INDIVIDUAL- AND POPULATION-LEVEL IMPACTS OF SUGAR-SWEETENED BEVERAGE HEALTH WARNINGS

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ABSTRACT

Anna H. Grummon: Individual- and Population-Level Impacts of Sugar-Sweetened Beverage Health Warnings
(Under the direction of Noel T. Brewer)

Introduction. Implementing health warnings on sugar-sweetened beverages (SSBs) could reduce consumption of these products and associated diseases. This dissertation aimed to design effective SSB warnings, evaluate their impact on actual SSB purchases, and model the expected effects of a national SSB health warning policy.

Methods. In the first study, a national sample of U.S. adults (n=1,360) completed an online randomized experiment investigating their responses to SSB health warnings with different characteristics. In the second study, I conducted a randomized controlled trial in a naturalistic replica of a convenience store to evaluate the impact of SSB health warnings on adults' (n=400) beverage purchases. The third study applied a microsimulation model of dietary behaviors and body weight to quantify the effects of a national SSB health warning policy on U.S. adults' SSB intake, total energy intake, body mass index (BMI), and obesity status over five years.

Results. In the first study, SSB health warnings that described the health effects of SSB consumption, began with the marker word "WARNING," and were displayed on an octagon-shaped (vs. rectangular) labels were perceived to be more effective than warnings without these characteristics (ps<0.001). In the second study, SSB health warnings reduced SSB purchases by 32.4 calories/transaction, a 22.4% reduction over the control arm (p=0.019). The third study found that implementing a national SSB health warning policy would reduce U.S. adults' average SSB intake by 26.2 calories/day (95% uncertainty interval [UI]: -28.3, -24.1) and total energy intake by 32.4 calories/day (95% UI: -34.2, -30.5). If sustained over five years, these dietary changes would reduce average BMI by 0.61 kg/m^2 (95% UI: -0.64, -0.57) and obesity prevalence by 2.1 percentage points (95% UI: -2.4%, -1.7%).

Conclusions. Small changes in the design of SSB health warnings will likely enhance their impact on SSB consumption and obesity. Implementing health warnings could improve population health.

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CHAPTER 1: OVERVIEW AND SPECIFIC AIMS

Obesity, diabetes, and cardiovascular disease are leading causes of death in the United States.[1] Consumption of sugar-sweetened beverages (SSBs) such as sodas, fruit drinks, and sports drinks is a significant contributor to these preventable conditions.[2–5] Despite the health risks of SSB consumption, the average American adult drinks a remarkable 30 to 40 gallons of SSBs every year, accounting for seven percent of daily caloric intake.[6–9] To reduce SSB consumption, state and local legislators have proposed requiring front-of-package health warnings on SSBs.[10–15] Even as policymakers' interest in SSB health warnings grows, there remain critical gaps in our knowledge of this policy.

One unanswered question about SSB health warnings is how to design warnings to maximize their effectiveness at discouraging SSB consumption. Approaches vary by country. For example, warnings proposed in the U.S. would describe the health effects of consuming SSBs,[10–14] while the health warning systems adopted in countries such as Chile do not describe health effects, but instead display nutrient disclosures that signal when a product exceeds recommended levels of sugar, sodium, saturated fat, or calories.[16] For example, SSBs in Chile display warnings that read "Alto en azúcares" ("High in sugars"). Another difference is warning label shape: in Chile, warnings are displayed on octagon-shaped labels, while SSB warnings in the U.S. would likely be displayed on rectangular labels. Finally, the proposed SSB health warnings in the U.S. begin with a marker word (usually "WARNING" or "HEALTH WARNING"[10–14]) that quickly alerts the reader to focus of the message, while labels in other countries typically do not use marker words.[16–18] Previous research suggests these warning characteristics might affect warnings' effectiveness,[19–27] but studies have not examined these characteristics side-by-side or in combination with one another.

Another unresolved question is whether SSB health warnings will affect actual consumer behaviors. Studies of similar text health warnings on cigarette packs find that warnings reduce smoking in adolescents.[28] Likewise, online randomized trials indicate that SSB health warnings affect important psychological antecedents to behavior change including intentions to purchase SSBs.[19–21] Because intentions are a strong predictor of behaviors,[29] including SSB consumption,[30–32] these studies indicate that SSB health warnings are a potentially promising strategy for reducing SSB purchases. While this evidence is suggestive, few studies have examined whether SSB health warnings change actual behaviors.[33,34] Understanding SSB warnings' impact on behavior is important: if effective, health warnings are a highly scalable intervention that could reduce SSB intake and associated chronic diseases.

Finally, research has not yet evaluated how a national SSB warning policy would affect population-level outcomes. Policymakers report wanting information on how different policy options would affect the health of their constituents.[35] But such information is difficult to capture with randomized trials, as trials are not easily implemented across entire populations, and studies focused on individual behavior rarely translate their effect sizes into population health outcomes. To overcome these challenges, simulation models can be used to quantify the potential population-level impacts of implementing different policy options.[36–40] These models estimate population-level outcomes by integrating information about a population's pre-policy (baseline) demographic structure and behaviors, how behaviors would change in response to a new policy, and how these behavior changes would influence key health outcomes. Such models have been used to examine the behavioral and health effects of other nutrition policies, including taxes on

SSBs[41–43] and changes to federal nutrition assistance programs,[39] but no research has quantified how a national policy requiring SSB health warnings would change population-level SSB consumption or associated health outcomes such as body weight.

This dissertation will investigate the influence of SSB health warnings on individual-level psychological and behavioral outcomes and will use these findings to quantify the expected population-level effects from implementing a national policy requiring SSB health warnings. First, I will conduct an online randomized experiment to identify promising warning designs. Then, I will conduct a randomized trial in a naturalistic convenience store laboratory setting. Finally, I will develop and apply a microsimulation model using nationally representative data from adults participating in the National Health and Nutrition Examination Surveys. The specific aims are to:

Aim 1. Evaluate the effect of warning characteristics on perceived message effectiveness.

Activities to address this aim:

a) Conduct an online randomized experiment in which adults (*n*=1,360) rate SSB health warnings that differ in: i) inclusion of a health effects statement, ii) inclusion of a nutrient disclosure, iii) inclusion of the marker word "WARNING" and iv) label shape (octagon vs. rectangle).
b) Identify the warning design that elicits the highest mean perceived message effectiveness ratings for use in Aim 2.

Aim 2. Evaluate the effect of SSB health warnings on SSB purchases and psychological antecedents.

Activities to address this aim:

a) Conduct a randomized trial in a naturalistic convenience store laboratory in which adults (*n*=400) are randomly assigned to either a health warning condition (SSBs display a health warning label developed based on Aim 1 results) or a control condition (SSBs display a control label) and select beverages to purchase with cash.
b) In a post-experiment survey, collect data on psychological antecedents to behavior change including message reactions and SSB perceptions and attitudes.

Aim 3. Estimate the effect of a national SSB health warning policy on population-level dietary and weight outcomes, overall and among sociodemographic subgroups.

Activities to address this aim:

a) Develop and validate a microsimulation model of dietary behaviors and body weight using dietary and anthropometric data from the National Health and Nutrition Examination Surveys cycles 2005-2014 (*n*~25,000); existing literature on SSB health warnings, SSB intake, and other dietary behaviors; and a validated model of body weight change.
b) Apply the model to simulate a national SSB health warning policy's impact on U.S. adults' SSB intake, total energy intake, body mass index, and obesity status over a five-year period, overall and among sociodemographic subgroups.
c) In sensitivity analyses, examine outcomes when varying assumptions about: (1) how warning impact changes over time; (2) the magnitude of warnings' impact on SSB intake; and (3) caloric compensation.

Together, this research will inform ongoing policy debates about how to improve Americans' dietary quality and will advance the science of nutrition policy evaluation. Findings will provide a deeper understanding of the potential psychological processes by which health warnings affect consumer behaviors, inform refinements of health behavior and health communication theory, and offer an innovative model for combining randomized trials with simulation modeling to understand the effects of nutrition policies.

CHAPTER 2: LITERATURE REVIEW

Introduction

On any given day, half of American adults consume a sugar-sweetened beverage (SSB),[9] and one in seven are heavy SSB consumers (consume more than 500 calories per day).[44] While some studies have reported declines in SSB consumption since the early 2000s, these reductions seem to have plateaued in recent years.[7,9] Further, at more than one serving per day, average SSB consumption among American adults remains well above the recommendations set forth in national dietary guidelines.[45,46] Across all food and beverage categories, SSBs remain the single largest contributor to added sugar intake[47] and are the fourth largest contributor to total caloric intake.[48]

These statistics are concerning because SSB consumption increases risk of several of the most pressing chronic diseases in the U.S., including obesity, type 2 diabetes, and cardiovascular disease.[2,4,5,49–52] Among unhealthy products, SSBs are often singled out as particularly problematic because they are high in calories but offer little or no nutritional value,[53–55] and because the liquid calories in SSBs cause faster increases in blood sugar[56] and lower feelings of fullness compared to solid foods.[57] Prominent researchers have even identified SSBs as perhaps "the single largest driver of the obesity epidemic."[54(p1805)] One meta-analysis of prospective cohort studies estimated that consuming one additional serving (12 ounces) of SSBs per day was associated with a 0.12-0.22 kg increase in weight over the course of a year.[2] Randomized controlled trials have suggested that the relationship between SSB consumption and weight gain may be even stronger (as high as 2.70 kg/year for each additional daily serving of SSBs).[52,58]

SSB consumption also increases risk of type 2 diabetes and cardiovascular disease, both indirectly via its influence on obesity (a known risk factor for poor cardiometabolic outcomes) and directly via its effects on metabolic and inflammatory processes.[3,4] A recent meta-analysis of prospective studies including more than 310,000 adults found that individuals in the highest quantile of SSB consumption (1-2 servings/day) had 26% greater risk of developing type 2 diabetes than those in the lowest quantile (no consumption or <1 serving/month).[59] In a separate meta-analysis of 17 cohort studies representing more than 10 million person-years, Imamura et al. estimated that 8.5% of type 2 diabetes cases in the U.S. are attributable to SSB consumption.[4] Likewise, mounting evidence suggests that SSB consumption increases risk of cardiovascular problems including hypertension, inflammation, adverse lipid profiles, and coronary heart disease.[3,60–62]

To reduce SSB consumption and the burden of SSB-related chronic diseases, legislators in five U.S. states and several major cities have proposed requiring front-of-package health warnings on SSBs.[10–15] Several recent studies have found that SSB health warnings reduce intentions to purchase SSBs,[19–21] suggesting that implementing warnings could be an effective, scalable means of reducing SSB purchases and consumption. However, major gaps remain in our understanding of SSB health warning policies. In particular, debate remains about how to design SSB health warnings to maximize their effectiveness at discouraging SSB consumption. Further, almost no research has established whether SSB health warnings change actual purchase behaviors. Finally, it remains unknown the extent to which implementing SSB health warning policies could change population-level SSB consumption and related health outcomes such as obesity. To address these gaps, I present a conceptual model of how SSB health warnings influence SSB purchases, consider implications of the model for designing effective SSB health warnings, and discuss how simulation models can be used to quantify expected population-level effects of implementing a national SSB health warning policy.

Overview of Conceptual Model

My conceptual model suggests that SSB health warnings will affect SSB purchases as well as psychological antecedents to behavior change (**Figure 2.1**). Broadly, I hypothesize that health warnings change how people think and feel about SSBs, which in turn affects their behaviors. Drawing on health behavior and health communication theories as well as empirical work on tobacco and SSB warnings, I focus on two sets of mechanisms by which SSB health warnings could exert their effects on behavior: message reactions and SSB perceptions and attitudes. While SSB consumption is the health behavior of interest, the model depicts warnings' influence on *purchases*, reflecting that Aim 2 will assess SSB purchases, not consumption. I assume that any changes in SSB purchases induced by the warnings would lead to later changes in consumption;[63] directly measuring how warnings affect consumption is beyond the scope of this dissertation. Additionally, I omit behavioral intentions from the model because the randomized trial in Aim 2 will directly assess a behavioral endpoint.

Effect of SSB Health Warnings on SSB Purchases

While no randomized controlled trials have examined whether SSB health warnings influence behavioral outcomes in retail settings, three experimental studies have demonstrated that health warnings significantly reduce SSB purchase intentions.[19–21] The Theory of Planned Behavior posits that intentions are a key determinant of behaviors.[29,64–66] Cross-sectional studies find that intentions to consume SSBs are positively associated with actual SSB consumption among adolescents,[31,32] and that intentions to limit SSB consumption are negatively related to

SSB consumption in adults.[30] Thus, I hypothesize that exposure to SSB health warnings will reduce SSB purchases relative to a control condition.

Psychological Antecedents and Potential Mechanisms

SSB health warnings may also affect psychological antecedents to behavior change. The conceptual model shows two sets of psychological antecedents, depicting four message reactions (attention, affective reactions, cognitive elaboration, and anticipated social interactions) as well as four SSB perceptions and attitudes (perceptions of added sugar content, positive consumption attitudes, positive product attitudes, and negative outcome expectations). Empirical work and theories of health behavior and health communication suggest that these psychological antecedents are potential mechanisms through which SSB health warnings may affect SSB purchases; hence, the conceptual model depicts these antecedents as intermediate variables on the pathway between health warnings and SSB purchases.

Message Reactions

Attention. According to theories of information processing (e.g., Hovland and colleagues' information-processing approach to communication[67]), consumers must attend to a warning for the warning to induce cognitive, affective, or behavioral responses.[67–69] While no randomized controlled trials of SSB health warnings have been conducted in naturalistic retail environments, online studies have found that viewers do pay attention to warnings.[19–21] Studies also suggest that greater attention to warnings is associated with stronger behavioral responses. For example, a recent randomized trial of pictorial tobacco warnings found that attention to the warnings was a key mediator of the warnings' effect on attempts to quit smoking.[70] Attention to other types of nutrition labels (i.e., non-warning labels) has also been found to explain the effect of these labels on purchase decisions. For example, in an eye tracking study examining different types of front-of-package nutrition labels, Bialkova and colleagues found that color-coded labels attracted more attention than monochrome labels, and that greater attention predicted stronger effects of color on food choice.[71]

Affective message reactions. Research suggests that attention to a warning will influence subsequent affective and cognitive message reactions.[70,72] Affective message reactions refer to the negative emotional responses a warning elicits, including emotions like fear, worry, and disgust.[72] While no studies have examined SSB health warnings' effect on these negative emotional responses, the proposed content of the warnings (i.e., messages indicating that SSB consumption causes negative health outcomes such as obesity) suggests that the warnings could elicit negative affective reactions. A growing body of research indicates that affect can strongly influence judgments and behaviors.[73] In particular, theories and frameworks including the Parallel Process Model (PPM),[74] the Extended Parallel Process Model (EPPM),[75] Protection Motivation Theory (PMT),[76,77] and the TRIRISK model[78] hypothesize that fear and worry can motivate individuals to engage in health-protective behaviors. Meta-analyses find that fear predicts intentions and behaviors across a variety of health behaviors,[79,80] including dietary behaviors.[81] Note that while some theories (e.g., PPM, EPPM, and PMT) posit that fear appeals may only be effective when they are accompanied by messages that increase self-efficacy, response-efficacy, or both,[80] meta-analyses have found that fear appeals change behaviors even in the absence of efficacy statements.[80,82,83] Thus, the proposed SSB health warnings, which do not include efficacy statements,[10–14,16] may still elicit affective message reactions. Support for the hypothesized relationship between SSB health warnings, affective message reactions, and SSB purchases also comes from a recent trial of pictorial warnings on cigarette packs, which found that warnings evoked fear and worry, and that these affective reactions were important antecedents to the effect of warnings on quit intentions and quit attempts.[70,84,85]

Cognitive elaboration. SSB health warnings may also exert their effects by eliciting cognitive elaboration. In the context of health warnings, cognitive elaboration refers to the extent to which a viewer thinks about the warning's content, the focal behavior targeted by the warning, or the health consequences of engaging in the behavior.[72,86,87] Scholars have argued that cognitive elaboration is central to attitude change,[87] and theories such as the Elaboration Likelihood Model posit that message elaboration is necessary for any subsequent shift in attitudes.[88] The novelty of a health warning label coupled with its fear appeal suggest it will stimulate greater cognitive elaboration than a less-evocative control label.[88,89] Indeed, in an online experiment, Donnelly and colleagues found that graphic SSB health warnings elicited more cognitive elaboration than a no-label control condition.[34] In turn, cognitive elaboration is thought to increase behavioral reactions to warnings. For example, research on tobacco health warnings has found that greater cognitive elaboration about the warning predicts stronger quit intentions and more quit attempts.[70,86,90]

Anticipated social interactions. Health warnings may affect behavior by sparking social interactions about the warnings. Research suggests that more emotionally evocative messages stimulate more social interactions about the message.[70,91,92] By describing the negative health consequences of SSB consumption, SSB health warnings are likely to be more emotionally evocative than control labels, and thus more likely to generate social interactions. In turn, several studies have found that social interactions about warnings are predictive of warnings' behavioral impacts.[92–94] For example, in a longitudinal observational study of more than 3,000 adult smokers in Canada, Mexico, and Australia, Thrasher and colleagues found that greater frequency of social interactions about cigarette health warnings was associated with more attempts to quit smoking.[93] Similarly, a recent randomized trial found that pictorial cigarette warnings sparked more social interactions about the warning labels than text warnings, and that more frequent social interactions predicted quit attempts.[70,92]

In the conceptual model, I depict SSB health warnings' influence on *anticipated* social interactions, rather than actual interactions, because participants in the randomized trial will complete their trial visit on their own and so will not have the opportunity to talk with others about the warnings during the trial. Everland found that anticipated social interactions increase message retention and learning, likely because anticipating future conversations about a message is an internal motivation that increases message processing and elaboration.[95] Thus, messages that elicit more anticipated social interactions (such as health warnings) may also exert stronger effects on behavior by heightening the extent to which consumers process and elaborate on the message. In sum, I expect that SSB health warnings will exert greater impact than control labels on four key message reactions – attention, affective reactions, cognitive elaboration, and anticipated social interactions.

SSB Perceptions and Attitudes

Perceptions of added sugar. In addition to influencing message reactions, recent research on SSB health warnings suggests that they affect the deliberative psychological antecedents to behavior change at the heart of many traditional theories of health behavior. For example, theories such as the Health Belief Model (HBM) suggest that knowledge, perceptions, and beliefs influence behaviors.[96–98] One aspect of SSB knowledge and perceptions that empirical research suggests may be important is consumers' perceptions of the added sugar content in SSBs. Online randomized trials of SSB health warnings have found that warnings increase perceptions and knowledge of added sugar. For example, online experimental studies have found that exposure to SSB health warnings increases perceptions of added sugar among both adolescents and parents.[19,21] Another study demonstrated that exposure to SSB warnings corrected parents' misperceptions about the added sugar content of certain types of SSBs such as fruit drinks, and that correcting these misperceptions led to lower intentions to purchase these products.[99] Similarly, some studies of tobacco warnings have found that warnings increase awareness of cigarette constituents, much like SSB warnings might increase awareness of added sugar as "constituent" in SSBs. For example, Borland and Hill found that Australian smokers' knowledge of the main constituents in tobacco increased after the introduction of text health warnings on cigarette packs.[100] Together, these studies suggest that exposure to SSB health warnings could affect consumers' perceptions of the added sugar content in SSBs.

While some argue that changing knowledge (e.g., by correcting misperceptions about added sugar) is insufficient to change behavior,[101] the literature suggests that there is a strong link between knowledge and dietary behaviors, including SSB consumption. A recent systematic review of 29 studies found that higher general nutritional knowledge is consistently related to more healthful dietary behaviors.[102] Population-based surveys have also found that higher general nutrition knowledge is negatively associated with both SSB purchases and SSB consumption, even after controlling for income, educational attainment, and other demographic characteristics.[103–105] Additionally, randomized trials of dietary interventions have reported that short-term improvements in nutritional knowledge predict long-term improvements in the healthfulness of dietary intake.[106] These studies suggest that changing consumers' perceptions of SSBs' added sugar content may lead to changes in SSB purchasing behavior.

Attitudes. Attitudes, or one's evaluation of an object or behavior, are another mechanism through which SSB health warnings may influence SSB purchases. The Theory of Planned Behavior (TPB) proposes that one's attitudes toward a health behavior are a key determinant of both intentions to perform that behavior and of actual behavioral performance.[29,66] Randomized trials have found that SSB health warnings reduce positive attitudes toward SSB consumption (i.e., *consumption attitudes*).[19,21] Meta-analyses generally support the importance of attitudes in predicting health behaviors,[107–109] including dietary behaviors.[110] Likewise, cross-sectional studies find that attitudes toward consuming SSBs are associated with SSB consumption in both adolescents[31,32,111] and adults.[30,112]

SSB health warnings might also change consumers' attitudes about SSBs themselves (i.e., *product attitudes*). In online randomized trials, exposure to labels with SSB health warnings reduced positive attitudes about SSBs (e.g., evaluations that SSBs are "cool," "healthy," or "attractive") compared to exposure to calorie labels without health warnings and to no-label control conditions.[19–21] In turn, more negative product attitudes may influence behaviors. For example, a randomized trial found that pictorial warnings increased smokers' negative attitudes toward their cigarette packs, and in turn, more negative pack attitudes predicted more quit attempts.[70]

Outcome expectations. Finally, SSB health warnings may affect outcome expectations. A central construct in Bandura's Social Cognitive Theory (SCT),[113,114] outcome expectations refer to one's beliefs about the physical, social, or self-evaluative outcomes a particular behavior is likely to produce, as well as one's subjective valuation of those outcomes.[113–115] SSB health warnings may increase negative outcome expectations by informing consumers of the health risks of consuming SSBs. Roberto and colleagues report that SSB health warnings increased participants' expectations that consuming SSBs would lead to weight gain, diabetes, tooth decay, and heart disease.[19,21] In turn, outcome expectations have been found to be predictive of a variety of health behaviors,[64] including SSB consumption[112] and other dietary behaviors such as fruit and vegetable consumption.[116–120] In sum, I expect that exposure to SSB health warnings will increase perceptions of added sugar in SSBs, reduce positive attitudes toward SSB consumption and SSB products, and increase negative SSB outcome expectations.

Designing More Effective Sugar-Sweetened Beverage Health Warnings

The conceptual model suggests that increasing warnings' impact on the proposed psychological antecedents could increase warnings' behavioral efficacy. Countries around the world vary considerably in how they design their SSB health warnings. Aim 1 of this dissertation will examine the impact of several warning characteristics on two of the psychological antecedents depicted in the conceptual model – negative affective reactions (specifically, fear) and cognitive elaboration – with an eye toward identifying a promising warning design for use in Aim 2's randomized controlled trial. Aim 1 will also examine the impact of warnings on perceived message effectiveness. Perceived message effectiveness refers to one's perceptions that a health warning message will or will not achieve its objectives and is a commonly used criterion for evaluating candidate health messages.[121,122] While perceived message effectiveness is not depicted in the conceptual model, recent research suggests that this construct is a useful proxy for changes in fear, cognitive elaboration, and behavior.[123,124] Aim 1 focuses on examining the impact of warning characteristics on these three outcomes – perceived message effectiveness,[70,123,125–128] fear,[70,129] and cognitive elaboration[70,130,131] – because these outcomes have been found to predict warnings' actual effectiveness.

Linking Individual- and Population-Level Outcomes

Findings from Aim 1 will suggest design features that may increase the impact of SSB health warnings. Findings from Aims 2 will give researchers and policymakers a sense of the magnitude of effect we might expect SSB health warnings to exert on individuals' short-term purchase behaviors. However, policymakers may also wish to know the longer-term, population-level consequences of requiring SSB health warnings, including the effects of warnings on population health outcomes like obesity prevalence. Randomized trials such as the study proposed for Aim 2 can provide important information about consumer responses to health warnings, but more information is needed to quantify the population-level health effects of mandating such warnings. For example, researchers must also consider pre-policy distributions of beverage consumption, the relationship between SSB consumption and other dietary behaviors, and on how diet affects body weight over time.

Simulation models provide a means for systematically combining this information to estimate population-level outcomes. Such models draw information from a variety of sources (e.g., observational studies, randomized trials, and theoretical predictions[38,132]) to generate plausible estimates about future trends in health behaviors and outcomes under different policy scenarios.[38] Researchers can then compare outcomes across scenarios to identify promising policy approaches for improving health. In the case of SSB health warnings, simulation models are currently the only means available for estimating policy impact on population health in the U.S.: because no U.S. states or cities have yet implemented SSB health warnings, nor have any randomized trials assessed the effect of SSB warning policies on long-term outcomes like obesity, simulation models are a necessary tool for understanding the potential for such policies to have meaningful effects on population health.

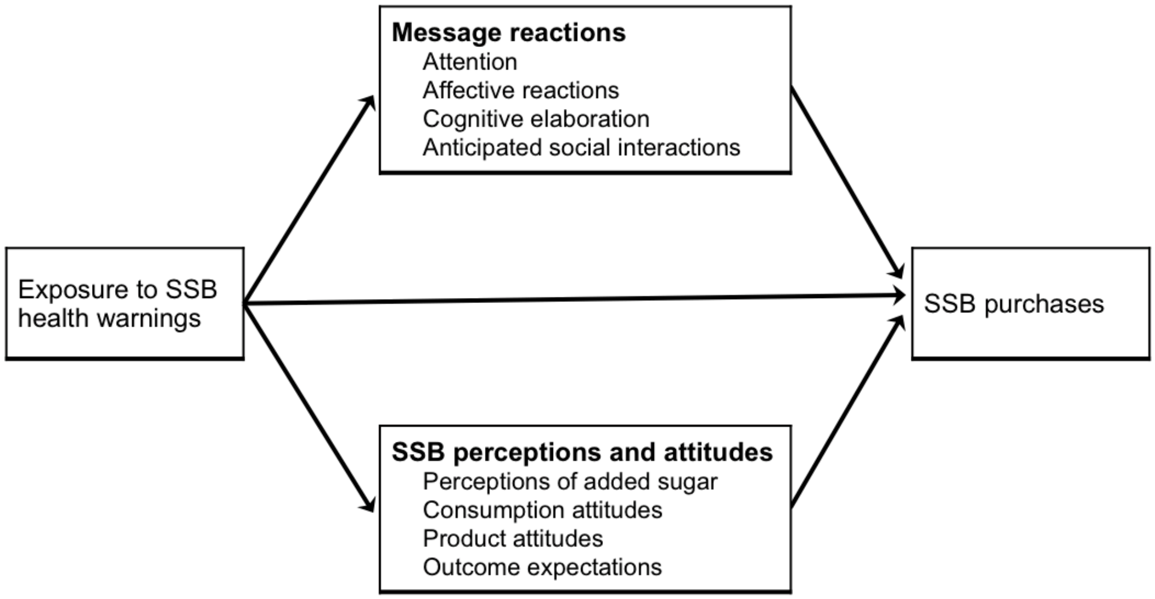
To date, only one study has applied simulation modeling to understand the potential effects of SSB health warning policies, using an agent-based model to estimate the effects of SSB warnings on SSB intake and body weight among adolescents living in Baltimore, Philadelphia, and San Francisco.[133] The authors reported that an SSB health warning would reduce obesity prevalence by 1.7 to 4.0 percentage points over a seven-year period. Additionally, microsimulation studies have found that other policies directed at SSB intake, such as SSB taxes and removing subsidies for SSBs from nutrition assistance programs, could significantly reduce SSB consumption, total energy intake, and obesity prevalence among adults.[39,41,134] Given the strong link between SSB consumption and weight gain, coupled with previous findings that SSB-directed policies can meaningfully affect population-level dietary and weight outcomes, I hypothesize that implementing a national SSB health warning policy would reduce American adults' SSB intake, total energy intake, body mass index, and obesity prevalence.

