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Characterizing Patterns of Adherence to Physical Activity Goals in Behavioral Weight Control

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CHARACTERIZING PATTERNS OF ADHERENCE TO PHYSICAL ACTIVITY GOALS IN BEHAVIORAL WEIGHT CONTROL

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DEDICATION

To my amazing mom, Susan. Thank you for your unwavering encouragement to endure the miles, the strength to overcome the seemingly insurmountable climbs, and the inspiration to enjoy the dance. It sure has been an incredible ride…we did it!

⟵ *three things* ⟶

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"We notice those chance events that occur at just the right moment, and bring forth just the right individuals, to suddenly send our lives in a new and important direction."

- James Redfield

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ABSTRACT

Introduction: Many individuals fall short of the physical activity (PA) goals provided during lifestyle programs, and there is considerable variability in weight loss response and adherence to recommendations for behavior change. Weight loss response within the early weeks of program initiation predicts future weight loss success; however, little is known about what distinguishes those who respond well to treatment from those who fail to respond. Exposing the behavioral patterns which underlie weight loss response may point towards targets for treatment optimization. The purpose of this study was to (1) characterize individuals with distinct patterns of adherence to PA goals during the first 2 months of an online behavioral weight loss intervention and determine whether these patterns were associated with 6-month weight loss and (2) describe weekly transitions in adherence to steps-based and minutes-based PA goals and self-monitoring behavior across 6 months of intervention.

Methods: Individuals participating in an online behavioral weight loss intervention were prescribed progressive goals for 7,000 to 10,000 daily steps and 50 to 200 minutes of weekly moderate-to-vigorous PA (MVPA). Goals increased incrementally during the initial two months (graded goal phase) and then stayed constant for the remainder of the program (fixed goal phase). Participants were instructed to self-monitor their total steps and minutes of MVPA daily on the study website. Individuals were classified each week as meeting the program goals for steps (yes/no) and minutes of MVPA (yes/no) based on self-monitoring records. A repeated-measures latent class analysis was conducted to

identify distinct subgroups during the initial 2 months. Associations between latent classes and sociodemographic characteristics, weight loss outcomes, and treatment engagement parameters were then examined. Further, individuals were categorized as (1) "adherent", (2) "suboptimally adherent", or (3) "nonadherent" to the steps-based goals and separately to the minutes-based goals, based on whether they met the weekly goal (yes/no) and self-monitored their physical activity (yes/no). Weekly transition probabilities were examined across 6 months using multinomial logistic regression. **Results:** Participants (*N*=212) were predominantly female (91.5%), middle-aged (mean = 47.9 ± 11.1 years) with an average BMI of 35.8 ± 5.9 kg/m^2, and 31.6% self-identified as a racial/ethnic minority. Three latent classes describing patterns of physical activity goal adherence were revealed: 27.3% had a high probability of consistently meeting both steps-based and minutes-based targets ("Both PA Goals"), 28.4% were estimated to meet the weekly MVPA goals but not the step goals ("MVPA Goals Only"), and the largest class (44.3%) had a low probability of attaining either weekly goal ("Neither PA Goal"). Weight losses at 6 months were significantly greater for members of the "Both PA Goals" class (estimated mean weight loss [95% CI]: -9.4% [7.4, 11.5]) compared to "MVPA Goals Only" (-4.8% [3.4, 6.1]) and "Neither PA Goal" (-2.5% [1.4, 3.6]). Factors differentiating these classes included age, gender, race/ethnicity, geographic region, and BMI at study entry, as well as engagement in other treatment components, such as group session attendance and self-monitoring of weight, dietary intake, and physical activity. The most consistent status among both types of goals was "nonadherent," while "suboptimally adherent" was most vulnerable to movement, particularly during the graded goal phase. Few individuals were initially "adherent" to

steps goals and had a high probability of either remaining “suboptimally adherent” from one week to the next or transitioning to a “nonadherent” status. Conversely, most individuals started out “adherent” to MVPA goals but were more likely to become less adherent for MVPA goals than steps goals during the graded goal phase (p=.0042). Across the fixed goal phase, the pattern of weekly adherence status did not differ significantly between steps-based versus minutes-based goals (p=.6530).

Conclusion: Distinct patterns of adherence to weekly program PA goals underscore the early period of behavioral weight control as a critical window of opportunity to detect individuals at risk of poor treatment outcomes. This study provides novel insights about behavioral typologies in obesity treatment as they relate to physical activity adherence and contributes a preliminary framework for identifying individuals in need of additional or different support for successfully adopting physical activity during lifestyle modification.

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INTRODUCTION

1.1 Problem Identification

Physical activity is one of the cornerstones of effective weight management programs,[1] and attainment of physical activity goals prescribed in obesity treatment is reliably associated with greater weight loss success.[2-4] However, over half of individuals do not meet program recommendations for physical activity by 6 months of treatment and there is substantial variability in physical activity adherence,[5,6] as well as in weight loss and obesity-related health outcomes.[7-9] Standard behavioral weight loss interventions often set uniform physical activity goals (e.g., 150 minutes per week of moderate-to-vigorous intensity physical activity [MVPA] and/or 10,000 total steps per day),[10,11] which may not accommodate individual differences in treatment response and adherence. Thus, to enhance the benefits of physical activity for weight control and overall health, it is necessary to understand the dynamics of how individuals adhere to physical activity goals recommended during treatment and how adherence patterns relate to successful weight loss and health outcomes.

Through observing patterns in adherence to physical activity, we can advance our understanding of the influence of behavioral typologies for physical activity on treatment outcomes. Most often, researchers report adherence to physical activity in behavioral weight control interventions based on whether or not physical activity was self-monitored or as aggregated values of self-reported physical activity (e.g., mean minutes of MVPA

per week, average steps per day, session frequency, or mean energy expenditure),[5] which overlook the underlying patterns of physical activity adherence. Characterizing distinct patterns of adherence to treatment recommendations, particularly early on in behavioral interventions when indicators of treatment response likely begin to emerge,[12-14] may suggest which individuals are more (or less) likely to meet program recommendations. Identification of unique patterns may also guide future research on the type of intervention recommendations to offer and critical time points when additional support is needed to maximize adherence, intervention effectiveness, and weight loss success.

Few studies have taken a micro-level approach when examining adherence to physical activity in terms of whether or not a prescribed goal was met,[15,16] and we are not aware of any studies combining adherence to physical activity goals with adherence to physical activity self-monitoring to evaluate transitions in adherence status at a weekly level during a behavioral weight control program. By evaluating how adherence changes from one week to the next, we can obtain more precise information regarding the shape of an individual's physical activity adherence profile and provide the appropriate support for improved engagement. For example, a shift in an individual's physical activity behavior from fully adherent in one week to suboptimal the following week may signal a critical time point for implementation of additional efforts that better align with an individual's adherence profile to assist them in returning to a fully adherent status. Personalized care can also be provided to an individual who consistently adheres to physical activity goals and self-monitoring through regular reinforcement and encouragement to continue following treatment recommendations.

Moreover, weekly adherence to commonly prescribed physical activity goals and self-monitoring behavior may be influenced by how the goal is operationalized (i.e., the type of goal recommended), which has not been explored in this context to our knowledge. Differences in adherence to a steps-based physical activity goal compared to adherence to a minutes-based physical activity goal may indicate a need to modify the type of physical activity recommendation(s) for an individual. Taken together, evaluating patterns of adherence to and operationalization of prescribed physical activity goals has the potential to inform new targets for intervention tailoring to promote physical activity adherence and improve weight loss outcomes.

The application of more detailed statistical modeling provides an opportunity for a more nuanced understanding of the underlying behavioral patterns describing how an individual adheres to physical activity goals over time. Latent class models characterize individuals based on their distinct response patterns.[17] More specifically, latent class analysis (LCA) is a technique that facilitates assessment and characterization of physical activity goal attainment with finer granularity than has previously been reported.[16] Multinomial logistic regression (MLR) for correlated data with a Markov chain model can further inform patterns of adherence by predicting how likely an individual is to meet a prescribed goal and/or self-monitor their physical activity, given their prior level of adherence.[18] While the relationship between overall adherence to physical activity and weight loss outcomes has been identified, investigating specific underlying patterns of adherence to physical activity goals prescribed during obesity treatment and their association with weight loss success is a requisite next step in refining behavioral weight

control recommendations and increasing adherence, which will ultimately enhance the health-related benefits of physical activity.[15]

1.2 Scope of the Research Project

This study aimed to identify distinct patterns of adherence to prescribed physical activity goals during the early period of a behavioral weight loss intervention and determine whether the distinct patterns were associated with weight loss. Additionally, this project explored the likelihood of meeting the prescribed physical activity goal and self-monitoring physical activity in one week based on adherence the previous week across the first 6 months of treatment.

1.2.a Purpose of Study 1

The purpose of Study 1 was to characterize distinct patterns of weekly adherence to physical activity goals prescribed in steps and prescribed in minutes of moderate-to-vigorous physical activity (MVPA) during the initial 2 months of an online behavioral weight loss program among adults with overweight and obesity using latent class analysis. Furthermore, this study determined whether these emergent classes of physical activity adherence were associated with weight loss.

> Specific Aim 1.1: To determine whether distinct patterns of adherence to prescribed physical activity goals for steps and minutes of MVPA emerge over 2 months among adults with overweight and obesity participating in an online behavioral weight loss intervention.
>
> Specific Aim 1.2: If there are distinct patterns of adherence to prescribed physical activity goals over 2 months, to determine whether these patterns are associated

with change in weight at 2 months among adults with overweight and obesity participating in an online behavioral weight loss intervention.

Specific Aim 1.3: If there are distinct patterns of adherence to prescribed physical activity goals over 2 months, to determine whether these patterns are associated with change in weight at 6 months among adults with overweight and obesity participating in an online behavioral weight loss intervention.

1.2.b Purpose of Study 2

The purpose of Study 2 was to explore the weekly conditional associations in adherence to different types of prescribed physical activity goals and adherence to physical activity self-monitoring during the first 6 months of a behavioral weight loss intervention. In other words, does meeting the specified program goal for physical activity and/or self-monitoring physical activity behavior in a given week influence the likelihood that an individual will meet the prescribed goal and/or self-monitor in the following week? This study examined weekly transitional probabilities for steps-based and minutes-based goals separately using parallel approaches. The study then explored whether the weekly transitional probabilities of meeting the physical activity goal and self-monitoring physical activity differ between physical activity goals expressed as steps per day versus goals expressed as minutes of MVPA.

Specific Aim 2.1: To establish the weekly transitional probabilities of adherence to prescribed daily steps and adherence to self-monitoring daily steps across successive weeks of the first 6 months of a behavioral weight control program. Participants will be characterized into 3 mutually exclusive categories that

represent both the frequency of self-monitoring daily steps and whether the absolute number of steps reported met the threshold of the prescribed goal.

Specific Aim 2.2: To establish the weekly transitional probabilities of adherence to prescribed minutes of MVPA and adherence to self-monitoring minutes of MVPA across successive weeks of the first 6 months of a behavioral weight control program. Participants will be characterized into 3 mutually exclusive categories that represent both the frequency of self-monitoring minutes of MVPA and whether the absolute number of minutes reported met the threshold of the prescribed goal.

Specific Aim 2.3: To compare the weekly transitional probabilities of physical activity adherence status (as defined by meeting the prescribed physical activity goal and self-monitoring physical activity) for steps-based goals versus minutes-based goals across 6 months of a behavioral weight control program.

1.3 Public Health Significance

This research project will provide a deeper understanding of how individuals adhere to physical activity goals during treatment, whether early adherence patterns relate to weight loss, and the type of physical activity goal prescription individuals are more likely to adopt. Additionally, the innovative use of LCA and MLR techniques to describe and predict patterns of adherence to physical activity goals prescribed during treatment and to self-monitoring of physical activity allows for a rigorous examination of underlying adherence profiles and potential predictors of adherence, which will advance the current literature regarding who may be more or less responsive to treatment recommendations. The exploration of weekly transitions in goal attainment and self-

monitoring will offer unique insights on the independent and joint influence of multiple physical activity-related behaviors on adherence to different types of commonly prescribed physical activity goals (daily steps and minutes of MVPA). Considering the substantial heterogeneity in adherence to physical activity goals and weight loss outcomes, findings from this research may inform which physical activity goal operationalization, or metric, is more amenable to promoting physical activity adherence and leading to weight loss. This research is particularly timely with the release of the updated public health guidelines for physical activity.[19] The accrual of MVPA in bouts of at least 10 minutes to count towards the recommended minimum of at least 150 minutes per week is no longer a requirement. Therefore, step goals may serve as an effective strategy to accumulate physical activity throughout the day, resulting in more people meeting the public health guidelines and improving their health. These data may also guide just-in-time adaptive interventions, which seek to provide additional or different interventions at critical points in the treatment process based on treatment response.[20] By adapting recommendations and strategies for an individual when they are most in need of and receptive to support, greater improvements may be achieved in physical activity adherence and, importantly, result in more favorable long-term health outcomes.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Prevalence of Overweight and Obesity

Overweight and obesity have reached unprecedented rates over the past three decades. According to the most recent national survey, obesity affects nearly 40% of adults in the United States, and more than 70% of adults are classified as overweight or obese.[21,22] Overweight is defined as having a body mass index (BMI; kg/m^2) of 25.0-29.9 and obesity is defined by a BMI $\geq$ 30.0.[23] The accumulation of abnormal or excessive adipose tissue increases an individual's risk of adverse health outcomes, such as heart disease, stroke, type 2 diabetes, hypertension, and numerous types of cancer.[1,24,25] Furthermore, the economic impact of obesity from national health care costs is estimated to be approximately $150-210 billion annually.[26,27] Considering these statistics, additional work is urgently needed to better understand and address the obesity epidemic.

2.2 Factors Associated with Overweight and Obesity

The complex interaction of biological, environmental, and behavioral factors influences an individual's susceptibility to obesity, as well as success with obesity treatment.[28] Exposure to an obesogenic environment (i.e., physical and social environments that promote weight gain and present barriers to weight loss), along with variations in genes and obesity-related phenotypes, influence an individual's behaviors and contribute to overweight and obesity. Physical inactivity and an unhealthy diet are among the most common modifiable behavioral risk factors which contribute to weight

gain, increased risk of chronic disease, and mortality.[24,29] Physical activity offers immediate health benefits, such as improved mood, glucose control, and sleep, as well as long-term benefits, including prevention of heart disease, improved motor function, and weight maintenance.[30] A physically active lifestyle can attenuate obesity-related health consequences, even in the absence of significant weight loss.[31] Despite these well-known benefits, approximately 80% of adults in the United States do not engage in the recommended amount of physical activity,[32] and individuals with higher weight status report less activity than their peers of normal weight.[33,34] Moreover, adults who are both physically inactive and have overweight or obesity are among those with the highest risk of a comorbidity.[35-37] Therefore, lifestyle changes for physical activity are often targeted in the treatment of obesity and recommended in behavioral weight loss guidelines.[1] A deeper understanding of how individuals respond to recommendations for modifying behavioral risk factors, such as physical activity, is essential for identifying and improving strategies to treat obesity, reducing adverse health outcomes, and enabling more individuals to accrue immediate and long-term physical activity-related health benefits.

2.3 Standard Behavioral Weight Control Interventions

Lifestyle modification is frequently recommended in the treatment of overweight and obesity. Weight loss of at least 5-10% is considered a clinically meaningful marker of success, given the improvements seen in cardiovascular disease risk factors and other obesity-related health consequences.[1] Standard weight control programs emphasize behavior change through a combination of dietary restriction and increased physical activity, which enhances weight loss to a greater extent than either component alone.

Grounded in theory (e.g., Social Cognitive Theory and Theory of Planned Behavior), programs promote key strategies of goal setting, self-monitoring, and feedback, along with problem-solving, relapse prevention, and social support. Sessions are often group-based and delivered by trained facilitators. This approach has been shown to reliably produce weight losses of 7-10%.[3,38-41] However, there is considerable variability in weight loss outcomes from behavioral weight control interventions, and weight regain is common.[4,42-44]

2.4 Physical Activity in Behavioral Weight Control

Physical activity is widely accepted and recommended as a key component of behavioral weight loss interventions.[1] The energy expended through physical activity contributes to weight loss when an individual reaches an overall state of caloric deficit. Recommendations for physical activity consist of programmed exercise and/or lifestyle activity, gradually progressing until the overall minimum program goal is reached. Programmed exercise involves planned, intentional activity performed at moderate-to-vigorous intensity over a defined period of time, such as brisk walking or biking for 30 minutes. The current national guidelines for adults recommend weekly aerobic exercise for a minimum of 150-300 minutes at moderate intensity, 75-150 minutes at vigorous intensity, or an equivalent combination of MVPA to reduce the risk of chronic disease and achieve substantial health benefits, including weight control.[19] Higher levels of physical activity are shown to contribute to greater reductions in chronic disease risk, initial weight loss, and long-term maintenance of weight loss.[45-48] Accordingly, standard behavioral weight loss programs often prescribe goals of at least 150-300 minutes of MVPA per week.[10,11,40]

Lifestyle activity, on the other hand, is acquired spontaneously at any intensity throughout the day from ordinary tasks, such as taking the stairs, parking farther away, and doing household chores. Step goals (e.g., 10,000 daily steps) have been utilized as an approach in behavioral weight control to encourage the accumulation of lifestyle activity throughout the day.[49] While an official national guideline has not been established for steps, recommendations for a steps-based physical activity goal are often provided in behavioral weight control programs.[11,40,41,50] Promotion of a steps-based goal may be an effective public health strategy for weight management, particularly since walking is the most common mode of physical activity among adults,[51,52] and the increased musculoskeletal movement contributes to greater daily energy expenditure. The most recent edition of the national physical activity guidelines emphasizes that any time spent being physically active counts towards the overall weekly total of at least 150 minutes by removing the 10-minute bout requirement.[19] Accumulating steps throughout the day may be an effective means for individuals to reach national recommendations for health benefits. Furthermore, a step is a straightforward metric, and commercial physical activity devices are widely available to measure and monitor steps.[53,54] To maximize the benefits of physical activity for weight control and improved health, daily step goals are commonly prescribed in addition to goals for minutes of MVPA. Given the ubiquity of these approaches, it is necessary to understand how individuals adhere to the physical activity goals prescribed during treatment.

2.5 Adherence in Behavioral Weight Control

Success with weight loss during obesity treatment is consistently seen among those who adopt healthy lifestyle changes and are adherent to program goals. Higher

levels of adherence, or the extent to which an individual's behavior coincides with recommendations, are associated with greater weight loss. This relationship is noteworthy with regards to attainment of the prescribed physical activity goals during the initial 6 months of treatment. In the seminal Diabetes Prevention Program (DPP), participants randomized to the lifestyle intervention arm who met the prescribed goal for 150 minutes per week of MVPA on average, as measured via self-report, were twice as likely to meet the program's 7% weight loss goal at 6 months than those who did not meet the activity goal.[6] Adherence to physical activity in DPP, as well as the landmark Look AHEAD study, was found to be among the strongest correlates of weight loss, indicating those who engaged in at least 150 minutes per week of MVPA achieved the greatest weight losses.[55] Furthermore, adults in another clinical weight loss trial who attained the prescribed MVPA goals, which gradually increased to 150 minutes per week over the initial 6 weeks of intervention, achieved greater weight loss at 6 months compared to those who were not adherent to recommendations.[2] A similar relationship has also been reported between daily step counts and weight loss outcomes among adults participating in a standard behavioral weight loss intervention.[56] Individuals who achieved at least 10% weight loss were taking an average of 10,000 steps per day, and every additional 1,000 steps per day was associated with a 0.21 kg weight loss. Certainly, meeting program goals and public health recommendations is advantageous for weight loss success in behavioral weight control.

Despite the well-established association between greater adherence to behavioral recommendations for physical activity and weight loss, adherence remains a significant challenge. The majority of individuals participating in programs for lifestyle modification

do not attain the prescribed physical activity goals by 6 to 12 months of intervention, as evidenced by reports of nonadherence in the range of 50-80%.[2,15,57] For example, approximately one-third of individuals averaged at least 150 minutes per week of MVPA at 12 months in the Look AHEAD study.[57] Even fewer (20.8%) attained a minimum of 250 minutes per week, which is recommended for maintenance of weight loss.[45] The low adherence rates found by 12 months of treatment suggest this time period may be too late to provide support to, or "rescue", those who are not responsive to recommendations. Identification of declining adherence earlier in the treatment process may allow detection of critical points when rescue efforts may be most beneficial.

The early phase of treatment is an ideal period to evaluate adherence to physical activity for meaningful indicators of intervention responsiveness and to preempt behavioral decline. Based on average weight loss, those who responded favorably during the early phase of treatment were more likely to achieve and maintain clinically meaningful weight loss compared to those who did not respond favorably.[14] Indeed, a lack of meaningful weight loss as early as 2 to 8 weeks from initiating treatment predicted poor long-term outcomes 1 to 8 years later.[12,13] Early patterns of weight loss, characterized by modest, moderate-and-steady, and substantial-and-early, across the initial 12 weeks of a behavioral weight loss intervention among adults were predictive of weight loss outcomes at 3, 6, and 15 months, suggesting distinct weight loss patterns in the early period of treatment initiation present as reasonable indicators of future weight loss success.[58] However, associations between the three identified weight loss patterns and physical activity throughout the intervention remain unclear, as this study only examined baseline levels of physical activity. If patterns of adherence to physical activity

can be detected early on in treatment and demonstrate an association with weight loss, they may indicate potential targets for intervention.

The sharp decline in adherence among participants overall has been detected during the initial phase of treatment. For example, the proportion of individuals who met or exceeded the exercise goal for a given week, as determined by submitted paper diaries, rapidly deteriorated from an initial rate of approximately 75% down to 45% during the first 2 months of a standard behavioral weight loss program, particularly as MVPA goals progressively approached the national guidelines and overall program recommendations of 150 minutes per week.[15] The proportion of individuals meeting the weekly physical activity goal continued to steadily decline throughout the remainder of treatment, with approximately 30% and 15% adherent by 6 and 12 months, respectively. In another study which evaluated the proportion of individuals meeting weekly physical activity goals when self-monitoring via electronic diary and pedometer, results were similar, where the majority attained the goal initially, about half remained adherent after 2 months, and less than one-third met physical activity goals by 6 months of treatment.[2] These findings further demonstrate poor adherence may be particularly concerning in the early weeks of treatment.

