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PSYCHOSOCIAL ASPECTS (SS JASER, SECTION EDITOR)

Adaptive Intervention Designs to Promote Behavioral Change in Adults: What Is the Evidence?

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Abstract

Purpose of Review Adaptive behavioral interventions tailor the type or dose of intervention strategies to individuals over time to improve saliency and intervention efficacy. This review describes the unique characteristics of adaptive intervention designs, summarizes recent diabetes-related prevention studies, which used adaptive designs, and offers recommendations for future research.

Recent Findings Eight adaptive intervention studies were reported since 2013 to reduce sedentary behavior or improve weight management in overweight or obese adults. Primarily, feasibility studies were conducted. Preliminary results suggest that just-in-time adaptive interventions can reduce sedentary behavior or increase minutes of physical activity through repeated prompts. A stepped-down weight management intervention did not increase weight loss compared to a fixed intervention. Other adaptive interventions to promote weight management are underway and require further evaluation.

Summary Additional research is needed to target a broader range of health-related behaviors, identify optimal decision points and dose for intervention, develop effective engagement strategies, and evaluate outcomes using randomized trials.

Keywords Adaptive intervention · Just-in-time adaptive intervention · Sequential multiple assignment randomized trial · Weight management · Physical activity

Introduction

Health behavior interventions, which facilitate a reduction in energy intake and greater energy expenditure, promote 5–9% weight loss on average during the first 6 months of treatment [1]. In conventional fixed interventions, commonly used to promote greater physical activity, weight loss, and reduced risk for type 2 diabetes [2], all program participants receive the same intervention sequence and dose without taking into account individual characteristics or treatment response. However, wide variation in response often occurs and some participants are slower to respond to conventional treatment than others [3–5]. In addition, some specific intervention components may have little or no relevance to an individual. The ongoing process of behavioral change is dynamic, potentially requiring different treatment approaches throughout the process. In contrast to fixed interventions, adaptive interventions offer the potential to vary treatment when initiating new behaviors or when transitioning into maintenance of newly adopted behaviors.

In adaptive interventions, the type or dose of the intervention is individualized based on personal characteristics or progress and repeatedly adjusted over time in response to ongoing performance [6]. These interventions may involve increasing the intensity of therapy (i.e., stepped up stepped care), decreasing the intensity of therapy (i.e., stepped down stepped care), transitioning to other types of therapy, or returning to maintenance therapy once acute problems are resolved [7]. The strategies used in adaptive interventions, called adaptive treatment strategies, individualize treatment via decision rules established a priori that recommend when and how the treatment changes based on the history of previous treatments and response to those treatments [8].

Adaptive interventions include a range of intervention approaches. Just-in-time adaptive interventions (JITAIs) use continuously collected data (e.g., via sensors, accelerometer, mobile application, or questionnaire) to adapt intervention components in the moment to support the behavior change

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process. Sequential multiple assignment randomized trials (SMART) represent another type of adaptive intervention where second-stage treatments are provided to sub-optimal responders following first-stage treatment. Finally, adaptive stepped-care interventions often begin with a low-intensity intervention that is increased (i.e., stepped up) if certain milestones are not achieved [9••, 10–12]. By beginning with a less intensive treatment, participants who are meeting treatment goals do not receive unnecessary treatment. In contrast, other stepped-care interventions include a stepped-down approach where all participants initially receive the strongest dose of treatment. Those who achieve sufficient progress defined a priori at a specified timepoint, transition to a lower intensity treatment [13]. A stepped-down approach requires fewer resources and lower burden for participants who are meeting treatment goals. Finally, the multiphase optimization strategy (MOST) uses an adaptive engineering-based approach to create the best intervention possible while working within realistic and specified resource limitations during intervention development and implementation. It is beyond the scope of this paper to adequately address MOST; the process is described elsewhere [14].

Adaptive intervention approaches hold promise for improving the care of people with diabetes by tailoring intervention strategies to individuals' medical history, treatment preferences, self-management support, and lifestyle goals [15]. Therefore, the purposes of this review paper are to (a) describe the unique characteristics of three types of adaptive interventions (i.e., JITAIs, SMART, and stepped care); (b) review the adaptive behavioral interventions published in the past 5 years; and (c) offer recommendations for future research to build the evidence base for adaptive interventions to facilitate greater behavioral change in adults.