Aim 3 will use a microsimulation model, which represents events at the individual level. By examining individuals, microsimulation models allow researchers to easily examine a policy's effects within specific demographic subgroups, information relevant to whether the policy can address sociodemographic health disparities. Previous research finds that SSB health warnings reduce intentions to purchase SSBs and hypothetical willingness to pay for SSBs.[19–21] If these findings extend to real-stakes endpoints, economic theory suggests that the effect of SSB health warnings on SSB intake will be directly proportional to baseline levels of SSB purchases and intake.[135] That is, groups with higher baseline SSB intake would experience larger absolute reductions in SSB purchases and intake compared to those with lower baseline intake, and in turn, would reap greater weight loss benefits. Racial/ethnic minorities have both higher SSB intake and higher rates of obesity than non-Hispanic whites.[7,9,44,136–138] Similar patterns are observed for individuals with lower educational attainment and lower income.[7,9,44,138–140] Because of their higher baseline SSB consumption, I hypothesize that implementing an SSB health warning policy would generate larger absolute reductions in SSB intake and obesity prevalence among racial/ethnic minorities and adults with lower education and lower income compared to non-Hispanic white adults and those with higher education and higher income, respectively. If these subgroups indeed experience larger benefits from SSB health warnings, a national policy requiring such warnings could help reduce persistent sociodemographic disparities.

Conclusion and Public Health Implications

Despite declines over the last decade, consumption of SSBs remains high. Given the well-established links between SSB consumption and negative health outcomes including obesity, type 2 diabetes, and cardiovascular disease, reducing SSB consumption should remain a public health priority. Requiring SSB health warnings offers a scalable, low-cost, and potentially politically feasible strategy for achieving this goal, but the individual- and population-level effects of such policies remain largely unknown. A deeper understanding of whether SSB health warnings influence real-stakes behaviors, and the potential psychological processes through which warnings exert their influence, can help policymakers design maximally effective SSB health warnings. Estimating warnings' impact on population-level consumption and health outcomes can inform the ongoing debates about these policies by suggesting whether SSB health warnings are a promising policy for improving population health and reducing health disparities.

Figure 2.1. Conceptual model



CHAPTER 3: DESIGNING EFFECTIVE SUGAR-SWEETENED BEVERAGE HEALTH WARNINGS[1]

Introduction

Excess consumption of sugar-sweetened beverages (SSBs) remains a pressing public health issue in the United States. Half of adults consume SSBs on any given day,[9] and average caloric intake from SSBs remains well above national dietary guidelines.[45,46] Evidence indicates that SSB consumption increases risk of developing obesity,[2,5] diabetes,[59,141] and heart disease.[3] To reduce consumption of SSBs, five states have proposed requiring front-of-package (FOP) health warnings on SSB containers.[10–14]

Even as interest in SSB health warning policies has grown, questions remain about how to design warnings to maximize their effectiveness. For example, warnings proposed in the U.S. describe the *health effects* of consuming SSBs.[10–14] In contrast, nutrition warning systems adopted in countries such as Chile do not describe health effects, but instead display a *nutrient disclosure* that signals when a product exceeds recommended levels of sugar, sodium, saturated fat, or calories. For example, SSBs in Chile display FOP warnings that read "Alto en azúcares" ("high in sugars").[16,142] Another difference is warning label *shape*: in Chile, warnings are displayed on octagonal labels, while SSB warnings in the U.S. would likely be displayed on rectangular labels. Additionally, the proposed SSB health warnings in the U.S.[10–14] begin with a

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marker word (usually "WARNING" or "HEALTH WARNING") that signals that the subsequent text is a warning message, while labels in other countries often do not use marker words.[16–18]

These four warning characteristics – health effects, nutrient disclosures, label shape, and marker words – could influence how effectively SSB health warnings discourage SSB consumption. For example, cigarette warnings that describe health effects elicit higher perceived effectiveness,[23] and warnings with health effects statements or nutrient disclosures have been found to reduce consumers' intentions to purchase SSBs.[19–21] Others have found that consumers associate the octagon shape with unhealthfulness.[22] Including marker words such as "CAUTION" or "WARNING" (or similar marker symbols[24]) may draw attention to warnings,[27,143,144] but makes messages longer, potentially reducing readability.

Limited research has examined these warning characteristics side-by-side or in combination with one another. The objective of this study was to examine the influence of health effects, nutrient disclosures, marker words, and label shape on perceptions of messages' effectiveness at discouraging SSB consumption. Based on previous research, we predicted that warnings that included health effects[21,23] or nutrient disclosures[20,25] would elicit higher perceived message effectiveness than warnings without these characteristics, and that octagon-shaped labels would elicit higher perceived message effectiveness than rectangular labels.[22,26] We did not make an *a priori* prediction regarding marker words because they might increase attention but reduce readability. We also examined whether these four warning characteristics elicit more fear or thinking about the harms of SSB consumption. We focused on perceived message effectiveness,[70,125–128] fear,[70,129] and thinking about harms[70,130,131] because these outcomes have been found to predict warnings' actual effectiveness. We also assessed whether warning characteristics affect consumers' knowledge of the health harms of SSB consumption and identified the warning color combinations perceived to be most effective.[22]

Methods

Participants

In April 2018, we recruited a convenience sample of 1,413 U.S. adults ≥18 years using Amazon Mechanical Turk (MTurk), an online platform commonly used by social and behavioral science researchers.[145–147] Research indicates that experiments conducted on MTurk replicate findings from studies conducted both in the lab[148] and via random-digit dial phone surveys.[149] Participants earned $2.20 for completing the 10-15 minute survey.

Impact of Warning Characteristics on Consumer Reactions

Procedures. The main experiment varied characteristics of SSB health warnings using a mixed between/within factorial design. First, we randomly assigned participants to one of four between-subjects conditions: 1) control ("Always read the Nutrition Facts Panel"), 2) health effects only ("Drinking beverages with added sugar contributes to obesity, diabetes, and tooth decay," adapted from California's proposed warnings[10]), 3) nutrient disclosure only ("High in added sugar," adapted from Chile's warnings[16]), and 4) health effects and nutrient disclosure. These four conditions represented the combination of two between-subjects factors, each with two levels: 1) whether the warning included *health effects* and 2) whether the warning included a *nutrient disclosure*.

Participants viewed their randomly assigned warning message four times, on four labels that differed on two within-subjects factors, each with two levels: whether the message began with the *marker word* "WARNING" and the *shape* of the warning label (rectangle vs. octagon). Thus, the experiment had four within-subjects conditions, each representing a different warning label design: 1) no marker and rectangle shape, 2) no marker and octagon shape, 3) "WARNING" marker and rectangle shape, and 4) "WARNING" marker and octagon shape. Participants viewed these four labels in a random order.

In total, we created 16 different warnings: one for each of the four between-subjects conditions, displayed on warnings that varied along each of the four within-subjects conditions (**Figure 3.1**). Participants viewed warnings presented mocked up on an unbranded bottle of soda (**Figure 3.2**). Presenting warnings on an unbranded soda bottle allowed us to focus participants' attention on the warning characteristics of interest while also presenting a realistic image of what SSB warnings might look like if implemented. To mimic Chilean labels, we displayed warnings in white text on a black background.

Measures. Participants viewed warnings one at a time. After viewing each warning, participants rated the warning on effectiveness at discouraging SSB consumption (primary outcome) and on thinking about the harms of SSB consumption and fear (secondary outcomes) (**Appendix A**). The survey assessed perceived message effectiveness (PME) with an adapted version of the UNC Perceived Message Effectiveness Scale.[124] PME is commonly used in message development studies[121] and was found in a recent meta-analysis to predict messages' actual behavioral efficacy.[123] Our three PME items read: "This label makes me concerned about the health effects of drinking beverages with added sugar;" "This label makes drinking beverages with added sugar seem unpleasant to me;" and "This label discourages me from wanting to drink beverages with added sugar." The 5-point response scale ranged from "strongly disagree" (coded as 1) to "strongly agree" (coded as 5). We averaged responses to these three items to create a composite score (Cronbach's alpha=0.93, range across conditions: 2.52 to 3.80).

The survey assessed thinking about the harms of SSB consumption using a single item, adapted from studies of cigarette warnings,[28,90,150] "How much does this label make you think about the health problems caused by drinking beverages with added sugar?" Finally, the survey assessed fear using one item also adapted from previous studies of cigarette warnings,[150,151] "How much does this label make you feel scared?" Response options for these items ranged from "not at all" (coded as 1) to "very much" (coded as 5).

Knowledge of Consequences of SSB Consumption

As a secondary outcome, we also assessed the effect of the between-subjects factors, health effects and nutrient disclosure, on knowledge of the health harms of SSB consumption. After rating all four warnings and completing the two items about color described below, participants indicated whether SSB consumption contributes to: obesity, diabetes, tooth decay, and heart disease. Because SSB consumption may increase risk of these outcomes,[2,3,152,153] we coded responses as correct if participants reported awareness of each health consequence and incorrect otherwise.

Most Discouraging Color Combinations

In a separate task, we also examined the warning label color combination participants perceived as most discouraging. After rating all four warnings, participants viewed a set of six rectangular warnings with the same text ("WARNING: High in added sugar") but different combinations of background, border, and text color (**Table 3.1**) displayed in a random arrangement. Participants selected the color combination that "would discourage you most from wanting to drink beverages with added sugar." Participants then completed an identical item for octagon-shaped warnings.

Attention Check and Demographics

Participants completed an attention check in which they were asked to intentionally not answer an item. Participants also provided information on their demographic characteristics and health behaviors.

The University of North Carolina, Chapel Hill Institutional Review Board approved this study. Prior to data collection, we pre-registered the study's sample size, primary hypotheses, design, and analysis plan on AsPredicted.org (https://aspredicted.org/7iz2y.pdf).

Analysis

We identified duplicate IP addresses and MTurk usernames and retained the record with the most complete data, or, when the amount of missing data was equivalent, the first record. This resulted in dropping 40 records. We also excluded 13 records for people who previously participated in pilot testing of the experiment, yielding a final analytic sample of *n*=1,360. These 1,360 participants each rated at least one warning and were included in analyses of the primary outcome (see CONSORT flow diagram in **Figure 3.3**). We used intent-to-treat analyses, analyzing all participants in their assigned conditions including those who did not pass the attention check.[154] We conducted analyses in Stata/SE version 15.1 (StataCorp LLC, College Station, TX).

We used mixed effects (i.e., multi-level) linear models to assess how the four manipulated warning characteristics (health effects, nutrient disclosure, marker word, and label shape) affected the primary outcome of perceived message effectiveness while accounting for the repeated measures design. We entered the within-subjects factors (marker word, label shape) as Level 1 variables and the between-subjects factors (health effects, nutrient disclosure) as Level 2 variables, treating the intercept as a random effect. Sample characteristics did not differ by experimental arm, so we conducted unadjusted analyses. The initial model included indicators for the four manipulated warning characteristics and all interactions between these four factors. The final model retained only significant interactions from the initial model. We used the same approach to examine the effects of warning characteristics on our secondary outcomes, thinking about harms and fear. We report raw means and average differential effects of each experimental factor on the outcomes as generated by the mixed models. We probed interactions by calculating means and average differential effects at different levels of the moderating factors.

In pre-specified analyses, we examined whether participant characteristics moderated the relationship between warning characteristics and PME. We examined six moderators: overweight/obese status (BMI ≥25 vs. <25 kg/m^2), obese status (BMI ≥30 vs. <30 kg/m^2), SSB consumption (≥ 4.5 vs. < 4.5 servings/week [sample median]), educational attainment (college degree or more vs. some college or less), income (>150% of the Federal Poverty Level [FPL] vs. ≤ 150% FPL), and race (white vs. non-white).

We assessed the impact of the two between-subjects factors (health effects and nutrient disclosure) on knowledge of SSB health consequences using general (i.e., not mixed) logistic regression, reflecting that participants responded to knowledge items only once, after seeing all of their assigned warnings. The initial models included both factors and their interaction; the interactions were not significant in any model so were removed from final models. To identify the color combinations perceived as most effective, we calculated the proportion of participants who selected each color combination as the "most discouraging" for each label shape (rectangular and octagonal).

Results

Sample

Participants' average age was 37.4 years (**Table 3.2**). About 17% of participants had a household income of 150% FPL or less. The sample was younger, more likely to identify as gay, lesbian, or bisexual, less likely to identify as Hispanic, more likely to smoke, and less likely to have a BMI in the obese category compared to nationally representative samples (**Table 3.3**). Nearly all participants (98%) passed the attention check. Sample characteristics did not differ by experimental condition. Missing demographic data ranged from 0.5% to 0.9%, except for BMI (6.0% missing) (**Table 3.4**).

Perceived Message Effectiveness

Main effects of experimental factors. Warnings that included health effects were perceived as more effective than warnings without health effects (average differential effect [ADE]=0.63, $p<0.001$) (**Figure 3.4**). Warnings with nutrient disclosures also led to higher PME compared to warnings without nutrient disclosures (ADE=0.32, $p<0.001$). Likewise, PME was higher for warnings that included the marker word "WARNING" (ADE=0.21, $p<0.001$) than warnings without a marker word and for warnings displayed on octagon-shaped labels compared to rectangular labels (ADE=0.08, $p<0.001$).

Interactions between experimental factors. Nutrient disclosure interacted with health effects (*p* for interaction <0.001, **Table 3.5**). Adding a nutrient disclosure led to higher PME when the warning did not include health effects (Mean [*M*]=2.75 vs. *M*=3.41; ADE=0.66, $p<0.001$) (**Figure 3.5**). However, the addition of a nutrient disclosure had no benefit when a health effects statement was also included (*M*=3.71 vs. *M*=3.70; ADE=-0.01, $p=0.90$).

Marker word interacted with health effects (*p* for interaction<0.001, **Table 3.5**). For warnings that did not include health effects, adding a marker word led to higher PME compared to not having a marker word (*M*=2.91 vs. *M*=3.24; ADE=0.32, *p*<0.001, **Figure 3.6**). For warnings that included health effects, adding a marker word still increased PME, but the impact was smaller (*M*=3.66 vs. *M*=3.75; ADE=0.09, *p*<0.001).

Marker word also interacted with nutrient disclosure (*p* for interaction<0.001). For warnings that did not include a nutrient disclosure, adding the marker word led to higher PME compared to warnings without a marker word (*M*=3.10 vs. *M*=3.35; ADE=0.25, *p*<0.001) (**Figure 3.7**). For warnings with a nutrient disclosure, adding the marker word again led to higher PME (*M*=3.47 vs. *M*=3.64; ADE=0.16, *p*<0.001), though the effect was smaller.

Interactions between experimental factors and participant characteristics. Only two of the twenty-four interactions between participant characteristics (income, education, race, overweight, obesity, or SSB consumption) and the experimental factors on PME were statistically significant, potentially indicating type I error. Nutrient disclosure had a smaller impact on PME for high SSB consumers compared to low-consumers (*p* for interaction=0.012). Octagon-shaped labels had a larger impact on PME for participants with an overweight/obese BMI than those with BMI in the normal range (*p* for interaction=0.038).

Fear and Thinking About Harms

Main effects of experimental factors. A similar pattern of results emerged for fear and thinking about harms, the secondary study outcomes. Of the warning characteristics, health effects had the largest impact on both thinking about harms (ADE=0.66, *p*<0.001) and fear (ADE=0.42, *p*<0.001) (Figure 3.4). Including a nutrient disclosure also increased thinking about harms (ADE=0.23, *p*<0.001) and fear (ADE=0.15, *p*=0.013). The marker word "WARNING" increased thinking about harms and fear (ADE=0.22 and 0.23, respectively, both *p*s<0.001). Finally, compared to rectangular labels, octagon-shaped labels elicited more thinking about harms (ADE=0.08, *p*<0.001) and fear (ADE=0.09, *p*<0.001).

Interactions between experimental factors. Nutrient disclosure again interacted with health effects, a finding replicated for both thinking about harms (*p* for interaction <0.001) and fear (*p* for interaction <0.05, Table 3.5). Including both health effects and a nutrient disclosure again did not perform better than including health effects alone (Figure 3.5). Marker word again interacted with health effects, showing a similar pattern as for PME (*p*s for interactions <0.001) (Table 3.5, Figure 3.6). However, unlike for PME, marker word did not interact with nutrient disclosure for either secondary outcome (*p*s for interactions >0.30).

Knowledge of Consequences of SSB Consumption

Knowledge that SSB consumption contributes to tooth decay was 2.1 percentage points higher among participants exposed to warnings that included health effects (*p*=0.048) (**Table 3.6**). Exposure to health effects messages did not affect knowledge that SSBs contribute to obesity or diabetes (*p*s >0.025), but led to *lower* knowledge that SSBs contribute to heart disease, information not included in the warnings, by 9.4 percentage points (60.8% vs. 51.4% answered correctly, *p*<0.001). Nutrient disclosures did not impact knowledge of any health outcome (*p*s >0.30).

Color Combinations Selected as Most Discouraging

For octagon-shaped labels, the majority of participants (75%) said that a warning with red background and white text would most discourage them from consuming beverages with added sugar (Table 3.1). Likewise, for rectangle-shaped labels, most (66%) participants indicated this color combination would most discourage them. The between-subjects factors (health effects and nutrient disclosure) did not impact color combination selections (*p*s>0.19).

Discussion

SSB health warnings are a promising policy strategy for reducing SSB consumption. Yet little is known about how to best design such warnings to maximize their impact. In this experimental study of U.S. adults, we found that warning characteristics influence reactions to SSB health warnings. Specifically, warnings that described health effects, included a nutrient disclosure, began with the marker word "WARNING," and were displayed on octagon-shaped labels were perceived to be more effective than warnings without these characteristics. These characteristics also increased thinking about the harms of SSB consumption and feelings of fear. Participants selected the red background with white text as the most discouraging color combination for both octagonal and rectangular warnings. Because past research has shown that these reactions (perceived message effectiveness,[70,123,125–128] thinking about harms,[70,130,131] and fear[70,129]) predict warnings' actual effectiveness, our findings suggest design choices that could increase the impact of SSB health warnings.

SSB health warnings proposed in the U.S. have all included health effects.[10–14] This is a wise choice, given that health effects had the largest impact of the warning characteristics we studied. This finding is consistent with cigarette warning research, which has found that health effects messages are generally more potent than "found in" statements identifying toxic products that contain cigarette smoke chemicals.[155] Others have suggested health effects increase perceived message effectiveness by providing contextualizing information that increases motivation to think about the warning message and helps consumers understand the harms of a particular product.[23,155] In contrast to the U.S., warning systems implemented in Latin American countries do not describe health effects, instead using nutrient disclosures.[16,17,142,156] These nutrient disclosures accompany all foods and beverages that exceed thresholds for certain nutrients, not just SSBs. Future research should compare health effects warnings to nutrient disclosures on a larger variety of products in U.S. and non-U.S. samples.

Adding more text to warnings in our experiment had diminishing returns. Across outcomes, the textual warning characteristics we manipulated (health effects, nutrient disclosure, and marker word) interacted with one another, such that the additional impact of a textual characteristic (e.g., a marker word) was generally lower when a message already included another textual warning characteristic (e.g., health effects) than when it did not. The interaction between health effects and nutrient disclosures was particularly large: adding a nutrient disclosure to a warning that did not include health effects increased perceived message effectiveness, thinking about harms, and fear, but adding a nutrient disclosure to a warning that already included a health effects statement had no additional influence on these outcomes. These results suggest that SSB health warnings may perform best when they include only a nutrient disclosure or only health effects, but not both. These findings are consistent with other studies suggesting that "less is more" when showing consumers comparative quality information.[157] Our findings also replicate studies from the tobacco warnings literature.[23,155] For example, cigarette warnings studies have shown the same pattern of "less is more" interaction such that combining the two forms of risk information (health effects and "found in" statements) did little or no better than presenting either one alone.[155]

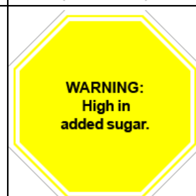
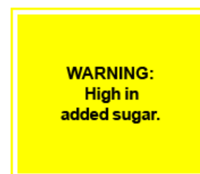
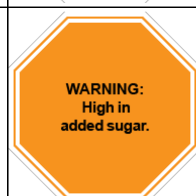
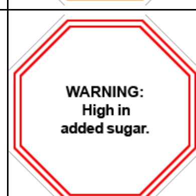
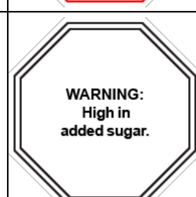
Consistent with previous research on SSB and tobacco warnings,[19,21,92] warning characteristics had similar impact regardless of participants' income, education level, and race/ethnicity. One exception was that nutrient disclosures had a slightly smaller influence on perceived message effectiveness for high SSB consumers compared to low consumers. This finding could be explained by the defensive processing literature, which suggests that resistance to messages is strongest among people engaging in the behavior targeted by the message.[158,159] The other exception was that the octagon shape had a larger influence on perceived message effectiveness for participants with an overweight/obese BMI.

Strengths of our experiment include the large sample from across the U.S. and that we randomly assigned participants to conditions using a fully factorial design. Limitations include using a convenience sample, which may limit the generalizability of the findings. However, recent research has found that experiments conducted on MTurk generally replicate findings of experiments conducted using probability-based samples.[147,149,160] Previous research has found that the impact of SSB health warnings on consumer perceptions varies by SSB type (e.g., fruit drinks vs. sodas).[99] Because we only displayed warnings on sodas, we were unable to examine whether SSB type moderated the impact of the manipulated warning characteristics on our study outcomes. We also displayed warnings on non-branded SSBs on a computer screen, and warnings were likely more noticeable than they would be if implemented on actual SSBs in retail settings. Finally, study outcomes were all based on self-report after brief exposure to the warnings. A recent meta-analysis indicates that self-reported perceived message effectiveness (our primary outcome) predicts actual behavior change for tobacco messages,[123] but future studies should examine whether warnings with these characteristics affect consumer behavior.

Conclusions

To maximize the impact of SSB health warnings, policymakers should consider adopting warnings that describe health effects, begin with the marker word "WARNING," and are displayed on an octagon-shaped label, as warnings with these characteristics are perceived to be more effective, and elicit more thinking about harms and fear, than warnings without these characteristics. Warnings that include a nutrient disclosure also increase perceived effectiveness over warnings that do not, but to a lesser extent than warnings with health effects. Further, including both a nutrient disclosure and health effects is unlikely to improve effectiveness over health effects alone. Future work should assess whether these principles apply to other types of warnings (e.g., on alcohol or junk food) and in other countries, and should examine whether warnings with these characteristics influence behavioral outcomes.

Table 3.1. Warning color combinations selected as “most discouraging”

Color Combination			**Octagonal Label**			**Rectangular Label**		
Background	**Border**	**Text**	**Image**	**%**	**N**	**Image**	**%**	**N**
Red	Red	White		75%	1,013		66%	894
Black	Black	White		13%	177		15%	202
Yellow	Yellow	Black		5%	73		0%	0
Orange	Orange	Black		3%	35		3%	41
White	Red	Black		3%	41		6%	82
White	Black	Black		1%	16		10%	136

Note. Table shows warning color combinations selected as most discouraging for both octagonal and rectangular warning labels, *n*=1,355 U.S. adults. For each shape, participants were shown all six color combinations in a random arrangement. Participants were asked to select the color combination that most discouraged them from wanting to consume beverages with added sugar. Sample size differs from primary analytic sample (*n*=1,360) because 5 participants did not respond to either item about color combinations.

Table 3.2. Participant characteristics, *n*=1,360 U.S. adults

Characteristic	***n***	**%**
Age		
18-29 years	361	27%
30-39 years	547	40%
40-54 years	295	22%
55+ years	149	11%
Mean (SD)	37.4	11.5
Gender		
Male	704	52%
Female	639	47%
Transgender or other	9	1%
Gay, lesbian, or bisexual	141	10%
Hispanic	122	9%
Race		
White	1,106	82%
Black or African American	127	9%
Asian	63	5%
Other/multiracial	47	3%
American Indian or Alaskan Native	8	1%
Native Hawaiian or Pacific Islander	1	0.1%
Education		
High school diploma or less	170	13%
Some college	313	23%
College graduate or associates degree	699	52%
Graduate degree	170	13%
Household income, annual		
$0-$24,999	234	17%
$25,000-$49,999	425	31%
$50,000-$74,999	322	24%
$75,000+	370	27%
Low income (≤ 150% of Federal Poverty Level)	224	17%
Current smoker	298	22%
Sugar-sweetened beverage consumption		
<1 time per day	866	64%
1 to <3 times per day	312	23%
3 or more times per day	175	13%
Body mass index (BMI, kg/m^2)		
Underweight	49	4%
Healthy weight	519	38%
Overweight	409	30%
Obese	301	22%
Not reported	82	6%
Mean (SD)	26.6	6.8
Passed attention check	1,338	98%

Note. Characteristics did not differ by experimental arms.

Table 3.3. Comparison of characteristics of the study sample (*n*=1,360 U.S. adults) to national estimates

Characteristic	Study Sample %	National Estimate %
Age[161]		
18-25 years	10%	9%
26-34 years	40%	12%
35-54 years	39%	26%
55-64 years	8%	13%
65+ years	3%	15%
Gender[162]		
Male	52%	49%
Female	47%	51%
Transgender or other[a]	1%	-
Gay, lesbian, or bisexual[163]	10%	2.3%
Hispanic[162]	9%	18%
Race[162]		
White	82%	77%
Black or African American	9%	13%
Asian	5%	6%
Other/multiracial	3%	3%
American Indian or Alaskan Native	1%	1%
Native Hawaiian or Pacific Islander	0.1%	0.2%
Education[164]		
High school diploma or less	13%	40%
Some college	23%	19%
College graduate or associate's degree	52%	30%
Graduate degree	13%	8%
Household income, annual[165]		
$0-$24,999	17%	21%
$25,000-$49,999	31%	22%
$50,000-$74,999	24%	17%
$75,000+	27%	40%
Current smoker[166]	22%	16%
Sugar-sweetened beverage consumption ≥ 1 time per day[b,167]	36%	30%
Body mass index classified as obese (≥30 kg/m^2)[168]	24%	40%

Note. National estimates are survey-weighted prevalence estimates from nationally representative surveys (e.g., Current Population Survey, National Health and Nutrition Examination Survey) or, when available, from Census data. See references for details on sources.
[a]National estimates provided by the Census Bureau include only proportion male and female, not transgender.
[b]National estimate is from data from 23 states and the District of Columbia, as reported by Park et al.,[167] because no national estimate was available.

Table 3.4. Missing data on participant demographic characteristics, *n*=1,360

Characteristic	*Missing data*	
	n	**%**
Age	8	0.59%
Gender	8	0.59%
Gay, lesbian, or bisexual	9	0.66%
Hispanic	8	0.59%
Race	8	0.59%
Educational attainment	8	0.59%
Household income, annual	9	0.66%
Current smoker	7	0.51%
Sugar-sweetened beverage consumption frequency	7	0.51%
Body mass index (BMI, kg/m^2)	82	6.03%

Table 3.5. Effects of sugar-sweetened beverage warning characteristics on perceived effectiveness, thinking about harms, and fear

	Perceived message effectiveness		**Thinking about harms**		**Fear**	
Warning Characteristic	**B**	**SE**	**B**	**SE**	**B**	SE
Level 2						
Health effects	1.08**	0.08	1.09**	0.08	0.67**	0.09
Nutrient disclosure	0.70**	0.08	0.54**	0.08	0.30**	0.09
Health effects x Nutrient disclosure	-0.67**	0.12	-0.63**	0.12	-0.26*	0.12
Level 1						
Marker word "WARNING"	0.36**	0.02	0.33**	0.02	0.37**	0.02
Octagon shape (vs. rectangle)	0.08**	0.01	0.08**	0.01	0.09**	0.01
Cross-Level						
Health effects x Marker word	-0.24**	0.02	-0.22**	0.03	-0.25**	0.03
Nutrient disclosure x Marker word	-0.08**	0.02	<0.01	0.03	-0.03	0.03
Intercept	2.53**	0.06	2.24**	0.06	1.74**	0.06

Note. Table shows unstandardized regression coefficients (B) from mixed effects linear regression models examining warning characteristics' impacts on perceived message effectiveness (5,431 ratings), thinking about harms (5,430 ratings), and fear (5,431 ratings) from 1,360 U.S. adults. Intraclass correlations were 0.85 for the perceived message effectiveness model, 0.80 for the thinking about harms model, and 0.82 for the fear model.
*p<0.05, **p<0.001.

