually_happened ~ first_wt + first_target, data = LOSE_MAINTAIN)

Residuals:
     Min       1Q   Median       3Q      Max
-110.582   -5.272   -0.544    4.613  150.584

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  12.235987   0.197010   62.11   <2e-16 ***
first_wt      0.936668   0.003833  244.34   <2e-16 ***
first_target -1.060323   0.005060 -209.57   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 9.747 on 66683 degrees of freedom
Multiple R-squared:  0.4724,    Adjusted R-squared:  0.4724
F-statistic: 2.986e+04 on 2 and 66683 DF,  p-value: < 2.2e-16
```

APPENDIX 3.5

```
Call:
lm(formula = FINAL$last_wt ~ FINAL$male + FINAL$first_wt + FINAL$avg_freq +
    FINAL$lose)

Residuals:
     Min       1Q   Median       3Q      Max
-104.286   -3.648   -0.217    3.578   82.694

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)     7.865636   0.108755  72.324   <2e-16 ***
FINAL$malet     1.721758   0.062089  27.731   <2e-16 ***
FINAL$first_wt  0.901413   0.001505 598.992   <2e-16 ***
FINAL$avg_freq -0.282404   0.012584 -22.442   <2e-16 ***
FINAL$lose2    -0.576250   0.058850  -9.792   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 7.389 on 91809 degrees of freedom
Multiple R-squared:  0.8618,    Adjusted R-squared:  0.8618
F-statistic: 1.431e+05 on 4 and 91809 DF,  p-value: < 2.2e-16