To identify relevant studies, a MEDLINE and PsycINFO search was conducted using the following combination of keyword search terms: *adaptive design*, *just-in-time adaptive intervention*, and *behavior* published since 2013. Studies conducted among people with diabetes were initially preferred. However, none of the behavioral studies identified included samples with diabetes; all of the studies published focused on increasing physical activity or facilitating weight management. Thus, the review centered on these domains, since physical activity and weight management are pertinent goals in diabetes prevention and care [15, 16]. Reference lists of relevant papers also were examined. A summary of the relevant characteristics of each study is provided in Tables 1 and 2.

Just-In-Time Adaptive Interventions

Mobile technology provides many opportunities for delivering interventions to meet an individual's immediate needs in the context in which the target behavior occurs. As sensing technologies are integrated with the mobile phone, health behavior interventions can be tailored to an individual's baseline characteristics and to changes in internal and contextual states and behavioral patterns [24]. A JITAI considers an individual's time-varying status and context to determine when the person is receptive to intervention while minimizing resources or waste [25].

The development of JITAIs includes several key components and important design principles (see Fig. 1). Timing is a critical feature of JITAIs and refers to when events or conditions are optimal to deliver support (e.g., when the person enters a high-risk situation such as the presence of highly palatable food) through ongoing monitoring of the individual [25]. Monitoring also is needed to avoid providing the wrong type of support (e.g., encourage physical activity when someone is ill) and to avoid providing support when it is unnecessary in an effort to conserve resources (e.g., time, effort, participant burden). States of vulnerability, or periods of heightened susceptibility to a negative outcome or maladaptive behavior, are periods when support can be beneficial during the intervention. These states can emerge rapidly and unexpectedly and vary widely both within and between individuals. JITAIs may offer support during these transient moments to provide support when needed to gradually move the person's actions, cognitions, or emotions in the desired direction [25].

JITAIs also seek to capitalize on states of opportunity or periods of heightened susceptibility to positive health behaviors [26••]. For example, a message to recall one's values (e.g., be a positive role model for my children) may offer support when someone encounters temptation to overeat. It is critical to ensure support is provided when receptivity is high (and not overwhelming) and when support can be received, processed, and acted upon. The goal of JITAIs is to offer the right type of support only when the opportunity is right and the person is in a state of vulnerability but also high receptivity to minimize disengagement and intervention fatigue.

To accomplish this goal, six key elements of a JITAI are considered during intervention design, including: (a) distal outcome; (b) proximal outcome(s); (c) intervention components or options; (d) decision points; (e) tailoring variables; and (f) decision rules [25, 26••]. The distal outcome is the ultimate goal of the JITAI in the target population (e.g., weight loss or greater physical activity). The proximal outcome(s) is an intermediate metric of response or success in achieving progression from the current state to the desired distal state [25]. Proximal outcomes may be mediators in a causal pathway through which the intervention is designed to impact the distal outcome or intermediate measures of the distal outcome [26••]. A JITAI may target multiple proximal outcomes simultaneously

Table 1 Summary of just-in-time adaptive interventions in adults to promote physical activity or weight management