To determine attainment of the prescribed physical activity goals, the behavior must be monitored. Self-monitoring, a key strategy used in behavioral treatment for weight management, allows an individual to evaluate how their behavior aligns with a desired goal.[59] More frequent self-monitoring of lifestyle behaviors, such as dietary intake and physical activity, is associated with improved self-regulation and weight loss outcomes.[60,61] Regarding adherence to weekly physical activity self-monitoring and

weight loss outcomes, individuals classified by high levels of physical activity self-monitoring (100%) via pedometer and electronic diary achieved greater weight loss at 6 months compared to those with low (< 50%) or no self-monitoring.[2] Higher frequency of self-monitoring physical activity using a paper diary has also been found to be predictive of greater weight loss, and some self-monitoring is associated with more weight loss than no self-monitoring.[62] Further, the change over time in the frequency of recording physical activity is suggested to better predict patterns of weight loss than the average frequency.[62] This may indicate an individual who increases the regularity of their monitoring is more likely to experience greater weight loss, whereas an individual who shifts from regular to infrequent monitoring may have less favorable outcomes. Collectively, these findings demonstrate the association between adherence to self-monitoring of physical activity behavior and weight loss outcomes. However, adherence to self-monitoring does not necessarily correspond to self-reported goal attainment. In other words, an individual may report some physical activity, but report at levels of physical activity which fall below the threshold required to meet the goal. Initial analyses of the relationship between physical activity goal attainment and eventual weight loss emphasize the need to illuminate patterns of goal attainment and identify strategies to assist individuals with meeting prescribed goals and achieve more favorable health outcomes.[63]

Identifying those who are more or less likely to meet a prescribed goal may guide tailored recommendations. Detecting these patterns early on in treatment may enable more individuals to adopt an active lifestyle for both immediate and long-term health benefits. However, inconsistencies in the measurement and report of adherence present a challenge in understanding the complexity of this phenomenon. There are substantial

differences in how adherence to physical activity has been reported (e.g., minutes of MVPA per week, steps per day, kilocalories expended, number of days of exercise/sessions attended, or number of self-monitoring records submitted).[5] Furthermore, mean values of adherence to the physical activity protocol are often reported at the group level, which fail to address questions of variability. Average adherence also does not allow detection of potentially meaningful patterns, or fluctuations, in behavior over time. Finally, studies examining either changes in adherence to self-monitoring physical activity or changes in adherence to the physical activity protocol alone may be incomplete since programs often include the combination of engaging in the behavior and monitoring the behavior. The correlation between these aspects should be accounted for by examining them together.[64] The differences in measurement and report of adherence to physical activity goals across studies restricts our ability to detect for whom recommendations are more or less effective, as well as potential underlying indicators which may be contributing to the sharp declines and variability in physical activity.

2.6 Characterizing Adherence Patterns in Behavioral Research

Latent class analysis (LCA) is a statistical model used to characterize individuals with distinct patterns of responses into meaningful, theoretically-relevant groups.[17,65,66] This person-centered approach has been used effectively to identify and compare health behavior clusters in observational and clinical trials of behavioral research, such as smoking cessation,[67] substance use,[68] academic achievement,[69] pubertal development,[70] and lifestyle behaviors.[71] LCA has also been applied to behavioral weight management interventions to examine underlying patterns of dietary and exercise behavior.[16,72] A

repeated-measures LCA was applied to two behavioral weight control trials for adults with hypertension and dyslipidemia during the first 6 months. Patterns were identified based on self-reported adherence to one physical activity goal prescribed as 180 minutes per week of MVPA and four dietary recommendations which targeted total fat, saturated fat, sodium, and fruit and vegetable intake.[16] Response patterns of goal adherence (i.e., whether each goal was met or unmet) resulted in the identification of distinct classes describing treatment responders and non-responders, which were also associated with weight loss. However, modeling the latent classes predominantly from dietary indicators leaves a gap in our understanding of how response patterns and interpretation of the classes may have emerged if physical activity adherence was the focus of the latent class model. Additionally, this study was limited to measurement of 7-day physical activity at baseline and 6 months and included only one type of activity (minutes per week of MVPA). More informative latent classes may result from including weekly measurement of adherence to minutes-based goals, as well as adherence to steps-based goals, which will advance the literature and clinical practice.

Nevertheless, greater weight loss was achieved among those who demonstrated greater behavioral changes in dietary intake and physical activity.[16] This research demonstrates the suitability of LCA in characterizing unique subgroups of individuals undergoing treatment for weight control based on how they respond behaviorally to recommendations. The current project will advance behavioral research using LCA through the identification of patterns of adherence specifically corresponding to commonly prescribed physical activity goals and their associations with weight loss outcomes. Uncovering patterns of physical activity behavior in relation to the physical

activity goals prescribed in a standard behavioral weight control program during the early period may elucidate the variability reported in physical activity participation and obesity treatment outcomes, offering opportunities to intervene early.

Multinomial logistic regression (MLR) is a tool which can be applied to further capture the variability in adherence between individuals.[18] MLR for correlated data with a categorical outcome of three or more categories is advantageous in determining the manner in which an individual exhibits a change in behavior between adjacent time points. For instance, in a previous study, logistic regression was applied to examine the likelihood of an individual's adherence level to dietary self-monitoring in a given week based on their adherence level in the preceding week among adults with overweight and obesity.[73] Adherence levels to dietary self-monitoring were categorized as adherent, suboptimally adherent, and nonadherent across separate phases of a behavioral weight control intervention. During the initial 2 months of treatment, individuals classified as suboptimally adherent in a given week had a higher probability of switching to fully adherent behavior than to nonadherent behavior the following week. Concurrently, individuals who were identified as nonadherent in a given week were more likely to remain nonadherent the following week rather than transition to a suboptimal or fully adherent status. This suggests that providing additional efforts to engage individuals who are making some behavioral changes early on in treatment, but are not fully meeting recommendations, may improve the likelihood that they will transition to a more adherent pattern of behavior rather than becoming nonadherent. It is also imperative to recognize when an individual is transitioning from an adherent status to a suboptimally adherent status in order to intervene before they are no longer engaged. While associations

between adherence level and weight loss were not reported, results of this study on dietary intake patterns point towards potential targets for individualized treatment to improve adherence to dietary self-monitoring. Further, a similar methodology applied to the physical activity domain warrants investigation.

The assessment of transitions in adherence to dietary self-monitoring serves as an effective model for exploring patterns of adherence to different types of prescribed physical activity goals and self-monitoring physical activity with finer granularity than has previously been reported. Patterns of self-monitoring dietary intake and the consistency of self-monitoring diet over time have been assessed,[73] but attainment of the prescribed dietary goal was not taken into account, nor were analyses extended to the physical activity domain. To our knowledge, no studies have examined the weekly changes in levels of adherence to multiple physical activity-related behaviors (i.e., attainment of the prescribed physical activity goals in conjunction with self-monitoring physical activity) by the type of physical activity goal (i.e., steps versus minutes of MVPA) across the first 6 months of a behavioral weight loss intervention. The comparison of transitions in adherence to steps-based goals versus minutes-based goals and self-monitoring of each type of activity over time will offer insight regarding the type of physical activity recommendation(s) individuals in behavioral weight control may be more likely to adopt, which can be applied to tailoring physical activity goals. Findings may also provide a meaningful description of the critical time points when rescue efforts may be most effective for improving long-term outcomes.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The dissertation project is a secondary analysis of an 18-month online behavioral weight control intervention for adults with overweight and obesity (iREACH^3; ClinicalTrials.gov identifier: NCT02688621). This chapter provides an overview of the iREACH^3 study and procedures, followed by a detailed description of the methodology used for the two studies that comprise this dissertation.

3.2 Overview of iREACH^3

The iREACH^3 study was a multi-site, randomized controlled trial investigating the effects of financial incentives on weight loss during an 18-month online behavioral weight control intervention in adults with overweight and obesity. The first 6 months of the program are the focus of this dissertation project and are described below. The Institutional Review Board at the University of South Carolina and the Committee on Human Research in the Behavioral Sciences at the University of Vermont approved this study. Written informed consent was provided by all participants.

3.2.a Participants and Enrollment

Individuals were recruited in eight cohorts between December 2015 to January 2018 from two clinical centers (South Carolina and Vermont) using a multi-faceted approach, including direct, community-based efforts (e.g., newsletters and flyers), targeted emails (e.g., distribution lists), and social media posts (e.g., Facebook). Eligible

individuals were required to have a body mass index (BMI; kg/m^2) between 25-50; be at least 18 years old; have access to a smartphone, computer, and the Internet; and have no medical contraindications to moderate intensity exercise (e.g., brisk walking). Individuals were excluded if they had a history of weight loss surgery; lost ≥ 10 lbs. in the previous 6 months; were taking medications that could affect weight (e.g., beta-blockers, corticosteroids, antipsychotics); had a recent cardiovascular event; were pregnant, breastfeeding, or planning to become pregnant during the study period; were enrolled in another weight control program; or lived over an hour from either study site.

Individuals who applied on the study website were screened by phone to determine potential eligibility. If likely eligible, they were invited to attend a group orientation session and, if interested in participating, consent was obtained. Following baseline assessment participants were cluster-randomized to receive either the online behavioral weight loss intervention enhanced by financial incentives or the online intervention alone. Those randomized to the behavioral intervention enhanced by financial incentives received monetary rewards for completing self-management behaviors during months 1-2 and for meeting weight loss goals at 2 and 6 months. Incentives were shown to promote behavior change and weight loss to a greater extent than the intervention without incentives.[74] Therefore, only data from participants randomized to the behavioral intervention alone were included in the proposed project.

3.2.b Behavioral Intervention Description

In brief, participants were provided with an online evidence-based, goal-directed behavioral weight control program grounded in theory (i.e., Social Cognitive Theory and Theory of Planned Behavior), which has been shown to be effective in previous

studies.[40,75] Intervention components included online synchronous group sessions; goals for weight loss, diet, and physical activity; self-monitoring; and feedback. Participants attended online group sessions delivered by a trained facilitator on a weekly basis for 6 months. Key strategies for behavior change included goal setting, self-monitoring, facilitator feedback, action planning, problem solving, relapse prevention, and social support.

All participants received weight loss, dietary, and physical activity goals. A weight loss goal of 10% of initial body weight was recommended. Calorie goals were tailored based on initial body weight and ranged from 1,200-1,800 kcals/day; fat gram goals corresponding to 25% calories from fat (33-50 g/day) were also provided. Physical activity goals were consistent for all participants, with goals prescribed for daily steps and minutes of MVPA each week. Table 3.1 provides a progression of the prescribed physical activity goals. During the initial 2 months, participants were instructed to gradually increase their daily steps from 7,000 to 10,000 steps per day and MVPA from 50 to 150 minutes per week. Goals for steps and MVPA increased on alternating weeks, allotting 2 consecutive weeks for a given goal. Starting in week 9, individuals were instructed to maintain a minimum of 10,000 steps per day and 200 minutes of MVPA per week and to maintain these targets for months 3 through 6 of the program. It should be noted that week 3 marked the first occurrence when recommendations for both physical activity goals were prescribed concurrently and, therefore, weeks 3 through 24 are the focus of the current study.

Participants self-reported their weight, whether they monitored their dietary intake (yes/no) and met their calorie goal that day (yes/no), and their physical activity (steps

acquired that day and minutes of planned MVPA) daily on the study website. In addition, they were asked to use a commercially available online self-monitoring diary (MyFitnessPal, UnderArmour, Inc.) to record their intake of all foods and beverages. Specific to physical activity monitoring, individuals were instructed to select their own preferred objective physical activity tracker (e.g., smartphone app, pedometer, or wearable activity tracker) prior to beginning the program and confirm their selection with study staff. The study recommended a reputable smartphone app (e.g., MyFitnessPal or Fitbit) if the individual did not identify their own physical activity tracker. Throughout the study period, participants were instructed to report their total number of steps daily on the study's website, as shown in Figure 3.1. They were also instructed to report their total number of exercise minutes daily (Figure 3.1). The study website allowed participants to make/update entries for a given day and the previous day only. Facilitators reviewed self-monitoring records and provided individuals with individualized, tailored feedback via email each week.

3.3 Measures

3.3.a Sociodemographic Characteristics

Participants reported their age, gender, race/ethnicity, education, employment status, and marital status at baseline via secure online questionnaire.

3.3.b Anthropometrics

Body weight was objectively measured by study staff at baseline, 2 months, and 6 months using a calibrated digital scale to the nearest 0.1 kg with participants wearing lightweight clothing and shoes removed. Absolute weight loss (in kilograms) and percentage of weight loss were calculated at 2 and 6 months relative to baseline. Height

was measured at baseline using a floor-based stadiometer and reported to the nearest 0.1 cm. BMI was calculated at baseline, 2 months, and 6 months as weight in kilograms divided by height in meters squared (kg/m^2).

3.3.c Physical Activity

Physical activity was measured by self-reported total number of steps and minutes of MVPA on the study website. Participants were instructed to enter the total number of steps taken and total minutes of MVPA performed, as monitored objectively by the activity tracker they selected prior to beginning the study, for each day of the study period. Participants were able to make entries or update an entry at any time for a given day, as well as the previous day; however, no entries could be made retrospectively beyond the previous day. Each week began on the day of the individual's scheduled group session, and all entries were date stamped. Self-reported physical activity data collected on the study website was used to determine adherence to the prescribed physical activity goals, as described in detail below for each study.

3.4 Study 1 Methodology

3.4.a Sample

Participants across the eight cohorts of iREACH[3] who were randomized to the behavioral intervention alone (*N*=212) were included in this study. Body weight data were obtained from 194 participants (92% of overall sample) at 2 months and 172 participants (81% of overall sample) at 6 months. These individuals were included in complete-case analyses for Specific Aims 1.2 and 1.3, respectively, in addition to intent-to-treat analyses using the full sample (*N*=212), as detailed in the statistical analysis section below.

3.4.b Measures

3.4.b.1 Treatment Engagement

Attendance at group sessions was documented weekly by the facilitator. Self-monitoring engagement was operationalized as the number of days an individual reported their weight, dietary intake (whether they self-monitored their dietary intake [yes/no] and whether they met their calorie goal [yes/no]), and physical activity (total steps and minutes of MVPA) on the study website.

3.4.b.2 Adherence to Physical Activity Goals

Weekly adherence was dichotomized for each type of physical activity goal: meeting the steps goals (yes/no) and meeting the minutes of MVPA goals (yes/no) based on the physical activity data reported on the study website. Inclusion of a partial goal attainment response option was considered; however, there is not currently an established threshold defining partial goal attainment to physical activity in terms of daily steps or minutes of MVPA and use of a non-standardized threshold has the potential to greatly influence the emergent latent classes and generalizability of the findings. Adherence to self-monitoring of physical activity (yes/no) was also considered for inclusion in the model as an observed variable, which could offer another layer of insight about behavior in the physical activity domain. However, there is a high correlation between self-monitoring and physical activity behavior (e.g., goal attainment). Thus, adherence to self-monitoring would be a redundant variable and unlikely to contribute additional meaningful information to the model. Inclusion of a redundant variable violates the local independence assumption of LCA due to within-cluster correlation, separation becomes an issue, and a lack of convergence may result. The selected approach to include

attainment of each of the physical activity goals without adherence to self-monitoring improves classification and precision of parameter estimates overall.

An index of the proportion of the steps goal achieved for each week was calculated by summing the total number of reported steps in a given week of the program and then divided by 7 days. This value was divided by the program goal for that week and multiplied by 100%. Participants were considered to have met the steps goal if their calculated proportion of the steps goal achieved that week was at or above 100% and not meeting the goal if the proportion was below 100%. A missing step-count entry was assumed to be zero for that day to accurately represent reporting behavior for daily steps and to avoid overestimating adherence. Since all steps were self-reported, they are subject to potential mis-estimation or entry error. Following the conventions of previous work, step counts less than 1,000 and greater than 30,000 were considered implausible or likely entry errors and were treated as missing (i.e., assumed to be zero).[76,77] To exemplify determination of adherence to steps-based goals, a participant reporting 42,800 total steps in week 4 when the program goal was 8,000 steps per day would have been classified as not meeting the steps goal, as calculated by the following: [(42,800 total steps that week / 7 days) / 8,000 steps per day] * 100% = 76%.

A similar procedure was applied to determine adherence to the minutes-based goals. Minutes of MVPA reported over the 7 consecutive days of a given week were summed, divided by the program MVPA goal, and multiplied by 100%. Participants were considered to have met the MVPA goal for that week if this proportion was at or above 100%. They were classified as not having met the goal for the week if this value was below 100%. Missing entries on any day were assumed to hold a value of zero.

Consistent with recommendations for handling potential mis-estimation or entry error from self-reported physical activity, minutes of MVPA in excess of 18 hours/day (or 1,080 minutes/day) were considered implausible and treated as missing. A value of zero was assumed in this instance.[78,79] Thus, in week 4 when the program goal was 50 minutes of MVPA, a participant reporting 60 minutes would have been classified as meeting the minutes of MVPA goal, as calculated by (60 minutes per week / 50 minutes per week) * 100% = 120%.

For clarification, it is possible that an individual could be discrepant in adherence status for steps versus minutes of MVPA in a given week. This is exemplified by the week 4 examples above in which the individual achieved 76% of the step goal and 120% of the minutes of MVPA prescribed. Here, the individual would be considered nonadherent for steps but adherent for minutes of MVPA.

We also calculated adherence using only days with submitted physical activity data to account for potential underestimation of true adherence from the aforementioned approach to handling missing data which assumed no physical activity occurred on a day if there was no self-monitoring record submitted. Therefore, the index of the proportion of the weekly steps goal achieved was divided by the number of days data were available rather than by 7 days. Combining these conservative and stringent approaches for characterizing physical activity goal adherence provides "bookends" of the true adherence and a fuller perspective on adherence.

3.4.c Statistical Analysis

Analyses were conducted using SAS version 9.4 (SAS Institute, Inc., Cary, NC) with a 0.05 level of significance. Descriptive statistics were used to summarize baseline

sociodemographic characteristics of the overall sample and of the emergent latent classes, reported as means and standard deviations for continuous variables and percentages for categorical variables. Markers of adherence, specifically the proportion of individuals meeting the physical activity steps-based goals and the minutes-based goals overall, number of days self-monitoring physical activity was completed, number of days of self-monitoring dietary intake was completed, number of days the weight-loss calorie goal was met, and proportion of group sessions attended, as well as change in body weight, were reported for the overall sample and for each emergent latent class, with comparisons made between the latent classes on these parameters. In standard behavioral weight control programs, participants are instructed to self-monitor dietary intake and physical activity as they aim to modify both lifestyle behaviors simultaneously, and both behaviors are associated with weight loss.[80,81] Therefore, report of dietary self-monitoring may provide additional information regarding potential synergistic effects.

The primary study obtained objectively measured body weight data for 92% and 81% of the overall sample at 2 and 6 months, respectively. Intent-to-treat analyses with multiple imputation was applied to handle missing weight data at each time point. This approach maintains the variability and overall sample size by pooling estimates from multiple datasets, which replace missing values with plausible values from available data after taking uncertainty into account, to avoid biasing inferences.[82] Alternative methods, namely single imputation, tend to bias parameter estimates by underestimating the variance and standard errors. Complete-case analysis was also implemented to allow comparison with results of analyses using the imputed data. To further inform inferences and generalizability of this study, the proportion of individuals who provided weight data

at 2 months and at 6 months, as well as those lost to follow-up at each time point, were reported.

3.4.c.1 Specific Aim 1.1:

A repeated-measures latent class analysis (LCA) was applied to identify subgroups of individuals with distinct patterns of adherence to weekly prescribed physical activity goals for steps and minutes of MVPA during the initial 8 weeks of treatment (PROC LCA version 1.3.2).[21-23] LCA is appropriate for determining the most prevalent, meaningful patterns of behavioral responses in the data over multiple observations in a single study, as has been demonstrated previously.[16] Importantly, LCA provides probability estimations for class membership and responses to specific items given class membership, while accounting for measurement error.[17] An advantage of LCA over alternative clustering methods, such as cluster analysis, is that LCA uses a probabilistic model to detect the underlying distribution of the responses rather than a measure of distance, and then separates similar response patterns into latent classes. Furthermore, LCA is a person-centered approach that examines categorical latent variables, as compared to factor analysis, which is a variable-centered technique applicable to continuous data. Latent trait analysis is a common technique applied to categorical variables; however, as with factor analysis, it is variable-centered. Finally, the aim of this study was to identify distinct subgroups that are currently unknown. Therefore, LCA is more suitable than logistic regression, which holds the assumption that classes are known.

For this study, two binary observed variables were used to inform the latent class models: (1) meeting the program steps goal (yes/no) and (2) meeting the program

minutes of MVPA goal (yes/no). These 4 distinct response options allowed discrimination between those who met one, both, or neither of the physical activity goals at each time point. Six time points (weeks 3-8) were used to capture the overall pattern in adherence to graded goals across the initial 2 months. According to standard LCA methods, a contingency table of the observed variables and responses across time was generated to depict all possible combinations of the adherence patterns with each cell containing the number of individuals who reported a certain pattern. To simplify the number of patterns displayed in the table, LCA detects the most prevalent patterns underlying the sample to inform meaningful latent classes. Summary statistics for models fit with 1 to 5 classes were inspected to guide model selection. These statistics included the likelihood-ratio test statistic (G^2), Akaike information criterion (AIC), and Bayesian information criterion (BIC). Best fit and parsimony were determined by lower AIC and BIC values, a statistically significant G^2, and the overall meaningfulness and interpretability of the response patterns derived from visual inspection. The resulting two sets of LCA parameters obtained from maximum likelihood estimation included the probabilities of latent class membership and the probabilities of being adherent conditional on latent class membership, which informed the interpretation and labeling of the latent classes. A threshold of 0.5 was used to determine the relevance of the probability of meeting the prescribed physical activity goal within a class, where <0.5 indicated low probability and ≥ 0.5 inferred high probability.[16]

Characteristics previously reported to be associated with adherence in lifestyle interventions for weight control (age, gender, race/ethnicity, education, employment status, marital status, and initial body weight and BMI) were then examined as predictors

of latent class membership using the three-step Bolck, Croon, and Hagenaars (BCH) method (LCA_Distal_BCH SAS macro version 1.1; http://methodology.psu.edu/).[83] The BCH method accounts for uncertainty from potential misclassification and is the recommended approach when examining covariates and outcomes of interest. Parameters in the LCA model are estimated (step 1), a weighting variable is then derived from the posterior probabilities of each latent class (step 2), and the weighted average of the variable of interest is calculated (step 3). Estimates of the expected values, standard errors, and confidence intervals for each variable were obtained within each class, and comparisons were made between classes using Wald chi-squared tests.

3.4.c.2 Specific Aim 1.2:

The BCH method was also applied to determine if distinct patterns of adherence to prescribed physical activity goals (defined by emergent latent classes over the initial 2 months of intervention) were associated with weight loss at 2 months (LCA_Distal_BCH SAS macro version 1.1). Analyses of completers (n=194, 92% of overall sample with available weight data at 2 months), as well as intent-to-treat, were conducted to examine changes in weight (kilograms and percentage). Intent-to-treat analyses with multiple imputation were carried out using SAS PROC MI. Based on the fraction of missing data at 2 months (0.08), 5 imputations were used, as is acceptable when missingness does not exceed 50%.[84] Once the 5 datasets with full weight data were created, they were analyzed separately via PROC LCA with distal outcomes. Results were then pooled and compared with the completers-only analysis.

3.4.c.3 Specific Aim 1.3:

The same statistical approach taken to address Specific Aim 1.2 was applied to determine if distinct patterns of adherence to prescribed physical activity goals (defined by emergent latent classes over the initial 2 months of intervention) were associated with weight loss at 6 months. A completers-only analysis (n=172, 81% of overall sample with available weight data at 6 months) was conducted, followed by intent-to-treat analyses with multiple imputation. The fraction of missing data at 6 months was 0.19 and, therefore, it five imputations was determined to be appropriate.[84] Results of the completers-only analysis were then compared with intent-to-treat outcomes.