> coef(favoredB)
   (Intercept)    FINAL$malet FINAL$first_wt FINAL$avg_freq    FINAL$lose2
     7.8656364      1.7217584      0.9014128     -0.2824041     -0.5762505
```

APPENDIX 4.1: FLOWCHART OF RANDOMIZATION PROCEDUR



APPENDIX 4.2. FOLLOW-UP QUESTIONNAIRE

Caloric Titration Method Follow Up Questionnaire

Q1 Name: PLEASE include your FULL (first and last) NAME! Thank you :)

Q2 How often do you weigh yourself?
- ❍ Several times per day (1)
- ❍ 1 time/ day (2)
- ❍ Several times/ week (3)
- ❍ Once a week (4)
- ❍ Less than once a week (5)
- ❍ Less than once per month (6)

Q3 Have you continued to record your weight in the CTM program website since the study's end (December 2012)? (Website: https://weightloss.human.cornell.edu/)
- ❍ YES (1)
- ❍ NO (2)

If NO Is Selected, Then Skip To Overall, how helpful did you find the...

Q3a How often do you use the CTM on-line program to track your weight? (https://weightloss.human.cornell.edu/)
- ❍ Several times per day (1)
- ❍ 1 time/ day (2)
- ❍ Several times/ week (3)
- ❍ Once a week (4)
- ❍ Less than once a week (5)
- ❍ Less than once per month (6)

Q4 Overall, how helpful did you find the CTM program in reaching your weight goal for the long term?
- ❍ Not at all helpful (1)
- ❍ Slightly helpful (2)
- ❍ Moderately helpful (3)
- ❍ Extremely helpful (4)

Q5 At this moment, how much do you feel in control of your weight (1 being not in control at all, 10 being in full control)?

- ❍ 1 = Not in control (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)
- ❍ 6 (6)
- ❍ 7 (7)
- ❍ 8 (8)
- ❍ 9 (9)
- ❍ 10 = In full control (10)

Q6 A close friend wishes to lose weight. How likely would you be to recommend the CTM program to your friend?

- ❍ Unlikely (1)
- ❍ Slightly Likely (2)
- ❍ Moderately Likely (3)
- ❍ Very Likely (4)

Q7 Please write any comments you have about the CTM program in the space below. In addition, please let us know what strategies you have tried to reach your weight goals since the program ended and how they have worked for you.

Q8 Read the following statements and determine to what extent each applies to you.

	1 = Not at all true (1)	2 = Hardly true (2)	3 = Moderately true (3)	4 = Exactly true (4)
1. I can always manage to solve difficult problems if I try hard enough. (1)	❍	❍	❍	❍
2. If someone opposes me, I can find the means and ways to get what I want. (2)	❍	❍	❍	❍
3. It is easy for me to stick to my aims and accomplish my goals. (3)	❍	❍	❍	❍
4. I am confident that I could deal efficiently with unexpected events. (4)	❍	❍	❍	❍
5. Thanks to my resourcefulness, I know how to handle unforeseen situations. (5)	❍	❍	❍	❍
6. I can solve most problems if I invest the necessary effort. (6)	❍	❍	❍	❍
7. I can remain calm when facing difficulties because I can rely on my coping abilities. (7)	❍	❍	❍	❍
8. When I am confronted with a problem, I can usually find several	❍	❍	❍	❍

solutions. (8)				
9. If I am in trouble, I can usually think of a solution. (9)	❍	❍	❍	❍
10. I can usually handle whatever comes my way. (10)	❍	❍	❍	❍

Q9 How strongly do you agree or disagree with the following statements?

	Strongly Disagree (1)	Disagree (2)	Somewhat Disagree (3)	Somewhat Agree (4)	Agree (5)	Strongly Agree (6)
Whether I gain, lose, or maintain my weight is entirely up to me. (1)	❍	❍	❍	❍	❍	❍
Being the right weight is largely a matter of good fortune. (2)	❍	❍	❍	❍	❍	❍
No matter what I intend to do, if I gain or lose weight, or stay the same in the near future, it is just going to happen. (3)	❍	❍	❍	❍	❍	❍