Reference	Distal outcome	Proximal outcome	Tailoring variable(s)	Intervention options/components	Decision points	Decision rules
S'itCoach (pilot) study [17]	Reduce sedentary behavior in office workers > age 30 ($n = 86$)	# Active minutes/day (default goal of 50 min)	#1. Sitting time	Set of 32 persuasive messages via text to hyperlink to take an active break; maximum of 3 messages sent/day	Interval of uninterrupted computer activity	If sitting duration ≥ 30 min, reminder sent to be active for 5 min.
B-MOBILE study (fully powered trial) [18]	Reduce percentage time sedentary in overweight/obese adults ($n = 30$)	Continuous minutes of sedentary behavior	#1. Sedentary time	3 random conditions: #1. Prompt 3-min break after 30 sedentary min #2. Prompt 6-min break after 60 sedentary min #3. Prompt 12-min break after 120 sedentary min	30, 60, or 120 continuous minutes of sedentary behavior	If meet sedentary time, audible prompt sent to meet activity goal.
Muller et al. (conceptual description of intervention) [19••]	Reduce sedentary behavior in older adults	# Active breaks during day	#1. Sitting time #2. ppt. location #3. Time of day #4. Support prompts #5. Response to support prompts	#1. Text message to promote light movement #2. Text message to offer feedback #3. Provide nothing	5:00–9:00 pm message sent based on tailoring variables	Based on accumulated sitting time (< or ≥ 30 min), location (home yes or no), time of day (evening yes or no), frequency of support prompts (3/day), and response to prompts (active yes or no)
DietAlert (pilot) study [20]	Weight loss in adults ($n = 12$)	Dietary lapse (exceeding meal or snack calorie goals)	21 potential triggers for dietary lapses (e.g., mood, socializing, watching TV, presence of high-calorie food, physical location, cravings, food cues)	For each risk factor, 7–10 micro-interventions developed based on risk for a dietary lapse; 157 total brief reflective exercises prompted (e.g., goal setting) or behavioral strategies provided (e.g., try deep breathing to reduce anxiety or stress)	Algorithm and variable selection model predict risk for a dietary lapse	Individualized based on relevant tailoring variable(s) and machine learning to predict a dietary lapse
MyBehavior (pilot) study [21]	Weight management ($n = 17$)	Minutes and frequency of PA and calorie intake	#1. Type of PA #2. Duration of PA #3. Location of PA #4. Calories expended during PA #5. Food item #6. Quantity of food consumed #7. Calorie content of food consumed #8. Lifelog list of PA and food events	10 (of 42) food and PA suggestions provided at beginning of day; 90% of suggestions based on ppt's most frequent activities/foods consumed (exploit strategy); and 10% based on infrequent activities/foods consumed (explore strategy)	Continuous exploit or explore strategy used to generate suggestions based on prior PA and food intake	Similar activities and food items are clustered to provide tailored suggestions using machine learning and behavioral theory

ppt, participant; *PA*, physical activity

Table 2 Summary of adaptive interventions in adults to promote weight management

Type of trial	Distal outcome	Tailoring variable(s)	Intervention components	Decision stage or point	Decision rules
Adaptive stepped-down trial (pilot study) [13]	Change in body weight in overweight or obese adults ($n = 52$)	Percent weight change	2-stage design: all participants randomized to stepped care received the same initial 6-week group sessions. If achieve 6-week weight-loss goal, stepped down to self-help. Received new weight-loss goal at week 6. If achieve new goal at week 12, stepped down to self-help. Those randomized to SBT at baseline received standard group-based sessions throughout.	Week 6 and week 12 of intervention	Optimal responder if lose ≥ 3% of session 1 weight at week 6. Optimal responder if lose second ≥ 3% goal at week 12. Sub-optimal responders continue with group-based SBT or rejoin group-based sessions
Adaptive stepped-up trial (pilot study) [22]	GWG in overweight or obese pregnant women > 8 weeks gestation ($n = 30$)	GWG progress	2 group randomized trial: education, goal setting/ action planning, mobile self-monitoring, active learning (experimental group) Standard prenatal visits with health care provider (control group)	Every 3–4 weeks from approximately 8 to 36 weeks gestation	Evaluate GWG weekly. Step up intervention dose every 3–4 weeks if GWG exceeds goal; 5 dosage increases possible (experimental group)
Adaptive SMART trial (fully powered trial) [23]	Change in body weight in obese adults ($n = 500$)	Percent weight change	2-stage SMART design: at baseline, randomize to week 3 or week 7 response assessment; begin with SBT for all If randomized to 3-week assessment timepoint and sub-optimal responder, re-randomized to either SBT + portion-controlled meals or switch to ABT. If randomized to 7-week assessment timepoint and sub-optimal responder, re-randomized to SBT + portion-controlled meals or switch to ABT.	Week 3 and week 7 of intervention	Sub-optimal responder if lose < 2.5% of session 1 weight by week 3 or < 5.0% of session 1 weight by week 7 Responders continue with SBT throughout trial

SBT, standard behavioral weight loss therapy; *GWG*, gestational weight gain; *SMART*, sequential multiple assignment randomized trial; *ABT*, acceptance-based behavioral treatment