3.5 Study 2 Methodology

3.5.a Sample

All participants randomized to the behavioral intervention alone were included in this study (*N*=212).

3.5.b Measures

3.5.b.1 Adherence to Physical Activity Goals

Data entered by participants on the study website were used to measure weekly adherence to the prescribed physical activity goals, which was dichotomized separately for each type of goal: steps per day (yes/no) and minutes of MVPA per week (yes/no). For steps, the total number of reported steps across 7 consecutive days of a given week was divided by 7 days. This value was then divided by that week's program steps goal and multiplied by 100%. The program steps goal was considered met if the proportion of steps was at least 100% of that week's prescribed goal; the goal was considered unmet if the proportion was less than 100%. A missing entry was assumed to be zero for that day.

To address implausible values or probable entry errors from self-reported physical activity, step counts less than 1,000 and greater than 30,000 were treated as missing and, thus, assumed to be zero.[76,77]

For minutes of MVPA, the total minutes of MVPA reported across 7 consecutive days of a given week were divided by the program MVPA goal and multiplied by 100%. The MVPA goal was considered met for that week if this proportion was at or above 100% of the prescribed program goal and unmet if it was below 100%. Minutes of MVPA exceeding 18 hours/day (or 1,080 minutes/day) were treated as missing and assumed to be zero.[78,79]

3.5.b.2 Adherence to Physical Activity Self-monitoring

Physical activity records entered by participants on the study website were used to determine adherence to self-monitoring (yes/no) independently for each type of physical activity goal: (1) steps per day and (2) minutes of MVPA per week. For steps, an individual was considered to have self-monitored steps for a given week if they submitted at least one record of any step count, including a value of zero. If no entry was submitted for steps on any of the 7 days, the individual was considered nonadherent to self-monitoring steps for that week. Similarly, for minutes of MVPA, an individual was considered to have self-monitored minutes of MVPA for a given week if they submitted at least one record of any number of minutes, including a value of zero. The individual was considered nonadherent to self-monitoring minutes of MVPA for that week if no entry is made for any of the 7 days. In other words, adherence to self-monitoring was determined based on whether or not an entry was submitted rather than the absolute value of the entry. The approach described here is consistent with previous work, which

categorized individuals as adherent if at least 1 record of any value of exercise minutes was submitted for a given week and nonadherent if no records were submitted.[81] Moreover, it is unlikely that an individual would have submitted self-monitoring records on all 7 days of each week during the entire study period. Defining adherence based on self-monitoring all 7 days would result in a significant loss of individuals who are suboptimally adherent or adherent, two of the three adherence categories which are described in detail below. Some self-monitoring of physical activity is associated with improved outcomes compared with no self-monitoring; therefore, defining adherence as at least 1 day of self-monitoring physical activity is a reasonable criterion.

3.5.b.3 Categorization of Groups

Within each type of physical activity goal, individuals were categorized into three mutually-exclusive categories for each consecutive week: (1) "adherent" if they met the goal and self-monitored, (2) "suboptimally adherent" if they did not meet the goal, but did self-monitor, and (3) "nonadherent" if they did not self-monitor, as outlined in Tables 3.2 and 3.3 for steps and minutes of MVPA, respectively. The definitions for "adherent", "suboptimally adherent", and "nonadherent" were selected in parallel with established categories for levels of aerobic physical activity and their relationship to the degree of health benefits obtained.[19] According to the national guidelines, adults are categorized as active/highly active when 150 minutes or more per week of MVPA are accrued, "insufficiently active" when some MVPA but less than 150 minutes per week is accrued, and inactive if no MVPA is accrued. Numerous cut-points have been used to categorize activity levels based on steps;[85] however, there is not currently a standard threshold. The decision to base adherence to both types of activity (i.e., steps and minutes of MVPA) on

the categories defined by the national guidelines for MVPA provides consistency in classification for this study.

It was assumed that those who did not self-monitor also did not meet the physical activity goal for that week, which is consistent with others examining adherence to physical activity goals.[6] It is possible the prescribed goal was met despite the individual not self-monitoring the activity, and the correlation between adherence to the goal and adherence to self-monitoring is acknowledged. There was also the potential for inaccurately categorizing more individuals as "suboptimally adherent" or "nonadherent" when they were in fact "adherent" due to the conservative assumption that the physical activity goal was not met if no self-monitoring occurred. However, goal attainment could not be determined without self-monitoring records.

3.5.c Statistical Analysis

All analyses were performed in SAS 9.4 (Cary, N.C.) at a 0.05 alpha level of significance. Descriptive analyses were conducted to characterize the sample, and frequencies were determined for the number of individuals meeting physical activity goals and self-monitoring physical activity each week. Marginal proportions of physical activity adherence categories ("adherent", "suboptimally adherent", and "nonadherent") were tabulated separately for each type of physical activity goal: (1) steps and (2) minutes of MVPA. Transition probabilities of adherence status ("adherent", "suboptimally adherent", and "nonadherent") were also summarized by type of physical activity goal using parallel approaches, as depicted in Figure 3.2. Each model began at week 3, which is when recommendations for both physical activity goals were first prescribed concurrently, and continued through the end of the 6-month period (week 24).

Furthermore, models were conditioned on the probability of maintaining the same adherence status or transitioning to another status in one week based on adherence status in the preceding week.

Multinomial logistic regression (MLR) for correlated data was used to determine the weekly transitional probabilities of adherence to different types of prescribed physical activity goals and physical activity self-monitoring. MLR is the standard technique for conducting robust analyses of longitudinal data with categorical outcomes of three or more predefined categories and modeling changes in patterns over time,[18] and this approach has been applied previously to patterns of adherence to self-monitoring dietary intake to inform behavioral transitions across different phases of intervention among adults participating in obesity treatment.[73] MLR fitted to a first-order Markov chain model provides estimates of the transitional probabilities between adjacent time points (e.g., the likelihood of meeting a goal and/or self-monitoring in one week given the level of adherence the previous week) and assumes the level of adherence in a given week is conditional on the level of adherence in the previous week. Advantages of MLR for correlated data over mixed models include more flexible distributional assumptions (i.e., non-normal distributions), consideration of within-individual correlations, and unbiased estimates of parameters and standard errors regardless of whether the correlation structure is accurately specified. Generalized estimating equations (GEE) were considered as an approach; however, GEE only provides estimates of marginal probabilities and lacks a likelihood function, which would not allow inferences to be made based on transitions between two adjacent time points or based on likelihood. Modeling transitions via Markov chain overcomes the limitations of GEE.[18]

3.5.c.1 Specific Aim 2.1:

Two separate regressions modeling the likelihood of being "adherent", "suboptimally adherent", or "nonadherent" were investigated based on the type of physical activity goal prescribed: (1) steps and (2) minutes of MVPA. For weekly transitional probabilities of adherence to prescribed daily steps and adherence to self-monitoring daily steps (Specific Aim 2.1), we first modeled the odds of transitioning into a less adherent status across all 22 equidistant time points (weeks 3-24). Then, analyses were repeated by physical activity goal phase (graded goal phase and fixed goal phase). The graded goal phase was defined by the odds of transitioning into a less adherent status when goals progressed incrementally during weeks 3-8. The fixed goal phase was defined by the odds of transitioning into a less adherent status when the goals remained the same across weeks 9-24.

3.5.c.2 Specific Aim 2.2:

Parallel to the abovementioned model for steps-based goals, the weekly transitional probabilities of adherence to prescribed minutes of MVPA and adherence to self-monitoring minutes of MVPA (Specific Aim 2.2) were modeled using MLR. Transitions in adherence status were first examined over the entire study period, followed by the graded goal phase and the fixed goal phase.

3.5.c.3 Specific Aim 2.3:

To address Specific Aim 2.3, comparisons were made between the model for steps-based goals versus the model for minutes-based goals on the odds of transitioning into a less adherent status across all time points, during the graded goal phase, and during the fixed goal phase.

3.6 Strengths and Limitations

There are several limitations of this dissertation project that should be taken into consideration. First, participants self-reported their physical activity, which has the potential for bias.[86,87] Individuals tend to overestimate physical activity when using self-report measures, partly due to recall and social desirability bias. When making an entry, participants may not have remembered the precise number of minutes they exercised that day or the previous day or mistyped their step count or minutes of exercise. Reporting may also have been influenced by participants knowing the facilitator would view activity records each week. Furthermore, it is unknown how physical activity-related content in the facilitator's individualized feedback email may have influenced attainment of the program goal or self-monitoring behavior. However, it is worth noting participants were instructed to measure steps and minutes of MVPA with an objective device and report their activity on a daily basis to minimize these concerns. Baseline physical activity was not measured in the primary study and, therefore, could not be accounted for in the current study. Missing data for physical activity and body weight are also a limitation. For physical activity data, it is unknown if participants engaged in activity or met the prescribed goals if they did not submit a self-monitoring record. Rather than excluding cases when individuals did not report any steps or minutes of MVPA, assuming no activity occurred provides a conservative approach to measuring adherence by reducing the potential for biased estimates from missing data and overestimation of activity, while also retaining the full sample and maintaining greater statistical power. The proportion of days physical activity was self-monitored during the study period were reported to provide additional information regarding these estimates. For weight data, the

primary study achieved high retention rates at 2 and 6 months (92% and 81%, respectively). To improve the validity and generalizability of inferences from this study, missingness was handled using intent-to-treat analyses with multiple imputation and compared with complete-case analyses. Finally, the statistical approach taken in Study 2 predicted an individual's level of adherence to the prescribed goal and self-monitoring conditional only on the level of adherence in the immediately preceding week and, therefore, the influence of other time points on a given week's adherence status could not be determined. Nevertheless, the approach selected provided a preliminary examination of adherence to physical activity goals and self-monitoring using MLR for correlated data.

Despite these limitations, this study is strengthened by the robust longitudinal dataset of self-reported physical activity engagement and body weight measures in a large, regionally diverse sample of adults with overweight and obesity participating in a lifestyle weight control program. Use of the non-experimental condition (i.e., participants randomized to the behavioral intervention only) improves generalizability, as this behavioral program was adapted from well-established weight management programs, such as DPP and Look AHEAD. These data address a cutting-edge research question about behavioral typologies associated with physical activity among individuals in behavioral obesity treatment. The application of more detailed statistical techniques to identify patterns in adherence to physical activity goals based on daily/weekly accrual and reporting of physical activity strengthens the significance of this study. Interpreting latent classes, as well as transitional probabilities as they relate to adherence to physical activity goals and self-monitoring in the context of behavioral weight management, using

meaningful descriptors has immediate relevance to clinicians and practitioners making recommendations for lifestyle modification in this population. This research also advances findings from previous work reporting patterns in self-monitoring physical activity and dietary behaviors to better understand the effects of goal attainment in conjunction with self-monitoring in the physical activity domain. Examination of different types of physical activity goals commonly prescribed in behavioral weight control interventions offers insights for goal operationalization, progression, and timing.

Table 3.1 Progression of program physical activity goals across 6 months

	Steps goals		**MVPA goals**
Week	(Daily)	(Weekly)	(Weekly)
1	No goal prescribed	No goal prescribed	No goal prescribed
2	7,000	49,000	No goal prescribed
3	7,000	49,000	50
4	8,000	56,000	50
5	8,000	56,000	100
6	9,000	63,000	100
7	9,000	63,000	150
8	10,000	70,000	150
9 – 24	10,000	70,000	200

Note: MVPA = moderate-to-vigorous physical activity (in minutes); week 3 corresponds with the first occurrence of concurrent recommendations for both physical activity goals.

Table 3.2 Categorization of groups for steps model

Week	Adherent	Suboptimally Adherent	Nonadherent
3	≥7,000 steps (≥100%) + ≥1 day of self-monitoring	1 to 6,999 steps (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
4-5	≥8,000 steps (≥100%) + ≥1 day of self-monitoring	1 to 7,999 steps (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
6-7	≥9,000 steps (≥100%) + ≥1 day of self-monitoring	1 to 8,999 steps (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
8-24	≥10,000 steps (≥100%) + ≥1 day of self-monitoring	1 to 9,999 steps (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring

Table 3.3 Categorization of groups for minutes of MVPA model

Week	Adherent	Suboptimally Adherent	Nonadherent
3-4	≥50 minutes (≥100%) + ≥1 day of self-monitoring	1 to 49 minutes (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
5-6	≥100 minutes (≥100%) + ≥1 day of self-monitoring	1 to 99 minutes (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
7-8	≥150 minutes (≥100%) + ≥1 day of self-monitoring	1 to 149 minutes (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
9-24	≥200 minutes (≥100%) + ≥1 day of self-monitoring	1 to 199 minutes (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring

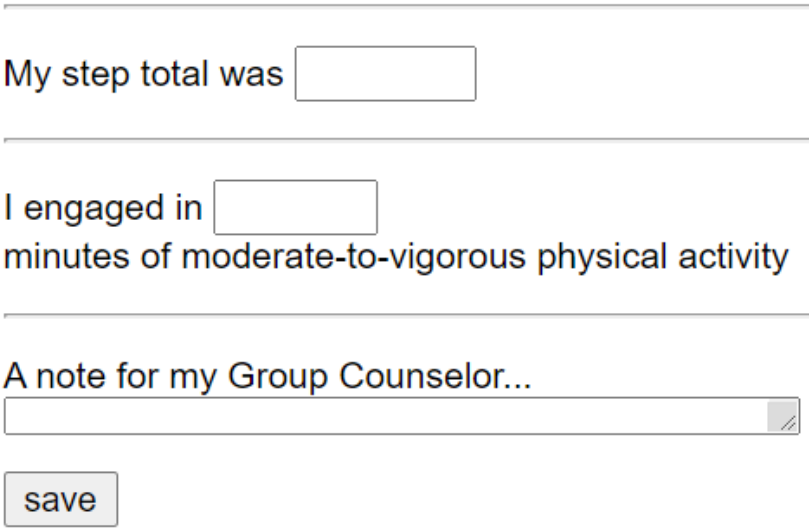
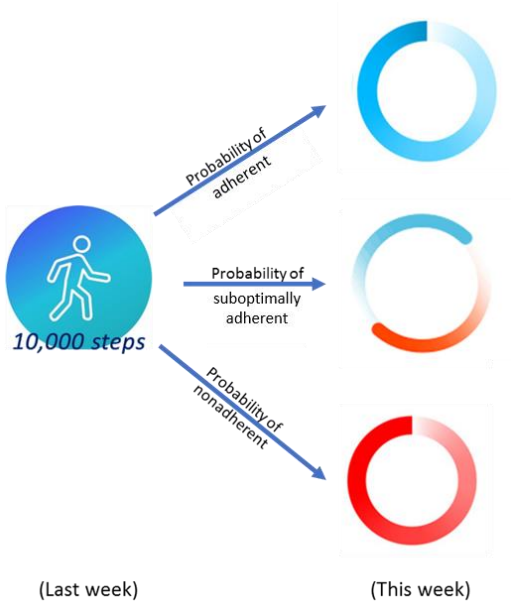


Figure 3.1 Study website entry form for daily physical activity.

(A) Model for steps-based goals



(B) Model for minutes-based goals

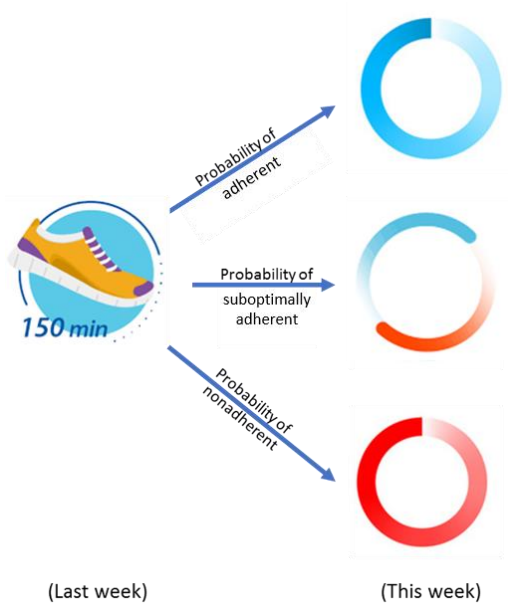


Figure 3.2 Abbreviated models illustrating the structure of transition probabilities of physical activity adherence status in one week given adherence status the previous week. (A) Model for steps-based goals; (B) model for minutes-based goals.

CHAPTER 4

DISTINGUISHING EARLY PATTERNS OF PHYSICAL ACTIVITY GOAL ATTAINMENT IN ONLINE BEHAVIORAL OBESITY TREATMENT[1]

[1] Stansbury ML, Harvey J, Krukowski R, Pellegrini C, Wang X, and West D. To be submitted for publication.

4.1 Abstract

Introduction: Weight loss response and adherence to behavioral recommendations, particularly physical activity (PA), vary substantially across individuals in lifestyle programs. While weight loss in the initial 4-8 weeks is shown to predict future weight loss, it is unclear what distinguishes those who respond to treatment from those who do not respond. Detecting early response indicators, such as poor adherence to PA, may provide targets for treatment tailoring. This study characterized individuals with distinct patterns of weekly adherence to prescribed steps-based and minutes-based PA goals during the first 8 weeks of an online behavioral weight loss intervention and determined whether these early adherence patterns were associated with sociodemographic characteristics, 6-month weight loss, and/or treatment engagement parameters.

Methods: Participants in the iREACH^3 study received an online behavioral weight loss intervention consisting of weekly group-based chat sessions, goals for calorie reduction and increased physical activity, and daily self-monitoring. Patterns of adherence to weekly goals for steps and minutes of moderate-to-vigorous physical activity (MVPA) were examined using repeated-measures latent class analysis. For each week, participants were considered adherent if the goal was met (≥ 100%) or nonadherent if the goal was unmet (< 100%) based on PA self-monitoring records. Adherence was considered separately for steps and minutes of MVPA goals. Body weight was objectively measured at baseline, 2 months, and 6 months. Weekly attendance at group intervention chat sessions, as well as daily self-monitoring and meeting calorie goals, were recorded.

Results: PA goal adherence among participants (N=212; 91.5% female, 31.6% racial minority, mean age of 47.9 ± 11.1 years, mean BMI of 35.8 ± 5.9 kg/m^2) clustered into

three unique subgroups: 27.3% had a high probability of consistently meeting both weekly PA goals ("Both PA Goals" class), 28.4% were estimated to meet the MVPA goals while never meeting the steps goals ("MVPA Goals Only" class), and the majority (44.3%) had the lowest probability of meeting either goal at any time ("Neither PA Goal" class). Members of the "Both PA Goals" class had significantly greater weight loss at 6 months (estimated mean weight loss [95% CI]: -9.4% [7.4, 11.5]) compared to the "MVPA Goals Only" class (-4.8% [3.4, 6.1]) and the "Neither PA Goal" class (-2.5% [1.4, 3.6]). The "Neither PA Goal" class was least likely to attend group sessions, self-monitor their weight, dietary intake, or PA, or meet their calorie goal. The "MVPA Goals Only" class self-monitored significantly less than the "Both PA Goals" class but was similar in attendance and meeting calorie goals.

Conclusions: Individuals at risk of poorer weight loss outcomes can be detected based on their pattern of attaining the prescribed PA goals within 2 months of program initiation. Therefore, distinct patterns of early PA goal adherence may signal potential targets for optimizing interventions with more effective PA strategies.

Keywords: Physical activity, Weight loss, Goal attainment, Adherence, Latent Class Analysis (LCA)

4.2 Introduction

Poor adherence to lifestyle programs and substantial variability of weight loss responses are persistent challenges in obesity treatment. Weight loss of 5-10% mitigates many obesity-related health conditions and, on average, lifestyle programs that combine dietary change and physical activity are successful in reaching this threshold.[38-41] Indeed, increased levels of physical activity are reliably associated with greater initial weight loss

and weight-loss maintenance. Yet, a considerable number of individuals fail to adhere to behavioral recommendations, particularly for physical activity. Standard programs generally provide the same exercise goals to all participants, which often increase in a linear fashion to at least 150 minutes per week of moderate-to-vigorous physical activity (MVPA), and also recommend increases in lifestyle activity (e.g., accumulate 10,000 steps per day). However, nonadherence to program physical activity goals can range from 50-80% by 6 to 12 months.[2,15,57] Thus, nonadherence greatly reduces the likelihood of these individuals reaching clinically meaningful weight losses and gaining health benefits associated with a physically active lifestyle. If we can identify who does or does not engage in recommended levels of physical activity earlier on in the treatment process, efforts can be made to provide timely support and improve outcomes for those individuals who may not be on a path to success.

An individual's weight loss response during the first 4 to 8 weeks of obesity treatment is predictive of their future weight loss.[88] Thus, it appears that those who will be most successful with weight control over the long term might be identified early on in program initiation. Ultimately, changes in behavior underlie changes in body weight, which raises the question as to whether early adherence to recommendations for behavioral modification contributes to weight loss response. Only a few studies have endeavored to distinguish weight loss responders and non-responders based on adherence during the initial weeks of treatment.[16,88-90] Markers of program adherence routinely include self-monitoring, session attendance, and dietary intake. However, operationalizing early nonadherence based on these more traditional metrics has proven difficult to this point, particularly since standard thresholds have not been established.[57,60]

Notably, the role of adherence to the program physical activity goals during program initiation on weight loss response has been largely unexplored.

It has been suggested that early adherence to physical activity may follow a similar pattern over time to that of weight loss response.[91,92] For instance, adults with overweight and obesity who met program recommendations for MVPA by 8 weeks of a lifestyle program were three times more likely to meet the national guidelines of 150 minutes per week of MVPA at 12 months compared to those who failed to meet the 8-week goal. [90,92] It is possible that those who achieve the physical activity goals early in the program may be better prepared to engage in higher levels of physical activity necessary for greater weight loss, as well as to maintain their weight loss over the long term. Should attainment of physical activity goals during the initial early period of a behavioral weight loss program also be predictive of eventual weight loss, it may provide a useful indicator of those at higher risk of poor obesity treatment outcomes and suggest a target for early behavioral intervention.

To date, the factors that differentiate individuals who go on to respond successfully to treatment from those with poor outcomes during this early period of treatment are not well understood. Classifying clinically relevant subgroups of individuals based on their adherence to program physical activity goals could further elucidate the variability reported in physical activity adherence and weight loss response. Recommendations for lifestyle modification may then be targeted more effectively to improve adherence and an individual's trajectory for successful weight loss outcomes. Therefore, the purpose of this study was to characterize individuals with distinct patterns of weekly adherence to physical activity goals prescribed in steps and in minutes of

MVPA during the initial 8 weeks of a behavioral weight loss intervention and determine whether these early adherence patterns were associated with 6-month weight loss, sociodemographic characteristics, and parameters of treatment engagement.