Table 3.6. Impact of manipulated warning characteristics on knowledge of health consequences of sugar-sweetened beverage consumption, *n*=1,360 U.S. adults

	Correct response that sugar-sweetened beverages contribute to….			
	Obesity	**Diabetes**	**Tooth decay**	**Heart disease**
Control warning, proportion correct	94.1%	90.9%	94.7%	61.0%
Impact of adding health effects	+1.2%	-1.5%	+2.1%*	-9.4%**
Impact of adding nutrient disclosure	+1.1%	+1.3%	-0.05%	+2.4%

*$p<0.05$, ** $p<0.001$.

Figure 3.1. Experimental conditions

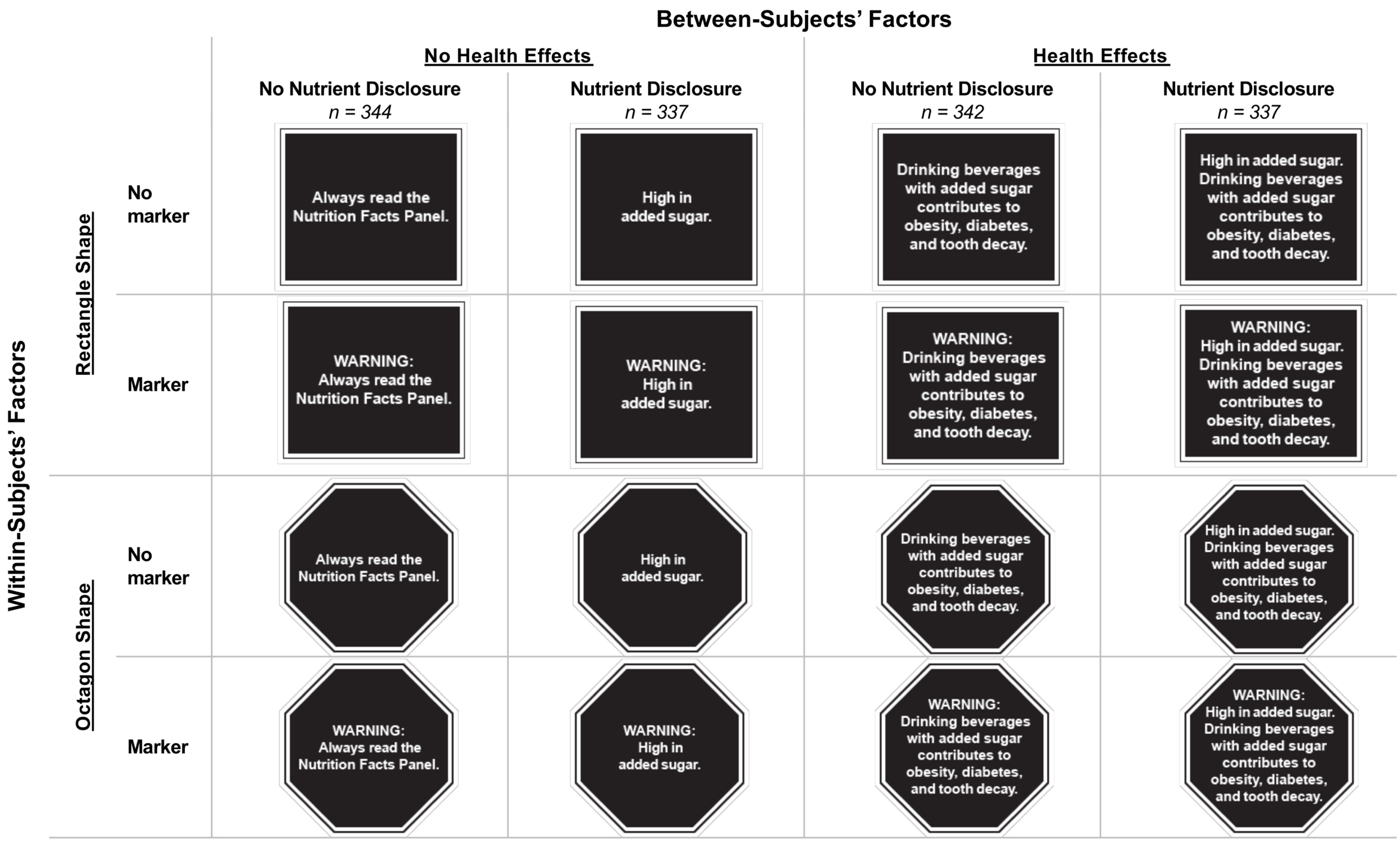


Figure 3.2. Example experimental stimulus

Figure 3.3. CONSORT flow diagram

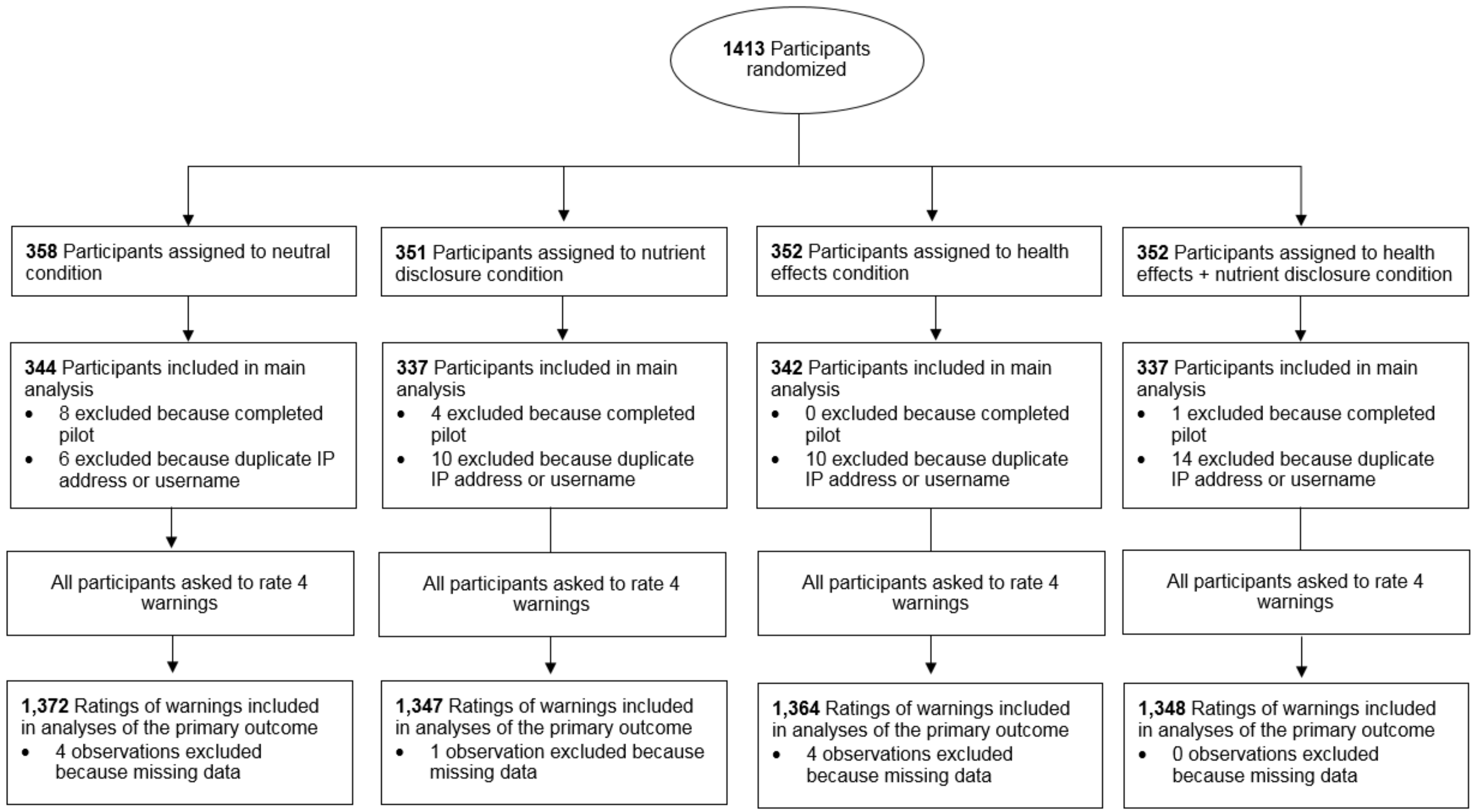
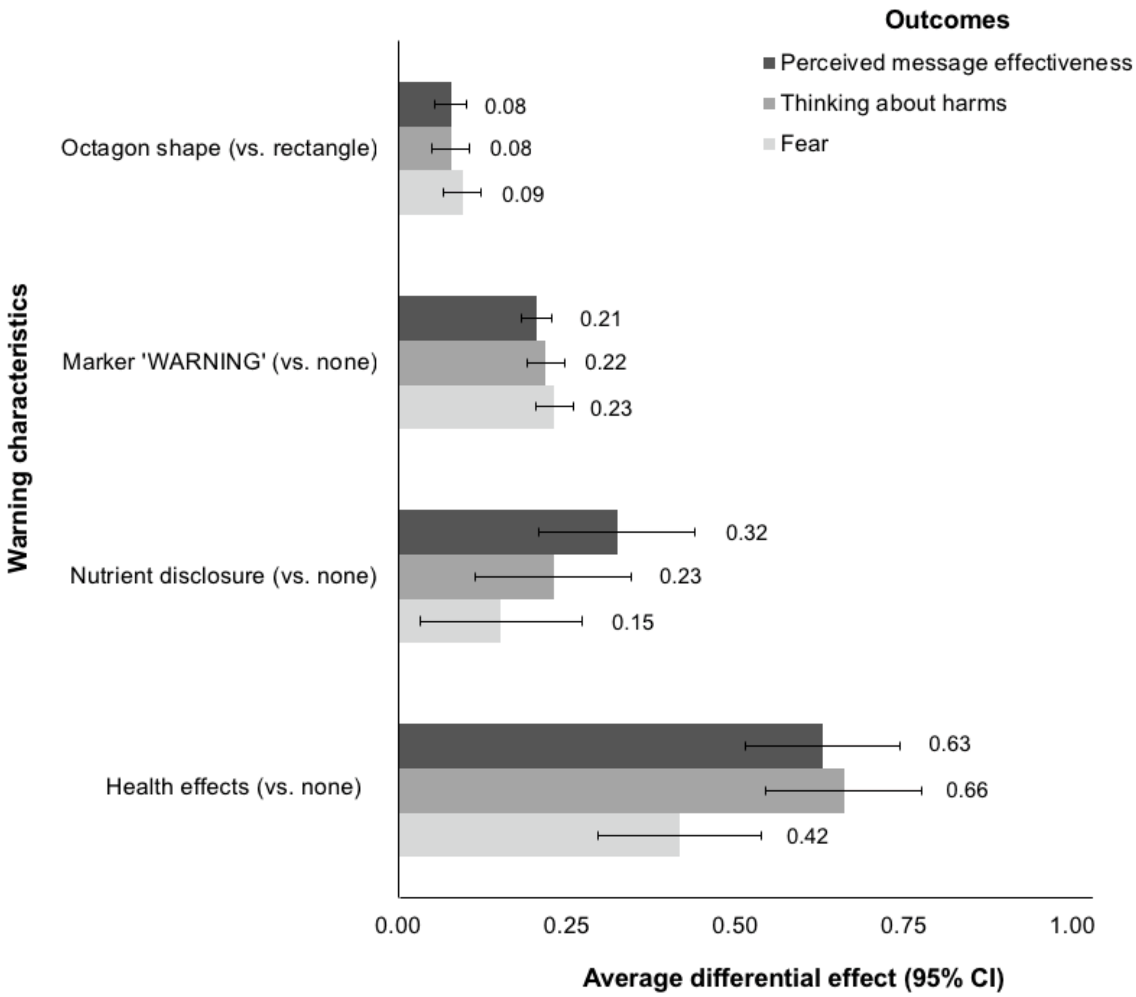
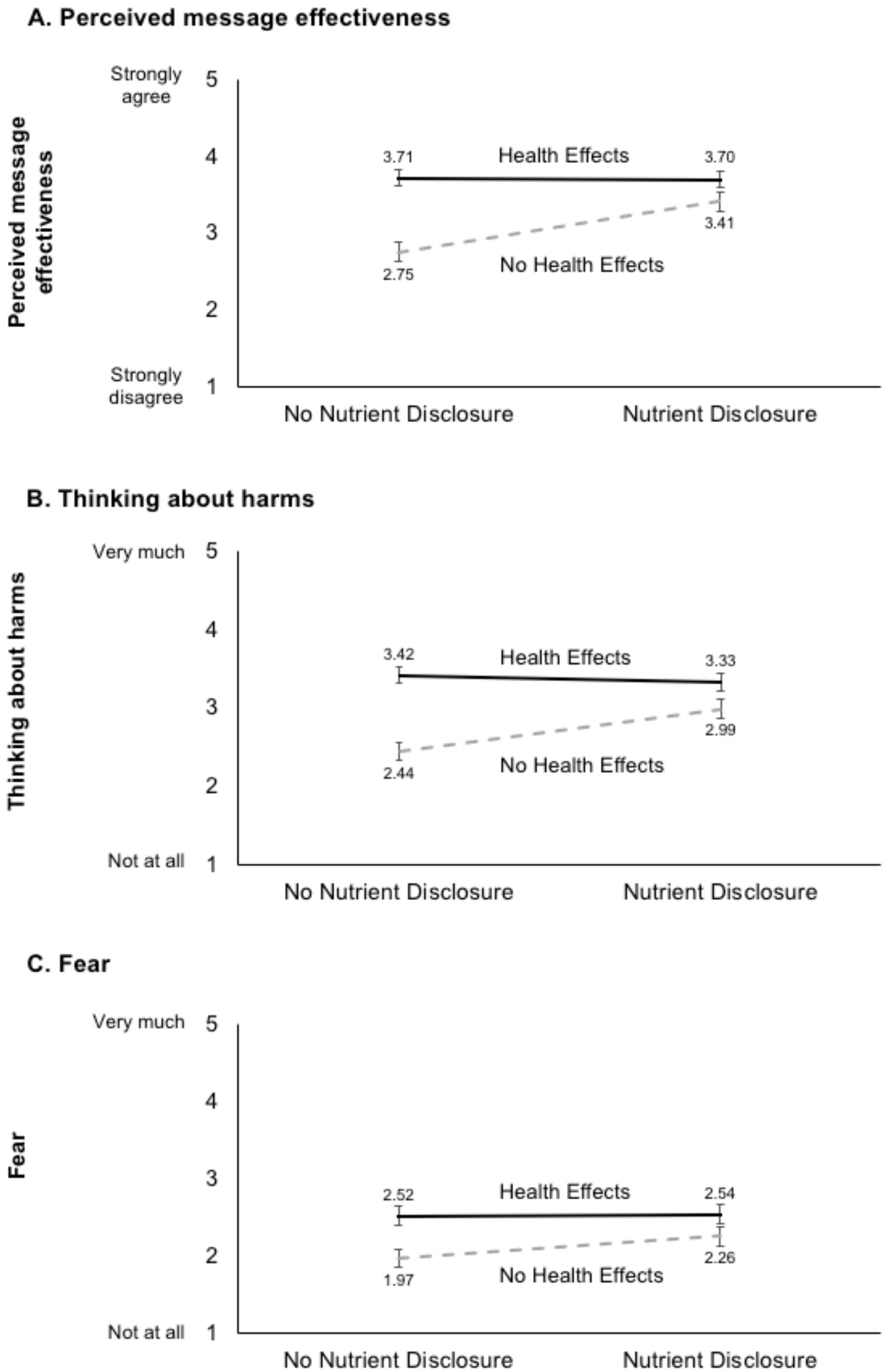


Figure 3.4. Impact of four warning characteristics on perceived message effectiveness, thinking about harms, and fear



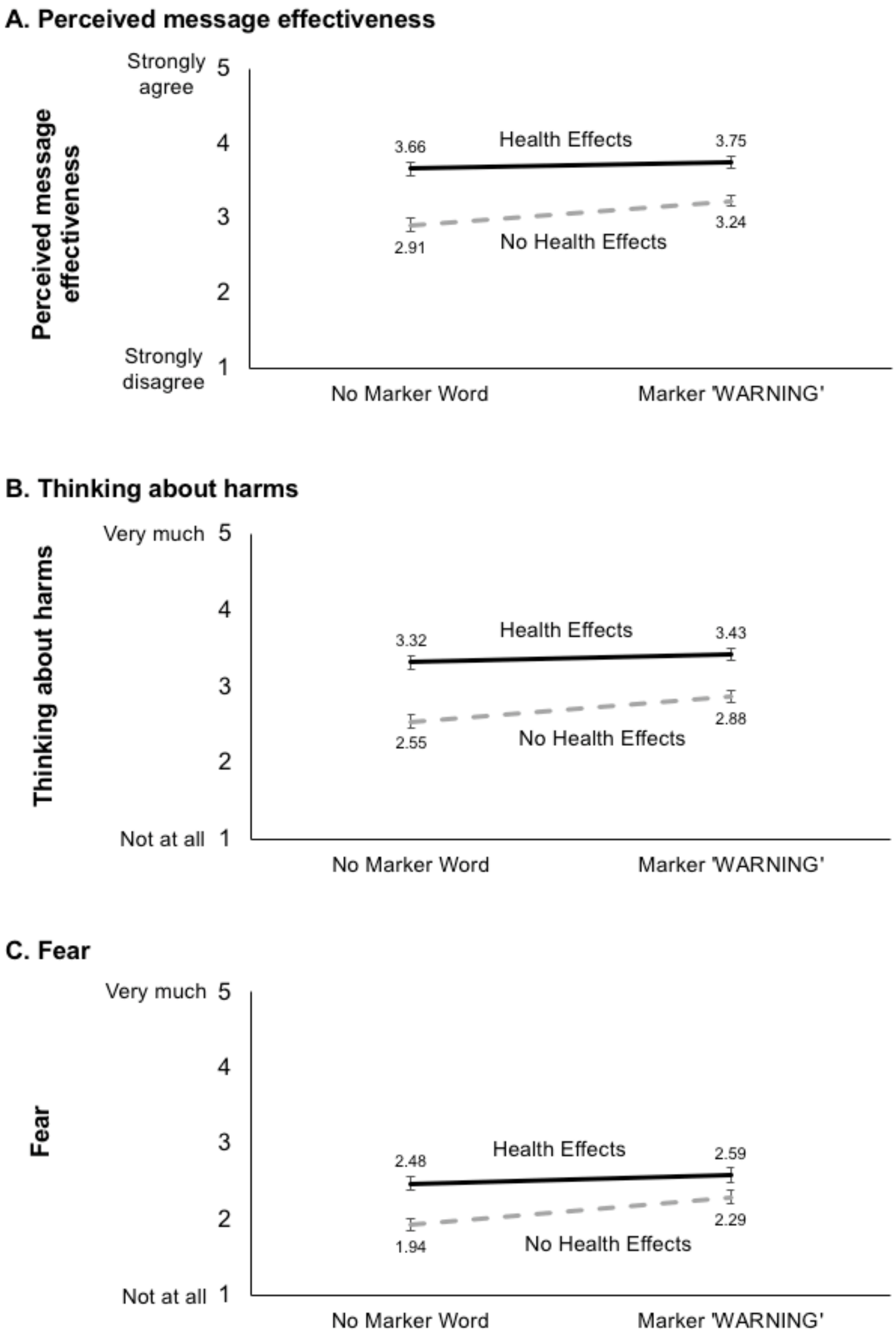
Note. Figure shows impact of the four manipulated warning characteristics on perceived message effectiveness (5,431 ratings), thinking about harms (5,430 ratings) and fear (5,431 ratings) among 1,360 U.S. adults.

Figure 3.5. Interaction between health effects and nutrient disclosure on perceived message effectiveness, thinking about harms, and fear



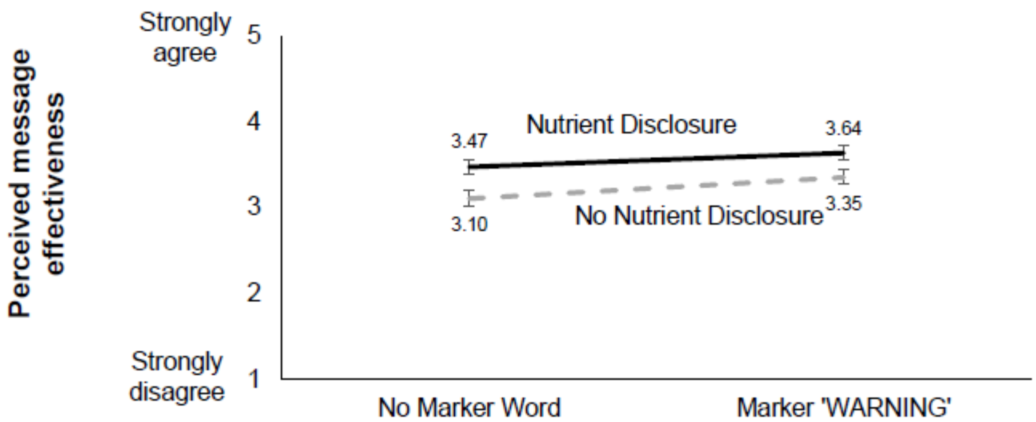
Note. Figure shows the interaction between health effects and nutrient disclosure on (A) perceived message effectiveness (5,431 ratings), (B) thinking about harms (5,430 ratings), and (C) fear (5,431 ratings) among 1,360 U.S. adults. Error bars show 95% confidence intervals.

Figure 3.6. Interaction between health effects and marker word on perceived message effectiveness, thinking about harms, and fear.



Note. Figure shows the interaction between health effects and nutrient disclosure on (A) perceived message effectiveness (5,431 ratings), (B) thinking about harms (5,430 ratings), and (C) fear (5,431 ratings) among 1,360 U.S. adults. Error bars show 95% confidence intervals.

Figure 3.7. Interaction between nutrient disclosure and marker word on perceived message effectiveness.



Note. Figure shows the interaction between nutrient disclosure and marker word on perceived message effectiveness (5,431 ratings) among 1,360 U.S. adults. Error bars show 95% confidence intervals.

CHAPTER 4: IMPACT OF SUGAR-SWEETENED BEVERAGE HEALTH WARNINGS ON BEVERAGE PURCHASES: A RANDOMIZED CONTROLLED TRIAL

Introduction

Excess consumption of sugar-sweetened beverages (SSBs) such as sodas, fruit drinks, and sports drinks is a pressing public health issue in the United States. Average SSB consumption among U.S. adults remains well above recommended levels,[9,45,169] increasing risk for several of the most common preventable chronic diseases in the U.S., including obesity, diabetes, and cardiovascular disease.[2–5] Nutrition education and other behavioral interventions can yield small reductions in SSB consumption among those they reach.[170] However, the consensus among experts is that policy action is needed to achieve meaningful population-wide improvements in dietary behaviors and diet-related diseases.[171–174] Requiring health warnings on SSB containers is one promising policy for addressing overconsumption of SSBs.

Five U.S. states have proposed policies that would require health warnings on the front of SSB containers.[10–15] Experimental research on SSB warnings can inform future policies in the U.S. and globally. Several online studies have assessed SSB health warnings' effect on hypothetical intentions to purchase SSBs,[19–21] but the effects on behavioral outcomes remain uncertain. One quasi-experimental study conducted in a hospital cafeteria found that graphic SSB health warnings (but not text health warnings) were associated with lower SSB purchases,[34] but this study did not use a randomized design. Another study used a randomized design and measured beverage purchases, but displayed beverages and health warnings on a computer screen, not in a retail environment.[33] To understand the impact of SSB health warnings on purchase behaviors, randomized controlled trials in naturalistic retail settings are needed. Such trials provide strong causal inference while also mimicking many real-world conditions consumers would experience if SSB health warning policies were implemented.

To inform obesity prevention policy, we conducted a randomized trial in an immersive, naturalistic convenience store laboratory to estimate the impact of SSB health warnings on SSB purchases. We hypothesized that SSB health warnings would reduce SSB purchases. We also assessed the impact of SSB health warnings on behavioral intentions, cognitive and affective responses to the labels, and SSB perceptions and attitudes.

Methods

Participants

Participants were adults 18 years or older; could read, write, and speak English; and were current SSB consumers, defined as consuming at least one serving (12 ounces [355 ml]) per week of SSBs as assessed using an adapted version of the BEVQ-15 beverage frequency questionnaire.[175] We recruited and enrolled participants from May to September 2018 using Craigslist, Facebook, email lists, university participant pools, in-person recruitment, and flyers. The University of North Carolina Institutional Review Board approved all study procedures and all participants provided their written informed consent.

Setting

The trial took place in a naturalistic convenience store laboratory located in the Fuqua Behavioral Lab at Duke University in Durham, NC, U.S.A. The laboratory store is a life-size replica of a typical convenience store, selling foods, beverages, and household products at real-world prices. Naturalistic laboratory stores like the one used in this study provide an immersive experience that simulates a real shopping trip.[176,177]

Products sold. Beverages for sale included popular SSBs in seven beverage categories: sodas, fruit drinks, sports drinks, energy drinks, sweetened ready-to-drink (RTD) teas, sweetened RTD coffees, and calorically flavored waters (**Table 4.1**). We examined household purchase data from North Carolina[178] to identify up to five popular products by volume purchased in each of the seven beverage categories. For all categories except sodas and fruit drinks, we selected one product to sell; we sold five types of soda and two types of fruit drinks because these beverage categories comprise the majority of SSB calories consumed by U.S. adults.[7,9] SSB containers were 8.0 to 16.9 ounces (236 to 500 ml), reflecting the typical amount consumed in a single sitting.[179]

For each SSB sold in the store, we also sold a non-sugar-sweetened beverage (non-SSB) that closely matched the selected SSB in brand, flavor, and container size (Table 4.1). Each soda, sports drink, energy drink, sweetened RTD tea, and flavored water was matched to the diet/low-calorie version of the product. Sweetened RTD coffee was matched to an unsweetened version of the same coffee, and fruit drinks were matched to similar 100% fruit juices. To more fully reflect the retail environment, the store also sold unflavored bottled water and non-calorically flavored sparkling water, despite these beverages having no corresponding SSBs.

The store also sold a variety of foods (e.g., chips, cookies, crackers, packaged fruit cups, nuts, cereal, canned soup, pasta) in both single-serving and multipack/family sizes as well as household products (e.g., shampoo, soap, toothpaste, napkins, garbage bags, over-the-counter medications, notebooks). These products were selected prior to our study by the Behavioral Lab to interest participants and mimic a typical convenience store.

Prices. Following others,[33] we set beverage prices based on standard retail prices in stores in lower- and middle-income areas surrounding the laboratory. To ensure participants selected beverages based on their preferences, rather than simply selecting the least expensive items, prices were held constant across conditions, and SSBs and non-SSBs were priced identically (Table 4.1). We kept prices for foods and household products at the levels that the Behavioral Lab had set previously to reflect real-world prices.

Procedures

We screened individuals for eligibility using an online questionnaire, inviting those eligible to schedule a time to visit Behavioral Lab to complete the study. At the study visit, participants enrolled and provided written informed consent. Advertisements and consent documents indicated that the study intended to examine factors affecting consumer behavior but did not reveal the study's focus on SSBs or health warnings.