(e.g., minutes and intensity of physical activity). JITAIs aim to influence the proximal outcome(s) through intervention options. These options include the content to deliver (e.g., information, advice, feedback), amount of support to provide (e.g., dose), and media employed for intervention delivery (e.g., phone call, text message). Intervention options are based on specified decision points when an intervention decision is made based on specific time of day, specific days of the week, following random prompts, or at pre-specified time intervals. The timing of the decision point should be aligned with how often meaningful change occurs in the tailoring variables. A tailoring variable is information collected to assess a state of vulnerability, opportunity, and receptivity to intervention support. This information may be collected passively without engagement from the participant (e.g., wearable devices), or actively where the participant responds to prompted queries (e.g., through ecological momentary assessment), or both. Finally, decision rules specify which intervention option to offer, for whom, and

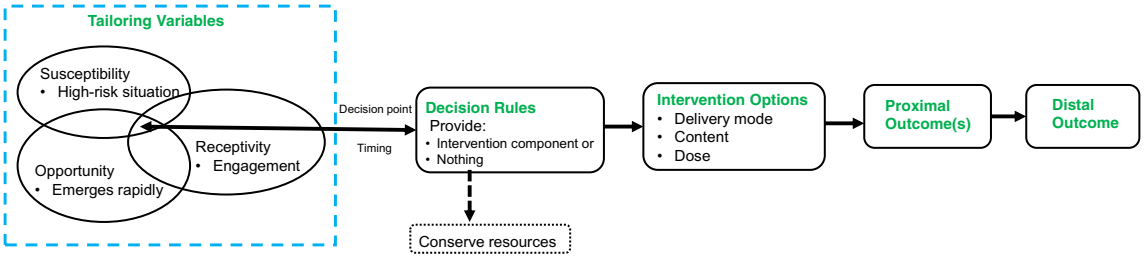

Fig. 1 Framework for developing just-in-time adaptive interventions. (From Nahum-Shani et al. [25] adapted with permission)

when in a systematic way defined a priori for each decision point.

JITAIs to Promote Physical Activity or Weight Management

Of the JITAIs reported to date, three were developed to reduce sedentary behavior by continuously monitoring activity level (see Table 1) [17, 18, 19••]. An audible prompt or text message was sent to study participants in all three studies when a defined period of sedentary behavior (e.g., 30 min) was detected. Most of the JITAI studies are in early development and assessment of feasibility, and findings are not yet available for one study [19••]. However, in the SitCoach study, office workers received a text message containing a hyperlink whenever at least 30 min of uninterrupted computer activity was detected [17]. The hyperlink redirected participants to a website that displayed a message persuading participants to be more active. A maximum of three messages per day were sent (at least 2 h apart), even if participants exceeded the sedentary threshold more often. Study findings revealed a reduction in computer activity of 10 min in the experimental group compared to 5.9 min in the control group after receiving a prompt to be active.

The aim of the B-MOBILE study, a third JITAI study, was to disrupt prolonged periods of sedentary behavior with brief walking breaks [18]. Since the most effective strategy for maximizing break frequency and duration is unknown, this study randomized participants to three different conditions using a within-subjects design. The experimental conditions included receiving a prompt to be active after the following intervals of continuous sedentary behavior: (a) 3-min break prompt after 30 min of sedentary behavior; (b) 6-min break prompt after 60 min; and (c) 12-min break prompt after 120 min. Following each prompt, participants could engage in physical activity, silence the prompt, or delay activity and receive another prompt after 30 min. When participants responded to a prompt by being active, they received a text message praising their accomplishment. Following the intervention, percentage time in sedentary behavior significantly decreased and percentage time in both light- and moderate-to-vigorous intensity physical activity significantly increased in all three experimental conditions ($p < 0.05$), with the 3-min break condition resulting in significantly greater reductions in percentage time being sedentary compared to the 12-min break condition ($p = 0.04$).

Two additional JITAI studies promoting weight management have been described. The DietAlert study was designed to help participants lose or maintain body weight by preventing dietary lapses using repeated sampling of potential food triggers through ecological momentary assessment (EMA) [20]. A dietary lapse was defined as exceeding individual calorie goals for meals or snacks. When participants reported the presence of potential triggers (e.g., mood, social interactions), the DietAlert application used a predictive learning algorithm to calculate level of risk for lapsing and determined three factors contributing to risk. If risk was high, a series of "micro-interventions" (e.g., brief, text-based modules) were delivered to the person to prevent a lapse. Based on a literature review, 21 potential triggers for lapsing were identified as tailoring variables. Participants were actively prompted via EMA six times per day approximately every 2 to 3 h to answer questions regarding the tailoring variables to capture change in these variables over time. EMA questions varied systematically throughout the day to minimize response burden. Information from tailoring variables was used to determine which intervention component to deliver to the participant and when to deliver it. Findings from a randomized trial implementing DietAlert are not yet available; however, research is ongoing to optimize DietAlert prior to a comparative trial.