If I eat properly, and get enough exercise and rest, I can control my weight in the way I desire. (4)	❍	❍	❍	❍	❍	❍

Q10 How strongly do you agree or disagree with these statements about yourself?

	Strongly Disagree (1)	Disagree (2)	Neither Agree nor Disagree (3)	Agree (4)	Strongly Agree (5)
There is really no way I can solve some of the problems I have. (1)	❍	❍	❍	❍	❍
Sometimes I feel that I'm being pushed around in my life. (2)	❍	❍	❍	❍	❍
I have little control over the things that happen to me. (3)	❍	❍	❍	❍	❍
I can do just about anything I really set my mind to. (4)	❍	❍	❍	❍	❍
I often feel helpless in dealing with the problems of life. (5)	❍	❍	❍	❍	❍
What happens to me in the future mostly depends on me. (6)	❍	❍	❍	❍	❍
There is little I can do to change many of the important things in my life. (7)	❍	❍	❍	❍	❍

Q11 Please write any comments or suggestions you have about the CTM program in the space below:

APPENDIX 4.3. CHARACTERISTICS BY GROUP

	Follow-Up by Treatment Group				
	Total	Control	CTM	Maintenance	p-value diff
Female (n, %)	31 (75.6)	10 (83.3)	16 (66.7)	5 (100)	0.219
Age, years (mean, SD)	53.46 (9.54)	53.75 (10.58)	52.73 (9.56)	56.00 (8.15)	0.79
BMI (kg/m^2)	30.28 (5.14)	33.31 (4.31)	29.99 (4.90)	24.37 (1.71)	0.002**
Body Weight (lbs)	191.37 (41.08)	211.14 (44.03)	190.81 (35.78)	146.62 (22.39)	0.009**
Education (years) *Highest level of education completed: 1st grade (1), 2nd grade (2), 3rd grade (3), 4th grade (4), 5th grade (5), 6th grade (6), 7th grade (7), 8th grade (8), 9th grade (9), 10th grade (10), 11th grade (11), 12 grade (finished high school (12), one yr college (13), two yrs college (14), three yrs college (15), college degree (17), masters degree (18), doctorate degree (19)*	16.34 (2.03)	15.75 (2.30)	16.43 (1.83)	17.40 (2.07)	0.307
Ethnicity (number of participants)					NA
American Indian	1	-	1	-	
White	39	12	22	5	
Other	1	-	1	-	
How often do you weigh yourself? N (%)					0.529
Several times per day (1)	-				
1 time/ day (2)	9 (22)	2 (16.7)	6 (25)	1 (20	
Several times/ week (3)	15 (36.6)	4 (33)	8 (33.3)	3 (60)	
Once a week (4)	7 (17.1)	2 (16.7)	5 (20.8)	-	
Less than once a week (5)	8 (19.5)	2 (16.7)	5 (20.8)	1 (20)	
Less than once per month (6)	2 (4.9)	2 (16.7)	-	-	
Have you continued to record your weight in the CTM program website since the study's end (December 2012)? *YES (1), NO (2)*	32 (78)	11 (91.7)	19 (79.2)	2 (40)	0.063
How often do you use the CTM on-line program to track your weight?					0.003**
Several times per day (1)	-				
1 time/ day (2)	2 (4.9)	-	2 (8.3)	-	
Several times/ week (3)	2 (4.9)	1 (8.3)	-	1 (20)	
Once a week (4)		-	-	-	
Less than once a week (5)	2 (4.9)	-	-	2 (40)	
Less than once per month (6)	3(7.3)	-	3 (12.5)	-	
Overall, how helpful did you find the CTM program in reaching your weight goal for the long term? *Not at all helpful (1), Slightly helpful (2), Moderately helpful (3), Extremely helpful (4)*	2.90 (0.86)	2.92 (1.00)	2.83 (0.82)	3.20 (0.84)	0.696
At this moment, how much do you feel in control of your weight (1 being not in control at all, 10 being in full control)?	5.76 (2.78)	5.42 (3.18)	6.08 (2.64)	5.00 (2.83)	0.655
A close friend wishes to lose weight. How likely would you be to recommend the CTM program to your friend? *Unlikely (1), Slightly Likely (2), Moderately Likely (3), Very Likely (4)*	3 (0.92)	2.67 (0.98)	3.17 (0.82)	3.00 (1.22)	0.316

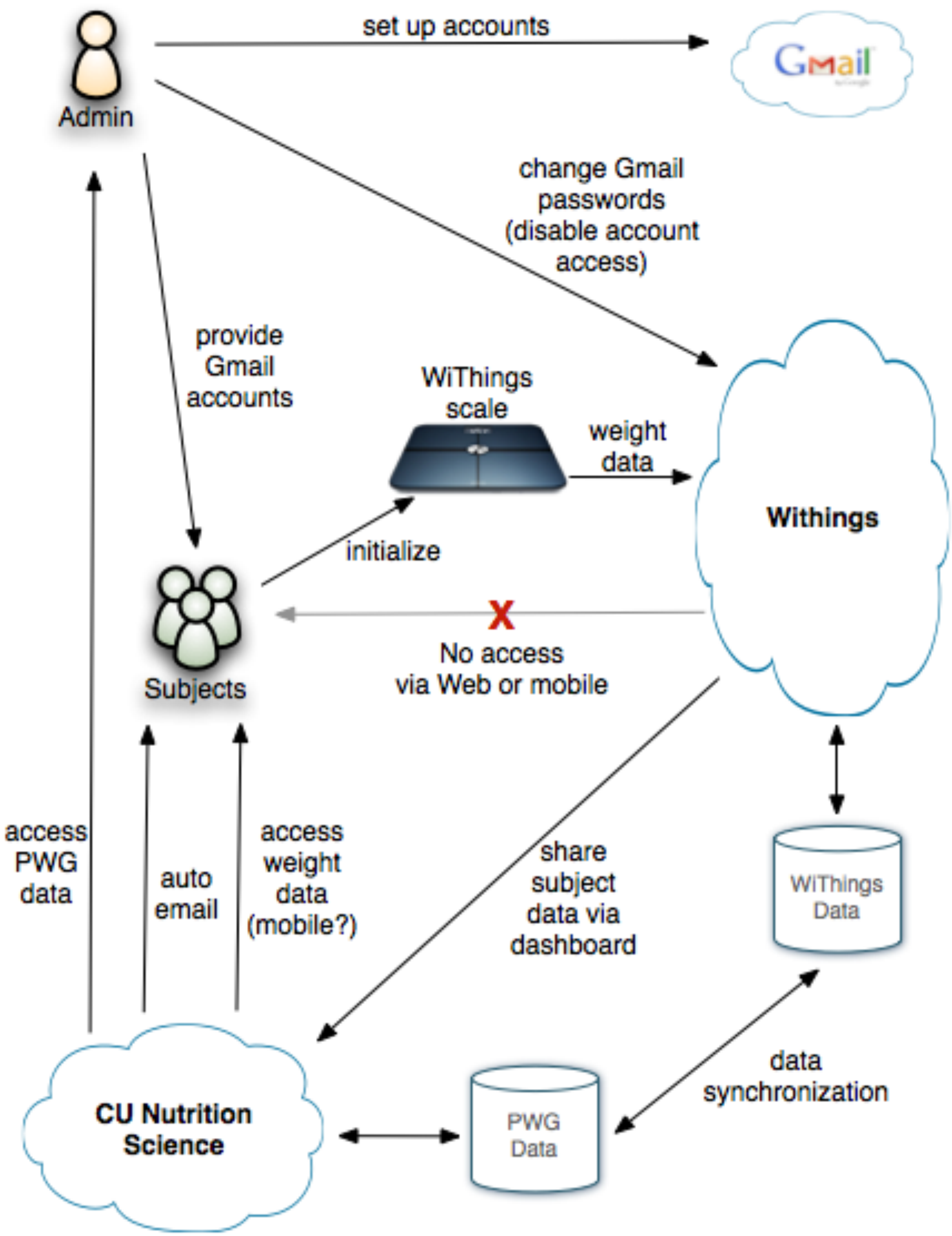
APPENDIX 4.4 COEFFICIENTS OF MIXED MODEL