When participants arrived for their study visit, we assigned them to one of two trial arms, health warning or control. Study staff consulted a randomly ordered, pre-populated list of allocations and assigned participants to the next allocation on the list. The list was generated prior to study start by an independent biostatistician using simple randomization in a 1:1 allocation ratio. In the health warnings arm, we applied a health warning label (**Figure 4.1**) directly to the front of all SSB containers in the store. The label displayed the message "WARNING: Beverages with added sugar contribute to tooth decay, diabetes, and obesity" in white text on a 1.5" red octagon with a thin white border. We chose this design for the SSB health warning because it performed well in an online randomized experiment.[180] For the control arm, we applied a 1" x 2.625" barcode label (Figure 4.1) to the front of all SSB containers. We chose a barcode image for the control label because beverage containers already display barcodes. We used a control label, rather than a no-label control arm, to control for the effect of putting a label on SSB containers.

When participants entered the store, they received a shopping basket and $10 in cash. We asked participants to shop as they usually would and to choose six products: two household products, two foods, and two beverages. We asked participants to place their choices in their basket and instructed them that one of these six would be randomly selected for them to purchase and take home using the $10 cash incentive provided at the start of the shopping task. This procedure ensured that selections were real-stakes, i.e., that all six items participants chose were items they actually wished to purchase.

Study staff left the store while participants completed the shopping task. When participants were ready to check out, we recorded all of products in their basket. Then, we numbered the products and drew a number out of a basket to randomly select one item for the participant to purchase with her incentive cash at the product's listed price. We gave the participant the change owed in cash. Participants then completed a questionnaire on a computer in a private room. Afterward, they received the item they had purchased in the shopping task and were debriefed about the purpose of the study.

Outcome Measures

The primary trial outcome was SSB calories purchased, calculated as the sum of calories/container from all SSBs in the participant's shopping basket when they completed the shopping task. Secondary purchase outcomes were purchase of any SSB, the number of SSBs purchased, and total calories purchased (from all products, including SSBs, non-SSBs, and foods).

To guide selection of psychological secondary outcomes, we used previous research on SSB and cigarette health warnings.[19–21,70,72,92] These outcomes were assessed in the post-shopping questionnaire with items and scales that have been validated or used in previous studies

(**Appendix B**). Psychological secondary outcomes were intentions to limit consumption of "beverages with added sugar", intentions to limit consumption of the specific categories of SSBs sold in the store (i.e., intentions to limit consumption of "sodas," "fruit drinks," etc.), whether participants noticed the label applied to the SSBs (health warning or control), degree of attention elicited by the label, cognitive elaboration (thinking about the label and thinking about the harms of SSB consumption), negative affect elicited by the label (e.g., fear, regret), anticipated social interactions about the label, perceived amount of added sugar in the SSB categories sold in the store, perceived healthfulness of consuming beverages with added sugar, positive attitudes toward the SSB categories sold in the store, and negative outcome expectations about consuming beverages with added sugar. Participants who reported they did not notice the label were not shown questions about attention, cognitive elaboration, negative affect, or anticipated social interactions; their responses to these items were coded with the lowest value.

Analysis

Power analyses indicated that the target enrollment of 400 adults would provide 80% power to detect a small standardized effect (Cohen's f^2 =0.02) or larger, assuming an α=0.05. Analyses of trial outcomes included all participants randomized (intent-to-treat analyses). We examined differences between trial arms in participant characteristics using χ^2 tests and *t*-tests for categorical and continuous variables, respectively. We used a critical α=0.05 and 2-tailed statistical tests. We completed data preparation and analyses in Stata SE version 15.1 (StataCorp LLC, College Station, TX) in 2018.

Analyses used ordinary least squares (OLS) regression to examine the impact of trial arm on SSB calories purchased controlling for any participant characteristics found to differ between trial arms. To examine if the effect of the health warnings on SSB purchases differed by participant characteristics, we added participant characteristics and their interaction with trial arm to separate OLS regression models for each characteristic. To examine secondary outcomes, analyses used OLS regression for continuous outcomes, logistic regression for dichotomous outcomes, and Poisson regression for count outcomes, again controlling for participant characteristics that differed between trial arms. We report unadjusted point estimates (means, proportions) and adjusted differences (ADs) controlling for participant characteristics that differed between arms. Results were identical in unadjusted analyses. We did not conduct interim analyses. Except where noted below, all outcomes and analyses described were pre-specified in the trial's Protocol and Statistical Analysis Plan (available from https://clinicaltrials.gov/ct2/show/NCT03511937).

Results

Participant Characteristics

We recruited and enrolled 400 adult SSB consumers, of whom all received their allocated intervention and were included in analyses (**Figure 4.2**). Participants were diverse: more than half were non-white, 10% identified as gay, lesbian, or bisexual, and more than half had annual household income of less than $50,000 (**Table 4.2**). In the eleven balance tests conducted, two were statistically significant. Participants in the health warning arm were more likely than participants in the control arm to be Hispanic (p=0.004) and to have body mass index (BMI) in the overweight range or higher (BMI $\geq$ 25 kg/m^2, p=0.03).

SSB Purchase Behaviors

Participants in the control arm purchased an average of 143.2 calories of SSBs (SE 9.7), the primary trial outcome (**Table 4.3**). Participants in the health warning arm purchased 109.9 calories of SSBs (SE 9.5). In adjusted analyses, health warnings led to a reduction of -32.4

calories of SSBs purchased (95% CI, -59.5, -5.2). The effect of SSB health warnings on SSB purchases did not differ by any of the ten participant characteristics we examined ($p>0.10$ for all interactions; **Table 4.4**). Health warnings also reduced the proportion of participants who purchased an SSB from 64% to 50% (AD, -13% [95% CI, -23%, -4%]) and reduced the number of SSBs participants purchased from 0.9 beverages to 0.7 beverages (AD, -0.2 SSBs [95% CI, -0.4, -0.03]).

Psychological Outcomes

The SSB health warning increased intentions to limit consumption of the specific categories of SSBs sold in the store (i.e., intentions to limit consumption of "sodas," "fruit drinks," etc.) ($p=0.005$), but intentions to limit consumption of "beverages with added sugar" did not differ by trial arm ($p=0.40$) (Table 4.3). Participants in the health warning arm were more likely to notice the trial label ($p<0.001$) and reported greater attention to the label ($p<0.001$). The health warning also led to more thinking about the warning message and harms of SSB consumption, higher levels of negative affect, and higher anticipation of talking with others about the label (all *p*s<0.001). Perceived amount of added sugar in SSBs, perceived healthfulness, positive product attitudes, and negative outcome expectations did not differ by trial arm.

Other Purchase Behaviors

To understand purchase behaviors more broadly, we also examined the impact of health warnings on calories purchased from foods, from non-SSBs, and from all sources (i.e., total calories from SSBs, non-SSBs, and foods) (Table 4.3). Only the latter, total calories from all sources, was registered as a secondary outcome. Participants in the health warning arm purchased somewhat more calories from non-SSBs than participants in the control arm (driven almost entirely by higher juice purchases), although the difference was not significant (AD, 12.4 calories [95% CI, -1.6, 26.5]). There were not significant differences between trial arms in calories purchased from foods (AD, -49.5 calories; 95% CI, -271.5, 172.5) or in total calories purchased from all sources (AD, -69.4; 95% CI, -296.5, 157.6).

Discussion

Our naturalistic randomized trial with 400 U.S. adults found that health warnings reduced SSB calories purchased. Consistent with previous studies,[19,21,180] the effectiveness of SSB health warnings did not differ across diverse population groups, including racial/ethnic minorities as well as adults with limited health literacy, lower education, lower income, and an overweight/obese BMI. The observed reduction of 32 SSB calories per transaction represents a 22% decrease over the control arm and could have meaningful population-level health implications if sustained over time. For example, recent microsimulation studies[39,42,181] have found that reducing average SSB intake by between 11 and 55 calories/day could lower obesity prevalence by 0.89 to 1.5 percentage points and type 2 diabetes incidence by up to 2.6 percentage points.

These findings fill an important gap in research on SSB health warnings. Few studies of SSB health warnings have measured actual behavior, instead assessing hypothetical purchase intentions.[19–21] Those that have measured behavioral outcomes either lacked a randomized design[34] or displayed beverages and health warnings on a computer screen, not in a retail environment.[33] Randomized trials in naturalistic, immersive settings like ours have the benefit of providing both a controlled environment while also simulating many of the conditions consumers would experience in the real-world if SSB health warning policies were implemented.

The weight loss benefits of reducing SSB consumption depend on the extent to which individuals compensate for decreased SSB consumption by increasing caloric intake from other sources.[182,183] Our trial provides some insights on compensatory behaviors. SSB health warnings induced a non-significant increase in calories purchased from non-SSBs (mostly juice), partially offsetting the reduction in SSB calories purchased. There were no significant differences between trial arms in calories purchased from foods or in total calories purchased from all sources. This could be due to the large variance in these outcomes overwhelming the differences between trial arms. For example, the standard deviation in total calories purchased (1134 calories) was more than an order of magnitude larger than the impact of health warnings on this outcome (-69 calories). Future studies with larger sample sizes are needed to more fully elucidate the effect of health warnings on calories purchased from different sources.

Few studies have examined how SSB health warnings exert their effects on behavior. The Tobacco Warnings Model[70,72] proposes that warnings operate by increasing attention, which in turn elicits stronger negative affect, more social interactions with others about the warning, more thinking about harms, and ultimately greater motivation for behavior change. We found support for this model. In our trial, SSB health warnings elicited more attention, greater negative affect, higher likelihood of social interactions, and more thinking about harms of SSB consumption than the control labels. Health warnings also increased participants' intentions to limit their consumption of the SSBs sold in the store. In contrast, there were no differences between trial arms in perceptions of added sugar content in SSBs, positive attitudes toward SSBs, or expectations that SSB consumption increases disease risk. These results stand in contrast to online studies reporting that SSB health warnings influence perceptions, attitudes, and beliefs about SSBs,[19–21] but are consistent with studies of pictorial cigarette warnings that find little effect of warnings on attitudes or perceptions of disease risk.[70,92]

Two key strengths of this study are the use of a randomized controlled design and the objective measurement of a behavioral outcome. Other strengths include the diverse sample of SSB consumers and the store setting that mimicked a true convenience store environment and displayed SSB health warnings on actual SSB containers. One limitation of this study is that participants had only a brief exposure to SSB health warnings. If SSB warning policies were implemented, consumers would see warnings every time they shopped for beverages. Donnelly and colleagues' quasi-experimental study found that the impact of graphic SSB health warnings on purchases was consistent over a two-week intervention period,[34] but effects beyond this time frame remain unknown. Another limitation is that the naturalistic store had some differences from real stores, including that the store sold beverages off of the shelf instead of from a refrigerated display case. The SSB health warning labels also obscured the branding on some products; to control for this, we placed both the health warning and control labels in similar locations on SSB containers.

Conclusions

Five U.S. states have proposed SSB health warning policies, but none have been implemented. Findings from this naturalistic randomized trial suggest that SSB health warning policies could reduce SSB purchases, providing timely information for policymakers as they seek to identify strategies to reduce overconsumption of SSBs.

Table 4.1. Beverages for sale in the convenience store laboratory

	Sugar-sweetened beverages (SSBs)		Non-sugar-sweetened beverages (Non-SSBs)				
Category	**Description**	**Example**	**Description**	**Example**	**# different products sold**	**Container size (fl. oz)**	**Price (USD)**
Sodas	Regular (non-diet) carbonated soft drinks and sodas	Coca Cola	Diet carbonated soft drinks and sodas	Diet Coke	5 SSBs, 5 non-SSBs	16.0 or 16.9	$1.46
Fruit drinks	Fruit-flavored drinks and juice drinks that are not 100% juice	Sunny Delight	100% fruit juices	Tropicana 100% orange juice	2 SSBs, 2 non-SSBs	10.0	$1.46
Sports drinks	Regular (non-diet) sports drinks	Gatorade, Orange	Diet or low-calorie sports drinks	Gatorade G2, Orange	1 SSB, 1 non-SSB	20.0	$1.46
Energy drinks	Regular (non-diet) energy drinks	Monster Energy Drink	Diet or low-calorie energy drinks	Monster Ultra Energy Zero	1 SSB, 1 non-SSB	16.0	$2.26
Ready-to-drink teas	Pre-packaged sweetened tea	Lipton Green Tea, Citrus	Pre-packaged non-calorically sweetened tea	Lipton Diet Green Tea, Citrus	1 SSB, 1 non-SSB	16.9	$1.46
Ready-to-drink coffees	Pre-packaged sweetened coffee	Kohana Cold Brew, Tahitian Vanilla	Pre-packaged unsweetened coffee	Kohana Cold Brew, Volcanic Black	1 SSB, 1 non-SSB	8.0	$2.26
Waters	Calorically-sweetened flavored waters	Vitamin Water, Xxx Acai-Blueberry-Pomegranate	Plain (unflavored) and non-calorically sweetened waters	Vitamin Water Zero, Xxx Acai-Blueberry-Pomegranate	1 SSB, 3 non-SSBs	16.9	$1.46

Table 4.2. Participant characteristics by trial arm

	Control n=200		Health Warning n=200	
Characteristic	***n***	**%**	***n***	**%**
Age				
18-29 years	132	66%	125	63%
30-39 years	41	21%	47	24%
40-54 years	19	10%	22	11%
55+ years	8	4%	6	3%
Mean (SD)	29.0	10.5	29.0	10.3
Gender				
Male	76	38%	83	42%
Female	121	61%	115	58%
Transgender or other	3	2%	2	1%
Gay, lesbian, or bisexual	20	10%	21	11%
Hispanic	9	5%	25	13%
Race				
White	93	47%	87	44%
Black or African American	43	22%	46	23%
Asian	51	26%	47	24%
Other/multiracial[a]	12	6%	17	9%
Low education (some college or less)[b]	47	24%	47	24%
Limited health literacy[c]	59	30%	66	33%
Household income, annual				
\$0-\$24,999	49	25%	47	24%
\$25,000-\$49,999	54	27%	61	31%
\$50,000-\$74,999	34	17%	22	11%
\$75,000+	63	32%	69	35%
Sugar-sweetened beverage consumption				
Low (≤ 60 oz/week[d])	100	50%	103	52%
High (> 60 oz/week[d])	100	50%	97	49%
Overweight (BMI ≥ 25 kg/m^2)	72	36%	93	47%

[a]Includes participants who marked "other race," American Indian/Native American, Native Hawaiian or Pacific Islander, or who marked multiple races.
[b]Educational attainment for participants ≤ 25 years (who may still be completing degrees) was assessed using mother's or father's educational attainment, whichever was higher.
[c]"Possibility" or "high likelihood" of limited health literacy based on score on the Newest Vital Sign questionnaire.[184]
[d]Sample median.
Note. Missing demographic data ranged from 0% to 1%. In the eleven balance tests conducted, two statistically significant differences between the health warning and control arm were observed: proportion Hispanic (p=0.004) and proportion overweight (p=0.03).

Table 4.3. Impact of sugar-sweetened beverage health warnings on purchase behaviors and psychological outcomes, *n*=400 adults

Outcome	**Control, *n*=200**		**Health Warning, *n*=200**				
	Unadj. Mean	**(SE)**	**Unadj. Mean**	**(SE)**	**Adj. impact of health warning[a]**	**95% CI**	
Purchase behaviors							
Calories purchased by source							
Sugar-sweetened beverages (SSBs)[b]	143.2	(9.7)	109.9	(9.5)	**-32.4***	**-59.5**	**-5.2**
Non-sugar-sweetened beverages[c]	32.9	(4.5)	47.1	(5.5)	12.4	-1.6	26.5
Foods[c]	2259.5	(75.6)	2208.7	(81.3)	-49.5	-271.5	172.5
Total calories purchased	2435.6	(77.5)	2365.6	(82.9)	-69.4	-296.5	157.6
Purchase of an SSB, % (N)	64%	(128)	50%	(100)	**-13%****	**-23%**	**-4%**
Number of SSBs purchased	0.9	(0.1)	0.7	(0.1)	**-0.2***	**-0.4**	**-0.03**
Behavioral intentions							
Intentions to limit consumption of beverages with added sugar[d]	4.7	(0.13)	4.8	(0.13)	0.2	-0.2	0.5
Intentions to limit consumption of specific SSBs[d]	5.0	(0.12)	5.5	(0.10)	**0.4****	**0.1**	**0.8**
Responses to trial labels							
Noticed trial label, % (N)	33%	(65)	75%	(150)	**37%*****	**32%**	**43%**
Attention to label[e,f]	1.5	(0.06)	3.1	(0.11)	**1.7*****	**1.4**	**1.9**
Thinking about warning message/harms[e,f]	1.2	(0.04)	2.3	(0.09)	**1.1*****	**0.9**	**1.3**
Negative affect elicited by label[e,f]	1.1	(0.02)	1.5	(0.05)	**0.4*****	**0.3**	**0.5**
Anticipated social interactions about label[e,f]	1.3	(0.05)	2.2	(0.09)	**0.9*****	**0.7**	**1.1**
SSB perceptions and attitudes							
Perceived amount of added sugar in SSBs[g]	3.6	(0.02)	3.6	(0.02)	0.07	-0.001	0.13
Perceived healthfulness of SSB consumption[d]	2.4	(0.06)	2.3	(0.06)	-0.10	-0.27	0.07
Positive SSB product attitudes[d]	4.1	(0.08)	4.1	(0.07)	-0.09	-0.31	0.13
Negative outcome expectations[d]	6.1	(0.07)	6.2	(0.06)	0.05	-0.13	0.23

[a]Adjusted difference in means between health warning and control arms, controlling for Hispanic ethnicity and overweight status. Boldface indicates statistical significance (*p<0.05, **p<0.01, ***p<0.001).
[b]Primary outcome.
[c]Calories purchased from non-sugar-sweetened beverages and from foods were not registered as secondary outcomes.

[d]Response scale for intentions, perceived healthfulness of SSB consumption, positive SSB product attitudes, and negative outcome expectations ranged from 1 to 7, with 7 indicating higher quantity or stronger endorsement.
[e]Participants who indicated that they did not notice the trial label were not shown items about attention, cognitive elaboration, negative affect, or anticipated social interactions; their responses to these items were coded with the lowest value.
[f]Response scale for attention, thinking about warning message/harms, and negative affect ranged from 1 to 5, with 5 indicating higher quantity or stronger endorsement.
[g]Response scale for perceived amount of added sugar ranged from 1 to 4, with 4 indicating higher quantity.

Table 4.4. Interaction of trial arm and participant characteristics in predicting total calories of sugar-sweetened beverages purchased, *n*=400 adults

	Adjusted impact of SSB health warning[a]	***p* for interaction**[b]
Age		
18-29 years	-15.4	0.10
30-39 years	-56.2	
40-54 years	-47.3	
55+ years	-186.3	
Gender[c]		
Male	-42.8	0.42
Female	-20.3	
Sexual orientation		
Straight or heterosexual	-32.9	0.74
Gay, lesbian, or bisexual	-18.1	
Ethnicity		
Not Hispanic	-31.3	0.78
Hispanic	-46.5	
Race		
White	-36.4	0.93
Black or African American	-34.7	
Asian	-26.4	
Other/multiracial[d]	-1.7	
Educational attainment[e]		
College degree or more	-27.3	0.31
Some college or less	-59.8	
Health literacy		
Adequate literacy[f]	-34.1	0.73
Low literacy[g]	-22.0	
Household income, annual		
$0-$24,999	-42.7	0.47
$25,000-$49,999	-25.5	
$50,000-$74,999	19.8	
$75,000+	-47.1	
Sugar-sweetened beverage consumption		
Low (≤ 60 oz/week[h])	-19.9	0.29
High (> 60 oz/week[h])	-48.3	
Overweight status		
Not overweight (BMI < 25 kg/m^2)	-21.0	0.32
Overweight (BMI ≥ 25 kg/m^2)	-48.5	

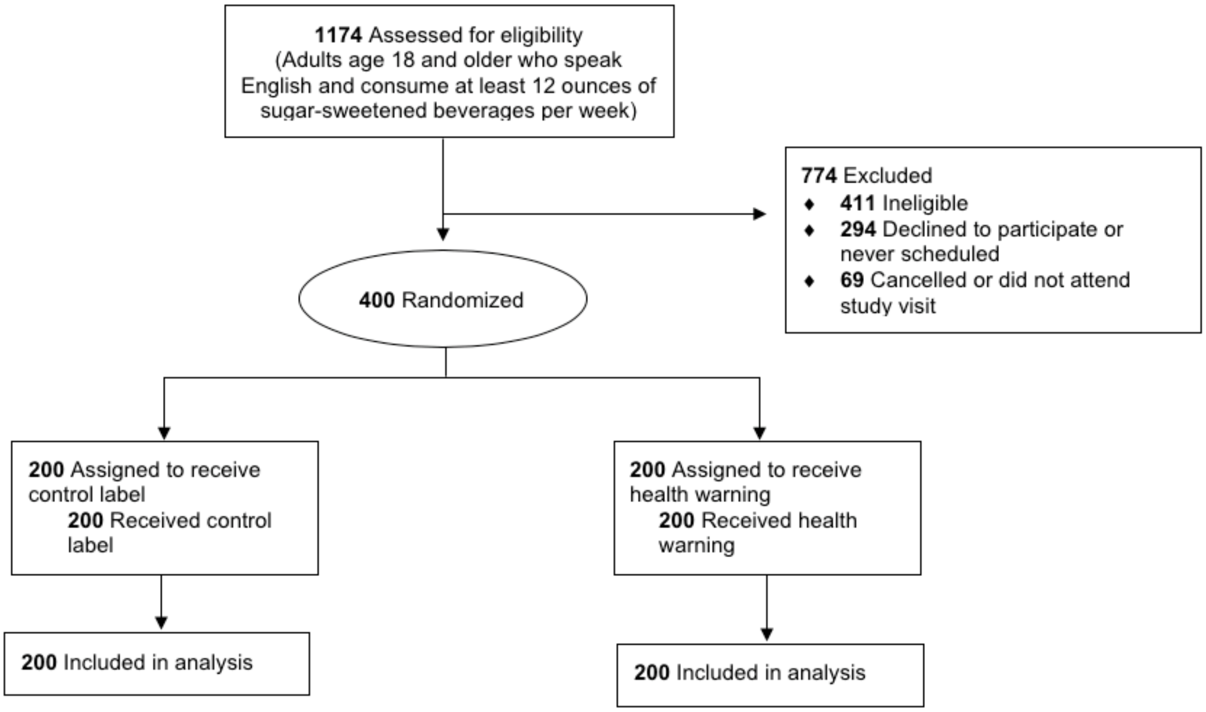
[a]Adjusted difference in means between health warning and control arms, controlling for Hispanic ethnicity and overweight status.
[b]*p* for interaction is from *t*-tests on the coefficient on the interaction term (for dichotomous moderators) and from Wald tests of joint significance of the coefficients on all interaction terms (for moderators with more than two levels).

[c]Analyses excluded the 5 participants who identified as transgender or other gender due to small cell size.
[d]Includes participants who marked "other race," American Indian/Native American, Native Hawaiian or Pacific Islander, or who marked multiple races.
[e]Educational attainment for participants ≤ 25 years (who may still be completing degrees) was assessed using mother's or father's educational attainment, whichever was higher.
[f] "Adequate literacy" based on score on the Newest Vital Sign questionnaire.[184]
[g]"Possibility" or "high likelihood" of limited health literacy based on score on the Newest Vital Sign questionnaire.[184]
[h]Sample median.

Figure 4.1. Sugar-sweetened beverage health warning label and control label used in the trial

Note. Actual sizes.

Figure 4.2. CONSORT flow diagram



CHAPTER 5: IMPACT OF A NATIONAL SUGAR-SWEETENED BEVERAGE HEALTH WARNING POLICY ON DIET AND OBESITY: A MICROSIMULATION ANALYSIS

Introduction

Nearly 40% of adults in the U.S. have obesity.[137] A leading cause of death,[185,186] obesity increases risk for cardiovascular disease, type II diabetes, and some cancers.[187,188] While the causes of obesity are complex, excess consumption of sugar-sweetened beverages (SSBs) is thought to be a key driver of the obesity epidemic.[3,5,54,189] Half of American adults consume SSBs on any given day,[9] and average consumption remains well above recommended levels.[9,45,169] SSB consumption is even higher among non-Hispanic black and Hispanic individuals,[9] as well as those with lower educational attainment and lower income.[139] To reduce the burden of obesity, policymakers continue to seek population-level strategies for addressing overconsumption of SSBs.[15]

Implementing health warnings on harmful products is a key tool that governments use to reduce harmful behaviors. For example, warnings on cigarettes are required in over 150 countries[190] and have been found to reduce smoking.[92] Increasingly, governments are also considering health warnings on foods and beverages, including SSBs. As of early 2019, five U.S. states have proposed policies that would require SSBs to display warnings describing the health harms of SSB consumption.[10–15] Online studies indicate that SSB health warnings reduce intentions to purchase SSBs[19–21] and recent experimental and quasi-experimental research indicates warnings reduce actual SSB purchases by up to 22%.[34,191]

While experimental studies provide insight into how consumer purchases are likely to change in response to an SSB health warning policy, it is unknown how these individual-level changes affect the population-level health outcomes of most interest to policymakers. These population-level impacts depend not just on warnings' effects on SSB purchases, but also on pre-policy beverage consumption patterns, the relationship between SSB consumption and other dietary behaviors such as total energy intake, and how dietary behaviors affect health outcomes like body mass and obestiy.[133] Simulation models can systematically integrate this information to estimate a policy's impact on the health of a nation.[38] Simulation models are an emerging tool in nutrition policy analysis: previous studies have used such models to examine SSB taxes,[41–43] changes to federal nutrition assistance programs,[39,134] and city-level SSB warning policies.[133] To inform ongoing policy debates, the objective of this study was to estimate the effects of national SSB health warning policy on U.S. adults' dietary behavior and body weight.

Methods

Overview

We applied a microsimulation model, representing events (e.g., changes in health states likes obesity) at the individual level.[192] We assessed outcomes over a five-year period. Because nearly all weight loss occurs in the first three years after a reduction in caloric intake,[183,193] a five-year time horizon is sufficient to capture the weight loss benefits resulting from simulated policy changes. **Appendix C** includes details on the development and validation of the model and **Table 5.1** describes key input parameters.

Study Population

Simulated individuals. We simulated cohorts of U.S. adults with varying demographic characteristics predictive of SSB intake,[7,9,44,139,179] as shown in **Figure 5.1**. We assigned each individual an age group (18-39 vs. 40-65 years), sex (male vs. female), race/ethnicity (non-Hispanic white, non-Hispanic black, and Hispanic or Mexican American), education level (some college or less vs. a college degree or more), and income level (≤ 185% of the Federal Poverty Level [FPL] vs. >185% FPL, the eligibility cutoff for nutrition assistance programs in many states). For each of the 48 combinations of these five characteristics, we created a simulated cohort populated by 1,000 individuals, yielding a total of 48,000 simulated individuals.

Baseline characteristics. We used Monte Carlo sampling to assign baseline (i.e., pre-policy) values for height, weight, and SSB intake to simulated individuals, drawing from cohort-specific distributions of these variables. We estimated the cohort-specific distributions using dietary recall and anthropometric data from the National Health and Nutrition Examination Survey (NHANES) cycles 2005-2014, stratified by demographic cohort. Based on previous literature[7,44,179,194,195] and existing U.S. SSB policies,[196,197] we defined SSBs as non-diet, nonalcoholic beverages with added sugars containing at least 5 calories per 100g, including sodas, sports drinks, energy drinks, fruit drinks, and sweetened coffees and teas, but excluding 100% juice and milk-based drinks.