Finally, the MyBehavior JITAI study used machine learning to automatically create contextualized and individualized suggestions to participants to increase physical activity and improve dietary intake based on continuously collected data [21]. The application included five key modules: (a) physical activity assessment; (b) dietary assessment; (c) lifelog generation (chronological list of activity and food log events); (d) physical activity and food clustering analysis to identify similarity in behaviors; and (5) suggestion generation to modify participants' behavior based on each individual's previously reported behavior. At the beginning of every day, MyBehavior generated 10 food and 10 activity suggestions that encouraged the person to continue positive activities (e.g., be physically active), make small changes in some situations (e.g. reduce

sedentary behavior), or avoid negative activities (e.g., avoid a large meal). Findings from a feasibility study revealed that the experimental group walked 10 min more/day on average compared to the control group ($p = 0.055$). There was no significant difference in the change in calorie intake between treatment groups. These findings will be used to refine the MyBehavior intervention for a larger randomized trial.

Sequential Multiple Assignment Randomization Trial Research Designs

The SMART approach is a second type of adaptive intervention trial. In SMART studies, participants are randomized several times at critical decision points to build and refine treatment strategies [7]. During treatment, not all individual participants respond or adhere to the treatment or respond to treatment within the same timeframe, indicating that what works for one person may not work for all people. Thus, sequential treatment is necessary when a high level of individual heterogeneity in response to treatment exists and when it is possible to identify non-responders [9••].

In order to provide an alternate treatment to non-responders, several questions must be answered including: (a) what is the best first-stage treatment? (b) What is the best subsequent treatment? (c) What is the optimal time to define non-response to initial treatment? (d) Should the decision regarding duration of first-stage treatment be individualized based on factors known about the person at baseline? (e) What other variables can be used to adapt the intervention over time to meet the changing needs of the individual (e.g., self-monitoring adherence)? Two types of tailoring variables, baseline, and intermediate variables exist in these designs. Baseline tailoring variables (e.g., demographic characteristics, previous weight loss attempts) include information obtained prior to the first decision stage. Intermediate tailoring variables are obtained any time during a decision stage to make treatment decisions at subsequent stages. Intermediate variables may be mediators of prior treatment or early indicators of long-term outcomes (e.g., proximal outcome). The entire package of treatment options, decision stages, decision rules, and tailoring variables constitute one adaptive intervention.

With SMART designs, multiple stages of treatment are deployed. Each stage of treatment corresponds to a decision stage, and randomization of participants occurs at the beginning of the decision stage. All participants are randomized at least once, and some or all participants may be randomized several times throughout the course of the trial. These trials enable investigators to examine an optimal sequence of treatment for each individual. Baseline tailoring variables that might be useful in making decisions about first-stage treatment as well as other intermediate tailoring variables that might be useful in making decisions about second-stage treatment can be identified [9••]. The primary aim of SMART designs is to address sequencing and timing questions to construct a high-quality adaptive intervention based on data rather than evaluate an existing fixed intervention.