```
Linear mixed model fit by REML t-tests use Satterthwaite approximations to
  degrees of freedom [lmerMod]
Formula: BMI ~ Time + Group:Time + Group + age + Male + BMI_base_COPY +
    (1 | ID)
   Data: Anova

REML criterion at convergence: 362.3

Scaled residuals:
     Min       1Q   Median       3Q      Max
-2.61607 -0.36892  0.00996  0.35292  2.26658

Random effects:
 Groups   Name        Variance Std.Dev.
 ID       (Intercept) 7.116    2.668
 Residual             3.009    1.735
Number of obs: 78, groups:  ID, 39

Fixed effects:
                      Estimate Std. Error       df t value Pr(>|t|)
(Intercept)           13.62113    4.47272 33.42000   3.045  0.00451 **
Time4                  0.80072    0.70817 36.00000   1.131  0.26566
GroupTreatment        -0.46522    1.21271 42.87000  -0.384  0.70316
GroupMaintainer       -1.43288    2.13075 39.80000  -0.672  0.50516
age                   -0.09856    0.05248 33.00000  -1.878  0.06926 .
MaleMale               0.04216    1.18155 33.00000   0.036  0.97175
BMI_base_COPY          0.69457    0.12227 33.00000   5.681 2.47e-06 ***
Time4:GroupTreatment  -0.90303    0.88037 36.00000  -1.026  0.31186
Time4:GroupMaintainer  0.09392    1.30580 36.00000   0.072  0.94306
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