Scenarios Simulated

We modeled two scenarios: a policy scenario assuming a national SSB health warning policy and a status quo scenario assuming no SSB health warning policy. In the policy scenario, we assumed that simulated individuals would change their SSB intake in response to the warnings, then modeled how change in SSB consumption would affect total energy intake, and finally translated change in total energy intake into change in body weight over time using a validated model of weight change dynamics.[183] In the status quo scenario, we assumed no change in SSB intake in response to health warnings. In both scenarios, we allowed SSB intake to change as individuals aged into the older category[7,9] and incorporated secular trends in total energy intake (see Appendix C for details).

Model Representations of Changes in Diet and Weight Over Time

SSB intake. In the policy scenario, we modeled how simulated individuals would respond to a SSB health warning policy. We assumed warnings would generate proportional changes in SSB intake. In the primary policy scenario, we assumed that SSB health warnings would yield an average reduction in SSB intake of 12.7%, the most conservative (i.e., smallest) estimate of warning impact from previous experimental[21,191] and quasi-experimental studies[34] measuring the effect of SSB warnings on willingness to pay or beverage purchases among adults. We allowed variation in individual responses to the SSB health warning policy by assigning each simulated individual a proportional change in SSB intake drawn from a triangular distribution of potential responses centered on a 12.7% reduction. In the primary policy scenario, we assumed that change in SSB intake would be constant over time; for example, if an individual reduced her SSB intake by 10%, we assumed this reduction would persist throughout the five-year simulation period. In the status quo scenario, we assumed no change in SSB intake except due to aging.

Total energy intake. Individuals who reduce their SSB intake may replace SSB calories with calories from other sources. Previous studies suggest that a 1.0 calorie reduction in SSB intake yields a reduction in total energy intake of 0.63 to 1.84 calories.[34,198–202] In the primary policy scenario, we accounted for potential compensatory eating and drinking by having each simulated individual sample from a uniform distribution of values for caloric compensation, following the approach used by Long et al.[181] and others.[42,203] We multiplied individuals' simulated change in SSB intake by their sampled compensation factor to yield change in total energy intake in calories/day.

Body weight. To translate change in total energy intake into change in body weight, we incorporated the National Institutes of Health validated model of weight change dynamics,[183] which quantifies how a change in net energy intake affects body weight over time. The weight change model was run in daily time steps over the five-year simulation period, updating each individual's body weight daily based on her net energy intake relative to her energy needs. We used these results to examine individual's body mass index (BMI, kg/m^2) and obesity status (BMI ≥ 30 kg/m^2), calculated using baseline height.

Calculating Population Outcomes

We estimated the effect of implementing a national SSB health warning policy on four outcomes: SSB intake, total energy intake, BMI, and obesity prevalence. To estimate policy impact, we used a difference-in-differences (DD) framework, comparing the change from baseline to the end of the 5-year simulation period in the SSB health warning policy model to change over time in the status quo model. All analyses weighted simulated individuals to produce estimates representative of the U.S. population. We report outcomes both overall and within demographic subgroups (e.g., by race/ethnicity). To explore the potential for warnings to reduce disparities, we also computed differences in warning impact between demographic subgroups (e.g., comparing warnings' impact on outcomes among white adults to warnings' impact among black adults).

We used Monte Carlo sampling from predetermined distributions of model input parameters (see **Table C.8**). We calculated average impacts as the mean of the DD estimates from 10,000 repetitions of the model. To reflect uncertainty in the point estimates, we report 95% uncertainty intervals (UIs) around these means, bounded by the 2.5^{th} and 97.5^{th} percentiles of the DD estimates. This study used de-identified secondary data and was exempt from review by the Institutional Review Board. We completed data preparation and analyses using Stata SE version 15.1 (StataCorp, LLC, College Station, TX).

Sensitivity Analyses

We assessed sensitivity to alternate assumptions about three key model parameters: (1) the trajectory of warning efficacy over time, (2) the extent to which warnings will reduce SSB intake, and (3) caloric compensation. First, we varied assumptions about how SSB health warnings' effectiveness may change over time. To date, only one study has examined the efficacy of SSB health warnings beyond immediate impacts, finding that graphic SSB health warnings exerted stable effects on SSB purchases over a two-week period.[34] We used literature on tobacco health warnings for additional estimates of how warning efficacy may change over time. Some studies have reported that cigarette warnings' efficacy wears out (decreases) by 1.1% to 4.8% per year,[204] while others found the opposite, i.e., that behavioral responses to cigarette warnings increase over time by as much as 20% per year.[129,205,206] In sensitivity analyses, we evaluated two scenarios: first, assuming the impact of SSB health warnings on SSB consumption decreases by 10% per year (about twice the maximum rate of decline observed in a prior study[204]) and second, assuming behavioral impact increases by 10% per year (about half the maximum rate of increase observed in a prior study[206]).

Second, we evaluated two alternate estimates of the impact of SSB health warnings on SSB consumption. Based on a quasi-experimental study of graphic SSB health warnings,[34] we evaluated warning impact when assuming SSB health warnings would yield a 14.8% reduction in SSB consumption. We also examined outcomes when assuming that warnings produce a 22.4% reduction in SSB consumption, the impact of text health warnings on SSB purchases observed in a recent randomized controlled trial.[191] Finally, we evaluated an alternate assumption about caloric compensation, assuming that a 1 calorie reduction in SSB intake would yield only a 0.63 calorie reduction in total energy intake, the most conservative estimate of caloric compensation (i.e., highest degree of compensation) from previous cross-over and randomized trials of SSB caloric compensation conducted among adults.[198,200,201]

Results

Validation

Simulated baseline average height, weight, and SSB intake accurately reflected actual population averages of these variables (**Tables C.3, C.4, and C.5**). We assessed the validity of the NIH weight change model by using the model to simulate BMI from 2007-2014 and comparing the simulated trends to observed trends in BMI over the same period. The model accurately reproduced secular trends in BMI (**Figure C.2**).

SSB Warning Impact in the Primary Policy Scenario

Relative to the status quo, implementing a national SSB health warning policy would reduce SSB intake over baseline consumption levels by 26.2 calories/day (95% uncertainty interval [UI], -28.3, -24.1) under primary policy scenario assumptions (**Figure 5.2**). In turn, the reduction in SSB intake would reduce total energy intake by 32.4 calories per day (95% UI, -34.2, -30.5) (Figure 5.2). These dietary changes would yield gradual reductions in BMI over time (**Figure 5.3**). At the end of the five-year simulation period, average BMI among individuals experiencing the SSB health warning policy would be 0.61 kg/m^2 lower than in the status quo model (95% UI, -0.64, -0.57) (Figure 5.2). In turn, national obesity prevalence would be reduced by 2.1 percentage points (95% UI, -2.4%, -1.7%) (Figure 5.2).

Reductions in SSB intake, total energy intake, BMI, and obesity were present for all demographic groups, including white, black, and Hispanic adults, younger and older adults, those with lower and higher education and income, and males and females (**Figure 5.4**). Some groups experienced larger reductions than others (**Table 5.2**). For example, black adults experienced larger reductions in obesity prevalence (-3.1 percentage points) than white adults (-1.7 percentage points) (difference in reductions, 1.4 percentage points; 95% UI, 0.7%, 2.1%), as did Hispanic adults compared to white adults (difference in reductions, 1.2 percentage points; 95% UI, 0.4%, 2.0%). Likewise, adults with lower education experienced larger reductions in obesity prevalence than adults with higher education (difference in reductions, 1.4 percentage points; 95% UI, 0.7%, 2.1%).

SSB Warning Impact in Sensitivity Analyses

Changes in warning impact over time. The dietary and health benefits of the SSB health warning policy were robust to different assumptions about the trajectory of warnings' efficacy over time. When assuming warning efficacy would decrease by 10% per year, the SSB health warning policy reduced average BMI by 0.56 kg/m^2 (95% UI, -0.59, -0.53) and obesity prevalence by 2.0 percentage points (95% UI, -2.4, -1.7%) (Figure 5.2). Results were nearly identical when assuming SSB health warning efficacy increased by 10% per year.

Magnitude of warnings' impact on SSB intake. When SSB health warnings were assumed to reduce SSB intake by 14.8%, reductions in BMI increased in magnitude (DD, -0.79 kg/m^2; 95% UI, -0.81, -0.77) as did reductions in obesity prevalence (DD, -3.9 percentage points; 95% UI, -4.1%, -3.6%) (Figure 5.2). Benefits were even larger when assuming SSB health warnings would reduce SSB consumption by 22.4% (Figure 5.2).

Caloric compensation. Using a more conservative assumption about caloric compensation reduced the impact of SSB health warnings somewhat (Figure 5.2). Reductions in total energy intake were smaller (DD, -16.5 calories/day; 95% UI, -17.4, -15.6) but still translated into significant reductions in BMI (DD, -0.34 kg/m^2; 95% UI, -0.36, -0.32) and obesity prevalence (DD, -1.6 percentage points; 95% UI, -1.8%, -1.3%).

Discussion

Our microsimulation analysis suggests that implementing a national policy requiring SSB health warnings could reduce SSB consumption and obesity prevalence. Average SSB consumption in the U.S. remains well above recommended levels,[9,45,169] increasing risk of obesity and other chronic diseases. Emerging evidence suggests SSB health warnings reduce SSB purchases,[21,34,191] and our analyses indicate these reductions could yield meaningful population-level improvements in body mass and obesity prevalence. We found that a 26 calorie/day reduction in SSB intake would result in a 2.1 percentage point decline in obesity prevalence, consistent with previous simulations showing that small but sustained dietary changes can affect obesity.[39,41–43,133,181] While this reduction in obesity prevalence may appear modest, on a national scale, it equates to nearly 5 million fewer adults with obesity.

Warnings reduced obesity prevalence in all demographic groups. Further, obesity reductions were significantly larger for black and Hispanic adults compared to white adults, and for adults with lower educational attainment (some college or less) compared to adults with higher educational attainment (college degree or more). These larger obesity reductions reflect two factors: (1) our assumption that health warnings would generate proportional reductions in SSB consumption, such that individuals with higher pre-policy SSB consumption would tend to experience larger absolute reductions in SSB consumption, and (2) the persistently higher levels of SSB intake and obesity among racial/ethnic minorities and among those with lower socioeconomic status.[139,140] If SSB health warnings do generate similar proportional reductions in SSB consumption across demographic groups, our results suggest that SSB health warnings could potentially help narrow sociodemographic disparities in diet and weight.

Our model indicated that health warnings could generate BMI and obesity reductions that are similar in magnitude to simulated reductions from a one-cent-per-ounce excise tax on SSBs.[42,181] Some have criticized SSB taxes for being regressive, as taxes impose disproportionate costs on low-income individuals.[207,208] Because health warnings do not raise the monetary price of SSBs, they may avoid this criticism. However, warnings would not raise revenues, which are often earmarked for public health or other initiatives that could disproportionately benefit the poor.[197,209,210]

Results were robust to a range of assumptions. One key finding was that assuming that SSB health warnings will become 10% less effective every year does not meaningfully change warnings' projected health benefits compared to assuming constant efficacy over time, suggesting policymakers should not reject SSB health warning policies simply because warning impact may wane over time. We also found that the benefits of an SSB health warning policy persisted even when using a conservative estimate of caloric compensation.[198,200,201]

Of the parameters we varied in sensitivity analyses, changing assumptions about SSB health warnings' impact on SSB consumption had the largest effect on projected dietary and health outcomes. Compared to the primary policy scenario, which assumed the most conservative reduction, using the largest estimate of warnings' impact on SSB consumption more than doubled the obesity reduction benefits of implementing a national SSB health warning policy. These findings suggest that policymakers interested in implementing SSB health warning policies should consider warning designs that maximize behavioral impact. For example, studies have found that warnings may be more effective when they include pictures,[20,34,72,92] are larger and more prominent,[211,212] or are presented on black[22] or red[180] labels.

Two key strengths of this study are that we used detailed, nationally-representative dietary and anthropometric data to establish characteristics of the simulated population and that we applied a validated model of weight change. In addition, we evaluated a range of sensitivity analyses to account for uncertainty about key parameters. This study also had several limitations. First, because no studies to date have estimated SSB health warnings' impact on SSB consumption, we used estimates of impact on willingness to pay or impact on purchases as proxies for impact on consumption. Second, we assumed that warnings would have a similar impact on SSBs regardless of where they were purchased. The SSB warning policies proposed in the U.S. stipulate that warnings would be displayed on packaged SSBs (e.g., a bottle of soda), on vending machines that dispense SSBs, and at the point-of-purchase of unsealed SSBs (e.g., where fountain drinks are sold),[10–14] but research is needed to determine whether warnings operate similarly across these contexts. We also assumed that SSB health warnings would exert the same proportional effect on SSB consumption for all demographic groups. Previous studies of both SSB health warnings[19,21,180,191] and cigarette warnings[92] have not found differences in warning efficacy by key demographic characteristics, but it is possible that individual characteristics may moderate SSB health warnings' impact on behavior in ways not reflected in our model, causing us to over- or under-estimate warnings' true benefits. Finally, our model did not incorporate the possibility that manufacturers will reformulate products in response to health warning policies, for example by lowering SSBs' calorie content to avoid triggering a mandatory warning, thereby providing healthier options for consumers.[213–215] This could cause us to underestimate warnings' benefits.

Conclusions

Average SSB consumption in the U.S. remains high,[9,45,169] increasing risk for obesity and weight-related chronic diseases. Our microsimulation analysis provides timely evidence that implementing a national SSB health warning policy could yield meaningful reductions in SSB intake, body mass, and obesity prevalence and potentially narrow sociodemographic disparities in these outcomes.

Table 5.1. Input parameters and sources

Parameter	Source(s)
Baseline Characteristics	
Height and weight distributions for each demographic group	National Health and Nutrition Examination Survey (NHANES) 2005-2014 cycles[216]
Distribution of usual SSB intake for each demographic group	NHANES 2005-2014 cycles[216]
Model Representations of Changes in Diet and Weight Over Time	
Change in SSB intake due to a health warning policy:	
Primary policy scenario	
Smallest reduction (12.7%)	Previous study of effect of health warnings on willingness to pay for SSBs;[21] systematic review of price elasticity of demand for SSBs[217]
Alternative scenarios	
Smallest reduction + decreasing effectiveness over time (-10%/year)	Previous study of change in cigarette warnings' effectiveness over time[204]
Smallest reduction + increasing effectiveness over time (+10%/year)	Previous study of change in cigarette warnings' effectiveness over time[206]
Medium reduction (14.7%)	Previous study of graphic health warnings' effect on SSB purchases[34]
Largest reduction (22.4%)	Previous study of effect on SSB health warnings on SSB calories purchased[191]
Change in total energy intake due to a change in SSB intake (i.e., caloric compensation)	
Primary policy scenario	
Sample from a distribution of possible values for caloric compensation suggesting a 1 calorie change in SSB intake yields a 0.63 to 1.84 calorie change in total energy intake	Range of estimates from previous studies[34,198–202]
Alternative scenario	
More conservative estimate of caloric compensation applied to all individuals (1 calorie change in SSB intake yields a 0.63 calorie change in total energy intake)	Previous crossover trial examining caloric compensation after supplementation with SSBs or artificially-sweetened beverages[198]
Change in body weight due to a change in total energy intake	Validated equations by Hall et al. (2011)[183]
Population Structure	
Population demographic distribution	American Community Survey Public Use Microdata Sample (ACS PUMS)[218]

Table 5.2. Differences between demographic groups in estimated impact of a national sugar-sweetened beverage health warning policy

	SSB intake (kcal/day)		**Total energy intake (kcal/day)**		**Body mass index (kg/m^2)**		**Obesity prevalence (percentage points)**	
Comparison	**Mean**	**(95% UI)**	**Mean**	**(95% UI)**	**Mean**	**(95% UI)**	**Mean**	**(95% UI)**
Black vs. white reduction	**7.1**	**(3.0, 11.3)**	**8.8**	**(5.0, 12.7)**	**0.19**	**(0.11, 0.27)**	**1.4%**	**(0.7%, 2.1%)**
Hispanic vs. white reduction	**5.4**	**(1.3, 9.3)**	**6.6**	**(2.7, 10.5)**	**0.17**	**(0.10, 0.25)**	**1.2%**	**(0.4%, 2.0%)**
Black vs. Hispanic reduction	-1.8	(-5.9, 2.4)	-2.2	(-6.3, 2.0)	-0.01	(-0.10, 0.07)	-0.2%	(-1.0%, 0.6%)
Young vs. old reduction	**8.4**	**(4.7, 12.2)**	**10.4**	**(6.6, 14.2)**	**0.14**	**(0.06, 0.21)**	-0.5%	(-1.2%, 0.3%)
Low vs. high education reduction	**14.4**	**(10.4, 18.3)**	**17.7**	**(14.2, 21.1)**	**0.30**	**(0.23, 0.37)**	**1.4%**	**(0.7%, 2.1%)**
Low vs. high income reduction	**10.7**	**(6.5, 14.9)**	**13.2**	**(9.3, 17.1)**	**0.19**	**(0.11, 0.26)**	0.6%	(-0.1%, 1.3%)
Male vs. female reduction	**11.8**	**(7.7, 16.0)**	**14.6**	**(10.9, 18.4)**	**0.19**	**(0.11, 0.26)**	0.2%	(-0.5%, 1.0%)

Abbreviations: SSB, sugar-sweetened beverage; UI, uncertainty interval.
Note. Positive values indicate the group listed first had a larger reduction than the group listed second. For example, black adults had a larger reduction in SSB intake than white adults. **Bolded** differences are statistically significant (95% uncertainty interval for the difference in impact does not cross zero).

Figure 5.1. Microsimulation model overview

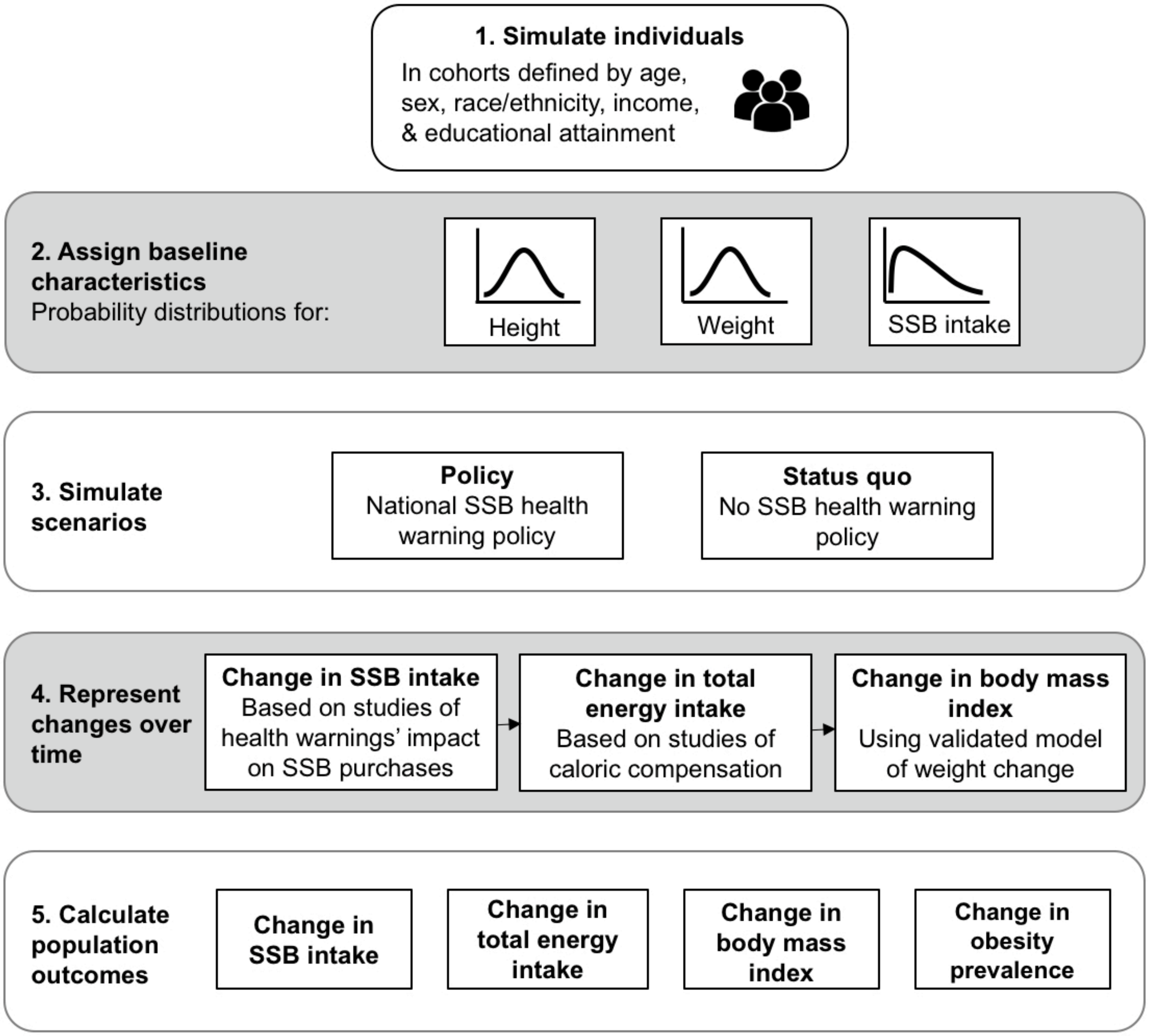


Figure 5.2. Estimated impacts of a national sugar-sweetened beverage health warning policy by model assumptions, mean (95% uncertainty interval)

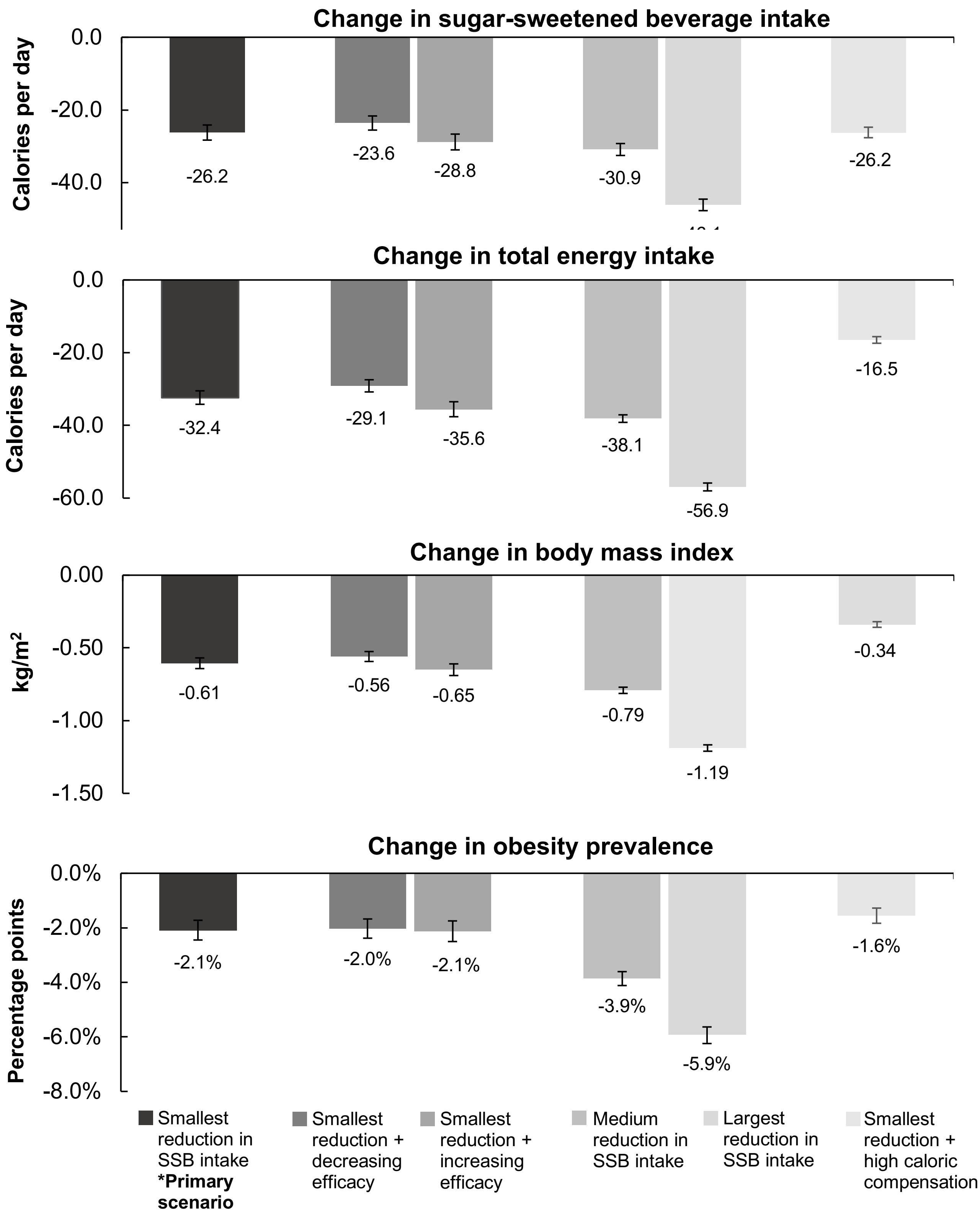


Figure 5.3. Impact of a national sugar-sweetened beverage (SSB) health warning policy on body mass index over five years, primary policy scenario