4.3 Methods

4.3.a Study Design

This study was a longitudinal analysis of an online, group-based behavioral weight control program (iREACH^3) designed to investigate the effects of financial incentives on weight loss.[74] Participants were cluster-randomized to receive 1) the online behavioral weight loss intervention enhanced by financial incentives or 2) the online behavioral intervention alone. iREACH^3 was a collaboration between the University of South Carolina (UofSC) and the University of Vermont (UVM), which was approved by the Institutional Review Board at UofSC and the Committee on Human Research in the Behavioral Sciences at UVM, respectively. All participants provided written informed consent.

4.3.b Participants

Individuals were recruited in cohorts by each clinical center between December 2015 to January 2018 using community-based efforts, targeted emails, and social media posts. Interested individuals were invited to apply through an online recruitment portal and were then followed up with a phone screening call to determine eligibility. Eligibility criteria included being at least 18 years old; having a body mass index (BMI) between 25-50 kg/m^2; and access to a smartphone, computer, and the Internet. Individuals were excluded if they had a medical contraindication to moderate intensity exercise (e.g., brisk walking); a recent cardiovascular event; history of weight loss surgery; recent weight loss

of 10 lbs. or more; were taking medications that could affect weight or were enrolled in another weight control program; were pregnant, breastfeeding, or planning to become pregnant; or lived over an hour of travel from either study site.

If eligible, individuals were invited to attend a group orientation session at which they provided informed consent. A baseline assessment was then conducted, followed by randomization to either the online, group-based behavioral weight control intervention alone or the online intervention enhanced with financial incentives. The current analyses were conducted using data from participants randomized to the behavioral intervention alone (i.e., the control group).

4.3.c Program Overview

A description of iREACH^3 has been previously reported.[74] In brief, all participants received an evidence-based, goal-directed behavioral weight control program, which included online, text-based synchronous group sessions delivered by a trained facilitator weekly for 6 months. Key strategies for behavior change included goal setting, self-monitoring, facilitator feedback, action planning, problem solving, relapse prevention, and social support. Participants were provided with a 10% weight loss goal, dietary goals of 1,200, 1,500, or 1,800 calories per day (25% from fat) based on their initial weight, and physical activity goals which progressed to 10,000 steps per day and 200 minutes of MVPA per week.

4.3.c.1 Physical activity goals

All participants received the same weekly program physical activity goals provided in terms of daily steps and minutes of MVPA with the goals gradually increasing each week, as outlined in Table 4.1. The current study focuses on weeks 3 to 8

of the program; week 3 is the first occasion when participants received both steps-based and minutes-based physical activity goals. The 8-week mark coincides with objectively measured body weight and is a timepoint consistent with previous early response research.[88]

4.3.c.2 Self-monitoring and feedback

Participants were also instructed to electronically self-report their body weight, dietary intake (indicating whether they completed detailed monitoring of their food and beverage intake in MyFitnessPal and whether they met their calorie goal), and physical activity (total steps and minutes of MVPA) daily on the study website. Participants used their own preferred objective physical activity tracker, such as a smartphone app (e.g., MyFitnessPal), pedometer or other wearable activity tracker (e.g., Fitbit) to track their activity. Facilitators reviewed self-monitoring records and provided individuals with tailored feedback via email each week.

4.3.d Measures

4.3.d.1 Sociodemographic characteristics

At baseline, participants reported their age, gender, race/ethnicity, education, employment status, marital status, and geographic region via secure online questionnaire.

4.3.d.2 Anthropometrics

Body weight at baseline, 2 months, and 6 months was measured at the clinical center on a calibrated digital scale to the nearest 0.1 kilogram. Absolute weight loss (in kilograms) and percentage of weight loss were calculated at 2 and 6 months relative to baseline. Height was measured at baseline using a floor-based stadiometer and reported

to the nearest 0.1 cm. BMI was calculated at each time point as weight in kilograms divided by height in meters squared (kg/m^2).

4.3.d.3 Treatment engagement

Group session attendance was documented by the facilitator weekly. Self-monitoring engagement was operationalized as the number of days an individual reported their weight, physical activity (total steps and minutes of MVPA), and dietary intake (whether they self-monitored their dietary intake [yes/no] and whether they met their calorie goal [yes/no]) on the study website.

4.3.d.4 Adherence to physical activity goal

Individuals were classified as meeting the daily steps goals (yes/no) and the weekly MVPA goals (yes/no) based on the physical activity data they reported on the study website. An index of the proportion of the steps goal achieved for each week was calculated by summing the total number of reported steps in a given week of the program and then divided by 7 days. This value was divided by the program goal for that week and multiplied by 100%. Participants were considered to have met the steps goal if their calculated proportion of the steps goal achieved that week was at or above 100% and not meeting the goal if the proportion was below 100%. Missing step count entries were assumed to be zero for that day. Step counts less than 1,000 and greater than 30,000 were considered implausible or likely entry errors and were treated as missing (i.e., assumed to be zero).[76,77]

Similarly, weekly adherence to the MVPA goal was calculated as a proportion of the stated program goal for that week. Minutes of MVPA reported over the 7 consecutive days of a given week were summed, divided by the program MVPA goal, and multiplied

by 100%. Participants were considered to have met the MVPA goal for that week if this proportion was at or above 100%. They were classified as not having met the goal for the week if this value was below 100%. It was assumed that individuals did not perform any MVPA on a day when an entry was missing. In addition, a daily report of MVPA in excess of 18 hours/day (or 1,080 minutes/day) was considered implausible and treated as missing (i.e., assumed to be zero).[78,93]

Adherence was also calculated using only days with submitted physical activity records to account for potential underestimation of true adherence from the aforementioned approach to handling missing data which assumes no physical activity occurred on a day if no self-monitoring record was submitted. Therefore, the index of the proportion of the weekly steps goal achieved was divided by the number of days data were available rather than by 7 days. Combining these conservative and stringent approaches for characterizing physical activity goal adherence provides "bookends" of the true adherence and a fuller perspective on adherence.

4.3.e Statistical Analysis

Descriptive statistics were used to summarize baseline sociodemographic characteristics, retention, and adherence measures of the sample. A repeated-measures latent class analysis (LCA) was applied to identify subgroups of individuals by distinct patterns of adherence to weekly prescribed physical activity goals for steps and minutes of MVPA during the initial 8 weeks of treatment (PROC LCA version 1.3.2).[94-96] The 8-week mark aligns with previous work examining early weight loss response,[12-14] as well as the first objective assessment of weight. Classification of 1) meeting the program steps goal (yes/no) and 2) meeting the program minutes of MVPA goal (yes/no) across 6 time

points (weeks 3-8) were used to inform the latent class models. To detect the most prominent patterns of adherence to each goal over time, models were fit for 1 to 5 classes and summary statistics were compared to guide model selection. Best fit and parsimony were determined by comparing the models by Akaike information criterion (AIC), Bayesian information criterion (BIC), entropy, and overall meaningfulness and interpretability of the response patterns. Two sets of parameter estimates for each latent class were obtained to further inform interpretation and labeling of the latent classes: 1) the probability of class membership and 2) the probability of meeting each of the weekly physical activity goals, given class membership. A threshold of 0.5 was used to determine the relevance of the probability of meeting the prescribed physical activity goal within a class, where < 0.5 indicated low probability and ≥ 0.5 inferred high probability.[16] That is to say, probabilities closer to one indicated individuals were more likely to meet the weekly goal and probabilities closer to zero indicated they were less likely to meet the goal. Analyses were first performed by assuming no physical activity was completed on days when a self-monitoring record was not submitted. Then, a sensitivity analysis was conducted modeling 1-5 classes with classification of meeting the steps goals (yes/no) and meeting the MVPA goals (yes/no) determined using only days when physical activity was reported. In this analysis, zero values were not assumed for days without self-monitoring reports. Instead, reported data were prorated for the number of days data was provided to obtain a more generous picture of adherence to the PA goals.

After selection of the optimal model, subgroups were compared on sociodemographic characteristics, weight loss outcomes, and treatment engagement parameters to further differentiate and characterize latent class membership

(LCA_Distal_BCH SAS macro version 1.1; http://methodology.psu.edu/).[83] The Bolck, Croon, and Hagenaars method (BCH) was applied to estimate associations between latent classes and each variable of interest (i.e., sociodemographic characteristic, weight loss outcome, and engagement with each treatment component) in separate models. The BCH method estimates parameters in the LCA model (step 1), derives a weighting variable from the posterior probabilities of each latent class (step 2), and calculates the weighted average of the variable of interest (step 3). Estimates of the expected values, standard errors, and confidence intervals for each variable were obtained within each class, and comparisons were made between classes using Wald chi-squared tests. The BCH method accounts for uncertainty from potential misclassification and is the recommended approach when examining covariates and outcomes of interest. Analyses of completers (i.e., only those with available body weight data), as well as intent-to-treat, were applied to examine changes in weight (kilograms and percentage) at 2 and 6 months. Intent-to-treat analyses with multiple imputation were conducted using SAS PROC MI. Five datasets with full weight data were created and analyzed separately via PROC LCA with distal outcomes. Results were pooled and compared with the completers-only analysis.

All analyses were conducted with SAS version 9.4 (SAS Institute, Inc., Cary, NC) and a 0.05 level of significance.

4.4 Results

4.4.a Sample Characteristics

Participants (*N*=212) were predominantly middle-aged women with obesity (mean BMI = 35.8 kg/m^2), and approximately one-third self-identified as belonging to a racial/ethnic minority group. Most had at least a college degree and were employed full

time, with half living in the Northeastern region of the U.S. and half in the Southeast (Table 4.2).

In the first weeks, 85-90% of individuals provided daily self-monitoring information, and self-monitoring rates remained above 77% through week 8, as shown in Table 4.3. One third of the sample achieved the targeted number of steps in the first week of having both steps and MVPA goals (week 3), followed by 11.8% meeting the steps goal by week 8 of the program. In contrast, 70.3% of participants met the initial MVPA goal. Although the proportion meeting the MVPA goal decreased over time as the target minutes of MVPA increased, 30.7% of the sample met the physical activity minute goal by the end of the 8 weeks, and 47.6% were still self-monitoring their minutes of MVPA but were not meeting the weekly goal.

4.4.b Latent Classes of Physical Activity Adherence Patterns

LCA models of one to five latent classes were assessed and revealed the three-class model to be optimal (Table 4.4). Best fit and parsimony were evident in the three-class model, which had the lowest BIC (600), an AIC that was substantially lower than the two-class model (473 vs. 572), good class separation (entropy = .86), and high posterior probabilities (i.e., the probability of membership in a specific latent class; mean = .93). Examination of the parameter estimates further revealed the model with three classes was the most relevant and were used to inform interpretation and labeling of the classes (Table 4.4).

Approximately 28.4% of individuals in the overall sample were estimated to be members of latent class 1, which depicted a pattern of meeting the weekly goal for minutes of MVPA during the weeks when goals were at or below 100 minutes but not

meeting the recommended total minutes once the goal progressed to 150 minutes. This class also displayed a pattern of never meeting the goal for steps. Thus, latent class 1 was labeled “MVPA Goals Only”. Latent class 2 emerged with 44.3% of individuals estimated to be members. Those belonging to class 2 exhibited a low probability of meeting either physical activity goal in any given week (all probabilities <.5), and consequently, the class was labeled “Neither PA Goal”. Finally, 27.3% of individuals were estimated to be in latent class 3 and followed a pattern of adherence to both physical activity goals across all time points, with the exception of falling short of meeting the 10,000-steps goal in week 8. Accordingly, this class was labeled “Both PA Goals” (Figure 4.1).

A subsequent LCA using the weekly average of only days with submitted physical activity data was conducted for models with one to five latent classes as a sensitivity analysis. Results using this operationalization of adherence also indicated the three-class model was the most appropriate (Table 4.5). Patterns of weekly adherence to the physical activity goals among the latent classes using this liberal approach to characterizing adherence were consistent with those detected in the LCA which assumed no physical activity occurred on days when records were missing.

4.4.c Predictors of Latent Class Membership

Sociodemographic characteristics further distinguished the latent classes (Table 4.6). Individuals in the “Both PA Goals” and “MVPA Goals Only” classes were significantly more likely to be older than those in the “Neither PA Goal” class (p=.0480 and p=.0074, respectively). Males had a significantly higher probability of being a member of the “Both PA Goals” class versus the “Neither PA Goal” class (p=.0442).

Those who self-identified as a racial/ethnic minority were approximately 2 times as likely to be a member of the "Neither PA Goals" class compared to the "Both PA Goals" class (p=.0499) and 2.3 times as likely to be a member of the "MVPA Goals Only" class compared to the "Both PA Goals" class (p=.0173), with no significant differences between "Neither PA Goals" and "MVPA Goals Only". Geographic region was also a statistically significant predictor of the latent classes; individuals living in the Northeast vs. the Southeast were about 2.5 times as likely to be a member of the "Both PA Goals" class relative to the "Neither PA Goal" class (p=.0341) and "MVPA Goals Only" class (p=.0098). Lastly, individuals in the "Neither PA Goal" class had a significantly higher BMI at study entry compared to the "MVPA Goals Only" class (p=.0122); however there were no significant differences in baseline BMI between the "Neither PA Goal" class and "Both PA Goals". Education, marital status, and employment status were not predictive of membership in latent classes of physical activity goal adherence.

4.4.d Associations Between Latent Class Membership, Retention and Weight Loss

Overall, retention to weight measurement outcome visits was high, with weight data available for 194 (92%) and 172 (81%) individuals at 2 and 6 months, respectively (Table 4.7). The "Neither PA Goal" class had a higher proportion of individuals missing weight data at 2 months (14%) and 6 months (35%) compared to the "MVPA Goals Only" class (5% at 2 and 6 months) and "Both PA Goals" class (0% at 2 months; 7% at 6 months).

At 2 months, individuals in the "Both PA Goals" class lost significantly more weight compared to those in the "MVPA Goals Only" class (mean difference [SE] = -2.1% [.6], p=.0006) and the "Neither PA Goal" class (-3.9% [.6], p<.0001) (Table 4.7).

The "MVPA Goals Only" class also lost significantly more weight than the "Neither PA Goal" class at 2 months (mean difference [SE] = -1.8% [.4], $p<.0001$). At 6 months, significant differences remained between all three latent classes. The "Both PA Goals" class experienced greater weight losses compared to the "MVPA Goals Only" (mean difference [SE] = -4.7% [1.3], $p=.0004$) and "Neither PA Goal" (mean difference [SE] = -6.9% [1.2], $p<.0001$) classes. The mean difference in weight loss between the "MVPA Goals Only" and "Neither PA Goal" classes was -2.3% [1.0] ($p=.0187$). Weight loss trajectories are depicted in Figure 4.2. Results of intent-to-treat analyses using multiple imputation for weight change data (data not shown) were consistent with the completers-only analyses reported here, which suggests the robustness of our findings.

4.4.e Associations Between Latent Class Membership and Treatment Engagement

Engagement patterns across the latent classes were consistent overall with weight loss outcomes (Table 4.8). On average, the "Neither PA Goal" class attended significantly fewer weekly group sessions (5.4 out of 8) compared to the "Both PA Goals" and "MVPA Goals Only" classes (7.3 and 7.1, respectively). The "Neither PA Goal" class also submitted about half the number of physical activity records as the "Both PA Goals" and "MVPA Goals Only" classes, on average. The proportion of days individuals self-monitored their body weight and dietary intake followed a similar pattern to that of physical activity self-monitoring. Additionally, the "Both PA Goals" class reported meeting their calorie goal during 59% of the 8-week period, followed closely by individuals in the "MVPA Goals Only" class (55%), while the "Neither PA Goal" class indicated meeting their calorie goal only 27% of the time. For self-reported physical activity, members of the "Both PA Goals" class reported approximately twice the number

of daily steps as those in the "MVPA Goals Only" and "Neither PA Goal" classes and accumulated an average of 200 minutes per week of MVPA. Within each of the classes, the average number of daily steps and minutes of MVPA appeared unchanged across all weeks (Figure 4.3). Lastly, the proportion of individuals who submitted physical activity self-monitoring records were consistently above 95% from week-to-week among the "Both PA Goals" and "MVPA Goals Only" classes, while the "Neither PA Goal" class demonstrated an overall trajectory of decline, with a peak of 77% in week 4 to 53% by week 8 (Figure 4.4).

4.5 Discussion

The current study demonstrates the salience of physical activity goal attainment as an early marker of program adherence and weight loss success in the context of behavioral weight control. Contrasting patterns of program goal attainment emerged with a class regularly achieving the weekly goals ("Both PA Goals") and another consistently falling below the physical activity targets ("Neither PA Goals"). Furthermore, a class of individuals meeting only the MVPA goals until the recommendation progressed to 150 minutes per week was also detected ("MVPA Goals Only"). Notably, the "Both PA Goals" and "MVPA Goals Only" classes were not dramatically different in their adherence to self-monitoring, attendance at group sessions, or reporting that they met their calorie goals. Instead, the primary distinction between the two classes was in their achievement of the physical activity recommendations. Thus, the more traditional adherence metrics,[97] such as self-monitoring, session attendance, and dietary intake, would have failed to distinguish these classes, whereas the physical activity patterns did set them apart from one another. Against the backdrop of greater weight losses in the

"Both PA Goals" class compared to the other two classes, the pattern of adherence to the physical activity goals during the early period of a lifestyle program emerges as a key factor in the trajectory of success.

The emergence of these three subgroups suggests the trajectory of adherence to physical activity goals during the initial 8 weeks of treatment is predictive of who will be most successful with weight loss. Our findings align with prior research of early response to obesity treatment, which indicates success can be predicted from weight loss response within the first 4-8 weeks of program initiation.[13,14,58,89,98] Individuals who displayed a pattern of early, substantial weight loss had the highest likelihood of experiencing clinically meaningful weight losses more than a year later relative to those with minimal response.[58] Further, a recent study observed that 40.7% of individuals ("early non-responders") failed to meet the program goal of at least 75 minutes of MVPA at 8 weeks and were unlikely to reach exercise goals in the long term.[91] The current study extends these findings by suggesting an individual's response to meeting one or both physical activity goals in the initial 8 weeks predicts the magnitude of their eventual weight loss. Specifically, if an individual starts out meeting both steps-based and minutes-based goals, they have the highest probability of achieving clinically meaningful weight losses at 6 months. In contrast, individuals who fall short of both physical activity goals early in treatment are at greatest risk of poor weight loss outcomes. Therefore, distinct patterns of physical activity goal attainment in the early period of obesity treatment likely present as reasonable indicators differentiating treatment responders and non-responders, as well as offering potential targets for intervention.

In the current study, the "MVPA Goals Only" and "Both PA Goals" classes would likely have appeared similarly engaged had the more traditional cluster of adherence metrics been used to inform the latent classes rather than physical activity goal attainment. Previous studies of lifestyle behaviors which utilize latent class analysis to detect subgroups with distinct adherence patterns have included parameters from multiple behavioral domains, which makes it challenging to determine how adherence to a specific behavior may relate to treatment response.[16,71,72,99] The unique contribution of specific adherence parameters, like physical activity goal attainment, may be obscured when adherence measures are clustered together to form a picture of overall engagement. Therefore, almost 30% of individuals who were bordering the physical activity recommendation thresholds and at risk of suboptimal responses may have gone undetected since all other signs suggested they were engaged and adherent to the treatment program. By modeling the latent classes on adherence to physical activity goals, we have illuminated the value of this underutilized marker of adherence, as well as identified a window of opportunity within the early weeks of intervention to provide additional or different support for those who are at risk of slipping below the recommended physical activity goals.

Lifestyle programs often prescribe goals in terms of both minutes of MVPA and daily step counts, resulting in two sets of physical activity recommendations. Steps goals proved to be less likely to be met than minutes goals, even early in the program. For example, in week 3 when both physical activity goals were first prescribed concurrently, 70% of individuals met the 50-minute MVPA goal, while only one-third of individuals (also the peak proportion relative to all other weeks) met the 7,000-steps goal. This was

surprising since steps could be accumulated throughout the day at any intensity, steps are a straightforward metric to track, and walking is the most common mode of activity in adults enrolled in a behavioral weight control program. The question arises as to whether the graded steps goals provided were overly ambitious. Participants were recommended to take 7,000 steps per day as their first steps goal and increase by 1,000 steps every two weeks, regardless of their actual daily step totals. The average adult takes around 5,000 steps per day,[100,101] so an additional 2,000 steps would result in traveling 1 to 2 more miles daily. Although the initial goals provided mirror those used in many successful weight control programs,[1,38,39] they may have been too lofty for many individuals in this population and contributed to early failure, which was difficult to overcome. According to goal-setting theory,[102-104] realistic goals that are challenging, yet attainable, contribute to increased effort, persistence, and self-efficacy. However, goals that are too far-reaching have the opposite effect, often leading to a lack of goal attainment. An individualized goal prescription, such as one that accounts for initial physical activity levels and progresses based on recent activity, may be a more effective approach to increasing physical activity goal attainment by improving self-efficacy and facilitating mastery experiences.[105-107]

The average amount of self-reported physical activity during this 8-week period was a distinguishing factor between the subgroups. Essentially, the "Both PA Goals" class reported high activity totals, followed by more moderate levels in the "MVPA Goals Only" class, and low activity totals among the "Neither PA Goals" class members. Upon further exploration, we found that the intervention did not appear to have increased steps or minutes of MVPA in a substantive way from week-to-week within each of the

classes. Even those most successful at regularly meeting recommended thresholds were not increasing their activity; rather, they initially reported relatively high levels and stayed fairly consistent. In other words, how members of a class started out in week 3 with respect to the two physical activity goals was how they finished at week 8. While it is unclear if the self-reported activity at week 3 reflects a true increase in response to the first program goals or was a continuation of an individual's baseline level (and thus, no change in activity), our findings provoke consideration as to whether lifestyle interventions that provide general, programmatic goals are potent for increasing physical activity. Personalized and adaptive goals provided to adults with overweight/obesity participating in physical activity interventions have been shown to increase activity[105-108] and may be a promising approach to increase MVPA and steps totals in the context of behavioral weight control. Investigating this question with objective measures of physical activity at baseline and over the early weeks may also provide more clarity and guidance for shaping recommendations.

This study found that individuals meeting both goals also achieved the best weight losses, which highlights the need to reevaluate how best to frame physical activity goals (i.e., in terms of steps, minutes, or both) to optimize lifestyle interventions for weight loss. No studies to our knowledge have directly compared minutes of MVPA, steps, and combined goals on physical activity levels or weight loss and, therefore, our study offers preliminary data to help inform adaptive interventions and guide refinement of best practices. While individuals who meet both MVPA minutes and steps goals were far more likely to be successful, lifestyle programs that include both physical activity goals should be aware that only about one fourth meet them, meaning nearly 75% do not

hit the combined goals. This generates a tension in how best to accommodate individuals at either end of the adherence spectrum. Adaptive physical activity goals offer a pragmatic approach to assist those who fail to achieve the physical activity goals with more realistic personalized targets, while also continuing to challenge individuals who are successful with increasing their activity to maintain a highly active lifestyle, to enhance the likelihood individuals remain successful in being physically active over time. Ultimately, our findings call attention to the importance of determining necessary parameters for physical activity goals; what behavioral target(s) should be prescribed, when goals should be provided, and whether initial goals should differ across participants all remain major considerations without strong empirical evidence to guide selection of these parameters.