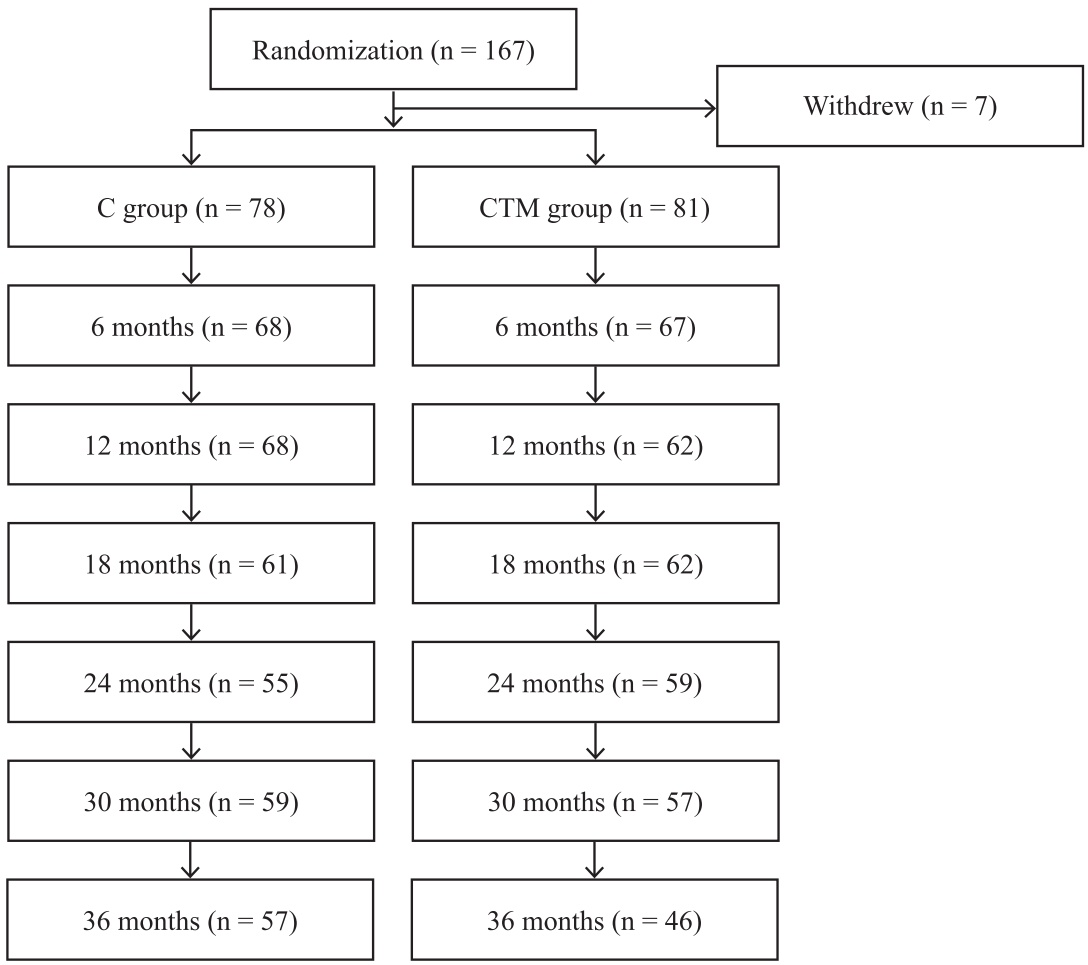
```
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
              Sum Sq Mean Sq NumDF DenDF F.value    Pr(>F)
Time           3.859   3.859     1    36   1.283   0.26491
Group          2.313   1.157     2    33   0.384   0.68390
age           10.611  10.611     1    33   3.526   0.06926 .
Male           0.004   0.004     1    33   0.001   0.97175
BMI_base_COPY 97.107  97.107     1    33  32.272 2.471e-06 ***
Time:Group     4.168   2.084     2    36   0.693   0.50678
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Group = Delayed Control:
 contrast   estimate        SE df t.ratio p.value
 3 - 4    -0.8007194 0.7081674 36  -1.131  0.2657

Group = Treatment:
 contrast   estimate        SE df t.ratio p.value
 3 - 4     0.1023126 0.5230163 36   0.196  0.8460

Group = Maintainer:
 contrast   estimate        SE df t.ratio p.value
 3 - 4    -0.8946378 1.0970883 36  -0.815  0.4202

Results are averaged over the levels of: Male
```