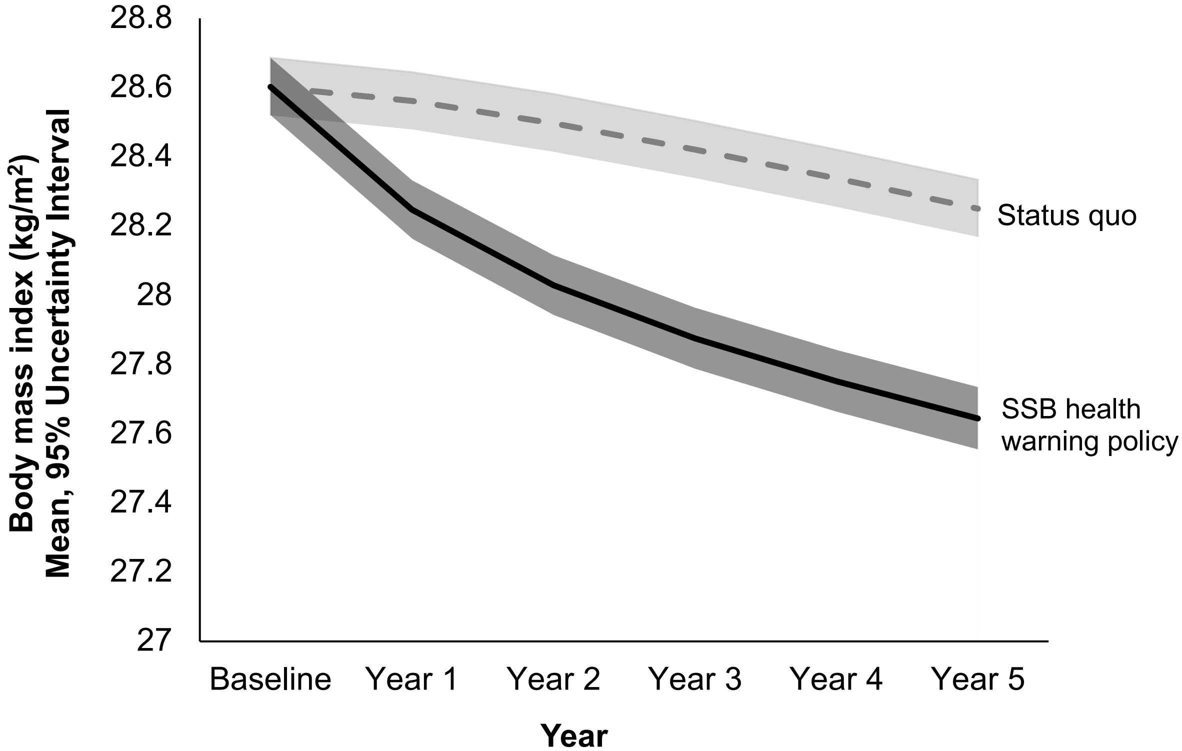
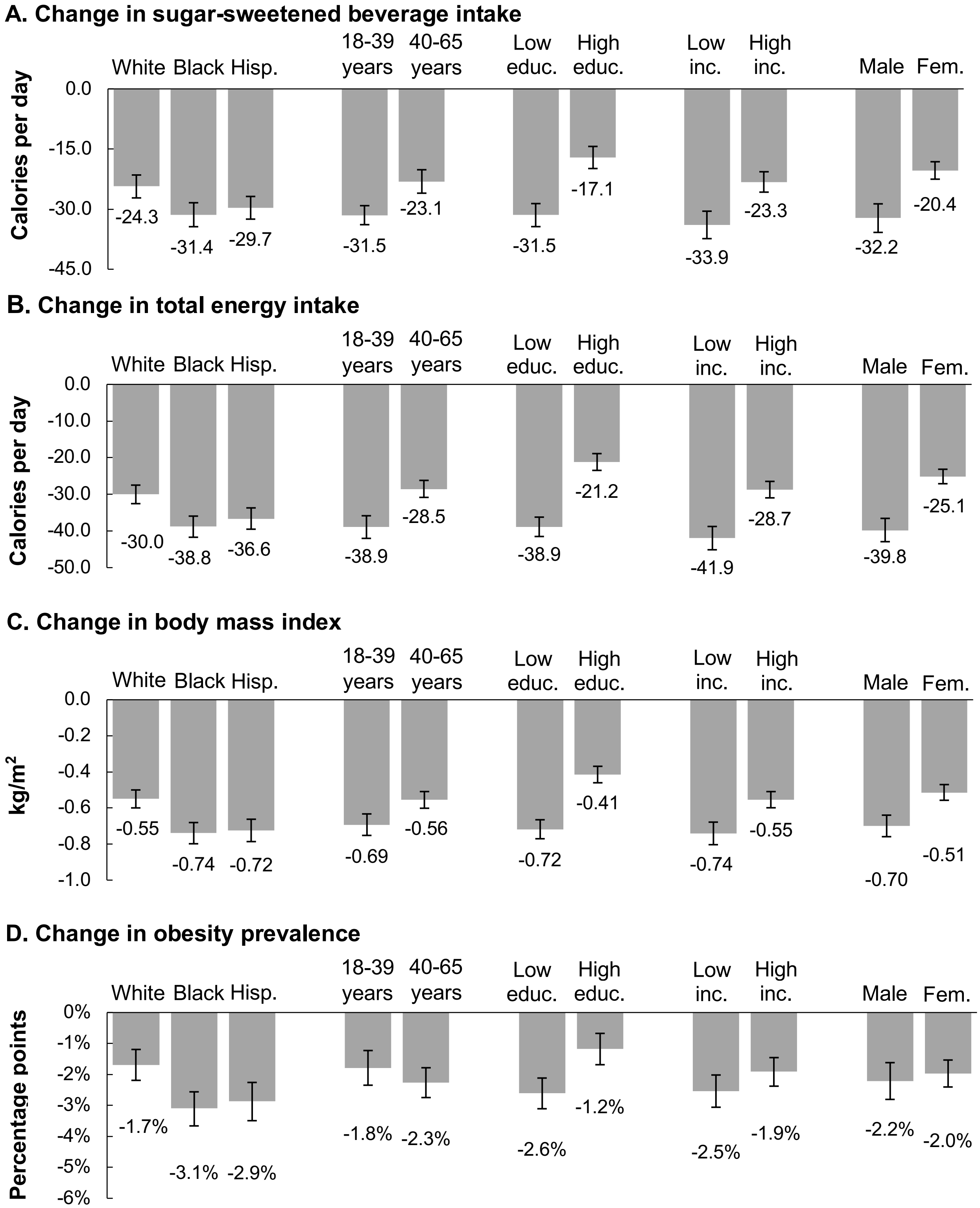


Figure 5.4. Estimated impacts of a national sugar-sweetened beverage health warning policy by demographic group, mean (95% uncertainty interval)



CHAPTER 6: DISCUSSION

Health warnings are an increasingly popular strategy for reducing consumption of unhealthful products. Five U.S. states have proposed policies to require health warnings on SSBs. Findings in this dissertation suggest the promise of these policies for reducing SSB consumption and related negative health outcomes such as obesity. Aim 1 found that SSB health warnings can be designed in ways that increase their perceived effectiveness and their ability to elicit fear and thinking about harms, three antecedents to behavior change. In Aim 2, I found that well-designed warnings can reduce real-stakes SSB purchases in a one-time shopping task in a naturalistic laboratory store. Aim 3 showed that, under reasonable assumptions, implementing a national SSB health warning policy could yield reductions in obesity prevalence equivalent to nearly five million fewer adults with obesity. Together, the studies in this dissertation suggest additional insights concerning the importance of designing SSB health warnings to maximize their impact, the potential for warnings to alleviate health disparities, the legal and ethical implications of warnings' effects on psychological antecedents, and the importance of uncertainty about how warnings' impact on behavior will change over time. I discuss these insights below. I then describe several cross-cutting strengths and limitations of the three studies and end with concluding thoughts.

Small Changes to Warning Design Matter

In Aim 1, I found that modifying the design of SSB health warnings affects how consumers react to warnings. Warnings that described the health effects of consuming SSBs were perceived to be more effective than warnings without these statements, and also elicited more fear and more thinking about harms. Likewise, beginning warning messages with the marker word "WARNING" increased perceived effectiveness, fear, and thinking about harms. Even arguably subtle differences in warning design, such as whether warnings were displayed on octagon-shaped labels instead of rectangular labels, influenced perceived effectiveness, fear, and thinking about harms. Because these outcomes predict warnings' actual effectiveness, Aim 1 results suggest design choices that may help maximize the impact of SSB health warnings.

When considered in the context of other experimental studies of SSB health warnings, Aim 2 also suggests that small changes to the design of SSB health warnings may matter. Two previous studies have evaluated the impact of text SSB health warnings on real-stakes beverage purchases. Neither found that the text warnings affected consumers' SSB purchases.[33,34] In contrast, in Aim 2, text SSB health warnings reduced participants' SSB purchases by more than 22%. Several reasons could explain why Aim 2's trial found that SSB warnings reduced purchases of these products while these two previous studies did not. One possibility is that the health warnings used in Aim 2 were stronger than those tested in previous studies. Aim 2's SSB health warning used each of the warning characteristics identified in Aim 1 as important for enhancing warning impact: the warning described the health effects of SSB consumption, included the marker word "WARNING," and was presented on an octagon-shaped label. In contrast, the warnings examined in the two previous studies lacked one or more of these characteristics. Recent systematic reviews show that strengthening tobacco warnings increases warnings' impact on attention, message processing, knowledge, and smoking behavior.[211,212] Perhaps strengthening SSB warnings, for example by using the warning characteristics identified in Aim 1, will increase the likelihood that such warnings will affect behavior.

How much of a difference might it make to implement well-designed SSB health warnings? Aim 3's microsimulation analysis indicates that even small improvements in warnings' effects on SSB consumption yield large population-level health benefits. For example, increasing SSB warnings' relative impact on SSB consumption from a 12.7% reduction to a 14.8% reduction would help the average American adult to lose an additional 0.18 kg/m^2 BMI units (or about 1.2 pounds) and reduce national obesity prevalence by an additional 1.8 percentage points, equivalent to an additional 3.7 million fewer adults with obesity. Larger improvements in warnings' effectiveness would lead to even more striking population health benefits. If SSB health warnings are assumed to reduce SSB consumption 22.4% instead of 12.7%, obesity prevalence reductions more than double, yielding an additional 8.9 million fewer adults with obesity. These results highlight importance of designing warnings to maximize their impact on SSB purchases and consumption.

SSB Health Warnings as a Pro-Equity Policy

SSB consumption varies considerably with demographic characteristics. Black and Hispanic adults consume more SSBs than non-Hispanic white adults, and adults with lower income and lower educational attainment consume more SSBs than adults with higher income and higher educational attainment.[7,9,44,139] These disparities in SSB consumption are mirrored by disparities in diet-related diseases: both obesity and diabetes prevalence are highest among black and Hispanic adults and those with low income and low education.[138,140,219,220] Together, the three studies in this dissertation suggest that SSB health warnings may help narrow these disparities. Both Aims 1 and 2 found that warnings exerted a similar impact across diverse population groups. In Aim 1, warning characteristics were equally effective regardless of participants' race/ethnicity, educational attainment, and income. Likewise, in Aim 2, SSB health warnings' impact on SSB purchases did not vary with participants' educational attainment, age, gender, sexual orientation, health literacy level, income, race, ethnicity, SSB consumption, or overweight status.

Aim 3 projected that SSB health warnings would narrow underlying racial/ethnic and sociodemographic disparities in SSB intake and obesity. Based on the results of Aims 1 and 2, as well as previous research showing that SSB health warnings are similarly effective across population subgroups,[19,21,180] Aim 3's microsimulation model assumed that warnings would exert the same proportional impact on SSB consumption across all demographic subgroups. Under this assumption, Aim 3 projected that a national SSB health warning policy would yield larger reductions in SSB consumption, body mass index, and obesity among racial/ethnic minorities compared to white adults. Likewise, reductions in SSB intake, body mass index, and obesity were significantly higher among adults with low educational attainment compared to those with high educational attainment. Alleviating health disparities remains a national public health priority.[221] By generating the largest benefits for groups with the highest baseline levels of SSB consumption and obesity, SSB health warnings show promise as a pro-equity policy.

Legal and Ethical Implications

Legally and ethically acceptable warnings would inform consumers without coercing them. Findings in Aims 1 and 2 provide insights on whether SSB health warnings might meet this standard. In both studies, SSB health warnings had little impact on health knowledge or disease risk perceptions. Aim 1 found that SSB health warnings increased knowledge that SSBs contribute to tooth decay, but had no impact on knowledge that SSBs contribute to obesity or diabetes and *reduced* knowledge that SSBs contribute to heart disease, the health harm not included in the warning message. In Aim 2, SSB health warnings had no impact on perceptions of added sugar in SSBs or expectations that SSBs would increase risk of various diseases. In contrast, Aims 1 and 2 found that SSB health warnings evoked more fear than control labels, and also aroused other negative emotions including shame, disgust, and guilt.

Tobacco warning litigation suggests that these two findings – that SSB health warnings evoke emotions without affecting knowledge or risk perceptions – could portend legal challenges for SSB warnings. Beverage companies are likely to challenge any SSB health warning policy on First Amendment grounds. While there remain unanswered legal questions regarding health warnings,[222–225] a 2012 suit filed against the Food and Drug Administration (FDA), *R.J. Reynolds Tobacco Co v. FDA*, gives some insight into how legal challenges against SSB warnings could unfold. In a 2-1 ruling on the case, the U.S. Court of Appeals for the D.C. Circuit struck down a FDA regulation requiring pictorial warnings on cigarette packs, citing First Amendment protections against restricting commercial speech.[226] The court's decision centered on two themes, both relevant for the SSB health warnings studied here.

First, the court questioned whether the pictorial warnings would be effective. In deciding the case, the court applied the *Central Hudson* standard to determine whether the FDA's proposed warnings violated First Amendment protections. This standard requires the government to show (among other criteria) that a law or regulation restricting free speech "directly advances a substantial government interest."[227] In *R.J. Reynolds,* the court's majority found that the proposed pictorial warnings were unconstitutional in part because the FDA failed to provide sufficient evidence that the warnings would "directly advance" its interest in reducing smoking rates.[226]

If courts use *Central Hudson* to evaluate SSB health warning policies, policymakers seeking to implement warnings will need to provide evidence that the warnings directly advance a substantial government interest. One stated intent of the SSB health warning policies proposed in the U.S. is to inform consumers; for example, proposed bills indicate that warnings are meant to "promote informed purchasing decisions"[10] and "increase knowledge."[13] Aims 1 and 2 found that warnings did not consistently improve consumers' knowledge of SSBs' health consequences or increase perceptions that SSBs contribute to disease risk, suggesting potential legal challenges over whether SSB health warnings further the government's stated goal of informing consumers. That said, Aims 1 and 2 also found that SSB health warnings induced more cognitive elaboration: in both studies, participants exposed to SSB health warnings reported that they thought more about the warnings and about the harms of SSB consumption than participants exposed to control labels. While increased cognitive elaboration did not lead to changes in knowledge or risk perception, one could argue that the warnings did indeed "promote informed purchasing decisions" simply by helping consumers keep the health harms of SSB consumption at top of mind. Additionally, other experimental studies have found that SSB health warnings increase knowledge and disease risk perceptions,[19,21,99] suggesting that additional research is needed to clarify the circumstances under which warnings affect these outcomes. Further, many have argued that courts should not apply *Central Hudson* to scrutinize health warning policies, but instead use the less stringent *Zauderer* standard, which would not require such a heavy burden of proof regarding warnings' impacts.[222]

The second theme of the *R.J. Reynolds* case relevant for SSB warnings centers on warnings' impacts on emotions. In its decision, the court took issue with the emotional elements of the FDA's proposed pictorial cigarette warnings, writing that the warnings "cannot rationally be viewed as pure attempts to convey information to consumers. They are unabashed attempts to evoke emotion (and perhaps embarrassment) and browbeat consumers into quitting."[226] The court's ruling focused on the warnings' "inflammatory images" and their inclusion of a "provocatively named" smoking cessation hotline number, rather than on the warning statement itself. The SSB warnings tested in this dissertation, as well as those proposed by U.S. lawmakers,[10–14] lack these more contentious characteristics. Still, even these milder SSB warnings evoked negative emotions, a finding that may mean that SSB health warning policies would face First Amendment challenges similar to those faced by pictorial tobacco warnings. On the other hand, many have argued that the court's decision in *R.J. Reynolds* painted a false dichotomy between conveying information and eliciting emotions,[223,228,229] noting that factual information can and often will elicit emotion. Further, research by Peters, Slovic, and colleagues has shown that when information does not generate affect, it lacks meaning and is weighed less heavily in judgment and decision-making, potentially resulting in worse decisions.[230–232] Warnings that do not evoke any emotion may be unlikely to generate meaning or be remembered by consumers. In this view, warnings' emotionality should be seen as part and parcel of their ability to further the government's interest in informing consumers, not as its antithesis.

We may want to take seriously the emotional consequences of SSB health warnings even if courts deem warning policies constitutional. For example, several scholars have noted that when a government policy attempts to convince consumers that some activity (e.g., consuming SSBs) is harmful, the policy may also reduce the enjoyment of those who continue engaging in the harmful activity,[233] imposing an "emotional tax" that reduces overall happiness without generating revenue.[234] Some have argued that, at a minimum, policymakers should account for these emotional costs in cost-benefit analyses.[235,236] Aim 3 results suggest that these emotional costs would need to be quite large to outweigh the substantial health benefits an SSB health warning policy would generate. However, other scholars go further, arguing that when warnings operate primarily by eliciting emotion, they disrespect consumers' autonomy and should be evaluated with the additional scrutiny given to other "coercive" policies.[237] On these grounds, policymakers concerned with preserving autonomy may prefer other policies over warnings to address SSB consumption, even if SSB health warning policies are cost-effective or welfare-enhancing. On the other hand, beverage companies also manipulate emotion to sell sugary drinks,[238] and requiring SSB health warnings – even emotionally evocative ones – could be viewed as a reasonable attempt to balance the scales.

Uncertainty About the Long-Term Effects of Warnings

If SSB health warning policies were implemented, consumers would have repeated exposure to the warnings. In Aim 2, a single exposure to SSB health warnings reduced SSB purchases in a one-time shopping task, but given the short duration of the study, I can only speculate on whether this reduction would be sustained over the long-term. To date, no studies have examined the effects of SSB health warnings beyond a two-week period.[34] Longer-term evaluations of cigarette warnings exist, but findings from these studies are inconclusive about the trajectory of warnings' impact: some have found that cigarette warnings' impact on smoking behavior wears out over time,[204] while others found the opposite, that behavioral responses to warnings increase over time.[129,205,206] Only longer studies will elucidate the trajectory of SSB health warnings' impact on beverage purchase behavior over time.

Aim 3 examined whether a plausible degree of wear out would undermine SSB warnings' impact on obesity. I found that declining warning efficacy over time had little influence on population outcomes. Assuming SSB health warnings would become 10% less effective every year (more than twice the rate of wear out observed in one study of cigarette warnings[204]) did not meaningfully change warnings' projected health benefits compared to an assumption of constant efficacy over time. These findings suggest that policymakers should not reject SSB health warning policies simply because warning impact may wane over time; even if it does, warnings would still produce meaningful population health benefits over the short-to-medium term.

Strengths and Limitations

A major strength of this dissertation is its use of a linked set of studies that addressed different aspects of SSB health warning policies. Aim 1 provided information on how warnings should be designed, Aim 2 provided causal evidence that warnings have promise as a strategy for reducing SSB purchases, and Aim 3 indicated that reducing SSB consumption could meaningfully improve population-level weight outcomes. The three studies fill important gaps in our understanding of the individual- and population-level impacts of SSB health warning policies, together generating insights that each alone could not. This dissertation also used high-quality measures and data sources. Aims 1 and 2 assessed theory-informed constructs known to predict behavior change using validated items and scales. In addition, Aim 2 assessed a real-stakes behavioral endpoint, making it one of the first randomized trials of SSB warnings to do so. Aim 3 integrated data from a variety of sources, including nationally representative data from the National Health and Nutrition Examination Survey (NHANES), considered the gold-standard for dietary and anthropometric data in the U.S. Finally, the three studies relied on strong methods suited to the research questions: Aims 1 and 2 used randomized designs to improve causal inference, and Aim 3 developed, validated, and applied a stochastic microsimulation model to estimate longer-term health outcomes in a nationally representative population.

An important limitation of Aims 1 and 2 was that both studies examined brief exposures to warnings online or in a lab-based convenience store. While I made attempts in both studies to increase realism, there were important differences between the study contexts and what consumers would likely experience if SSB health warnings were implemented, including that consumers would have repeated exposure to warnings in a variety of retail environments and on a larger array of SSB products that used Aims 1 and 2. In short, while these studies benefitted from random assignment to treatment arms and tight experimental control, they had imperfect external validity. Additionally, while Aims 1 and 2 had diverse participants, both studies relied on convenience samples, and results may not generalize to the entire U.S. population. An important limitation of Aim 3 is the inherent need for models to be simplifications of the real world. As one example, Aim 3 did not model the full complexity of dietary behaviors. Some have estimated that individuals make more than 200 decisions every day about what and how much to eat and drink.[239] Aim 3's microsimulation did not model all of these potential daily decisions, instead focusing on daily SSB intake and daily total energy intake.

The findings in this dissertation may not generalize to health warnings on other foods or beverages. Several Latin American countries have passed or implemented laws requiring front-of-package warnings on any food or beverage – not just sugary drinks – that exceeds thresholds for sugar, sodium, saturated fat, or calories.[16,142] It remains unknown whether the results of this dissertation extend to warnings that accompany such a large variety of products. Previous work suggests that health warnings exert greater influence when displayed on products consumers view as healthier, and a limited influence when displayed on products consumers already believe are unhealthy,[99] suggesting that health warnings on other foods or beverages might influence purchases and consumption only for products consumers perceive as healthful. But this possibility remains unstudied. Also unknown is how implementing warnings on a wider variety of foods and beverages would impact health outcomes. This dissertation focused on how implementing a national SSB health warning policy would affect obesity prevalence, but warnings on other products (e.g., those high in sodium) could also affect other diet-related outcomes (e.g., hypertension).

Conclusions

The U.S. has the regulatory authority at the local, state, and federal level to require SSB health warnings, and five U.S. states and several major cities have proposed SSB health warning policies. This dissertation suggests that well-designed SSB health warnings are likely to reduce SSB consumption and obesity, improving public health. These benefits may be largest for racial/ethnic minorities and adults with lower education, suggesting that warnings could be a pro-equity policy. Policymakers should consider implementing SSB health warnings as a strategy for improving population health and reducing health disparities.

APPENDIX A: MEASURES IN AIM 1

Construct	# of items	Items	Response scale	Reliability[a]
Perceived message effectiveness	3	This label makes me concerned about the health effects of drinking beverages with added sugar. This label makes drinking beverages with added sugar seem unpleasant to me. This label discourages me from wanting to drink beverages with added sugar.	1=Strongly disagree 2=Somewhat disagree 3=Neither agree nor disagree 4=Somewhat agree 5=Strongly agree	0.93
Fear	1	How much does this label make you feel scared?	1=Not at all 2=A little bit 3=Somewhat 4=Quite a bit 5=Very much	NA
Thinking about harms	1	How much does this label make you think about the health problems caused by drinking beverages with added sugar?	1=Not at all 2=A little bit 3=Somewhat 4=Quite a bit 5=Very much	NA

[a]Chronbach's α for measures with three items and NA for single-item measures.

APPENDIX B: MEASURES IN AIM 2

Construct	# of items	Items	Response scale	Reliability[a]
Behavioral intentions				
Intentions to limit consumption of beverages with added sugar	3	In the next week, I want to drink less than 1 beverage with added sugar.	1=Not at all 3=A little 5=Somewhat 7=Very much	0.91
		In the next week, I plan to drink less than 1 beverage with added sugar.	1=Not at all 3=A little 5=Somewhat 7=Very much	
		In the next week, I am likely to drink less than 1 beverage with added sugar.	1=Not at all likely 3=A little likely 5=Somewhat likely 7=Very likely	
Intentions to limit consumption of specific SSBs	5	In the next week, I am likely to drink less than 1 [beverage category] like these.[b]	1=Not at all likely 3=A little likely 5=Somewhat likely 7=Very likely	0.78
		…regular (non-diet) soda or soft drink…		
		…regular (non-diet) energy drink…		
		…regular (non-diet) sports drink or regular flavored water…		
		…fruit-flavored drink (not 100% juice)…		
		…sweetened pre-packaged tea or coffee…		
Responses to trial labels				
Noticed trial label[c]	1	Some of the beverages in the store may have had extra red stop sign [white rectangle] labels (stickers) added on top of the regular packaging, like in this picture. Did you see these labels?	0=No 1=Yes	NA
Attention to label[d]	2	The labels grabbed my attention.	1=Strongly disagree 2=Disagree 3=Neither agree nor disagree 4=Agree 5=Strongly agree	0.83
		I read and looked closely at the labels.		

Construct	# of items	Items	Response scale	Reliability[a]
Thinking about warning message and harms[d]	2	How much did you think about the information that the labels convey?	1=Not at all 2=A little bit 3=Somewhat 4=Quite a bit 5=Very much	0.87
		How much did the labels make you think about the health problems caused by drinking beverages with added sugar?		
Negative affect elicited by label[d]	6	How much did the labels on the beverages make you feel…	1=Not at all 2=A little 3=Somewhat 4=Very 5=Extremely	0.90
		…anxious?		
		…scared?		
		…ashamed?		
		…guilty?		
		…disgusted?		
		…regretful?		
Social interactions about label	1	How likely are you to talk about the labels with others in the next week?	1=Not at all likely 2=A little likely 3=Somewhat likely 4=Very likely 5=Extremely likely	NA
Social cognitive outcomes				
Perceived amount of added sugar in SSBs	5	A normal can of soda is 12 ounces. How much added sugar do you think is in one 12-ounce serving of [beverage category] like these?[b]	1=None 2=A little 3=Some 4=A lot	0.57
		…regular (non-diet) sodas or soft drinks…		
		…regular (non-diet) energy drinks…		
		…regular (non-diet) sports drinks or regular flavored water…		
		…fruit-flavored drinks (not 100% juice)…		
		…sweetened pre-packaged tea or coffee…		
Perceived healthfulness of SSB consumption	5	For each beverage, say how healthy or unhealthy it is for you to drink that beverage every day.[b]	1= Unhealthy … 7=Healthy	0.74
		…regular (non-diet) sodas or soft drinks like these		
		…regular (non-diet) energy drinks like these		

Construct	# of items	Items	Response scale	Reliability[a]
		…regular (non-diet) sports drinks or regular flavored waters like these		
		…fruit-flavored drinks (not 100% juice) like these		
		…sweetened pre-packaged teas or coffees like these		
Positive SSB product attitudes	10	Say how unappealing or appealing you think each beverage is.[b]	1=Unappealing … 7=Appealing	0.79
		…regular (non-diet) sodas or soft drinks like these		
		…regular (non-diet) energy drinks like these		
		…regular (non-diet) sports drinks or regular flavored waters like these		
		…fruit-flavored drinks (not 100% juice) like these		
		…sweetened pre-packaged teas or coffees like these		
		Say how uncool or cool you think each beverage is.[b]	1=Uncool … 7=Cool	
		…regular (non-diet) sodas or soft drinks like these		
		…regular (non-diet) energy drinks like these		
		…regular (non-diet) sports drinks or regular flavored waters like these		
		…fruit-flavored drinks (not 100% juice) like these		
		…sweetened pre-packaged teas or coffees like these		
Negative outcome expectations	4	Drinking beverages with added sugar every day would increase my risk of…	1=Not at all … 7=A lot	0.78
		…weight gain		
		…diabetes		
		…tooth decay		
		…heart disease		

[a]Chronbach's α for measures with three or more items, Spearman's rho for two-item measures, and NA for single-item measures.
[b]These items included images of the products in this beverage category sold in the trial store. For example, items about "regular (non-diet) sodas or soft drinks" showed images of the 5 regular sodas sold in the trial store.

[c]This item had two versions, one for the health warning arm and one for the control arm. Participants responded to their arm's version of the item. Items displayed a mocked up generic bottle of soda with a blank trial label (i.e., no text or image, but the appropriate color and shape) on the front-of-package.
[d]Items were only asked of participants who indicated they had noticed the trial label.

APPENDIX C: TECHNICAL APPENDIX FOR AIM 3

Model Overview

We developed and applied a stochastic microsimulation model[192] to simulate the effects of a sugar-sweetened beverage (SSB) health warning policy on SSB intake and total energy intake (both in calories/day), and in turn, the associated changes to body mass index (BMI, kg/m^2) and obesity (BMI $\geq$ 30 kg/m^2) over time. First, we created an analytic sample by simulating individuals with varying demographic characteristics (age, sex, race/ethnicity, etc.), as shown in **Figure C.1**. We then assigned each individual baseline characteristics (height, weight, and SSB intake) by sampling from cohort-specific probability distributions for these variables. We examined two scenarios: a policy scenario assuming a national SSB health warning policy, and a status quo scenario assuming no policy change. We represented changes in dietary behaviors and body weight over time in each scenario. In the policy scenario, this involved representing how SSB intake would change in response to a hypothetical warning policy, how this change in SSB intake would translate into changes in total energy intake (TEI), and how total energy intake affects body weight over time. This latter step incorporated a validated model of weight change dynamics[183] run in daily time steps for a five-year period. Finally, we calculated population outcomes, examining the effect of implementing a national SSB health warning policy on SSB intake, total energy intake, BMI, and obesity prevalence. To estimate policy impact, we used a difference-in-differences (DD) framework, comparing the change from baseline to the end of the 5-year simulation period in the SSB health warning policy model to change over time in the status quo model. Analyses weighted observations to create a sample representative of the U.S. population.

Key parameter inputs and their sources are listed in **Table C.1**. We conducted data preparation and simulations using Stata SE Version 15.1 (StataCorp, College Station, TX).