The identification of subgroups with patterns of adherence that appear to emerge early on may suggest a broader behavioral phenotype that underlies the consistently observed discrepancies in obesity prevalence and weight loss based on sociodemographic characteristics, such as age, gender, race/ethnicity, and geographic region.[55,109,110] Notably, individuals in the "Neither PA Goals" class were more likely to be younger, female, identify as a racial/ethnic minority, live in the Southeast, and have a higher BMI at study entry. These findings build on previous research that has shown identifying as white, male, older, and having a lower initial BMI predict success with program activity goal attainment over the short and long term.[6] There is also indication in the early weight loss response literature that weight loss non-responders are more likely to be younger and female compared to responders.[90] Our work advances the literature by offering additional clues as to which non-modifiable individual characteristics pair with distinct modifiable

behavioral patterns (i.e., early adherence to physical activity goals), allowing for more precise targeted support during program initiation.

There are several limitations of this study, including the use of self-reported physical activity, which has the potential for bias and is typically less accurate than objective measures of MVPA.[86,87] Additionally, baseline physical activity was not measured and, therefore, cannot be accounted for in the current study. When data were missing (i.e., a participant did not self-report), it could not be determined whether the prescribed goal was met, and the goal was assumed to be unmet. Our secondary analysis of adherence to physical activity goals based only on days with reported physical activity data reflected similar patterns to our analysis that assumed the goal was unmet if it was not self-monitored, which gives us greater confidence in the patterns detected. Future research would benefit from analyses of latent classes using objectively measured and continuously monitored physical activity, which also account for baseline activity levels and would not be subject to the same issues with missing data. Finally, the sample consisted primarily of middle-aged, well-educated females and may not generalize to populations who are younger, older, or identify as male.

Despite these limitations, this study is strengthened by the robust longitudinal dataset from a large and otherwise diverse sample of adults with overweight and obesity. In addition, the high proportion of participants providing objectively measured weight data at 2 and 6 months and determination of latent classes using an established online weight management program improve the validity and generalizability of inferences from this study. Examination of two sets of physical activity recommendations using a latent class approach begins to address the need to disentangle the effects of steps-based and

minutes-based goals in the context of behavioral weight control to inform goal operationalization, progression, and timing.

In conclusion, a latent class analysis of adherence to weekly physical activity goals prescribed in steps and minutes of MVPA as part of a comprehensive online behavioral weight control program revealed three distinct subgroups of adults with overweight/obesity: “Both PA Goals”, “MVPA Goals Only”, and “Neither PA Goal”. Factors differentiating these classes include race/ethnicity, geographic region, age, gender, and BMI at study entry, as well as engagement in other treatment components, such as self-monitoring and group session attendance. Furthermore, latent class membership was significantly associated with weight losses at 2 and 6 months, indicating that those who do not meet prescribed physical activity goals during the initial 8 weeks are at highest risk of poorer treatment outcomes. Detection of these early adherence patterns and the characteristics that distinguish the subgroups emphasize a need to identify individuals behaviorally at risk for failure and determine the most appropriate recommendations to improve their trajectory for success. These data address a cutting-edge research question about behavioral typologies associated with physical activity among individuals in behavioral obesity treatment and may serve as useful indicators of early treatment response with immediate relevance to clinicians and practitioners making recommendations for lifestyle modification in this population.

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Table 4.1 Progression of prescribed physical activity goals

	Steps goals		**MVPA goals**
Week	(Daily)	(Weekly)	(Weekly)
1	No goal prescribed	No goal prescribed	No goal prescribed
2	7,000	49,000	No goal prescribed
3	7,000	49,000	50
4	8,000	56,000	50
5	8,000	56,000	100
6	9,000	63,000	100
7	9,000	63,000	150
8	10,000	70,000	150
9 – 24	10,000	70,000	200

Note: MVPA = moderate-to-vigorous physical activity (in minutes); week 3 corresponds with the first occurrence of concurrent recommendations for both physical activity goals.

Table 4.2 Baseline sociodemographic characteristics of overall sample

Characteristic	*N* = 212
Age (years), M ± SD	47.9 ± 11.1
Gender, n (%)	
Female	194 (91.5)
Male	18 (8.5)
Race/ethnicity, n (%)	
White	145 (68.4)
Minority^	67 (31.6)
Education, n (%)	
College degree or higher	169 (79.7)
Some college or less	43 (20.3)
Marital status, n (%)	
Married or living as married	118 (55.7)
Single or not married	94 (44.3)
Employment status, n (%)	
Employed full time	152 (71.7)
Employed part time or unemployed	60 (28.3)
Geographic region, n (%)	
Northeast (Vermont)	106 (50.0)
Southeast (South Carolina)	106 (50.0)
BMI (kg/m^2), M ± SD	35.8 ± 5.9

Note: Values presented as means ± standard deviations or frequencies (percentages);
^ minority groups include African American, Asian, Hispanic, and Pacific Islander.

Table 4.3 Proportion of individuals who provided self-monitoring and met physical activity goals each week

	Week					
	3	4	5	6	7	8
Steps	73 (34.4)	45 (21.2)*	43 (20.3)	35 (16.5)*	31 (14.6)	25 (11.8)*
MVPA	149 (70.3)*	149 (70.3)	111 (52.4)*	97 (45.8)	68 (32.1)*	65 (30.7)
Both^	70 (33.0)	45 (21.2)	40 (18.9)	32 (15.1)	25 (11.8)	19 (9.0)
Steps	110 (51.9)	145 (68.4)*	140 (66.0)	141 (66.5)*	137 (64.6)	141 (66.5)*
MVPA	34 (16.0)*	40 (18.9)	71 (33.5)*	79 (37.3)	100 (47.2)*	101 (47.6)
Steps	29 (13.7)	22 (10.4)*	29 (13.7)	36 (17.0)*	44 (20.8)	46 (21.7)*
MVPA	29 (13.7)*	23 (10.9)	30 (14.2)*	37 (17.5)	43 (20.3)*	47 (22.2)

Note: Values presented as frequencies (percentages) of individuals out of overall sample. MVPA = moderate-to-vigorous physical activity; * indicates program physical activity goal increased that week; ^ individuals in "Both" are also included in "Steps" and "MVPA".

Table 4.4 Summary statistics for LCA models of 1-5 latent classes of adherence to physical activity goals, assuming physical activity goal unmet on non-reported days (*N*=212)

# of latent classes	**# of parameters estimated**	**Log-likelihood**	***G²***	***df***	**AIC**	**BIC**	**Entropy**
1	12	-1427.67	1238.05	4083	1262.05	1302.33	1.00
2	25	-1069.50	521.73	4070	571.73	655.64	.91
3	38	-1007.02	396.76	4057	472.76	600.31	.86
4	51	-983.08	348.89	4044	450.89	622.07	.87
5	64	-968.33	319.38	4031	447.38	662.20	.85

3-class model	**Class 1: *MVPA Goals Only***	**Class 2: *Neither PA Goal***	**Class 3: *Both PA Goals***
Latent class prevalence (SE)	.28 (.06)	.44 (.04)	.27 (.05)
*Probability (SE) of meeting PA goal**			
Week 3: Steps	.25 (.10)	.07 (.03)	**.89** (.06)
MVPA	**.89** (.05)	.41 (.06)	**.98** (.02)
Week 4: Steps	.06 (.10)	.01 (.01)	**.70** (.07)
MVPA	**.94** (.04)	.38 (.06)	**.98** (.02)
Week 5: Steps	.09 (.05)	.00 (.00)	**.64** (.09)
MVPA	**.83** (.10)	.10 (.04)	**.90** (.07)
Week 6: Steps	.05 (.06)	.00 (.00)	**.55** (.08)
MVPA	**.67** (.09)	.07 (.03)	**.87** (.07)
Week 7: Steps	.01 (.04)	.00 (.00)	**.53** (.09)
MVPA	.39 (.08)	.02 (.02)	**.74** (.10)
Week 8: Steps	.03 (.03)	.00 (.00)	.40 (.08)
MVPA	.39 (.08)	.00 (.00)	**.71** (.08)
Posterior probability	.89	.96	.95

Note: G^2 = likelihood-ratio test statistic; *df* = degrees of freedom; AIC = Akaike information criterion; BIC = Bayesian information criterion; Entropy: range = 0-1. Shaded bar indicates selection of the optimal model. * Values shown as probabilities (standard errors) for "Yes" responses (i.e., the prescribed physical activity goal was met for that week). Probability of meeting goal > .5 in bold for interpretation.

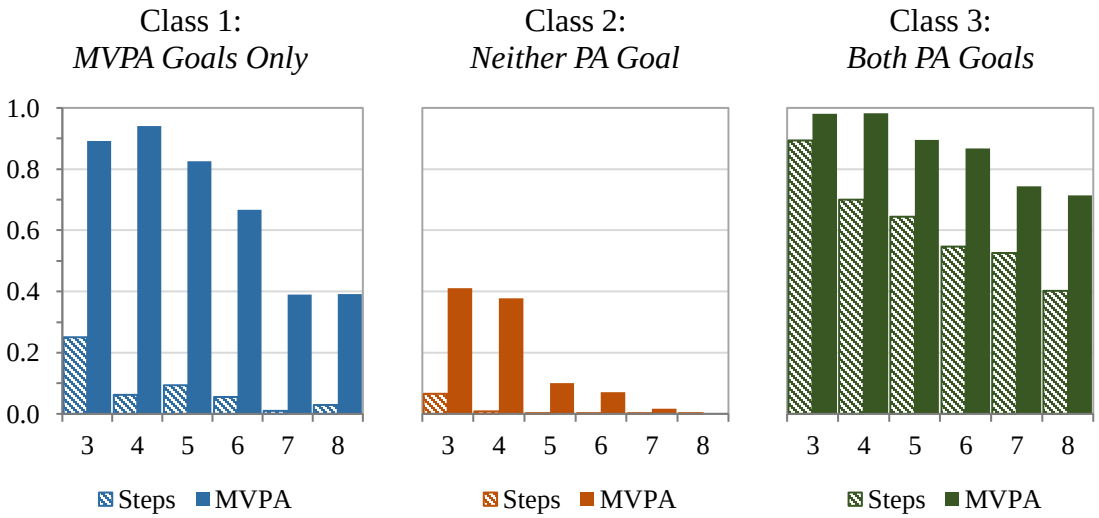


Figure 4.1 Probability of meeting weekly prescribed physical activity goals given membership in latent class (*N*=212).

Table 4.5 Summary statistics for sensitivity analysis of LCA with models of 1-5 latent classes of adherence to physical activity goals using only days with reported physical activity data (*n*=196)

# of latent classes	# of parameters estimated	Log-likelihood	G^2	*df*	AIC	BIC	Entropy
1	12	-1344.47	1100.99	4083	1124.99	1164.33	1.00
2	25	-1081.25	574.53	4070	624.53	706.49	.88
3	38	-1027.06	466.17	4057	542.17	666.73	.81
4	51	-996.02	404.08	4044	506.08	673.26	.86
5	64	-980.61	373.27	4031	501.27	711.07	.87

3-class model		**Class 1: *Neither PA Goal***	**Class 2: *MVPA Goals Only***	**Class 3: *Both PA Goals***
Latent class prevalence (SE)		.37 (.05)	.34 (.06)	.29 (.04)
*Probability (SE) of meeting PA goal**				
Week 3:	Steps	.13 (.06)	.47 (.08)	**.95** (.03)
	MVPA	**.58** (.07)	**.92** (.04)	**.96** (.03)
Week 4:	Steps	.07 (.04)	.23 (.06)	**.91** (.05)
	MVPA	.19 (.07)	**.95** (.04)	**.95** (.03)
Week 5:	Steps	.11 (.06)	.29 (.08)	**.92** (.05)
	MVPA	.19 (.07)	**.76** (.08)	**.92** (.06)
Week 6:	Steps	.03 (.03)	.14 (.06)	**.85** (.05)
	MVPA	.13 (.05)	**.73** (.09)	**.83** (.06)
Week 7:	Steps	.04 (.04)	.17 (.06)	**.82** (.06)
	MVPA	.03 (.03)	**.51** (.08)	**.65** (.07)
Week 8:	Steps	.02 (.02)	.09 (.04)	**.78** (.07)
	MVPA	.01 (.02)	.49 (.08)	**.68** (.07)
Posterior probability		.94	.88	.93

Note: G^2 = likelihood-ratio test statistic; *df* = degrees of freedom; AIC = Akaike information criterion; BIC = Bayesian information criterion; Entropy: range = 0-1. Shaded bar indicates selection of the optimal model. * Values shown for the 3-class model as probabilities (standard errors) for "Yes" responses (i.e., the prescribed physical activity goal was met for that week). Probability of meeting goal > .5 in bold for interpretation.

Table 4.6 Effects of sociodemographic characteristics on probability of latent class membership

Characteristic	**Class 1: *MVPA Goals Only*** (n=60; 28.3%)	**Class 2: *Neither PA Goal*** (n=94; 44.3%)	**Class 3: *Both PA Goals*** (n=58; 27.4%)
Age (years)	50.8 [47.7, 53.9][a]	45.2 [42.9, 47.6][b]	49.0 [46.1, 52.0][a]
Gender			
Female	.94 [.87, 1.0][ab]	.95 [.90, .99][a]	.84 [.74, .94][b]
Race/ethnicity			
Minority^	.42 [.28, .56][a]	.34 [.24, .44][a]	.18 [.07, .28][b]
Education			
College degree or higher	.86 [.76, .96]	.73 [.64, .82]	.84 [.75, .94]
Marital status			
Married or living as married	.53 [.39, .67]	.51 [.40, .62]	.66 [.53, .79]
Employment status			
Employed full-time	.79 [.68, .91]	.66 [.57, .76]	.72 [.60, .84]
Geographic region			
Northeast	.44 [.30, .58][a]	.44 [.33, .54][a]	.67 [.54, .80][b]
BMI (kg/m^2)	34.2 [32.5, 35.9][a]	37.0 [35.8, 38.3][b]	35.4 [33.9, 36.8][a]

Note: Values for age and BMI presented as estimated means [95% confidence intervals]. Values for gender, race/ethnicity, education, marital status, employment status, and geographic region presented as estimated probabilities [95% confidence intervals].
^ Minority groups include African American, Asian, Hispanic, and Pacific Islander.
[a, b, c] Different letters for a characteristic denote significant differences between classes at $p < .05$.

Table 4.7 Estimated mean weight losses for latent classes at 2 months and 6 months among completers

Weight loss	**Class 1:** ***MVPA Goals Only***	**Class 2:** ***Neither PA Goal***	**Class 3:** ***Both PA Goals***
	(n=57)	(n=81)	(n=58)
2 months (kg)**	-3.1 [2.5, 3.7]	-1.5 [1.0, 2.1]	-5.5 [4.3, 6.7]
2 months (%)**	-3.4 [2.8, 4.0]	-1.6 [1.0, 2.1]	-5.5 [4.5, 6.4]
	(n=57)	(n=61)	(n=54)
6 months (kg)*	-4.2 [3.0, 5.5]	-2.4 [1.3, 3.4]	-9.6 [7.2, 12.0]
6 months (%)*	-4.8 [3.4, 6.1]	-2.5 [1.4, 3.6]	-9.4 [7.4, 11.5]

Note: Values presented as estimated means [95% confidence intervals]. All between-class comparisons statistically significant at 2 months (***p*'s < .001) and at 6 months (**p*'s < .05).

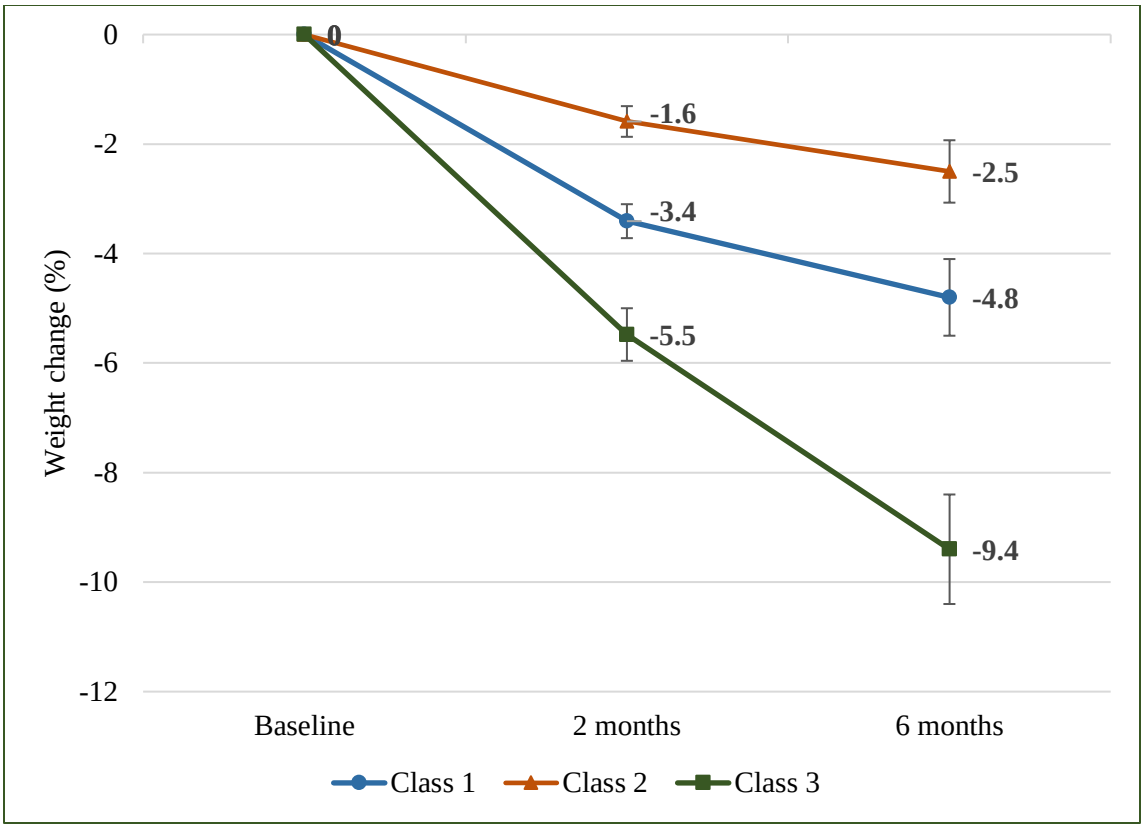


Figure 4.2 Percentage of weight loss by latent class at 2 and 6 months among completers. Bars represent the standard error of the mean. Class 1: "MVPA Goals Only", Class 2: "Neither PA Goal", Class 3: "Both PA Goals".

Table 4.8 Treatment engagement during weeks 1-8 overall and by latent class

	Overall (*N*=212)	**Class 1: *MVPA Goals Only*** (n=60)	**Class 2: *Neither PA Goal*** (n=94)	**Class 3: *Both PA Goals*** (n=58)
	M ± SD	M [95% CI]	M [95% CI]	M [95% CI]
Attendance				
Number of sessions attended (out of 8)*	6.4 ± 1.9	7.1 [6.9, 7.4][a]	5.4 [4.9, 5.8][b]	7.3 [7.1, 7.5][a]
Proportion of sessions attended (out of 8)*	79.9 ± 23.7	89.0 [85.6, 92.4][a]	67.0 [60.8, 73.1][b]	91.5 [88.7, 94.4][a]
Self-Monitoring				
Number of days no self-monitoring (weeks 1-2)†	3.3 ± 3.8	2.1 [1.4, 2.8][a]	5.5 [4.6, 6.4][b]	1.0 [.5, 1.6][c]
Number of days no self-monitoring (weeks 3-8)‡	14.8 ± 13.9	7.6 [5.5, 9.7][a]	26.0 [23.1, 28.9][b]	4.0 [2.6, 5.3][c]
Number of days no self-monitoring (weeks 1-8)*	18.1 ± 16.9	9.7 [7.1, 12.3][a]	31.5 [27.9, 35.0][b]	5.0 [3.4, 6.5][c]
Body weight, number of days reported*	33.3 ± 16.1	39.2 [36.1, 42.3][a]	20.7 [17.3, 24.0][b]	45.9 [43.5, 48.3][c]
Body weight, proportion of days reported*	59.4 ± 28.8	69.9 [64.4, 75.5][a]	36.9 [30.9, 42.9][b]	81.9 [77.6, 86.2][c]
Dietary intake, number of days reported*	36.7 ± 16.0	43.7 [40.8, 46.5][a]	23.8 [20.4, 27.2][b]	49.2 [47.5, 50.9][c]
Dietary intake, proportion of days reported*	65.6 ± 28.5	78.0 [72.9, 83.1][a]	42.5 [36.5, 48.5][b]	87.8 [84.8, 90.8][c]
Met calorie goal, number of days reported*§	24.8 ± 14.3	30.7 [27.0, 34.5][a]	14.9 [12.3, 17.6][b]	33.0 [30.0, 36.0][a]
Met calorie goal, proportion of days reported*§	44.3 ± 25.5	54.9 [48.1, 61.6][a]	26.7 [22.0, 31.3][b]	58.9 [53.6, 64.3][a]
Steps, number of days reported‡	28.8 ± 11.9	33.1 [31.1, 35.2][a]	18.8 [15.9, 21.6][b]	37.7 [36.3, 39.0][c]
Steps, proportion of days reported‡	68.5 ± 28.4	78.9 [73.9, 83.9][a]	44.6 [37.9, 51.4][b]	89.7 [86.5, 92.9][c]
MVPA, number of days reported‡	28.2 ± 11.9	32.9 [30.8, 35.0][a]	18.0 [15.2, 20.8][b]	37.1 [35.7, 38.4][c]
MVPA, proportion of days reported‡	67.2 ± 28.4	78.4 [73.4, 83.4][a]	42.8 [36.2, 49.4][b]	88.3 [85.1, 91.5][c]

Self-reported physical activity				
Steps, steps/day on days when steps reported‡	7302 ± 3011	6514 [5830, 7197][a]	5629 [5006, 6251][a]	10383 [9914, 10852][b]
Steps, steps/day with missing assumed 0 steps‡	4804 ± 3431	5018 [4511, 5524][a]	1928 [1519, 2338][b]	9259 [8751, 9768][c]
MVPA, mins/week on days when MVPA reported‡	112 ± 87	130 [115, 145][a]	34 [27, 41][b]	201 [179, 223][c]
MVPA, mins/week with missing assumed 0 mins‡	104 ± 89	130 [115, 145][a]	28 [21, 34][b]	201 [179, 223][c]

Note: Values for overall sample presented as means ± standard deviations. Values within classes presented as estimated means [95% confidence intervals] or estimated proportions [95% confidence intervals]. * Indicates adherence measure out of 56 days (weeks 1-8); † indicates adherence measure out of 14 days (weeks 1-2); ‡ indicates adherence measure out of 42 days (weeks 3-8); § calorie goal assumed unmet if no self-report provided. [a, b, c] Different letters for a treatment engagement parameter denote significant differences between classes at $p < .05$