APPENDIX 5.1: A VISUAL REPRESENTATION OF HOW THE DATA WAS SECURED FROM PARTICIPANTS



APPENDIX 5.2: RANDOMIZATION AND FOLLOW-UP OF STUDY PARTICIPANTS



APPENDIX 5.3. REGRESSION COEFFICIENTS FOR THE EFFECT OF WEIGHING FREQUENCY ON WEIGHT

```
Call:
lm(formula = Weight_36_mo_mean ~ Weighttarget + Group + Gender +
    Frequency_of_weighing_n_per_week_at_36_mo_TOTAL, data = Wide,
    subset = na.omit(Weight_36_mo_mean))

Residuals:
    Min      1Q  Median      3Q     Max
-26.408  -8.191  -1.232   4.539  23.537

Coefficients:
                                                Estimate Std. Error t value Pr(>|t|)
(Intercept)                                      15.1355    12.2322   1.237    0.223
Weighttarget                                      0.9430     0.0769  12.262 2.67e-15 ***
GroupExperiment                                  -0.2496     3.7112  -0.067    0.947
Genderfemale                                     -3.8594     4.1765  -0.924    0.361
Frequency_of_weighing_n_per_week_at_36_mo_TOTAL  -0.2390     0.5130  -0.466    0.644
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 11.27 on 41 degrees of freedom
  (57 observations deleted due to missingness)
Multiple R-squared:  0.8288,    Adjusted R-squared:  0.8121
F-statistic: 49.63 on 4 and 41 DF,  p-value: 3.476e-15
```

```
> anova.ALL<-aov(meanwt~Gender+Weighttarget_copy+group*Time+Frequency_per_week,data=Seven)
> summary(anova.ALL)
                   Df Sum Sq Mean Sq  F value   Pr(>F)
Gender              1 208748  208748 1737.397  < 2e-16 ***
Weighttarget_copy   1 367303  367303 3057.042  < 2e-16 ***
group               1    137     137    1.141 0.285782
Time                5   2632     526    4.380 0.000616 ***
Frequency_per_week  1    474     474    3.949 0.047263 *
group:Time          5    411      82    0.684 0.635797
Residuals         743  89271     120
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
196 observations deleted due to missingness
```

```
Linear mixed model fit by REML t-tests use Satterthwaite approximations to degrees of
  freedom [lmerMod]
Formula: meanwt ~ Gender + Weighttarget_copy + group + Time + group:Time +
    Frequency_per_week + (1 | subjectdbkey)
   Data: Seven

REML criterion at convergence: 6102.4

Scaled residuals:
    Min      1Q  Median      3Q     Max
-6.8127 -0.5147  0.0296  0.4951  4.5540

Random effects:
 Groups       Name        Variance Std.Dev.
 subjectdbkey (Intercept) 43.81    6.619
 Residual                 34.34    5.860
Number of obs: 911, groups:  subjectdbkey, 158
```

```
Fixed effects:
                     Estimate Std. Error        df t value Pr(>|t|)
(Intercept)          -2.93547    3.63270 167.30000  -0.808  0.42020
Gendermale           -0.32066    1.45680 158.60000  -0.220  0.82607
Weighttarget_copy     1.02101    0.02643 158.10000  38.625  < 2e-16 ***
groupExperiment      -0.06203    1.41420 353.70000  -0.044  0.96504
Time2                 1.39819    0.96446 755.50000   1.450  0.14755
Time3                 1.71660    0.99716 760.70000   1.721  0.08557 .
Time4                 1.84576    1.02270 756.80000   1.805  0.07151 .
Time5                 2.14170    1.06906 759.70000   2.003  0.04549 *
Time6                 3.18100    1.03941 757.70000   3.060  0.00229 **
Time7                 5.17836    1.05550 759.30000   4.906 1.14e-06 ***
Frequency_per_week   -0.24555    0.10701 891.40000  -2.295  0.02199 *
groupExperiment:Time2 -1.08108   1.36646 761.30000  -0.791  0.42910
groupExperiment:Time3 -1.51250   1.38482 758.60000  -1.092  0.27509
groupExperiment:Time4  0.50020   1.46908 765.40000   0.340  0.73359
groupExperiment:Time5  0.49479   1.49292 763.30000   0.331  0.74041
groupExperiment:Time6  1.50656   1.47314 760.90000   1.023  0.30678