Study Population

Simulate Individuals

The first step of the simulation was to create an analytic sample of simulated individuals. We assigned these simulated individuals five demographic characteristics that are predictive of SSB intake:[7,9,44,139,179] age (18 to 39 years, 40 to 65 years), race/ethnicity (using categories from the National Health and Nutrition Examination Survey [NHANES] of non-Hispanic White, non-Hispanic Black, and Hispanic/Mexican American), sex (male, female), educational attainment (some college or less, college degree or more), and income (at or below 185% of the Federal Poverty Line [FPL], above 185% FPL, a common eligibility cutoff for nutrition assistance programs). This approach is similar to the one used by Basu and colleagues.[39] For each combination of the five demographic characteristics, we created a cohort populated by 1,000 individuals for a total of 48 cohorts (2 age groups * 3 race/ethnicities * 2 sexes * 2 educational categories * 2 income categories = 48 total combinations). The analytic sample thus comprised 48,000 simulated individuals. We allowed age, but not other demographic characteristics, to vary over time in the model. Aging is discussed further below.

Baseline Characteristics

Data source. We used the National Health and Nutrition Examination Survey (NHANES) to estimate distributions of height, weight, and SSB intake among U.S. adults. NHANES is a continuous, multistage cross-sectional survey that provides detailed dietary and anthropometric data representative of the civilian, non-institutionalized U.S. population. It is the most comprehensive nationally-representative dataset for assessing dietary intake and anthropometrics.[216] NHANES collects dietary data via interviewer-administered 24-hour recalls in which participants report detailed information about all of the foods and beverages they consumed during the previous 24 hours (midnight to midnight). Interviews are conducted using the United States Department of Agriculture's Automated Multiple Pass Method, considered the gold standard method for 24-hour recalls.[240] NHANES staff also directly measure participants' height and weight using standardized protocols.[241] All analyses accounted for the complex survey features of NHANES using the techniques recommended by the National Center for Health Statistics.[242]

We assessed SSB consumption for each demographic cohort using the first day of dietary recall data.[7,9,44,179] This approach is consistent with previous studies describing usual SSB intake[7,9,44,179,181,195] as well as National Cancer Institute recommendations for estimating mean usual intake in a population.[243,244] Following previous work,[194] we defined SSBs as non-diet, nonalcoholic beverages with added sugars containing at least 5 calories per 100g, including beverages such as sodas, sports drinks, energy drinks, fruit drinks, and sweetened coffees and teas. We did not consider sweetened milk or sweetened milk substitutes to be SSBs, consistent with most policy definitions of SSBs (e.g., what products are subject to SSB taxe[196,197]) and previous literature.[7,44,179,194,195] We calculated total SSB intake by summing caloric intake from all SSBs reported on the dietary recall.

NHANES has collected dietary recall and anthropometric data since 1988. We elected to use the 2005-2014 cycles of NHANES to determine distributions of baseline values for several reasons. First, pooling multiple survey waves increases power to estimate anthropometric and dietary variables within the 48 demographic subgroups (sample size in each cohort ranges from 22 to 1,134). Second, starting in the 2003-2004 cycle, NHANES began using the Automated

Multiple Pass Method (AMPM) for collecting dietary data. The APMP has been shown to reduce measurement error compared to other recall procedures,[245] so dietary intake data collected before 2003 may not be comparable to later survey years, and therefore, we did not examine survey cycles prior to 2003. We also excluded the 2003-2004 survey cycle because our analyses indicated that mean SSB intake was significantly higher in 2003-2004 compared to later survey years, but that there were not statistically significant differences in SSB intake by survey year after 2003-2004 (**Table C.2**). The rise in obesity prevalence during the 1990s and early 2000s also may have plateaued during this period.[138,246]

Height and weight. We assigned each simulated individual a height in meters and body weight in kilograms. We created cohort-specific probability distributions of these variables by computing survey-adjusted means and standard deviations for each cohort using NHANES anthropometric data. Because height and weight co-vary (taller people tend to weigh more), we sampled height and weight from cohort-specific bivariate normal distributions, using the covariance observed between height and weight within each cohort in NHANES. To avoid implausible values, if an individual's sampled value for height was greater than the sex-specific maximum height observed among all adults participating in NHANES during the 2005-2014 cycles, we replaced the sampled value with this maximum value. That is, simulated individuals could be no taller than the tallest person of their sex in NHANES 2005-2014. Similarly, if the simulated individual's sampled value for height was less than their sex-specific minimum observed in NHANES, we replaced the sampled value with the minimum value. We repeated this process for removing extreme values for simulated weights. Simulated heights and weights were nearly identical to actual heights and weights, both overall and within demographic cohorts (**Tables C.3 and C.4**).

SSB intake. We also assigned each simulated individual a baseline SSB intake amount in calories/day. The distribution of calories consumed from SSBs is both zero-inflated (i.e., there are a considerable number of non-consumers of SSBs on any given day) and right-skewed. To reflect this, we used a two-part model to assign simulated SSB intake. First, we established whether a simulated individual was an SSB consumer vs. non-consumer. Non-consumers were assigned a value of 0 calories/day of SSB consumption. Second, we established the amount of SSBs consumed, in calories/day, among SSB consumers. We describe these two steps below.

To establish simulated individuals' status as an SSB consumer vs. non-consumer, we first assigned each simulated individual a random number by drawing from a uniform distribution with lower bound of zero and upper bound of one. We compared this randomly-drawn value to NHANES data on the proportion of individuals in each demographic cohort who were SSB consumers (i.e., consumed any calories from SSBs on the recall day). If the randomly-drawn value was less than or equal to the proportion of SSB consumers in their cohort, the simulated individual was established as an SSB consumer for the simulation; otherwise, the simulated individual was established as a non-consumer and assigned a value of 0 calories/day of SSB intake.

For each simulated individual who was established as an SSB consumer, we assigned a value for amount of SSBs consumed by sampling from cohort-specific distributions of the amount of SSB calories consumed among SSB consumers in NHANES. The distribution of SSB intake among consumers is right-skewed; to reflect this, we described SSB intake with a gamma distribution, similar to the approach used by Kristensen and colleagues to describe total calorie intake.[247] Gamma distributions are defined by two parameters: shape and scale. To estimate these parameters for each cohort, we converted the cohort-specific survey-adjusted means and standard deviations into the gamma distribution's shape and scale parameters using the following:

$$\alpha = shape = \frac{\mu^2}{s^2} \quad \text{(Eq. 1)}$$

$$\beta = scale = \frac{s^2}{\mu} \quad \text{(Eq. 2)}$$

We assigned each simulated SSB consumer an amount of SSB intake in calories/day by drawing from their cohort-specific gamma distribution, $\sim Gamma(\alpha, \beta)$. To avoid extreme values, if the sampled value for SSB consumption as greater than the maximum value for SSB consumption observed among all adults participating in NHANES during the 2005-2014 cycles, we replaced the sampled value with this maximum value. Simulated mean SSB intake was nearly identical to actual SSB intake within cohorts and overall (**Table C.5**), supporting our use of this two-step approach to establish simulated SSB intake.

Updating SSB intake due to aging. Among adults, SSB intake declines with age.[7,9] To reflect this change, when a simulated individual aged into the older cohort, we assigned the individual a new value for SSB intake. Using cohort-specific distributions defined by the individual's new age group, we re-sampled values for probability of being an SSB consumer and amount consumed given consumption, following the steps described above.

Scenarios Simulated

We modeled two scenarios: a policy scenario assuming a national SSB health warning policy and a status quo scenario assuming no SSB health warning policy. In the policy scenario, we assumed that simulated individuals would change their SSB intake in response to the warnings, then modeled how change in SSB intake would affect total energy intake, and finally translated change in total energy intake into change in body weight over time using a validated model of weight change dynamics.[183] Each of these steps is described in more detail below. In the status quo scenario, we assumed no change in SSB intake in response to health warnings. In both scenarios, we allowed SSB intake to change as individuals aged into the older category[7,9] and incorporated secular trends in total energy intake, as described below.

Model Representation of Changes in Diet and Weight Over Time

SSB Intake

Initial change in SSB intake due to health warnings. In the primary policy scenario, we modeled change in SSB intake in response to health warnings based on previous literature on the effect of health warnings on willingness to pay for SSBs (sensitivity analyses apply alternate assumptions about the effect of warnings on SSB intake, see below for details). Specifically, Roberto and colleagues found that SSB warnings proposed by California reduced willingness to pay (WTP) for SSBs by 10.53% compared to a no label control.[21] Reductions in willingness to pay are economically equivalent to a price increase; we thus conceptualized health warnings as increasing the price of SSBs by 10.53%. To allow for uncertainty in our estimate of reactions to the SSB health warning policy, each simulated individual sampled a proportional change in WTP from a triangular distribution, centered on -10.53% with lower and upper bounds determined using resulted reported by Roberto and colleagues:

$$lower\ bound = \frac{[WTP_T + 1.96(SE_T)] - [WTP_C - 1.96(SE_C)]}{WTP_C} \quad \text{(Eq. 3)}$$

$$upper\ bound = \frac{[WTP_T - 1.96(SE_T)] - [WTP_C + 1.96(SE_C)]}{WTP_C} \quad \text{(Eq. 4)}$$

Where WTP_T and SE_T are the mean and standard error, respectively, of WTP for the treatment (SSB health warning) group and WTP_C and SE_C are the mean and standard error, respectively, of WTP for the control group.

Next, we converted this proportional change in WTP into an estimate of change in quantity purchased. The extent to which a proportional increase in the price of a product will reduce purchases of that product is expressed as the product's own-price elasticity of demand, defined as the percentage change in quantity purchased per percentage change in price:

$$Price\ Elasticity_{SSBs} = \frac{\%\ \Delta\ quantity\ SSBs\ purchased}{\%\ \Delta\ price\ of\ SSBs} \qquad \text{(Eq. 5)}$$

Powell et al.[217] systematically reviewed studies estimating the price elasticity of SSBs, reporting an average elasticity of -1.21. To solve Equation 5 for $\%\ \Delta\ Quantity\ Purchased$, we multiplied the proportional change in WTP from health warnings by Powell and colleagues' estimate of average price elasticity of demand for SSBs. This calculation yielded the proportional reduction in quantity of SSBs purchased in response to health warnings:

$$Price\ Elasticity_{SSBs} * \Delta\ \%\ WTP = \%\ \Delta\ Quantity\ Purchased \qquad \text{(Eq. 6)}$$

We then multiplied this proportional change in quantity purchased by the simulated individual's baseline (pre-policy) SSB intake, yielding an absolute change in SSB intake in calories:

$$\Delta SSB\ intake\ (kcal) = \Delta SSB\ intake(\%) * usual\ SSB\ intake\ (kcal) \qquad \text{(Eq. 7)}$$

Updating change in SSB intake due to aging. As shown in Equation 7, the absolute change in SSB intake depended on individuals' baseline usual SSB intake. When individuals' usual SSB intake changed because they aged into the older cohort, we also recalculated their change in SSB intake by multiplying their sampled proportional change in SSB intake by their new value for usual SSB intake (i.e., re-calculating Eq. 7 with the new value of usual SSB intake).

Change in SSB intake in the status quo model. In the status quo model, we assumed there were no changes in SSB intake, except those due to aging as described above.

Total Energy Intake

Initial change in total energy intake. It is possible that individuals who reduce their SSB intake will also make other changes to their diet, for example increasing their consumption of substitute goods (e.g., juice) and decreasing their consumption of items that could be complements to SSBs (e.g., potato chips). The weight-loss benefits of reducing caloric intake from SSBs depend on these reductions being translated into reductions in total energy intake (TEI); weight loss benefits would be negligible if individuals fully compensate for their decreased SSB intake by increasing caloric intake from other items.[182] Previous literature has found that a 1.0 calorie change in SSB intake is associated with a 0.63 to 1.84 calorie change in total energy intake (**Table C.6**).[34,198–202] To incorporate the potential for caloric compensation in the policy model, we calculated individuals' net change in total energy intake by multiplying their change in SSB intake by a 'compensation' scaling parameter drawn from a uniform distribution with lower bound of 0.63 and upper bound of 1.84.[34,198–202] This is similar to the approach used by Long et al.[181] and others.[42,203]

$$\Delta TEI\ (kcal) = \Delta SSB\ intake(kcal) * compensation\ factor \qquad \text{(Eq. 8)}$$

Updating change in total energy intake due to aging. Equation 8 demonstrates that change in total energy intake depended on change in SSB intake (Eq. 8). As discussed above, the value for change in SSB intake was updated for individuals who age into an older age group. For these individuals, we also recalculated their change in total energy intake by multiplying their updated absolute change in SSB intake by their sampled compensation factor (i.e., re-calculating Eq. 8 with the new value for change in SSB intake).

Accounting for secular trends in total energy intake. In both the policy and status quo models, we incorporated secular trends in energy intake into our estimates of simulated individuals' change in total energy intake. Specifically, we estimated linear secular trends in total energy intake from 2005 to 2014 using NHANES dietary intake data, finding that average daily total energy intake decreased by 4.0 kcal/year over this period (though note this trend was not statistically significant at $\alpha = 0.05$). We projected this trend forward, assuming each simulated individual would reduce her daily total caloric intake by 4 kcal/day/year. This trend was applied in addition to any change in SSB intake and total energy intake in response to an SSB health warning policy. Thus, each individual's change in total energy intake reflected change in SSB consumption (if any), change in total energy intake in response to changes in SSB consumption (again, if any), and secular trends.

Body Weight

To estimate change in weight in response to change in total energy intake, we incorporated a validated model of weight change dynamics developed by the National Institutes of Health (NIH).[183] This model quantifies how a change in total energy intake χ affects body weight *M(t)* over time, estimating change in weight as:

$$\frac{\partial M(t)}{\partial t} = \frac{[\chi(t) - \kappa(t)(M(t) - M_0)]}{\tau} \qquad \text{(Eq. 9)}$$

Where M_0 is an individual's baseline body weight (before any changes in caloric intake), τ is the degree of weight change expected from a given net caloric intake, κ is the individual's energy expenditure given resting metabolic rate and physical activity, and $\chi(t)$ is net change in energy intake calculated in Equation 8 above. Hall and colleagues provide the following equations to determine τ and κ:

$$\tau = \frac{\eta_f + \rho_f + c\eta_l + c\rho_l}{(1-d)(1+c)} \qquad \text{(Eq. 10)}$$

$$\kappa(t) = \frac{1}{(1-d)}\left(\frac{\gamma_f + c\gamma_l}{(1+c)} + P(t)\right) \qquad \text{(Eq. 11)}$$

Equation 10 describes the efficiency of fat synthesis (η_f) and protein synthesis (η_l), energy content per unit of fat tissue (ρ_f) and lean tissue (ρ_l), relative change in lean mass per change in fat mass (c), and adaptive thermogenesis *d*. Equation 11 describes catabolic energy breakdown given resting metabolic rates of fat and lean tissue γ_f and γ_l and physical activity *P*. Hall et al.[183] provide parameters values to calculate τ and κ (**Table C.7**).

We ran the weight change dynamics model in daily time steps for five years, meaning each individual's weight was updated daily based on her weight the previous day and on the weight change she experienced on the simulated day as estimated using Equation 9. Weight change occurred if total energy intake on a given day was less than energy expenditure $\kappa(t)$. In the primary policy scenario, we assumed that the value for change in total energy intake was constant during the simulation (that is, the value for change in total energy intake is carried forward each day), except for updates due to aging and secular trends, described above. That is, if a simulated individual is assigned a change in total energy intake of -10 calories/day (i.e., their caloric intake on day 1 of the simulation is assumed to be 10 calories/day below their day 0 energy expenditure), we assumed this change in total energy intake persisted throughout the simulation period (i.e., remained at 10 calories/day below day 0 energy expenditure), except for changes due to aging or secular trends as described above. We also assume no changes in physical activity during the simulation period, consistent with other SSB policy simulations.[39]

While change in total energy intake was carried forward over the course of the simulation, daily weight loss was not constant, because total energy expenditure can vary with time. In the case of caloric reduction, energy expenditure gradually declines, reflecting that individuals with lower body weight have lower resting metabolic rates and thus lower energy expenditure, all else equal. This means that at a given reduction in net energy intake, weight loss slows over time. The NIH offers the following heuristic to understand weight change over time: a previously weight-stable individual who permanently reduces her caloric intake by 10 calorie/day (say, from 2,000 to 1,990 calories/day) can expect to lose about 1 pound over the long-run, with half of this weight loss occurring in the first year after she makes the dietary change, and nearly all of the weight loss occurring within three years.[193]

Calculating Population Outcomes

We estimated the impact of an SSB health warning policy on four outcomes: SSB intake, total energy intake, BMI, and obesity prevalence. We used a difference-in-differences (DD) framework to estimate policy impact on these outcomes. For each outcome, we compared the change from baseline to the end of the five-year simulation period in the policy model to the change over time in the status quo model. We calculated policy impact as the mean difference-in-differences in the outcomes under each scenario, weighting individual observations to reflect the U.S. population. We computed weights using the 2012-2016 American Community Survey Public Use Microdata Sample (PUMS).[218] Specifically, we used PUMS to estimate the survey-weighted proportion of individuals in each of the 48 cohorts, calculating the weight for each cohort j as:

$$weight_j = \frac{Proportion\ in\ Cohort_j * Total\ Population\ Size}{Cohort_j\ Size} \quad \text{(Eq. 12)}$$

Uncertainty Analyses

Uncertainty analyses were conducted by Monte Carlo sampling from predetermined distributions (**Table C.8**). We calculated average impacts as the mean of the DD estimates from 10,000 repetitions of the model. To reflect uncertainty in the point estimates, we report 95%

uncertainty intervals (UIs) around these means, bounded by the 2.5th and 97.5th percentiles of the DD estimates.

Sensitivity Analyses

We assessed model sensitivity to alternate assumptions about key model parameters by modifying the primary policy scenario to assess alternate values for three key parameters: (1) the trajectory of warning efficacy over time, (2) the extent to which warnings will reduce SSB intake, and (3) caloric compensation.

Scenarios 2 and 3: Changes in Warning Impact Over Time.

Our primary policy scenario assumed a constant proportional effect of SSB health warnings on SSB consumption over the five-year simulation period. Our estimates of changes in body weight and obesity prevalence will be inaccurate if the health warnings exert strengthening or diminishing effects on SSB intake over the simulation period. Donnelly and colleagues found that graphic SSB health warnings exerted a consistent effect throughout their two-week intervention period,[39,4234] but to date there are no studies assessing whether SSB health warnings' effects would remain constant after longer exposures.

Given the lack of long-term studies on SSB health warnings, we examined literature on tobacco warnings to gather plausible estimates of changes in warning efficacy over time. Some observational studies of tobacco warnings suggest that the effects of health warnings may wear out over time. For example, Hitchman and colleagues[204] examined trends from 2002-2011 in American and Canadians' likelihood of forgoing a cigarette at least once in the past month in response to cigarette health warnings. The authors report that warnings' effect on forgoing behavior declined by about 1.1% per year in the United States and by about 4.8% per year in Canada.

Other studies have found the opposite: that cigarette warnings' effectiveness *increases* rather than wears out over time. For example, one observational study found that cigarette health warnings' effect on forgoing behavior increased by more than 20% per year among Canadians and Australians in the two years after new pictorial health warnings were implemented.[206] A recent randomized trial also found that cigarette warnings' impact on participants' cigarette forgoing behavior increased during the study's four-week follow-up, even as participants' emotional and cognitive reactions to the warnings waned.[205] Scholars have also suggested that habit formation could cause consumer responses to nutrition policies to increase (rather than wear out) over time.[248]

To examine the impact of different assumptions about the trajectory of warning effectiveness over time, Scenarios 2 and 3 varied these trajectories based on previous research. Specifically, in **Scenario 2**, we reduced the impact of SSB health warnings on SSB consumption (as estimated in Equation 7 above) by 10% each year, about double the decay rate found in Hitchman and colleagues' analyses of cigarette forgoing.[204] In **Scenario 3**, we increased the impact of SSB health warnings on SSB consumption by 10% each year, about half the rate of increase found in Swayampakala and colleagues' analyses of cigarette forgoing.[206] In both Scenario 2 and 3, we applied the primary policy scenario's assumptions about consumers' responses to SSB health warnings and caloric compensation.

Scenarios 4 and 5: Magnitude of Warnings' Impact on SSB Intake

In the primary policy scenario, we estimated the effect of health warnings on SSB intake using data from previous literature on SSB health warnings' impact on willingness to pay,[21] coupled with information about the price elasticity of demand for SSBs.[217] We used these values in the primary policy scenario because they provided the most conservative (i.e., smallest) estimate of health warnings' impact across recent randomized and quasi-experimental studies of SSB warnings.[21,34,191] In addition to this primary scenario, in Scenarios 4 and 5 we examined two alternative estimates of the effect of health warnings on SSB consumption.

In **Scenario 4**, we used estimates of SSB health warning impact drawn from a recent quasi-experimental study of graphic health warnings' effect on beverage purchases in a hospital cafeteria. In this study, Donnelly and co-authors[34] found that the graphic health warnings reduced total beverage calories purchased by about 14.8% (from 88 calories/transaction to 75 calories/transaction). The authors reported that this reduction was driven by substitution from SSBs to water; thus, we assumed all of the beverage calorie reduction was from SSB calories (rather than from, e.g., juice calories). We assigned each individual a proportional change in SSB intake by drawing from a triangular distribution, centered on -14.8% with lower and upper bounds determined using Donnelly et al.'s results:

$$lower\ bound = \frac{[BeverageCalories_T + 1.96(SE_T)] - [BeverageCalories_C - 1.96(SE_C)]}{BeverageCalories_C} \quad \text{(Eq. 13)}$$

$$upper\ bound = \frac{[BeverageCalories_T - 1.96(SE_T)] - [BeverageCalories_C + 1.96(SE_C)]}{BeverageCalories_C} \quad \text{(Eq. 14)}$$

Where $\text{BeverageCalories}_T$ and SE_T are the mean and SE, respectively, of beverage calories purchased per transaction for the treatment (graphic SSB health warning) period and $\text{BeverageCalories}_C$ and SE_C are the mean and SE, respectively, of beverage calories purchased per transaction for the control period. We then multiplied this proportional change in quantity purchased by the simulated individual's baseline (pre-policy) SSB intake using Equation 8, yielding an absolute change in SSB intake in calories/day.

In **Scenario 5**, we estimated the impact of SSB health warnings on SSB purchases using data from our team's recent randomized controlled trial of text SSB health warnings.[191] Participants in that trial were randomly assigned to either a health warning condition (SSBs displayed a text health warning label) or to a control condition (SSBs displayed a control label); they then shopped for foods, beverages, and household items in a naturalistic convenience store laboratory. We used data on participants' SSB purchases to examine the extent to which an individual's SSB purchases changed in response to the health warning using the following:

$$\ln(SSB\ calories\ purchased) = \beta_0 + \beta_1 WARNING + \beta X' \quad \text{(Eq. 15)}$$

Where SSB calories purchased are total calories from SSBs the participant purchased, WARNING is an indicator for whether the participant was in the health warning arm (WARNING = 1) vs. control arm (WARNING = 0), and X' is a vector of participant characteristics (Hispanic ethnicity and overweight/obese status) that were unbalanced across treatment arms. Log-transforming SSB purchases allowed us to estimate the proportional difference in SSB calories purchased when a health warning was (vs. was not) present; this difference is given by: $\%\,\Delta\, SSB\ calories\ purchased = 100(e^{\hat{\beta}_1} - 1)$ where $\hat{\beta}_1$ is the estimated coefficient from Equation 15. We fit Equation 15 using a generalized linear model with a log link and a gamma family distribution, reflecting the zero-inflation in SSB calories purchased. Results indicated that the SSB health warning reduced SSB calories purchased by 22.4%. We used the estimated coefficient and its delta-method standard error to estimate a normal distribution of responses to the SSB health warning policy and assigned individuals a value for their proportional change in SSB intake ($\Delta\, SSB\ intake(\%)$) by sampling from that probability distribution. As above, we used Equation 8 to translate this proportional change in quantity purchased into an absolute change in SSB intake in calories/day.

Scenario 6: Caloric Compensation

In the primary policy scenario, we assigned simulated individuals a value for their degree of caloric compensation by drawing from a distribution of compensation factors based on previous studies.[34,198–202] In **Scenario 6**, we took a more conservative approach to caloric compensation. In this scenario, we assumed that all simulated individuals would compensate 37% of any reductions in SSB calories (i.e., would have a compensation factor of 0.63), the most conservative estimate of compensation from the cross-over and randomized trials of SSB caloric compensation in adults.[198,200,201] As in the primary policy scenario, we applied this compensation factor in Equation 5 to translate change in SSB intake into change in total energy intake.

Model Validation

In addition to examining simulated vs. actual height, weight, and SSB intake by cohort, we also assessed the validity of the NIH weight change model by using the model to simulate BMI from 2007-2014 and comparing the simulated trends to observed trends in BMI over the same period. First, we used NHANES 2005-2014 to estimate secular trends in caloric intake from 2005-2014, expressed as an average change in caloric intake per day per year. We then implemented the NIH weight change dynamics model (Equations 9-11), using the secular trend in energy intake as the value for change in total energy intake χ and using adult participants in the NHANES 2005-2006 cycle as our analytic sample. To ensure adequate sample size within cohorts and to mirror the major demographic groups examined in obesity surveillance studies,[138] we collapsed the 48 cohorts used in the main simulation into 12 cohorts defined by age (18 to 39 years, 40 to 65 years), race (non-Hispanic White, non-Hispanic Black, and Hispanic/Mexican American), and sex (male, female).

We projected weight change for 2005-2006 NHANES adults through 2013-2014, allowing us to compare simulated and observed mean BMI across four cycles of NHANES (2007-2008, 2009-2010, 2011-2012, and 2013-2014). For each survey cycle, we compared each cohort's average simulated BMI to that cohort's average observed BMI as estimated in

NHANES. Average simulated BMI estimates for each cohort were within the statistical error of the observed average BMI estimates for each of the four survey cycles and did not show any systematic bias (**Figure C.2**).