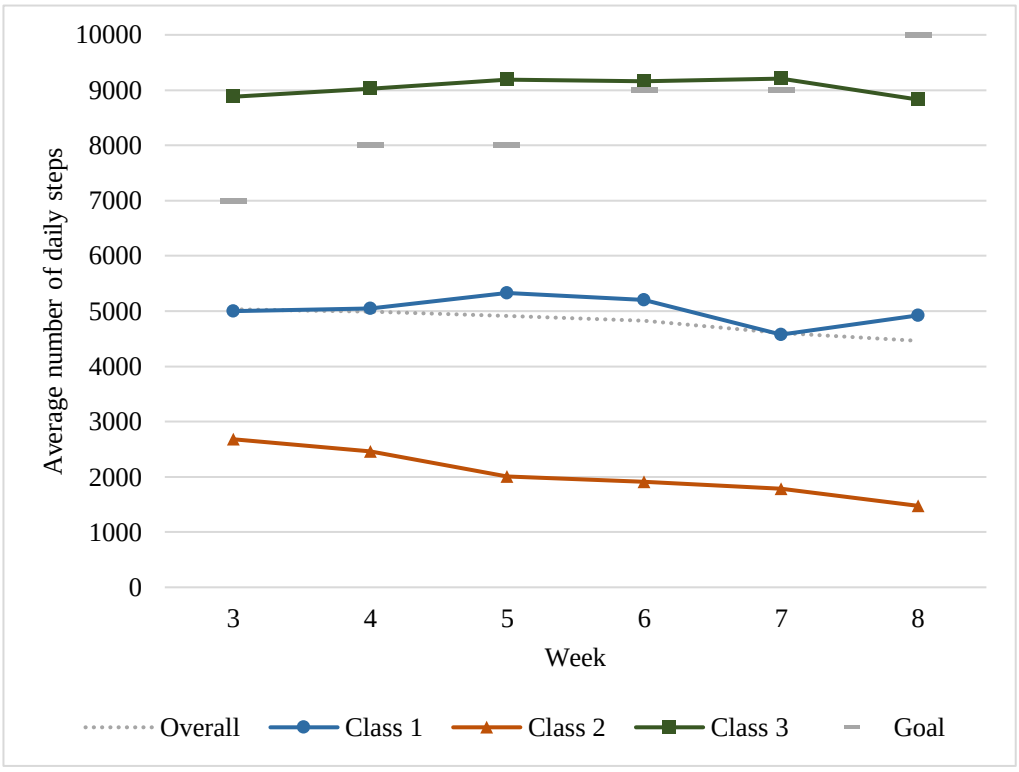
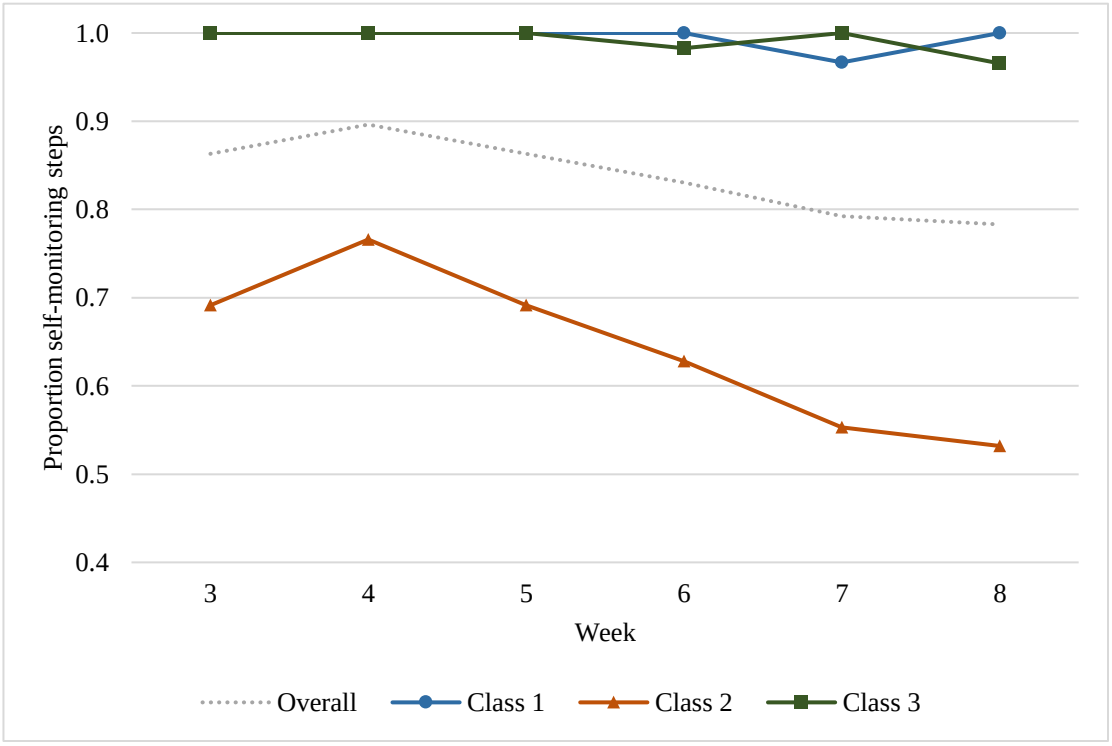


Figure 4.3 Average weekly physical activity totals (*N*=212). Class 1: "MVPA Goals Only", Class 2: "Neither PA Goal", Class 3: "Both PA Goals".



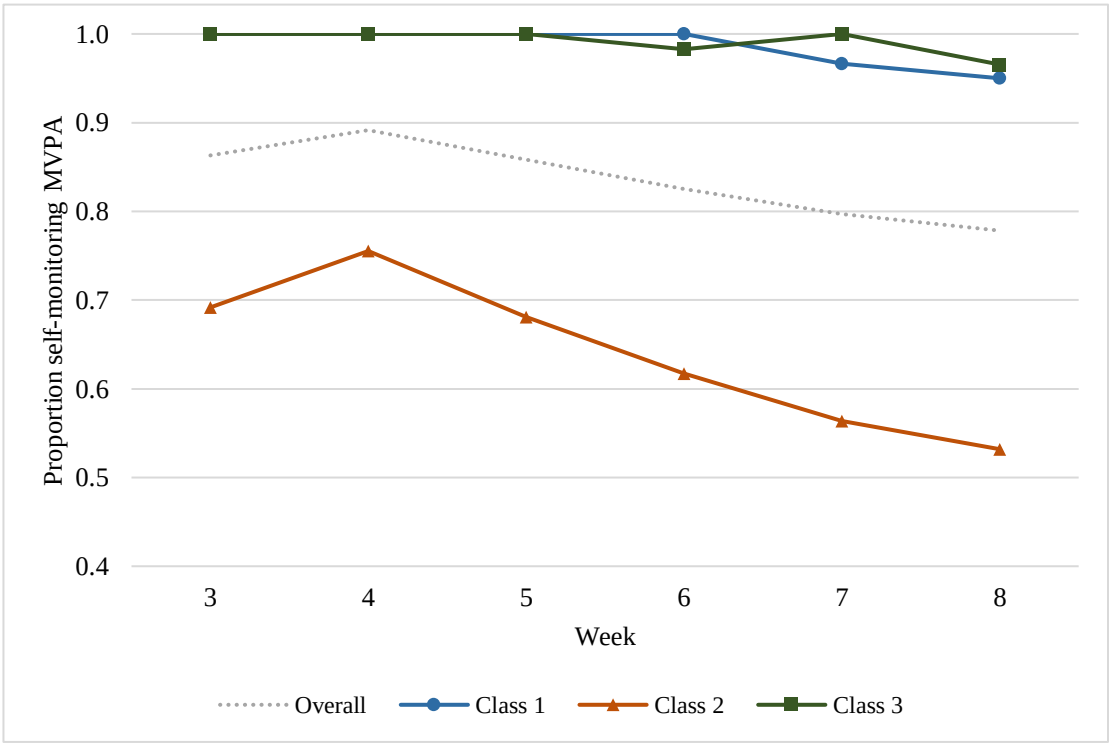


Figure 4.4 Proportion of individuals self-monitoring physical activity (*N*=212).
Class 1: "MVPA Goals Only", Class 2: "Neither PA Goal", Class 3: "Both PA Goals".

CHAPTER 5

DESCRIBING TRANSITIONS IN ADHERENCE TO PHYSICAL ACTIVITY SELF-MONITORING AND GOAL ATTAINMENT AMONG ADULTS WITH OVERWEIGHT/OBESITY IN A LIFESTYLE PROGRAM[2]

[2] Stansbury ML, Harvey J, Krukowski R, Pellegrini C, Wang X, and West D. To be submitted for publication.

5.1 Abstract

Introduction: Distinguishing underlying patterns of adherence to physical activity (PA) goals commonly prescribed in lifestyle programs may indicate subgroups at risk of poor treatment outcomes and reveal important targets for early intervention. This study described the probabilities of weekly transitions in adherence to steps-based and minutes-based PA goals and self-monitoring behavior during a 6-month online behavioral weight loss intervention.

Methods: Participants were prescribed PA goals for steps (7,000 to 10,000 daily steps) and minutes of MVPA (50 to 200 minutes) each week as part of a lifestyle program. Goals gradually increased during the initial 2 months, followed by 4 months of fixed goals. PA was self-reported daily on the study website. For each week, participants were categorized as (1) "adherent", (2) "suboptimally adherent", or (3) "nonadherent" based on whether self-monitoring records were submitted (yes/no) and whether the program PA goal was met (yes/no). The probability of transitioning into a less adherent status was examined using multinomial logistic regression.

Results: Individuals (N=212) were predominantly well-educated, middle-aged females with obesity, and 31.6% self-identified as a racial/ethnic minority. Initially, 34.4% were categorized as "adherent" to *steps goals* (51.9% "suboptimally adherent" and 13.7% "nonadherent"), and there was a high probability of either remaining "suboptimally adherent" from one week to the next or transitioning to a "nonadherent" status. On the other hand, 70.3% of individuals started out "adherent" to *MVPA goals* (16.0% "suboptimally adherent" and 13.7% "nonadherent"), with the greatest likelihood of movement in and out of "suboptimally adherent" behavior. A comparison of steps-based

versus minutes-based goals revealed individuals were more likely to transition to a less adherent status for minutes-based goals during the graded goal phase (p=.0042). No significant differences were seen between these two goal types in the probability of transitioning during the fixed goal phase (p=.6530).

Conclusions: States of vulnerability to poor PA adherence can emerge rapidly and early on in obesity treatment. There is a window of opportunity within the initial two months to bring more people towards "adherent" behavior, especially those who engage in self-monitoring but fail to meet the prescribed goals. While this study describes the probability of adhering to steps-based and minutes-based targets, it will be prudent to determine how individual characteristics and contextual states relate to these behavioral patterns, which can inform how best to adapt interventions.

Keywords: Physical activity, Adherence, Self-monitoring, Lifestyle intervention

5.2 Introduction

Adherence to physical activity is a pervasive challenge in behavioral weight control. Many individuals fail to achieve program recommendations and adopt a physically active lifestyle.[6,15] As a result, these individuals do not obtain the multitude of immediate and long-term health benefits associated with engaging in physical activity, including chronic disease prevention and weight management.[1,30] A deeper understanding about the underlying pattern of an individual's adherence to program recommendations may reveal information about what contributes to deteriorations in physical activity and indicate important targets for intervention.

Ordinarily, all individuals receive the same programmatic goals, which gradually progress to high levels of physical activity.[10,11,111] Recommendations are most often

provided for moderate to vigorous intensity physical activity (MVPA) in terms of minutes-based goals. More recently, steps-based goals have been incorporated as a means of bolstering the accumulation of movement throughout the day. Individuals who achieve program MVPA goals tend to lose more weight and are more likely to maintain high levels of activity in the future,[2,6,55,63,112] but it is unclear if this association also holds for steps-based goals in behavioral weight control. Furthermore, the stability in adherence to steps-based and minutes-based goals over time, as well as differences in adherence between these two types of goal prescriptions, have yet to be identified. Responsiveness to program recommendations, along with a more precise description of how the type and timing of physical activity goals impact adherence, can reveal key areas for consideration when prescribing physical activity for behavioral weight control and guide intervention tailoring for those at risk of poor adherence.

Self-monitoring of physical activity is a widely used strategy to enhance an individual's awareness of their behavior and promote fulfillment of recommendations.[1,59] As a cornerstone of lifestyle programs, self-monitoring serves as a reliable indicator of weight loss and physical activity engagement.[2,60] Indeed, it has been reported that failure to initiate self-monitoring of MVPA as part of a behavioral weight loss program, as well as inconsistent self-monitoring, are associated with weight gain and lower levels of physical activity.[113] Whether self-monitoring of steps follows a similar pattern remains to be determined. Describing how individuals adhere to self-monitoring of different types of program physical activity goals from one week to the next may point towards which type of metric (steps or minutes of MVPA) individuals are more likely to engage in during behavioral weight control. Others have examined transitions in levels of adherence to

dietary self-monitoring in one week given adherence in the previous week, and demonstrated that individuals were most likely to switch from a suboptimal self-monitoring status to fully adherent status during the initial two months of treatment.[73] Later in treatment, individuals who engaged in suboptimal self-monitoring of dietary intake were unlikely to revert to an adherent pattern. In other words, after the first 2 months of treatment, failure to fully self-monitor dietary intake foreshadowed discontinuation of self-monitoring. A similar approach would be advantageous in the physical activity domain to isolate potential targets for behavior modification and address high-risk time points, ultimately improving adherence in behavioral weight control and enhancing the health-related benefits of physical activity.

Examination of weekly adherence for the different types of physical activity goals would be most insightful for goal operationalization, progression, and timing because lifestyle programs tend to provide goals on a weekly basis. Does meeting the specified program physical activity goal and self-monitoring physical activity in one week indicate whether an individual will meet the goal and self-monitor in the following week? To address this question, we aimed to (1) establish the weekly transitional probabilities of adherence to prescribed daily steps and adherence to self-monitoring daily steps, (2) establish the weekly transitional probabilities of adherence to prescribed minutes of MVPA and adherence to self-monitoring minutes of MVPA, and (3) investigate whether the weekly transitional probabilities differed between steps-based goals versus minutes-based goals, across 6 months of an online behavioral weight control program.

5.3 Methods

5.3.a Study Design

The iREACH^3 study was a randomized controlled trial of an Internet-delivered, group-based behavioral weight control program conducted by the University of South Carolina (UofSC) and University of Vermont (UVM). A detailed description of the study has been published previously.[74] so methods will be described only briefly. Participants received either 1) the online program augmented with financial incentives for achieving behavioral and weight loss goals or 2) the online program alone. Participants randomized to the online program alone (N=212) were included in the present investigation. The UofSC Institutional Review Board and the UVM Committee on Human Research in the Behavioral Sciences approved the iREACH^3 study, and written informed consent was obtained by all participants.

5.3.b Participants

Recruitment occurred in cohorts over a two-year period at UofSC and UVM. Eligible individuals had a body mass index (BMI) of 25-50 kg/m^2 and were at least 18 years of age with access to a smartphone, computer, and the Internet. Individuals also resided within one hour from either clinical center and did not have any medical contraindications to moderate intensity exercise or walking for exercise. Those who had a recent cardiovascular event, history of weight loss surgery, recent substantial weight loss, or were concurrently enrolled in another weight management program were excluded from the study. Individuals interested in participating completed an initial questionnaire on the study recruitment website and were subsequently contacted by phone to determine eligibility. If eligible, individuals were encouraged to attend a group orientation session

for detailed information about the study and the opportunity to give informed consent. Individuals then completed a baseline assessment conducted by study staff and were randomized to either 1) the online program augmented with financial incentives or 2) the online program alone.

5.3.c Program Overview

The iREACH^3 intervention was a goal-oriented behavioral weight control program delivered online, which has been shown effective in previous iterations.[40,75] Participants received 24 weekly online group sessions delivered synchronously by an experienced facilitator via text-based chat. Topics discussed in these 60-minute group sessions were supplemented with lesson online materials, activities, and other resources on the study website to reinforce key strategies for self-regulation, such as goal setting, problem solving, action planning, and relapse prevention. Program goals included weight loss of 10% by 6 months through calorie reduction and increased physical activity. Daily intake of 1,200, 1,500, or 1,800 calories (with ≤ 25% of calories from fat) were advised based on body weight at study entry. Graded goals for two types of physical activity, steps, and minutes of MVPA, were provided. Starting in week 3 both step and minutes of MVPA targets were prescribed (7,000 daily steps and 50 minutes of MVPA). These goals increased incrementally through week 8 (graded goal phase). At week 9 both step and MVPA goals reached the program goals of 10,000 daily steps and 200 minutes of weekly MVPA. These levels were maintained as a minimum level of activity through the remainder of the program (fixed goal phase).

Participants were instructed to self-monitor their weight, dietary intake, and physical activity primarily using the study website's daily diary. Specifically, for each

day of the study period, participants entered their weight, whether they tracked their food and beverage intake in MyFitnessPal (a commercially-available mobile app for dietary and exercise self-monitoring) and met their weight-loss calorie goal, the total number of steps accumulated throughout the day, and the total minutes of planned exercise taken at moderate-to-vigorous intensity on that day. Participants were asked to track their physical activity using an app on their smartphone (e.g., MyFitnessPal) or another electronic device (e.g., wearable activity tracker) and enter the values displayed when recording their steps and minutes of MVPA in the website's daily diary. The facilitator reviewed participants' self-monitoring records and emailed tailored feedback on a weekly basis with positive reinforcement of healthy lifestyle choices, constructive guidance promoting potential areas for change, and reminders of the program recommendations.

5.3.d Measures

5.3.d.1 Sociodemographic characteristics

Age, gender, race/ethnicity, education, employment status, marital status, and geographic region were self-reported at baseline.

5.3.d.2 Anthropometric

Body weight was objectively measured by study staff at baseline, 2, and 6 months using a calibrated digital scale to the nearest 0.1 kilogram with participants wearing lightweight clothing and shoes removed.

5.3.d.3 Physical Activity

The total number of steps and minutes of MVPA were self-reported by participants daily on the study website. Weekly totals for steps and for minutes of MVPA

were calculated by summing the daily reported values with each week beginning on the day of the individual's scheduled group session.

5.3.d.4 Adherence to physical activity goal

Adherence to the steps goals (yes/no) and MVPA goals (yes/no) was determined separately for each week of the program. For steps, the total number of steps for a given week was divided by 7 days. This value was then divided by that week's program steps goal and multiplied by 100%. The program steps goal was considered met if the proportion of steps was at least 100%; the goal was considered unmet if the proportion was less than 100%. For minutes of MVPA, the total minutes of MVPA for a given week were divided by the program MVPA goal and multiplied by 100%. The MVPA goal was considered met for that week if this proportion was at or above 100% and unmet if it was below 100%. A value of 0 was assumed for missing and implausible entries (i.e., step counts less than 1,000 or greater than 30,000[76,77], and minutes of MVPA exceeding 1,080 minutes/day[78,93]).

5.3.d.5 Adherence to physical activity self-monitoring.

Adherence to self-monitoring steps (yes/no) and minutes of MVPA (yes/no) was based on whether or not an entry was submitted by an individual as opposed to the absolute value of the entry. Specifically, an individual was considered to have self-monitored steps for a given week if they submitted at least one record of any step count, including a value of 0. If no entry was submitted for steps on any of the 7 days, the individual was considered nonadherent to self-monitoring steps for that week. Similarly, an individual was considered to have self-monitored minutes of MVPA for a given week if they submitted at least one record of any number of minutes, including a value of 0.

The individual was considered nonadherent to self-monitoring minutes of MVPA for that week if no entry was made on any of the 7 days. The approach described here is consistent with previous work, which categorized a participant as adherent if at least 1 record of any value of exercise minutes was submitted for a given week and nonadherent if no records were submitted.[81]

5.3.d.6 Categorization of physical activity adherence.

Individuals were categorized into three mutually-exclusive categories for each type of physical activity goal: (1) "adherent" if they met the goal and self-monitored, (2) "suboptimally adherent" if they did not meet the goal, but did self-monitor, and (3) "nonadherent" if they did not self-monitor (Table 5.1). The definitions for "adherent", "suboptimally adherent", and "nonadherent" were selected in parallel with established categories for levels of aerobic physical activity and their relationship to the degree of health benefits obtained.[19] According to the national guidelines, adults are categorized as active/highly active when 150 minutes or more per week of MVPA are accrued, "insufficiently active" when some MVPA but less than 150 minutes per week is accrued, and inactive if no MVPA is accrued. Numerous cut-points have been used to categorize activity levels based on steps;[85] however, there is not currently a standard threshold. The decision to base adherence to both types of activity (i.e., steps and minutes of MVPA) on the categories defined by the national guidelines for MVPA provides consistency in classification for this study. It was assumed that those who did not self-monitor also did not meet the physical activity goal for that week.

5.3.e Statistical Analysis

Descriptive analyses were conducted to characterize the sample, and frequencies were determined for the number of individuals meeting physical activity goals and self-monitoring physical activity each week. Marginal proportions of physical activity adherence ("adherent", "suboptimally adherent", and "nonadherent") were tabulated separately for each type of physical activity goal: (1) steps and (2) minutes of MVPA. Transition probabilities of adherence ("adherent", "suboptimally adherent", and "nonadherent") were also summarized by type of physical activity goal using parallel approaches, as depicted in Figure 5.1. Each model began at week 3 when recommendations for both physical activity goals were first prescribed concurrently and continued through the end of the 6-month period. Furthermore, models were conditioned on the probability of maintaining the same adherence status or transitioning to another status in one week based on adherence status in the preceding week.

The likelihood of being "adherent", "suboptimally adherent", or "nonadherent" were examined using multinomial logistic regression for correlated data separately for each type of physical activity goal: (1) steps and (2) minutes of MVPA. We first modeled the odds of transitioning into a less adherent status across all time points (weeks 3-24). Then, analyses were repeated by physical activity goal phase (graded goal phase and fixed goal phase). The graded goal phase was defined by the odds of transitioning into a less adherent status when goals progressed incrementally during weeks 3-8, while the fixed goal phase was defined by the odds of transitioning into a less adherent status when the goals remained the same across weeks 9-24. Finally, comparisons were made between the model for steps-based goals versus the model for minutes-based goals on the odds of

transitioning into a less adherent status (1) across all time points, (2) during the graded goal phase, and (3) during the fixed goal phase. All analyses were performed in SAS 9.4 (Cary, N.C.) at a 0.05 alpha level of significance.

5.4 Results

5.4.1 Participant Characteristics

All participants randomized to the online program alone (*N*=212) were included in this study (Table 5.2). On average, participants were 47.9 years old with a BMI of 35.8 kg/m^2. The majority of participants were female, and approximately one-third self-identified as a racial/ethnic minority. Most participants had at least a college degree (79.7%) and were employed full time (71.7%). Retention was high, as demonstrated by 81.1% of individuals completing the 6-month assessment visit.