SMART Trial to Promote Weight Management

Sherwood et al. [23] are conducting a fully powered SMART study to evaluate the impact of standard behavioral weight loss treatment (SBT) compared to SBT augmented with portion-controlled meals or to acceptance-based behavioral treatment (ABT) (see Table 2). The study uses a two-stage design where participants are randomized initially with equal probability to response assessment at intervention week 3 or week 7. Those who are randomized to week 3 are considered sub-optimal responders if they lose < 2.5% of their starting weight by week 3 and/or 28 days after intervention session 1, whichever comes first; those randomized to week 7 are considered sub-optimal responders if they lose < 5.0% of their starting weight by week 7 or 63 days after session 1, whichever comes first. Participants identified as sub-optimal responders are re-randomized to either SBT augmented with portion-controlled meals or they switch from SBT to ABT. Participants identified as responders at either week 3 or week 7 continue with SBT. The study aims to evaluate, among sub-optimal responders to SBT, whether augmenting SBT with portion-controlled meals or switching to an alternate therapy (ABT) is more effective and the optimal timing for identifying sub-optimal responders (intervention week 3 or week 7). Providing portion-controlled meals reduces the need for behavioral control and decision-making whereas ABT is designed to enhance the capacity for self-regulation. Which approach is an optimal first- or second-stage treatment is unknown as both intervention approaches could be beneficial. Waiting until week 7 to augment care or switch to an alternate treatment may be less beneficial if participants who are having difficulty losing weight begin to feel less optimistic about their likelihood for success. This study is currently underway and study findings will provide an evidence base for the development of an individualized adaptive intervention for adult weight control.

Stepped Care to Optimize Weight Management

Stepped care is another type of adaptive intervention in which a sequence of intervention strategies is tailored to each individual's progress during treatment. Stepped-care designs can take one of two forms: a stepped down or stepped-up design. These intervention studies assess participant progress at several points throughout the intervention and modify treatment

delivery as needed. Stepped-up approaches increase intervention intensity when response to an initial, low-intensity program is low or absent. While stepped-down approaches progress from greater to lower treatment intensity for those who meet treatment goals. The a priori decision rules for stepping up or down treatment intensity in weight control studies, for example, are usually based on facilitating clinically meaningful goals by treatment end (e.g., 10% weight loss by 6 months).

Recently, the change in weight was evaluated using a stepped-down approach compared to a standard behavioral weight loss program (BWLP) among overweight or obese adults in a pilot study (see Table 2) [13]. Participants were randomly assigned at baseline to either a BWLP or a BWLP that included a stepped-down component at weeks 6 and 12. A 3% weight-loss goal was established for all participants at week 6 and again at week 12 to help participants achieve a clinically significant weight loss of 9% across the 18-week intervention. Following the first 6 weeks, participants in stepped care who met their 3% weight-loss goal were required to discontinue attendance at the weekly group sessions and encouraged to continue their weight loss efforts using the provided treatment manual (i.e., self-help). Those not meeting the 3% goal continued with the weekly group sessions for another 6 weeks. All participants then were assigned another 3% weight-loss goal based on their current weight for weeks 6–12. Participants in the stepped-care condition who met their second 3% weight-loss goal were then stepped down to self-help at week 12, while those who failed to meet the goal at week 12 returned to weekly group sessions (even if they were using self-help from weeks 6–12). During weeks 6 to 12, approximately 50% of participants in the stepped-care condition who were stepped down to less intense treatment did not meet their 3% weight-loss goal and rejoined the group sessions. At week 18 (treatment end), the standard BWLP participants lost nearly 3% more weight than the stepped-down participants (7.8% vs. 4.9%), but this was not statistically significant ($p > 0.05$).

In contrast to a stepped-down approach to weight management, Downs et al. [22] implemented an adaptive stepped up, stepped-care pilot intervention among pregnant overweight or obese women to prevent excessive gestational weight gain (GWG) from approximately 8- to 36-week gestation. A customized intervention plan for each participant was developed based on her energy intake, physical activity, planned and self-regulatory behaviors, and the extent to which she met GWG goals. GWG was determined weekly and decision rules were applied in 3- to 4-week cycles to determine when and how the intervention was stepped up in dosage and delivery of additional intervention components. If a participant's weight gain was within the recommended guidelines, she continued to receive the same level of intervention for the next 3- to 4-week cycle. If, however, a participant exceeded her GWG goal, the intervention was stepped up to include additional active learning components (e.g., onsite exercise session with instructor). If she exceeded her GWG goal at the next evaluation cycle, the intervention was adapted again with other active learning components (e.g., portion control and food containers) to better manage GWG. Five dosage increases were possible. Baseline data have been collected for this study and only preliminary results have been reported for one participant. Results from the full trial will enable a more individually tailored and adaptive approach to effectively manage weight gain during pregnancy.