groupExperiment:Time7  1.00419   1.52934 760.20000   0.657  0.51162
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
                   Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)
Gender                  2       2     1 158.55    0.05   0.82607
Weighttarget_copy   51225   51225     1 158.08 1491.88 < 2.2e-16 ***
group                   0       0     1 168.79    0.00   0.95315
Time                 2609     435     6 764.58   12.66 1.183e-13 ***
Frequency_per_week    181     181     1 891.45    5.27   0.02199 *
group:Time            218      36     6 758.13    1.06   0.38699
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
$contrasts
Time = 2:
 contrast               estimate       SE     df t.ratio p.value
 Control - Experiment  1.1065512 1.796683 348.06   0.616  0.5384

Time = 3:
 contrast               estimate       SE     df t.ratio p.value
 Control - Experiment  1.8024403 1.820602 365.09   0.990  0.3228

Time = 4:
 contrast               estimate       SE     df t.ratio p.value
 Control - Experiment  1.5359300 1.921367 416.55   0.799  0.4245

Time = 5:
 contrast               estimate       SE     df t.ratio p.value
 Control - Experiment -0.6510182 1.946900 434.61  -0.334  0.7382

Time = 6:
 contrast               estimate       SE     df t.ratio p.value
 Control - Experiment -1.6728763 1.923201 424.06  -0.870  0.3849

Time = 7:
 contrast               estimate       SE     df t.ratio p.value
 Control - Experiment -1.2200160 1.988680 462.32  -0.613  0.5399

Results are averaged over the levels of: Gender
```

```
Call:
lm(formula = Wide$Frequency_of_weighing_n_per_week_at_36_mo_TOTAL ~
    Wide$Weight_36_mo_mean + Wide$Weight_36_mo_mean + Wide$Group +
        Wide$Weighttarget + Wide$wtchg.cut)

Residuals:
    Min      1Q  Median      3Q     Max
-4.6885 -0.9003 -0.5008  0.2849 18.4837

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)             -0.248966   1.650172  -0.151    0.880
Wide$Weight_36_mo_mean  -0.009504   0.030166  -0.315    0.753
Wide$GroupExperiment     2.978809   0.524258   5.682  1.4e-07 ***
Wide$Weighttarget        0.016351   0.033839   0.483    0.630
Wide$wtchg.cutmaintained 1.126635   0.793281   1.420    0.159
Wide$wtchg.cutgained     0.315017   1.030386   0.306    0.760
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.628 on 97 degrees of freedom
  (56 observations deleted due to missingness)
Multiple R-squared:  0.2672,	Adjusted R-squared:  0.2294
F-statistic: 7.074 on 5 and 97 DF,  p-value: 1.12e-05
```

```
Call:
lm(formula = Wide$Frequency_of_weighing_n_per_week_at_36_mo_TOTAL ~
    Wide$Group * Wide$wtchg.cut + Wide$Gender + Wide$Weighttarget)

Residuals:
    Min      1Q  Median      3Q     Max
-3.4880 -1.1785 -0.3437  0.5680 17.5809

Coefficients:
                                            Estimate Std. Error t value Pr(>|t|)
(Intercept)                                 -3.37116    2.11486  -1.594  0.11425
Wide$GroupExperiment                         3.51310    1.20267   2.921  0.00436 **
Wide$wtchg.cutmaintained                     1.58505    0.94992   1.669  0.09849 .
Wide$wtchg.cutgained                         0.26877    0.94821   0.283  0.77745
Wide$Genderfemale                            1.39066    0.64538   2.155  0.03371 *
Wide$Weighttarget                            0.02162    0.01174   1.842  0.06859 .
Wide$GroupExperiment:Wide$wtchg.cutmaintained -1.30351    1.48095  -0.880  0.38098
Wide$GroupExperiment:Wide$wtchg.cutgained    -0.30698    1.42638  -0.215  0.83006
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.586 on 95 degrees of freedom
  (56 observations deleted due to missingness)
Multiple R-squared:  0.3049,	Adjusted R-squared:  0.2537
F-statistic: 5.954 on 7 and 95 DF,  p-value: 9.284e-06
```