5.4.2 Rates of Adherence to Physical Activity

Daily Steps: On average, participants self-monitored their steps on at least 1 day per week during two-thirds of the 6-month period (67.7%), and 12.4% met the prescribed step goals each week. Approximately one-third of participants started out "adherent" to the 7,000 daily steps goal. Rates declined as the goal progressed to 10,000 daily steps, and 6.1% of individuals remained "adherent" by 6 months. Most individuals self-monitored their steps but did not meet the prescribed step goals early on ("suboptimally adherent"). As was seen with "adherent", the proportion of individuals classified as "suboptimally adherent" also declined over time. In contrast, there was a 40% increase in the proportion who were "nonadherent" over time, with more than half of participants no longer self-monitoring daily steps at the conclusion of the study period (Figure 5.2 A).

Minutes of MVPA: Comparable to daily steps, participants self-monitored their total minutes of MVPA on at least 1 day per week during 67.7% of the 6-month period, on average; however, more than twice as many individuals (27.4%) met the weekly minutes of MVPA goals relative to the steps goals. Most participants (70.3%) were "adherent" to the initial 50-minute MVPA goal. "Adherent" behavior drastically declined as MVPA goals progressed in the graded phase, followed by a slower rate of deterioration in the fixed goal phase to 14.2% by 6 months. The proportion of those classified as "suboptimally adherent" increased sharply during the graded phase before gradually declining throughout the remaining weeks. Finally, the proportion of individuals considered "nonadherent" to minutes of MVPA closely mirrored those seen for steps over time (Figure 5.2 B).

5.4.3 Transitions in Adherence to Physical Activity

The weekly transitional probabilities of adherence to prescribed physical activity goals and adherence to self-monitoring physical activity across successive weeks of the behavioral weight control program are summarized for daily steps and minutes of MVPA in Table 5.3, with movement between adherence statuses illustrated in Figure 5.3.

Daily Steps: During the initial 8 weeks as goals progressed from 7,000 to 10,000 daily steps, the probability that an individual would remain "adherent" was 29%, while the probability of transitioning from "adherent" to "suboptimally adherent" was 67%. If an individual was "suboptimally adherent" to the 7,000-step goal in week 3, they had an 81% chance of remaining "suboptimally adherent" and a 15% chance of transitioning to "nonadherent" when the goal increased to 10,000 steps at week 8. Across the fixed goal phase, those who were "suboptimally adherent" at the end of the graded phase (week 8)

had a 53% chance of continuing to be "suboptimally adherent", 44% chance of transitioning to "nonadherent", and 4% chance of transitioning to "adherent" at the conclusion of 6 months. An individual was expected to remain "adherent" at the end of the program 15% of the time if they were "adherent" in week 3; however, if they had been "adherent" in week 8, the chances of being "adherent" at the end of the program increased to 32%. Individuals had the highest likelihood of remaining "suboptimally adherent" or transitioning from "nonadherent" to "suboptimally adherent" between weeks 3 and 4 (95% and 31%, respectively; Table 5.4).

Minutes of MVPA: In the graded goal phase, individuals had a 40% chance of remaining "adherent" to the 150-minute recommendation at week 8 if they were initially "adherent" to the 50-minute target, in addition to a 49% chance of transitioning from "adherent" to "suboptimally adherent" (Table 5.3). Individuals were likely to remain "suboptimally adherent" at week 8 approximately 71% of the time if their initial status had been "suboptimally adherent," with equal chances of moving from "suboptimally adherent" to a "nonadherent" or "adherent" status. During the period when prescribed MVPA was fixed at 200 minutes per week (weeks 9-24), an individual was most likely to transition from "suboptimally adherent" to either "nonadherent" (46%) or "adherent" (48%), but not likely to remain "suboptimally adherent". An individual was expected to remain "adherent" at the end of the program 19% of the time, given that they were "adherent" to the initial 50-minute MVPA goal, and doubled their chances of being "adherent" at the end of the program (37%) if they were "adherent" at the 8-week mark. The greatest chances of remaining in a "suboptimally adherent" status or transitioning to "adherent" (87% and 51%, respectively), as well as the highest likelihood of transitioning

from “nonadherent” to “suboptimally adherent” (24%) occurred between weeks 3 and 4 (Table 5.4).

The most stable status across the 6-month period for both steps-based and minutes-based goals was “nonadherent”. If an individual was “nonadherent” to the initial program goals, they were estimated to remain “nonadherent” at the end of the 8-week graded phase 90% of the time and transition to “suboptimally adherent” 10% of the time. The likelihood of remaining “nonadherent” increased in the fixed goal phase to 98%. An individual had a 100% probability of being “nonadherent” at week 24 given that they had been “nonadherent” to the initial physical activity goals at week 3. The transition directly from “nonadherent” to “adherent” was not expected to occur.

5.4.4 Comparison of Adherence Categories for Daily Steps vs. Minutes of MVPA

Multinomial logistic regressions revealed that individuals were significantly more likely to transition to a less adherent category over time for daily steps and for minutes of MVPA (all *p*-values <.0001; Table 5.5). For adherence to daily steps, individuals were 1.09 times more likely to be in a less adherent category each week across the 6-month period, 1.24 times more likely to be less adherent during the graded goal phase, and 1.07 times more likely to transition to a less adherent during the fixed goal phase. For adherence to minutes of MVPA, individuals were 1.11 times more likely to transition to a less adherent category each week over the entire 6 months. During the graded and fixed goal phases, individuals were 1.39 and 1.06 times more likely to be in a less adherent category each week, respectively.

Although a trend was noted between models for daily steps and minutes of MVPA in the odds of being in a less adherent category when examining the entire 6-

month period (p=.0739), the differences were not statistically significant. However, when daily steps and minutes of MVPA were compared by goal phase, individuals were significantly more likely to be in a less adherent category for minutes of MVPA relative to steps during the graded physical activity goal phase (p=.0042). In other words, participants were more likely to be less adherent with respect to MVPA goals than they were to step goals during the graded phase. No significant differences were seen in the propensity to be adherent between steps- and minutes-based goals during the fixed goal phase (p=.6530).

5.5 Discussion

To our knowledge, this study is the first to describe the stability of adherence to weekly self-monitoring and attainment of physical activity goals prescribed in terms of daily steps and weekly minutes of MVPA during an online behavioral weight control program. Few individuals met the initial steps-based goals and subsequently either remained in a "nonadherent" or "suboptimally adherent" status from one week to the next or transitioned from "suboptimally adherent" to "nonadherent" over time. Conversely, most individuals started out "adherent" to the minutes-based goals but demonstrated greater movement between adherence statuses from week-to-week than was seen for steps-based goals. While weekly transitions tended towards less adherent behavior for both types of goals across the study period, there were distinct occasions within the early weeks that signal opportunities for greater engagement with the physical activity recommendations.

The weekly transitional probabilities described in this study underscore the initial two months of a lifestyle program as a formative period which contributes to an

individual's chances of future physical activity adherence. Those who met the earliest physical activity recommendations were most likely to be "adherent" at six months relative to those who started out "suboptimally adherent" or "nonadherent". Intriguingly, the likelihood of long-term adherence increased two-fold if an individual remained "adherent" through the graded goal phase. Our findings substantiate previous studies that demonstrate the first two months of program initiation serve as a critical juncture associated with better long-term program adherence, weight loss and health-related outcomes.[13,14,73,90,92] From a theoretical perspective, successful adoption of the physical activity recommendations may be attributed to increases in self-efficacy and mastery experiences during program initiation from frequent, intentional exposure to self-monitoring and goal attainment;[102-104] although, this warrants further investigation. Future studies should examine whether targeting this early period with strategies to facilitate consistent self-monitoring in conjunction with attaining physical activity recommendations substantially increases an individual's chances of long-term success in achieving physical activity targets and in losing weight.

It should be noted that few individuals actually achieved this stability in adherent behavior, which is of concern. Indeed, nonadherence was the most consistent status and was increasingly more likely over time, regardless of the type of physical activity goal. Recently, it has been suggested that adults with overweight may prefer monitoring minutes-based activity rather than step counts.[114] However, our study did not detect a difference in monitoring behavior between these two types of physical activity. It may be that the method of submitting daily step totals and minutes of MVPA concurrently in the study website's digital diary contributed to the matching rates of self-monitoring between

both types of physical activity. Nevertheless, a considerable proportion of individuals failed to track their activity and were unlikely to reengage with self-monitoring despite regular reminders of program physical activity goals and prompts to self-monitor provided in weekly emailed feedback, group meetings, and online lessons. Providing wearable devices to those who fail to engage with manual self-monitoring methods may improve adherence by facilitating continuous physical activity tracking and minimizing the burden associated with manual self-monitoring.[115,116]

"Suboptimally adherent" behavior appeared to be the most vulnerable to transitions, particularly with respect to minutes-based goals. It is striking that the individuals who self-monitored their MVPA but did not meet the prescribed goal at 2 months still had a nearly 50% chance of transitioning to fully "adherent" behavior at 6 months by meeting recommendations during the fixed goal phase when they had not previously met the goals in the graded phase. A similar pattern was reported in a previous study with regards to weekly dietary self-monitoring where individuals who demonstrated "suboptimal adherence" to self-monitoring their dietary intake had the greatest propensity for transitioning to "adherent" behavior during the first 2 months of a lifestyle program but not after that time.[73] It is possible that being vulnerable to transitions represents an intervention opportunity to increase the likelihood of transitioning to fully adherent behavior. Supporting individuals with coaching sessions at the first signs of vulnerability might foster increases in their MVPA or step counts.[117-119] A change in status from "adherent" to "suboptimally adherent" exemplifies one event which triggers implementation of a coaching session to quickly bring the individual back

on a trajectory of success and avoid a decline to "nonadherent" behavior when it may be too late to reengage them in program recommendations.

In order to capitalize on the early weeks of program initiation and move more individuals towards "adherent" behavior, reevaluating how physical activity recommendations are structured for traditional behavioral weight control is warranted. From the hypothesis-generating data of this study, it is apparent that providing everyone with the same type and incremental, linear progression of physical activity goals does not accommodate the dynamic process of lifestyle change for each individual. After all, some people will never fulfill the recommended goals, while others will start out "adherent", but will no longer meet the recommended targets once the goals reach a certain level of physical activity. From a clinical perspective, it is imperative to appreciate that the continuation of conventional treatment will not help these vulnerable subgroups transition to "adherent" behavior. Instead, it may be important to provide tailored goals that adapt based on the individual's recent physical activity and, thus, providing more realistic, attainable incremental physical activity targets.[105-107,117]

While this study took the formative step of describing behavioral patterns, it does not tell us precisely how best to adapt treatment. There are likely other factors, such as cognitive, affective, and motivational components, influencing whether individuals are adherent to physical activity that should be explored to guide treatment tailoring.[120-124] For example, does exercise become unpleasant or untenable for some individuals when MVPA goals progress to at least 150 minutes, which contributes to them no longer adhering to recommendations? Do other individuals experience boredom with their exercise routine or a lack of motivation to pursue the goals? To what extent does a sense

of self-efficacy impact attainment of steps-based or minutes-based goals? There may also be other contextual factors influencing adherence, such as a vacation, illness/injury, or other barriers to physical activity, which interrupt their routine. Clearly, there is much more to explore before we can make a firm clinical conclusion about what these data suggest for physical activity recommendations in behavioral weight control.

This research advances our understanding of the effects of different types of physical activity goals commonly prescribed in behavioral weight control interventions on goal attainment combined with self-monitoring among a large sample of adults with overweight and obesity. However, findings should be considered with the following limitations in mind. First, participants were predominantly well-educated women with obesity, and results may not generalize to other populations. Next, it cannot be determined if there are differences in adherence to goals prescribed in terms of daily steps or minutes of MVPA based on an individual's exercise history or level of activity when entering the study. If program physical activity goal attainment differs between individuals who are inactive at study entry versus those who are already engaging in some physical activity at baseline, recommendations may be tailored based on this parameter. Although the goals offered in the iREACH[3] program are similar to those provided by other behavioral weight control programs,[10,11] patterns of goal attainment noted in this study may not generalize to other programs that recommend substantively different types or doses of physical activity or to physical activity promotion programs without an emphasis on weight loss. Exploring the behavioral patterns of adherence to other physical activity recommendations and programs will be advantageous in determining whether there are specific physical activity thresholds for the number of

steps and minutes of MVPA that optimize adherence. Furthermore, it is possible that some individuals categorized as "nonadherent" in a given week did in fact meet the physical activity goal for that week; however, goal attainment could not be determined if they did not submit their activity record on the website. Providing technology to assist with self-monitoring could remove barriers associated with manual tracking of physical activity. Finally, an individual's level of adherence to the prescribed goal and self-monitoring was conditional only on the immediately preceding week's level of adherence, and whether other time points influence adherence status is an area for future study. Nevertheless, the approach selected allows for a preliminary examination of dynamic adherence to physical activity goals and self-monitoring.

In conclusion, this study begins to identify key transition points in the behavior change process as it relates to physical activity adherence for steps-based and minutes-based goals in a behavioral weight loss program and provides a useful framework for detecting responsiveness to program recommendations. Moreover, it may assist with shaping more effective physical activity recommendations in lifestyle programs, particularly during the early period of program initiation. The initial two months provide a window of opportunity to assist more people to transition towards "adherent" behavior, especially those who engage in self-monitoring but fail to meet the physical activity goals. As a result, researchers and clinicians should consider physical activity self-monitoring and goal attainment concurrently as indication of an individual's adherence status. Emphasis should be placed on strategies which help people start and reach the 2-month mark with consistent self-monitoring and attainment of physical activity recommendations since this appears to be a formative period for continued adherence.

Future research should investigate how these transitional patterns in physical activity adherence status are influenced by individual characteristics and contextual factors, as well as how they relate to weight loss and other health-related outcomes, to inform optimization of treatment recommendations.

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Table 5.1 Categorization of adherence to program physical activity goals

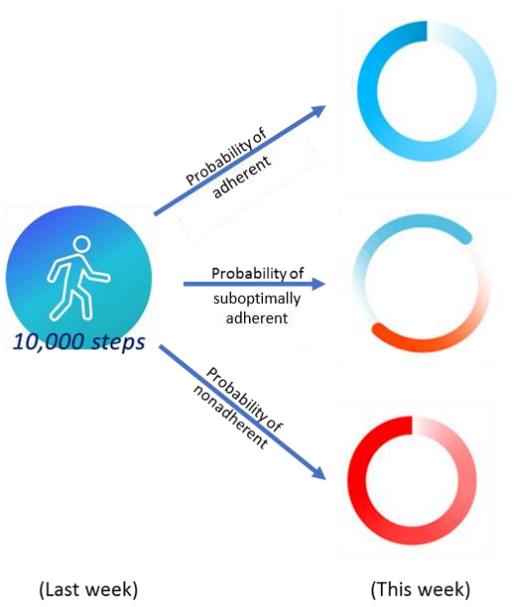
(A) Steps-based goals

Week	Adherent	Suboptimally Adherent	Nonadherent
3	≥7,000 steps (≥100%) + ≥1 day of self-monitoring	1 to 6,999 steps (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
4-5	≥8,000 steps (≥100%) + ≥1 day of self-monitoring	1 to 7,999 steps (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
6-7	≥9,000 steps (≥100%) + ≥1 day of self-monitoring	1 to 8,999 steps (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
8-24	≥10,000 steps (≥100%) + ≥1 day of self-monitoring	1 to 9,999 steps (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring

(B) Minutes-based goals

Week	Adherent	Suboptimally Adherent	Nonadherent
3-4	≥50 minutes (≥100%) + ≥1 day of self-monitoring	1 to 49 minutes (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
5-6	≥100 minutes (≥100%) + ≥1 day of self-monitoring	1 to 99 minutes (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
7-8	≥150 minutes (≥100%) + ≥1 day of self-monitoring	1 to 149 minutes (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring
9-24	≥200 minutes (≥100%) + ≥1 day of self-monitoring	1 to 199 minutes (0% < x < 100%) + ≥1 day of self-monitoring	No self-monitoring

(A) Model for steps-based goals



(B) Model for minutes-based goals

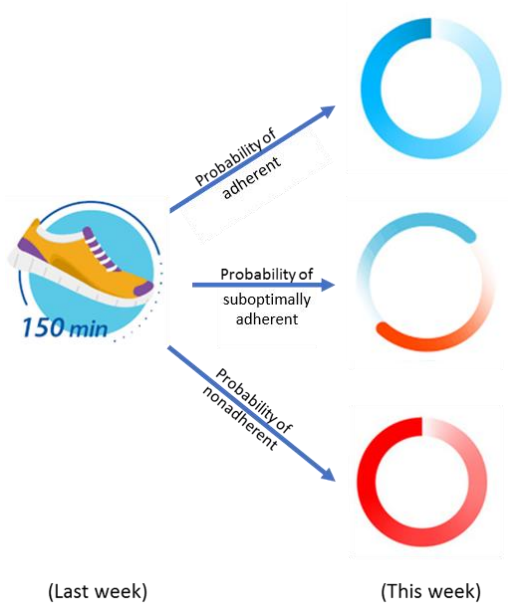


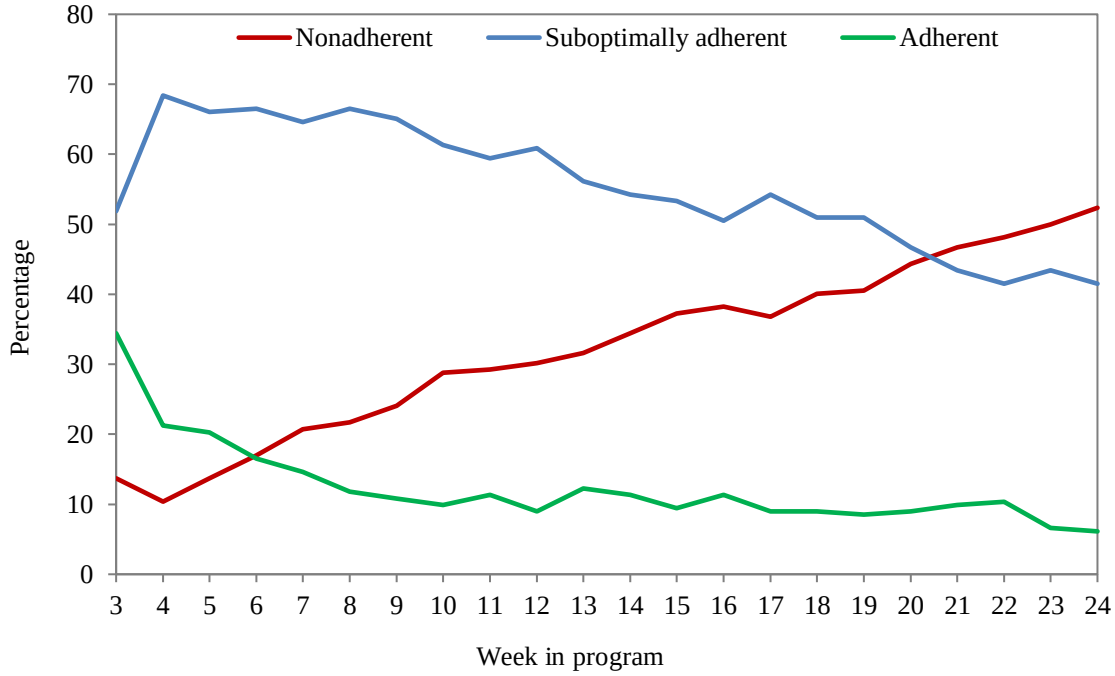
Figure 5.1 Abbreviated models illustrating the structure of transition probabilities of physical activity adherence status in one week given adherence status the previous week. (A) Model for steps-based goals; (B) model for minutes-based goals.

Table 5.2 Baseline sociodemographic characteristics of overall sample

Characteristic	*N* = 212
Age (years), M ± SD	47.9 ± 11.1
Gender, n (%)	
Female	194 (91.5)
Male	18 (8.5)
Race/ethnicity, n (%)	
White	145 (68.4)
Minority^	67 (31.6)
Education, n (%)	
College degree or higher	169 (79.7)
Some college or less	43 (20.3)
Marital status, n (%)	
Married or living as married	118 (55.7)
Single or not married	94 (44.3)
Employment status, n (%)	
Employed full time	152 (71.7)
Employed part time or unemployed	60 (28.3)
Geographic region, n (%)	
Northeast (Vermont)	106 (50.0)
Southeast (South Carolina)	106 (50.0)
BMI (kg/m^2), M ± SD	35.8 ± 5.9

Note: Values presented as means ± standard deviations or frequencies (percentages);
^ minority groups include African American, Asian, Hispanic, and Pacific Islander.

(A) Adherence to steps-based goals



(B) Adherence to minutes-based goals

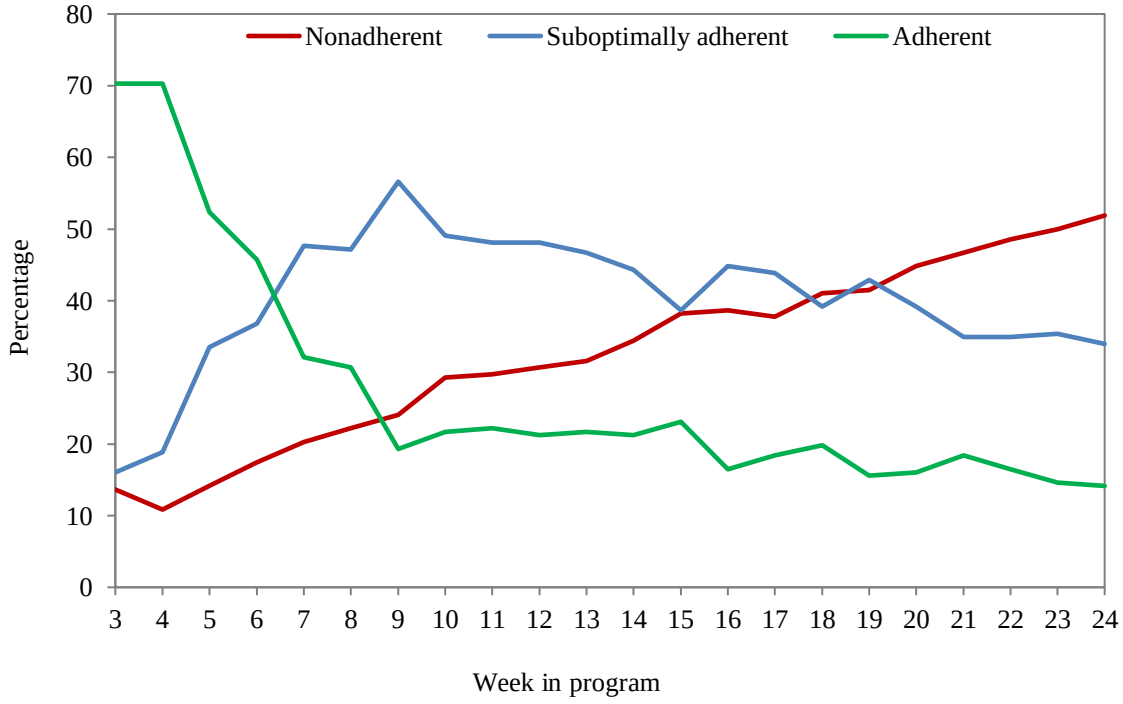


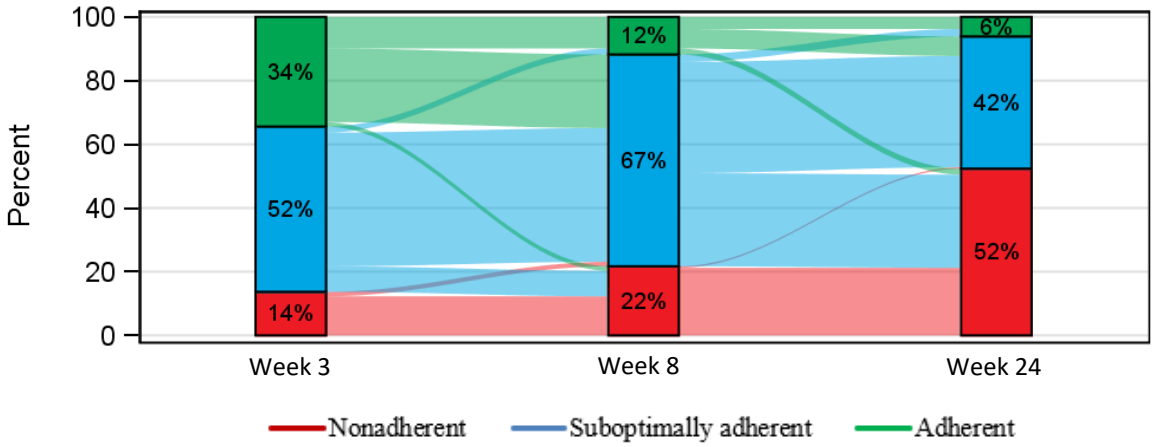
Figure 5.2 Weekly marginal proportions of individuals in each physical activity adherence category. (A) Adherence to steps-based goals; (B) Adherence to minutes-based goals.