Future Research Needs Using Adaptive Designs

While the research reported to date using adaptive interventions to promote physical activity or weight management is in the early stages of development, preliminary feasibility studies suggest that an adaptive approach to intervention delivery may be effective. The duration of sedentary behavior was reduced and minutes spent in physical activity were increased following JITAIs. In addition, efforts to promote weight loss or limit excessive weight gain during pregnancy are using an adaptive approach to better meet participant needs. Adaptive intervention strategies may reduce resource waste and subject burden by ensuring that each individual receives an intervention dose sufficiently large to meet his or her needs but not larger. An adaptive design also may enhance intervention efficacy by improving the saliency of specific intervention components [27]. The use of portion-controlled meals to assist weight loss may be beneficial for people who live alone and do little cooking, for example, whereas the development of self-regulatory skills, such as the planning ahead promoted in ABT, may be more beneficial for others.

Given that the field of adaptive interventions is emerging, several areas of research are needed. The primary aim of an adaptive SMART, for example, is to construct a high-quality intervention, while the primary aim of a randomized trial is to evaluate a fully developed intervention compared to a suitable control [9••]. Randomized trials are needed across the various types of adaptive intervention studies to determine whether greater intervention efficacy is indeed achieved. These trials will require resources and a concerted effort of time and expertise to be successfully completed. Given the limited findings to date, feasibility and efficacy studies are needed followed by larger effectiveness trials.

Furthermore, research is needed to target additional health-related behaviors besides physical activity and weight management. Only the MyBehavior study reported to date assessed dietary intake and attempted to improve dietary quality [21]. Accurately, estimating food group, calorie, and nutrient intakes is complex given the wide array of foods available,

difficulty estimating food portions, and potential for social desirability and recall bias [28, 29]. However, eating behaviors are intricately involved in reducing risk for chronic disease and preventing excessive weight gain. Research is urgently needed to improve the reliability and validity of (continuous) dietary assessment in real time using mobile technology to develop decision rules for delivering intervention components at optimal decision points. The application of adaptive lifestyle interventions for diabetes self-management also is needed. The incorporation of continuous glucose monitoring in relation to diet and physical activity behaviors holds promise for providing critical information in implementing precision medicine to reduce blood glucose variability and personalized treatment plans [30].

JITAIs, in particular, require continuous monitoring to capture between-person and within-person variability to target states of vulnerability, opportunity, and receptivity [25]. These states change over time and new data analytic methods are needed to improve decision rules for intervention delivery. Similarly, a greater understanding of the factors which promote intervention engagement and reduce intervention fatigue also are needed [25]. For example, in the B-MOBILE study, the 3-min physical activity break prompt after 30 min of sedentary behavior was effective in decreasing sedentary behavior; however, half of study participants reported that they least preferred this prompt condition and sometimes preferred being sedentary for the purpose of relaxation [18]. Strategies for promoting positive health behaviors and discouraging negative health behaviors are needed to formulate good decision rules in JITAIs [26••].

Finally, health behavior models and theories often used to guide intervention development are static and linear in nature and may fail to capture the within-person variability that occurs over time [24]. As adaptive interventions tailor intervention components to each individual based on progress toward the distal outcome, prior responses to intervention components, and current environmental, social, and/or physiological data, current health behavior theories may be inadequate. The ability to capture data longitudinally enables interventions to be tailored to each person during the course of the intervention. Theoretical intervention models need to expand from explaining between-person change to within-person change over time and also address the timing of intervention delivery. The intervention components which are effective at promoting behavior initiation versus behavior habituation need to be identified and empirically evaluated.

Conclusions

In summary, optimized adaptive interventions hold promise for greater and sustained intervention impact. The aim of these interventions is to deliver the right component at the most effective dose and time to avoid delivering an intervention component when it is not necessary. Research efforts to develop and refine adaptive interventions to promote physical activity and weight management, in particular, are underway and they are in the early stages of evaluation. Physical activity and a healthy lifestyle for optimal weight management lie at the cornerstone of diabetes prevention and treatment. Effectively tailoring intervention components to the individual at the right time has the potential to change the field of behavioral science and advance diabetes prevention and treatment.

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Compliance with Ethical Standards

Conflict of Interest Carla K. Miller declares that she has no conflict of interest.

Human and Animal Rights and Informed Consent All reported studies/experiments with human or animal subjects performed by the authors have been previously published and complied with all applicable ethical standards (including the Helsinki Declaration and its amendments, institutional/national research committee standards, and international/national/institutional guidelines).

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