Table 5.3 Summary of weekly transitional probabilities of adherence to physical activity by program goal phase

	Adherence status at time$_t$					
	"Nonadherent"		**"Suboptimally Adherent"**		**"Adherent"**	
Adherence status at time$_{t-1}$	**STEPS**	**MVPA**	**STEPS**	**MVPA**	**STEPS**	**MVPA**
Graded PA Goal Phase: Week 8 (given week 3)						
Nonadherent	**.897**	**.897**	.103	.103	.000	.000
Suboptimally Adherent	.155	.147	**.809**	**.706**	.036	.147
Adherent	.041	.107	.671	.490	**.288**	**.403**
Fixed PA Goal Phase: Week 24 (given week 8)						
Nonadherent	**.978**	**.979**	.022	.021	.000	.000
Suboptimally Adherent	.440	.460	**.525**	**.060**	.035	.480
Adherent	.160	.277	.520	.354	**.320**	**.369**
Full 6-month Period: Week 24 (given week 3)						
Nonadherent	**1.000**	**1.000**	.000	.000	.000	.000
Suboptimally Adherent	.536	.647	**.445**	**.294**	.018	.059
Adherent	.315	.396	.534	.416	**.151**	**.188**

Note: Transition probabilities describe the likelihood of remaining in an adherence status or transitioning to another status in one week given adherence status in the previous week; bold indicates remaining in the same adherence status.

(A) Adherence to steps-based goals



(B) Adherence to minutes-based goals

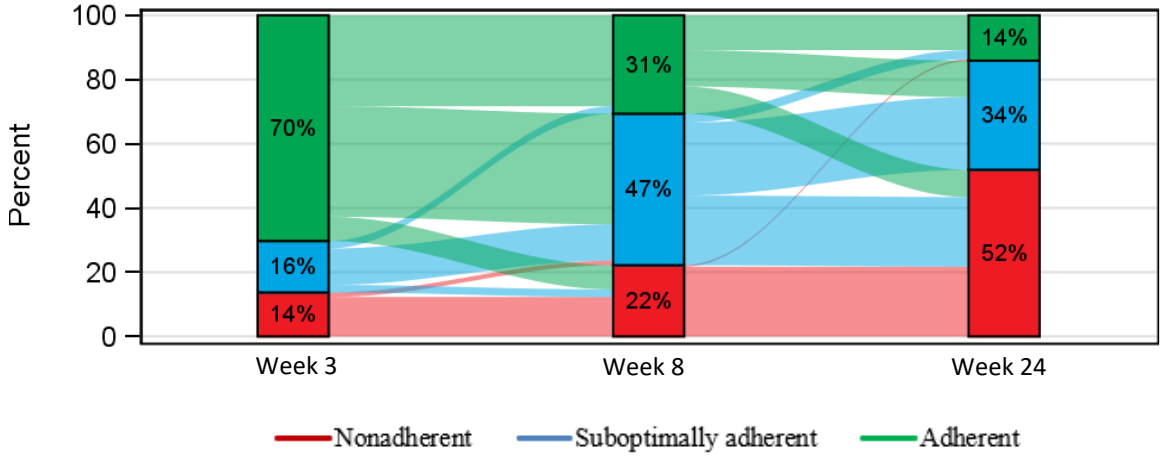


Figure 5.3 Transitions in weekly adherence status by goal phase. Solid bars represent the marginal proportions of individuals in each adherence category at a given time point; bands represent the proportion transitioning to another category or remaining in the same category at one time point given the previous time point. (A) Adherence to steps-based goals; (B) Adherence to minutes-based goals.

Table 5.4 Weekly transitional probabilities of adherence to physical activity

	Adherence status at time$_t$					
	"Nonadherent"		**"Suboptimally Adherent"**		**"Adherent"**	
Adherence status at time$_{t-1}$	**STEPS**	**MVPA**	**STEPS**	**MVPA**	**STEPS**	**MVPA**
Week 4						
Nonadherent	**.690**	**.724**	.310	.241	.000	.034
Suboptimally Adherent	.018	.290	**.945**	**.500**	.036	.471
Adherent	.000	.007	.438	.107	**.562**	**.886**
Week 5						
Nonadherent	**.818**	**.826**	.182	.174	.000	.000
Suboptimally Adherent	.076	.225	**.821**	**.625**	.103	.150
Adherent	.000	.013	.378	.282	**.622**	**.705**
Week 6						
Nonadherent	**.931**	**.933**	.069	.067	.000	.000
Suboptimally Adherent	.057	.099	**.864**	**.690**	.079	.211
Adherent	.023	.018	.419	.243	**.558**	**.739**
Week 7						
Nonadherent	**.861**	**.838**	.139	.135	.000	.027
Suboptimally Adherent	.092	.141	**.823**	**.782**	.085	.077
Adherent	.000	.010	.457	.361	**.543**	**.629**
Week 8						
Nonadherent	**.818**	**.814**	.182	.186	.000	.000
Suboptimally Adherent	.073	.109	**.854**	**.713**	.073	.178
Adherent	.000	.015	.516	.294	**.484**	**.691**
Week 9						
Nonadherent	**.826**	**.809**	.174	.191	.000	.000
Suboptimally Adherent	.092	.130	**.872**	**.790**	.035	.080
Adherent	.000	.000	.280	.492	**.720**	**.508**
Week 10						
Nonadherent	**.902**	**.902**	.098	.098	.000	.000
Suboptimally Adherent	.109	.125	**.841**	**.708**	.051	.167
Adherent	.000	.024	.391	.341	**.609**	**.634**
Week 11						
Nonadherent	**.869**	**.871**	.131	.113	.000	.016
Suboptimally Adherent	.069	.077	**.846**	**.760**	.085	.163

Adherent	.000	.022	.381	.348	**.619**	**.630**
Week 12						
Nonadherent	**.839**	**.857**	.161	.143	.000	.000
Suboptimally Adherent	.095	.088	**.857**	**.765**	.048	.147
Adherent	.000	.043	.458	.319	**.542**	**.638**
Week 13						
Nonadherent	**.875**	**.846**	.125	.154	.000	.000
Suboptimally Adherent	.085	.118	**.806**	**.735**	.109	.147
Adherent	.000	.000	.368	.311	**.632**	**.689**
Week 14						
Nonadherent	**.925**	**.925**	.075	.075	.000	.000
Suboptimally Adherent	.092	.111	**.849**	**.737**	.059	.152
Adherent	.000	.000	.346	.348	**.645**	**.652**
Week 15						
Nonadherent	**.918**	**.918**	.082	.082	.000	.000
Suboptimally Adherent	.104	.149	**.817**	**.691**	.078	.160
Adherent	.000	.000	.542	.244	**.458**	**.756**
Week 16						
Nonadherent	**.911**	**.914**	.089	.086	.000	.000
Suboptimally Adherent	.080	.098	**.850**	**.829**	.071	.073
Adherent	.000	.000	.200	.408	**.800**	**.592**
Week 17						
Nonadherent	**.877**	**.890**	.123	.110	.000	.000
Suboptimally Adherent	.065	.074	**.897**	**.811**	.037	.116
Adherent	.000	.000	.375	.200	**.625**	**.800**
Week 18						
Nonadherent	**.885**	**.888**	.115	.113	.000	.000
Suboptimally Adherent	.130	.151	**.817**	**.699**	.052	.151
Adherent	.053	.051	.263	.231	**.684**	**.718**
Week 19						
Nonadherent	**.859**	**.862**	.141	.115	.000	.023
Suboptimally Adherent	.120	.157	**.824**	**.771**	.056	.072
Adherent	.000	.000	.368	.405	**.632**	**.595**
Week 20						
Nonadherent	**.930**	**.909**	.070	.091	.000	.000
Suboptimally Adherent	.130	.165	**.806**	**.692**	.065	.143
Adherent	.000	.000	.333	.364	**.667**	**.636**

Week 21						
Nonadherent	**.904**	**.895**	.096	.105	.000	.000
Suboptimally Adherent	.141	.169	**.778**	**.651**	.081	.181
Adherent	.000	.000	.316	.294	**.684**	**.706**
Week 22						
Nonadherent	**.899**	**.909**	.101	.081	.000	.010
Suboptimally Adherent	.141	.176	**.793**	**.716**	.065	.108
Adherent	.000	.000	.238	.333	**.762**	**.667**
Week 23						
Nonadherent	**.922**	**.922**	.078	.068	.000	.010
Suboptimally Adherent	.136	.122	**.818**	**.743**	.045	.135
Adherent	.000	.057	.545	.371	**.455**	**.571**
Week 24						
Nonadherent	**.934**	**.934**	.066	.066	.000	.000
Suboptimally Adherent	.130	.133	**.815**	**.667**	.054	.200
Adherent	.000	.032	.429	.484	**.571**	**.484**

Note: Transition probabilities describe the likelihood of remaining in an adherence status or transitioning to another status in one week given adherence status in the previous week; bold indicates remaining in the same adherence status.

Table 5.5 Comparison of steps-based goals versus minutes-based goals on odds of transitioning to less adherent status weekly

	STEPS		**MVPA**		
	OR	(95% CI)	OR	(95% CI)	p-value
Overall (6 months)	1.0895	(1.0883, 1.0907)	1.1095	(1.1081, 1.1109)	0.0739
Graded PA Goal Phase[a]	1.2371	(1.1736, 1.3041)	1.3907	(1.3092, 1.4773)	**0.0042**
Fixed PA Goal Phase[b]	1.0668	(1.0502, 1.0837)	1.0616	(1.0462, 1.0772)	0.6530

Note: OR = odds ratio, transitioning to less adherent category over time; CI = confidence interval; [a] initial 2 months of intervention; [b] months 3 through 6 of intervention; $p < .05$ level of significance.

CHAPTER 6

DISCUSSION

6.1. Major Findings and Implications

Adherence is a persistent challenge in behavioral weight control, particularly for physical activity.[5,6] Conventional lifestyle programs generally provide the same physical activity goals to everyone and produce weight losses of 5-10%,[10,11] yet there is considerable variability in individuals' physical activity and weight loss responses during treatment.[7,125] Weight loss response within the early weeks of initiating treatment is indicative of long-term weight loss.[13,14] However, few studies have examined whether adherence to physical activity recommendations sets apart those who respond to treatment from those who are not responsive during this early period.[92] In the face of the persisting obesity epidemic,[126] it is imperative that individuals at risk of poor treatment outcomes are identified quickly and offered appropriate, timely support to improve their trajectory of success. This study undertook formative steps to (1) characterize individuals with distinct patterns of weekly adherence to prescribed steps-based and minutes-based physical activity goals during the first 2 months of an online behavioral weight loss intervention and determine whether these early adherence patterns were associated with sociodemographic characteristics, 6-month weight loss, and/or treatment engagement parameters and (2) describe the probabilities of weekly transitions in adherence to steps-based and minutes-based physical activity goals and self-monitoring behavior across 6 months.

To examine Aim 1, a repeated measures latent class analysis was conducted using self-reported physical activity data from the study website. Participants were classified as having met the program goals for steps (yes/no) and minutes of MVPA (yes/no) during the initial 2 months on weeks when both goals were prescribed. Three distinct classes were detected based on attainment of the weekly program goals: a group which consistently met both physical activity goals ("Both PA Goals"), a group achieving only the minutes-based goals ("MVPA Goals Only"), and a group of those who never met the prescribed goals ("Neither PA Goal"). Sociodemographic characteristics (age, gender, race/ethnicity, geographic region, and BMI at study entry) were predictive of latent class membership. Treatment engagement parameters for attendance; self-monitoring of weight, diet, and physical activity; and average number of self-reported steps and minutes of MVPA further differentiated these classes. Finally, weight loss responses were significantly associated with latent class membership, allowing early identification of the risk of poor weight loss outcomes based on early patterns of physical activity goal achievement.

While behavioral patterns during a lifestyle program have been identified previously based on a combination of adherence to treatment recommendations,[16,72] the current study begins to extricate the unique contribution of adherence to physical activity targets and underscores goal attainment as a useful marker of adherence. The proportions in membership across the three latent classes indicate there is a large degree of variability in adherence patterns rather than a single pattern common to the majority of individuals engaged in a weight control program. This finding builds on other evidence reporting differences in physical activity goal attainment and adherence.[6,92,125] Strikingly, "Both PA

Goals" and "MVPA Goals Only" classes were quite similar on self-monitoring parameters, attendance at group sessions, and reporting that they met their calorie goals relative to the "Neither PA Goal" class, indicating that meeting the physical activity targets was a predominant distinguishing factor. Had analyses focused only on more traditional markers of adherence,[97] without consideration for physical activity goal attainment, distinctions between these subgroups may not have emerged and individuals at risk of poor outcomes would slip under the radar. These findings suggest that physical activity goal attainment is a relevant early indicator of adherence in behavioral weight loss and that latent class analysis is advantageous for distinguishing program responders from non-responders. What remains unknown is whether increasing physical activity goal attainment during program initiation enhances eventual weight loss outcomes. Researchers and clinicians should be aware of the unique characteristics of these subgroups and prioritize the early weeks of intervention to target physical activity goal attainment.

Additional research was undertaken to examine changes in weekly adherence status to commonly prescribed physical activity goals in a lifestyle program. For each weekly steps-based and minutes-based target across the 6 months of intervention, individuals were categorized as (1) "adherent" if they met the goal and self-monitored, (2) "suboptimally adherent" if they did not meet the goal, but did self-monitor, and (3) "nonadherent" if they did not self-monitor. Few individuals initially met the steps-based goals and, thus, were most likely to either remain "suboptimally adherent" or "nonadherent" or transition from "suboptimally adherent" to "nonadherent". In contrast, adherence to the initial minutes-based goals was high; however, there was a greater

likelihood of movement in and out of adherence statuses for MVPA goals relative to steps goals during the initial 2 months of treatment.

It appears there is a brief, yet crucial, timeframe during the early weeks of a weight loss intervention to bring more individuals towards "adherent" behavior. Individuals showing signs of "suboptimally adherent" behavior, particularly for MVPA, may have the most potential of becoming "adherent" if targeted early. In another study, a similar pattern was detected in adherence to weekly self-monitoring of dietary intake, which indicated those who were "suboptimally adherent" to self-monitoring were most susceptible to transitioning to "adherent" behavior during program initiation.[73] This same study also reported a high degree of stability in "nonadherent" behavior over time, which is comparable to our finding that "nonadherent" was the most consistent or stable status across all time points regardless of the type of physical activity goal prescribed. Furthermore, these behavioral patterns closely parallel patterns of non-response reported in the weight-loss literature where individuals who demonstrate poor weight loss by 1-2 months (i.e., early non-responders) are likely to remain non-responsive throughout the remainder of treatment.[13,14,88] Thus, it would be reasonable to conclude that failure to attain the physical activity targets is a useful indicator that an individual is at high risk for poor weight loss outcomes.

Our study offers insights into the complexity of the behavior change process for physical activity in weight control. Against the backdrop of the findings that many individuals did not increase their physical activity behavior in alignment with the recommended goals across the initial two months, as well as the emergence of a subgroup who met only the MVPA goals but no subgroup meeting only the steps goals, the

identified transition probabilities can be better appreciated. Regarding steps-based goals, there was a greater overall consistency in remaining in the same status from one week to the next since most people failed to meet the initial steps goals and tended not to adequately increase steps over time such that they met the steps goals. However, greater movement occurred in relation to minutes-based goals since there were substantially more individuals who reported engaging in enough MVPA to hit the lower goals early on, but who failed to increase their activity as the goals progressed. In addition, each time the physical activity goals increased, there was a sizeable drop in adherence, as has been observed by others.[15] This implores the reevaluation of the type, timing, and progression of physical activity goals during lifestyle programs. The early identification of adherence status and transitions over time is advantageous for isolating critical time points where treatment adaptation may be beneficial to consider. Overall, lifestyle programs should identify those at risk during the initial weeks of intervention and tailor treatment rather than continuing with the traditional treatment approach. Adapting interventions based on early transitions in adherence status may help more people to successfully adopt behavioral recommendations and improve health outcomes.

6.2. Limitations

Results of this study should be interpreted with the following limitations taken into consideration. First, the iREACH^3 study was an online behavioral weight control intervention which included predominately middle-aged women with overweight/obesity. Therefore, findings may not generalize to other populations or settings. While gender was a significant predictor of latent class membership, a sample with a larger proportion of males is warranted to confirm these preliminary findings among men. It is also unclear

whether similar behavioral patterns detected here would be seen in worksite, healthcare, or commercial programs; using different physical activity targets; or in programs that target physical activity outside of the weight loss context.

Next, although participants were instructed to electronically monitor their steps and minutes of MVPA, these data were self-reported on the study website, and self-report has the potential for entry error or bias.[87,127] Additionally, the number of minutes of MVPA could have been overestimated if an individual considered activity performed at light intensity as a part of their MVPA minutes. Consequently, it is possible there were instances of misclassification of true MVPA goal attainment. Objectively collected physical activity data in future research is encouraged to verify the accuracy of the latent classes and transitional probabilities.[128]

Finally, missing data represent a limitation to this study, with increasing amounts of data missing with each week of the intervention. It could not be determined whether individuals who did not self-monitor their physical activity also did not meet the prescribed goal. To avoid overestimating adherence, we took the conservative approach by assuming the goal was not met on days when data were not submitted. However, analyses were also conducted that classified individuals based on only days when physical activity was reported and resulted in similar latent classes to those detected in the original models. This brings us greater confidence in our selection of the best fitting model and the validity of the identified classes. Also, no differences were seen in the frequency of missing data between steps-based and minutes-based goals. Therefore, missing data likely would not explain the observation of an "MVPA Goals Only" class but no class displaying a pattern of only meeting the steps goals, as well as any

differences between the transitional probabilities. Nevertheless, there remains some uncertainty in how missing data may have impacted latent class membership or the consistency of adherence status over time. Despite these limitations, our work reveals new insights into distinct behavioral typologies and goal attainment in the emerging area of early response to behavioral weight control.

6.3. Future Directions

Collectively, our findings suggest patterns of adherence to physical activity recommendations detected early on in lifestyle programs provide useful information regarding who is more or less likely to be successful long term. Research in behavioral medicine has been largely variable-centered, which often assumes there is a linear pattern of associations between variables in the data and that the population is homogenous in this pattern. This study demonstrates the considerable value of complementing variable-centered approaches with a person-centered approach, such as latent class analysis, to reveal subgroups with distinct behavioral patterns.[17] These patterns can then be used to guide intervention tailoring to better match individuals with the most appropriate treatment recommendations.

Based on the patterns detected in this study, groups of individuals who do not fully adhere to initial physical activity recommendations could be provided with additional or different support early in treatment. For example, those who demonstrate early failure to self-monitor their physical activity manually could be provided with tools to facilitate continuous monitoring, such as a wearable activity tracker.[115] This technology can also be leveraged to detect states of vulnerability to poor physical activity adherence and trigger a recommendation in real time. Coaching sessions that focus on

physical activity may also be implemented to help an individual build awareness as to where their current level of activity stands in relation to the recommended goal and apply behavior change techniques more precisely to the individual's circumstances.[117-119]

Future research should also endeavor to determine whether there are optimal thresholds for physical activity in terms of total daily steps or minutes of MVPA during behavioral weight control. A subgroup of individuals who achieved clinically meaningful weight losses reported about 200 minutes per week of MVPA and 10,000 daily steps by two months of starting a lifestyle program, which suggests these may be ideal physical activity targets for weight loss induction. However, there may be intermediate "sweet spots" in the early weeks of program initiation that distinguish treatment responders and non-responders and indicate who is likely to successfully adopt a physically active lifestyle. Adaptive physical activity goals would be a practical way to assist those who struggle to achieve the thresholds by introducing more personalized progressions. Replication of our findings with implementation of different physical activity goals from those prescribed in iREACH^3 would bring further clarity in determining optimal thresholds for early detection of treatment responsiveness. Collectively, these insights would further inform targets for intervention, particularly by guiding the selection of parameters and decision rules required for adaptive interventions, which have strong potential for enhancing positive behavior change for more people by tailoring treatment strategies and recommendations.[129]

Research would benefit from ascertaining how the distinct behavioral patterns revealed in this study interact with individual characteristics, preferences, and barriers to physical activity to predict an individual's weight loss response, which would further

guide adaptive research designs.[130] Individual characteristics, such as sense of self-efficacy; cognitive, motivational, and affective states; exercise history; and preferences for physical activity would further characterize the identified subgroups and those who are vulnerable to transitions in adherence status. It is also likely that barriers to physical activity, especially during the initial period of engaging in a lifestyle program, play a role. Assessment of these factors in real time, in the context of the individual's daily life, and in tandem with monitoring physical activity behaviors are possible through techniques, such as ecological momentary assessment.[131,132] A deeper understanding of these factors will enable us to build more complete profiles of subgroups at risk of poor outcomes and to better target their unique needs. Finally, physical activity is consistently associated with successful weight loss maintenance.[49,57,133] Thus, assessing physical activity adherence patterns beyond 6 months will further extend this area of research.

In summary, physical activity is a cornerstone of behavioral weight control, yet there is wide variability in adherence to the program physical activity goals and in weight loss responses. Determining what distinguishes individuals who are responsive from those who are non-responsive is necessary to improve the effectiveness of obesity treatment and tailor programs to best support the needs of each individual. This study provides a preliminary description of behavioral patterns in adherence that may serve as useful indicators of treatment responsiveness, particularly during the early period of lifestyle modification. Practical implications and recommendations for future studies are offered based on this formative work.

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