Figure C.1. Microsimulation model overview

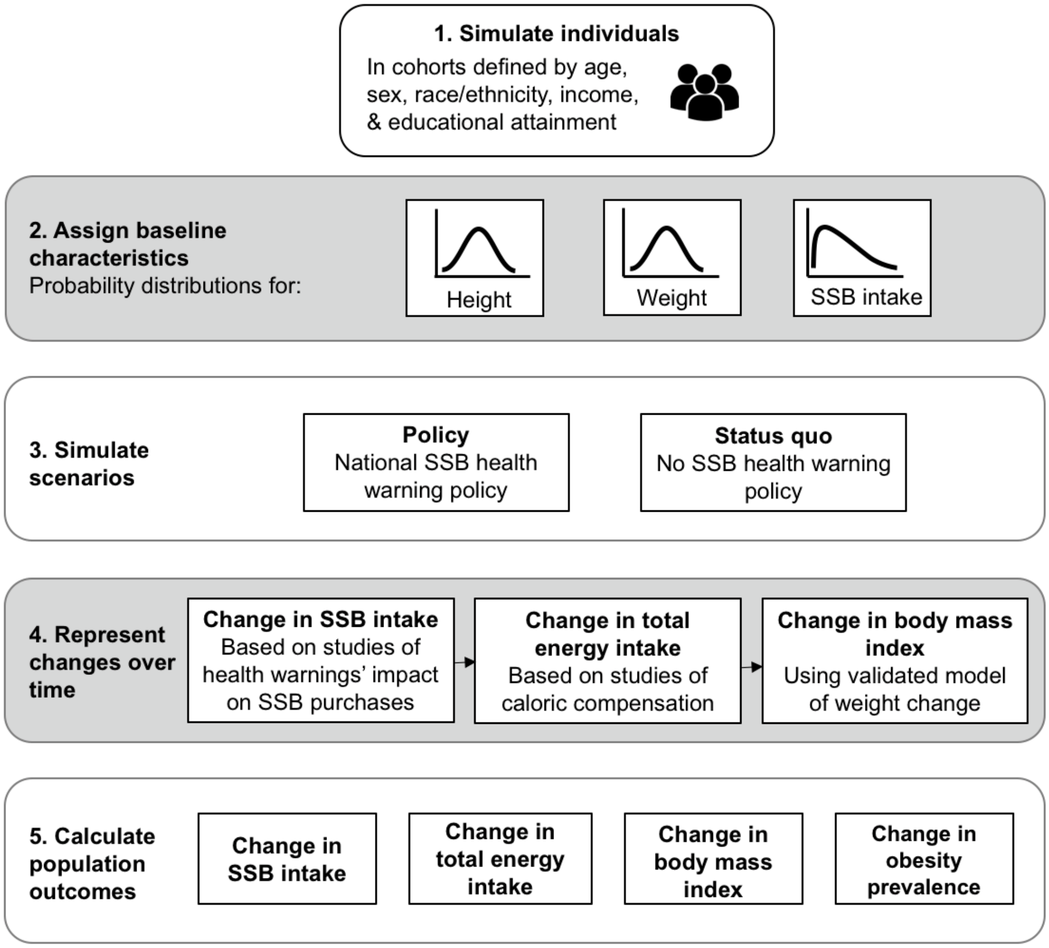
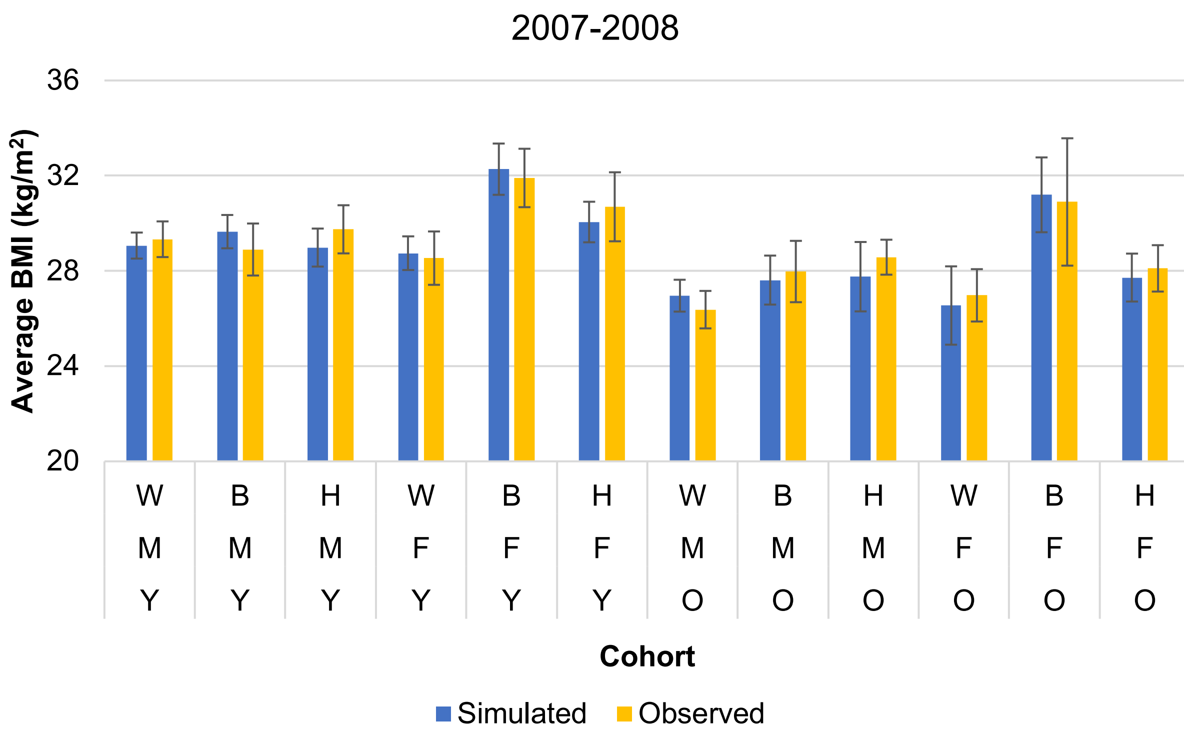
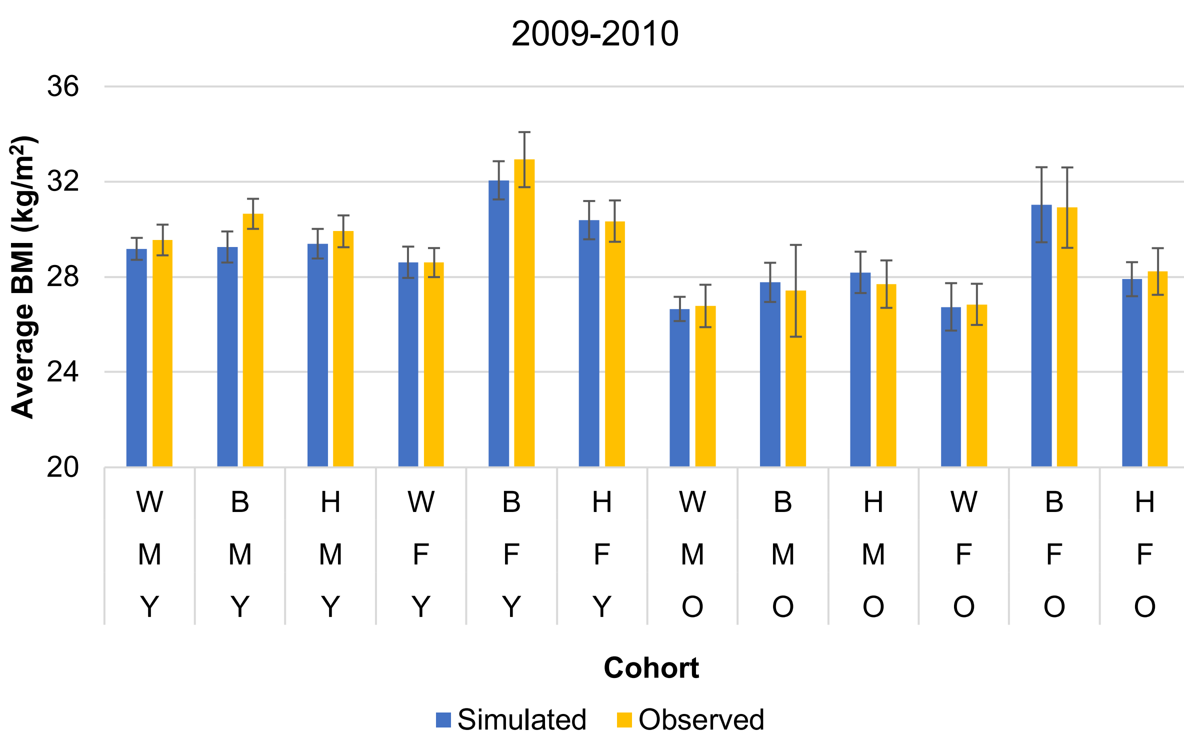
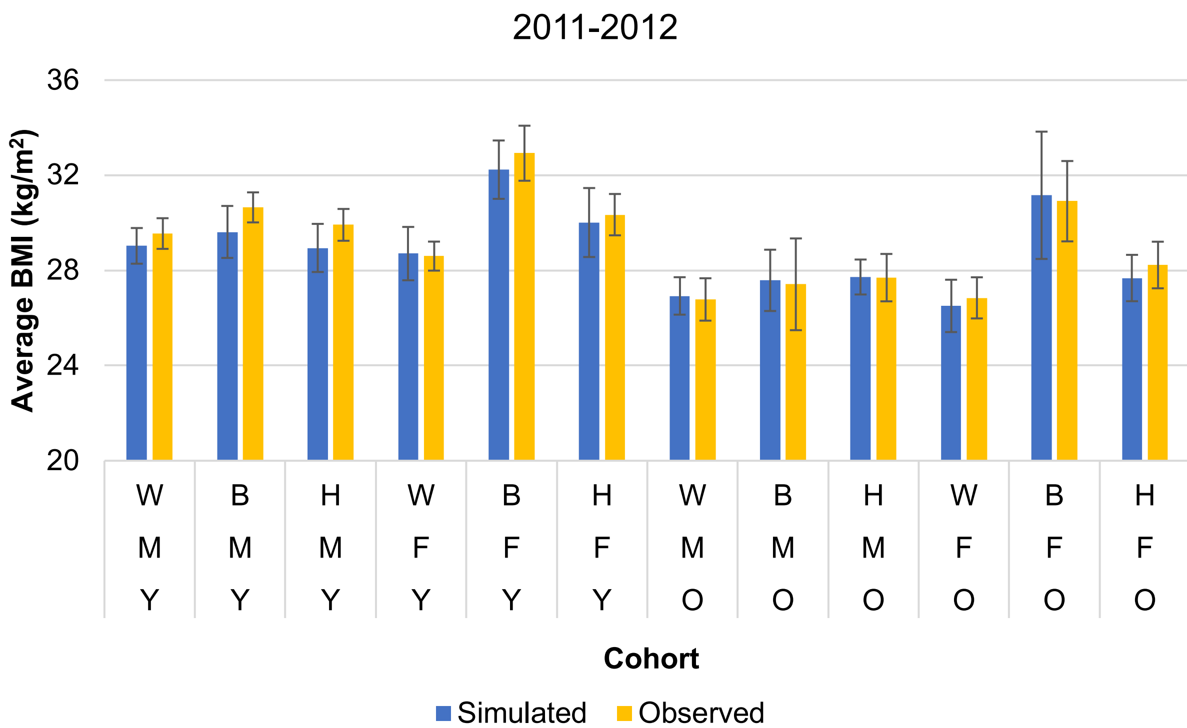
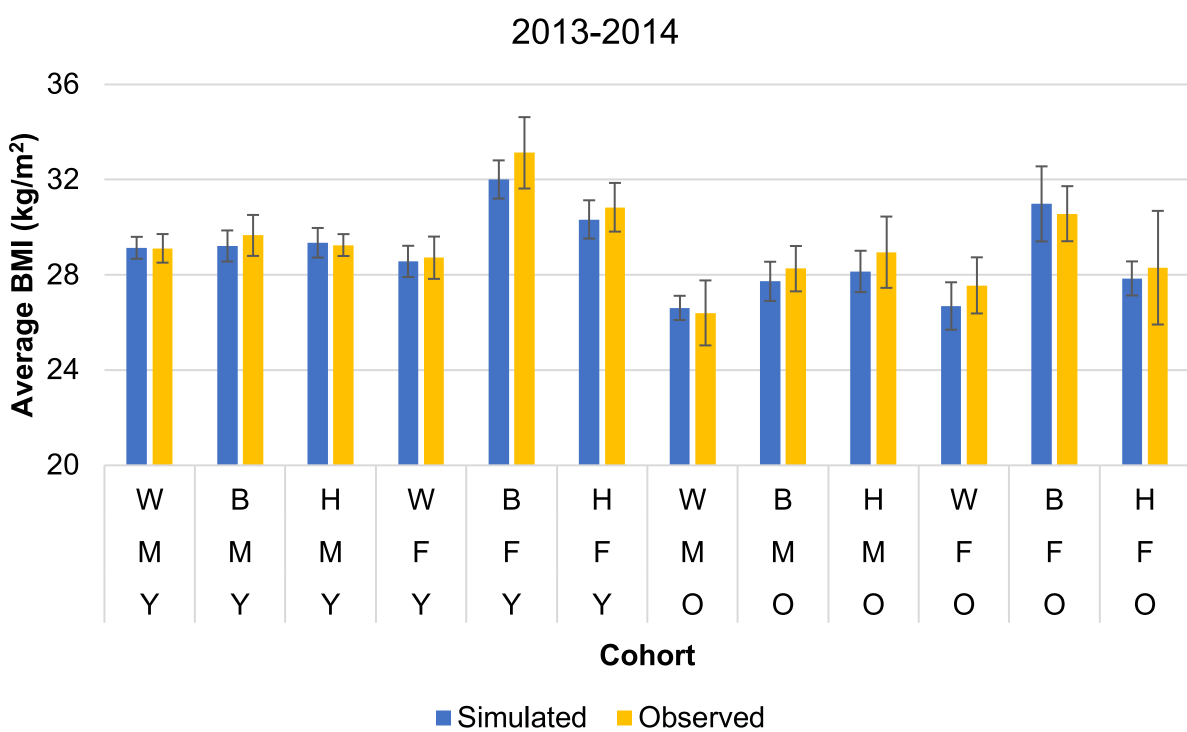


Figure C.2. Average simulated vs. observed body mass index (BMI), by cohort and year









Note: Cohort labels: First letter: race, non-Hispanic white (W), non-Hispanic black (B), or Hispanic/Mexican American (H); second letter: sex, male (M) or female (F); third letter: age group, 18-39 years (Y) or 40-65 years (O).

Table C.1. Input parameters and sources

Parameter	Source(s)
Baseline Characteristics	
Height and weight distributions for each demographic group	National Health and Nutrition Examination Survey (NHANES) 2005-2014 cycles[216]
Distribution of usual SSB intake for each demographic group	NHANES 2005-2014 cycles[216]
Model Representations of Changes in Diet and Weight Over Time	
Change in SSB intake due to a health warning policy:	
Primary policy scenario	
Smallest reduction (12.7%)	Previous study of effect of health warnings on willingness to pay for SSBs;[21] systematic review of price elasticity of SSBs[217]
Alternative scenarios	
Smallest reduction + decreasing effectiveness over time (-10%/year)	Previous study of change in cigarette warnings' effectiveness over time[204]
Smallest reduction + increasing effectiveness over time (+10%/year)	Previous study of change in cigarette warnings' effectiveness over time[206]
Medium reduction (14.7%)	Previous study of graphic health warnings' effect on SSB purchases[34]
Largest reduction (22.4%)	Previous study of effect on SSB health warnings on SSB calories purchased[191]
Change in total energy intake due to a change in SSB intake (i.e., caloric compensation)	
Primary policy scenario	
Sample from a distribution of possible values for caloric compensation suggesting a 1 calorie change in SSB intake yields a 0.63 to 1.84 calorie change in total energy intake	Range of estimates from previous studies[34,198–202]
Alternative scenario	
More conservative estimate of caloric compensation applied to all individuals (1 calorie change in SSB intake yields a 0.63 calorie change in total energy intake)	Previous crossover trial examining caloric compensation after supplementation with SSBs or artificially-sweetened beverages[198]
Change in body weight due to a change in total energy intake	Validated equations by Hall et al. (2011)[183]
Population Structure	
Population demographic distribution	American Community Survey Public Use Microdata Sample (ACS PUMS)[218]

Table C.2. SSB intake (calories/day), adults 18-65 years participating in NHANES, 2003-2014

	2003-2004	2005-2006	2007-2008	2009-2010	2011-2012	2013-2014
Mean	244.1[a]	215.2[b]	210.3[b]	206.3[b]	207.3[b]	196.6[b]
(SD)	(295.1)	(276.5)	(275.7)	(272.0)	(275.4)	(279.9)

[a,b]Means with different superscripts are different from one another at $\alpha = 0.05$.

Table C.3. Actual vs. simulated mean height by cohort

Cohort					Actual height (meters)	Simulated height (meters)	% difference
Age	Sex	Race	Educ.	Income			
O	M	W	High	High	1.79	1.79	<0.01%
O	M	W	High	Low	1.78	1.78	<0.01%
O	M	W	Low	High	1.77	1.77	<0.01%
O	M	W	Low	Low	1.77	1.77	<0.01%
O	M	B	High	High	1.79	1.79	<0.01%
O	M	B	High	Low	1.77	1.77	<0.01%
O	M	B	Low	High	1.77	1.77	<0.01%
O	M	B	Low	Low	1.76	1.76	<0.01%
O	M	H	High	High	1.74	1.74	<0.01%
O	M	H	High	Low	1.71	1.71	<0.01%
O	M	H	Low	High	1.72	1.72	<0.01%
O	M	H	Low	Low	1.70	1.70	<0.01%
O	F	W	High	High	1.64	1.64	<0.01%
O	F	W	High	Low	1.62	1.62	<0.01%
O	F	W	Low	High	1.63	1.63	<0.01%
O	F	W	Low	Low	1.62	1.62	<0.01%
O	F	B	High	High	1.65	1.65	<0.01%
O	F	B	High	Low	1.66	1.66	<0.01%
O	F	B	Low	High	1.64	1.64	<0.01%
O	F	B	Low	Low	1.63	1.63	<0.01%
O	F	H	High	High	1.60	1.60	<0.01%
O	F	H	High	Low	1.58	1.58	<0.01%
O	F	H	Low	High	1.58	1.58	<0.01%
O	F	H	Low	Low	1.56	1.56	<0.01%
Y	M	W	High	High	1.80	1.80	<0.01%
Y	M	W	High	Low	1.79	1.79	<0.01%
Y	M	W	Low	High	1.78	1.78	<0.01%
Y	M	W	Low	Low	1.77	1.77	<0.01%
Y	M	B	High	High	1.79	1.79	<0.01%
Y	M	B	High	Low	1.81	1.81	<0.01%
Y	M	B	Low	High	1.77	1.77	<0.01%
Y	M	B	Low	Low	1.77	1.77	<0.01%
Y	M	H	High	High	1.76	1.76	<0.01%
Y	M	H	High	Low	1.75	1.75	<0.01%
Y	M	H	Low	High	1.73	1.73	<0.01%
Y	M	H	Low	Low	1.71	1.71	<0.01%
Y	F	W	High	High	1.66	1.66	<0.01%
Y	F	W	High	Low	1.65	1.65	<0.01%
Y	F	W	Low	High	1.65	1.65	<0.01%
Y	F	W	Low	Low	1.64	1.64	<0.01%
Y	F	B	High	High	1.64	1.64	<0.01%
Y	F	B	High	Low	1.65	1.65	<0.01%
Y	F	B	Low	High	1.63	1.63	<0.01%

Cohort					Actual height	Simulated	%
Age	**Sex**	**Race**	**Educ.**	**Income**	**(meters)**	**height (meters)**	**difference**
Y	F	B	Low	Low	1.64	1.64	<0.01%
Y	F	H	High	High	1.61	1.61	<0.01%
Y	F	H	High	Low	1.60	1.60	<0.01%
Y	F	H	Low	High	1.60	1.60	<0.01%
Y	F	H	Low	Low	1.59	1.59	<0.01%
Unweighted Average					**1.69**	**1.69**	**<0.01%**

Note. Age groups: 40-65 years (O), 18-39 years (Y); Sex: Male (M), Female (F); Race/ethnicity: non-Hispanic White (W), non-Hispanic Black (B), Hispanic/Mexican American (H); Education: Some college or less (Low), College degree or more (High); Income: ≤ 185% Federal Poverty Level [FPL] (Low), > 185% FPL (High).

Table C.4. Actual vs. simulated mean weight by cohort

Cohort					Actual weight	Simulated	%
Age	**Sex**	**Race**	**Educ.**	**Income**	**(kg)**	**weight (kg)**	**difference**
O	M	W	High	High	90.63	90.63	-0.01%
O	M	W	High	Low	93.03	93.06	0.04%
O	M	W	Low	High	94.57	94.58	<0.01%
O	M	W	Low	Low	92.31	92.44	0.13%
O	M	B	High	High	97.84	97.87	0.04%
O	M	B	High	Low	89.63	89.64	0.01%
O	M	B	Low	High	96.15	96.18	0.04%
O	M	B	Low	Low	89.25	89.55	0.33%
O	M	H	High	High	90.86	90.86	<0.01%
O	M	H	High	Low	96.34	96.35	0.02%
O	M	H	Low	High	89.30	89.32	0.03%
O	M	H	Low	Low	84.45	84.48	0.03%
O	F	W	High	High	72.92	73.04	0.16%
O	F	W	High	Low	79.81	79.96	0.19%
O	F	W	Low	High	79.14	79.24	0.13%
O	F	W	Low	Low	80.49	80.68	0.23%
O	F	B	High	High	87.59	87.65	0.07%
O	F	B	High	Low	85.67	85.79	0.14%
O	F	B	Low	High	87.91	88.01	0.12%
O	F	B	Low	Low	88.29	88.43	0.16%
O	F	H	High	High	74.07	74.17	0.13%
O	F	H	High	Low	70.07	70.17	0.14%
O	F	H	Low	High	75.59	75.64	0.07%
O	F	H	Low	Low	75.53	75.60	0.09%
Y	M	W	High	High	87.11	87.12	0.01%
Y	M	W	High	Low	85.27	85.30	0.03%
Y	M	W	Low	High	85.26	85.30	0.06%
Y	M	W	Low	Low	83.90	84.17	0.32%
Y	M	B	High	High	92.44	92.59	0.16%
Y	M	B	High	Low	91.09	91.10	0.01%
Y	M	B	Low	High	89.14	89.28	0.16%
Y	M	B	Low	Low	85.51	85.66	0.18%
Y	M	H	High	High	87.13	87.17	0.04%
Y	M	H	High	Low	77.65	77.72	0.09%
Y	M	H	Low	High	88.07	88.26	0.21%
Y	M	H	Low	Low	82.58	82.67	0.11%
Y	F	W	High	High	70.84	70.92	0.11%
Y	F	W	High	Low	70.29	70.35	0.09%
Y	F	W	Low	High	74.11	74.29	0.25%
Y	F	W	Low	Low	76.85	77.36	0.66%
Y	F	B	High	High	84.03	84.16	0.14%
Y	F	B	High	Low	84.48	84.72	0.28%
Y	F	B	Low	High	77.61	77.73	0.15%

Cohort					Actual weight	Simulated	%
Age	**Sex**	**Race**	**Educ.**	**Income**	**(kg)**	**weight (kg)**	**difference**
Y	F	B	Low	Low	85.07	85.51	0.51%
Y	F	H	High	High	65.48	65.53	0.07%
Y	F	H	High	Low	64.76	64.89	0.21%
Y	F	H	Low	High	74.24	74.49	0.34%
Y	F	H	Low	Low	73.44	73.66	0.30%
Unweighted Average					83.29	83.40	**0.1%**

Note. Age groups: 40-65 years (O), 18-39 years (Y); Sex: Male (M), Female (F); Race/ethnicity: non-Hispanic White (W), non-Hispanic Black (B), Hispanic/Mexican American (H); Education: Some college or less (Low), College degree or more (High); Income: ≤ 185% Federal Poverty Level [FPL] (Low), > 185% FPL (High).

Table C.5. Actual vs. simulated mean SSB intake by cohort

Cohort					Actual SSB intake	Simulated SSB	%
Age	Sex	Race	Educ.	Income	(kcal/day)	intake (kcal/day)	difference
O	M	W	High	High	131.0	131.1	0.09%
O	M	W	High	Low	188.1	188.1	<0.01%
O	M	W	Low	High	224.4	224.4	0.02%
O	M	W	Low	Low	322.3	322.2	-0.03%
O	M	B	High	High	220.4	220.4	-0.04%
O	M	B	High	Low	127.2	127.2	<0.01%
O	M	B	Low	High	269.0	269.0	-0.01%
O	M	B	Low	Low	252.0	252.1	0.05%
O	M	H	High	High	175.0	175.0	-0.02%
O	M	H	High	Low	167.4	167.4	-0.02%
O	M	H	Low	High	237.0	237.0	-0.01%
O	M	H	Low	Low	267.3	267.3	<0.01%
O	F	W	High	High	76.8	76.9	0.10%
O	F	W	High	Low	120.1	120.1	-0.01%
O	F	W	Low	High	135.2	135.1	-0.02%
O	F	W	Low	Low	219.8	219.8	-0.03%
O	F	B	High	High	154.6	154.5	-0.03%
O	F	B	High	Low	214.3	214.4	0.05%
O	F	B	Low	High	185.5	185.6	<0.01%
O	F	B	Low	Low	235.5	235.4	-0.05%
O	F	H	High	High	105.9	105.8	-0.01%
O	F	H	High	Low	248.6	248.6	0.02%
O	F	H	Low	High	146.3	146.2	-0.04%
O	F	H	Low	Low	169.3	169.3	-0.02%
Y	M	W	High	High	188.7	188.7	0.01%
Y	M	W	High	Low	183.0	183.0	0.02%
Y	M	W	Low	High	319.6	319.5	-0.01%
Y	M	W	Low	Low	440.8	440.8	<0.01%
Y	M	B	High	High	253.3	253.1	-0.05%
Y	M	B	High	Low	270.3	270.3	0.01%
Y	M	B	Low	High	350.5	350.5	<0.01%
Y	M	B	Low	Low	328.2	328.2	-0.02%
Y	M	H	High	High	246.6	246.5	-0.02%
Y	M	H	High	Low	199.2	198.4	-0.43%
Y	M	H	Low	High	347.6	347.8	0.06%
Y	M	H	Low	Low	317.6	317.6	<0.01%
Y	F	W	High	High	101.7	101.7	0.02%
Y	F	W	High	Low	132.7	132.7	0.03%
Y	F	W	Low	High	179.9	179.8	-0.07%
Y	F	W	Low	Low	289.3	289.2	-0.03%
Y	F	B	High	High	186.5	186.6	0.03%
Y	F	B	High	Low	111.6	111.6	-0.05%
Y	F	B	Low	High	228.3	228.2	-0.03%

Cohort					Actual SSB intake (kcal/day)	Simulated SSB intake (kcal/day)	% difference
Age	**Sex**	**Race**	**Educ.**	**Income**			
Y	F	B	Low	Low	283.7	283.7	-0.03%
Y	F	H	High	High	180.1	180.2	0.05%
Y	F	H	High	Low	198.1	198.1	0.02%
Y	F	H	Low	High	201.8	201.8	0.02%
Y	F	H	Low	Low	227.9	228.1	0.06%
Unweighted Average					215.8	215.8	-0.01%

Note. Age groups: 40-65 years (O), 18-39 years (Y); Sex: Male (M), Female (F); Race/ethnicity: non-Hispanic White (W), non-Hispanic Black (B), Hispanic/Mexican American (H); Education: Some college or less (Low), College degree or more (High); Income: ≤ 185% Federal Poverty Level [FPL] (Low), > 185% FPL (High).

Table C.6. Studies assessing energy compensation in response to changes in SSB intake

Author (Year)	**Design**	**Sample**	**Duration**	**Total energy intake (kcal) change per SSB kcal reduced[a]**
DiMeglio (2000)[202]	Cross-over trial, non-blinded	7 males and 8 females with mean BMI in the normal range (~21)	4 weeks	-1.17
Donnelly (2018)[34]	Quasi-experimental study	40,768 bottled beverage purchases from a hospital cafeteria in MA	16 weeks	-1.0[b]
Finkelstein (2013)[199] – Study 1	Cross-sectional study	28,584 households (114,336 HH-by-quarter observations)	1 year	-1.00
Finkelstein (2013)[199] – Study 2	Cross-sectional econometric (IV) study	28,584 households (114,336 HH-by-quarter observations)	1 year	-1.84
Reid[200] (2007)	Randomized controlled trial, blinded	133 non-dieting women in the UK with BMI 17 – 24.9	4 weeks	-0.67
Tordoff[198] (1990)	Cross-over trial, blinded	9 females and 21 males in the U.S. with BMI ~25	9 weeks	-0.63
Van Wymelbeke[201] (2003)	Repeated cross-over trial, blinded	12 males and 12 females in France, normal weight	3x2 week trials	-0.92

[a]Assuming 12-ounce serving of SSBs = 140 kcal, see Long et al.[181] (2015).
[b]Qualitative estimate, authors did not calculate exact compensation value

Table C.7. Energy metabolism parameter values for use in NIH model of weight change

Parameter	Definition	Mean value +/- SD
η_f	Fat synthesis efficiency	230 kcal/kg +/- 100
η_l	Protein synthesis efficiency	180 kcal/kg +/- 20
ρ_f	Energy content per unit change in body fat	9400 kcal/kg +/- 50
ρ_l	Energy content per unit change in lean tissue	1800 kcal/kg +/- 50
c	Relative change in lean mass per change in fat mass	0.54 +/- 0.1
d	Adaptive thermogenesis parameter	0.24 +/- 0.1
γ_f	Resting metabolic rate of fat	3.6 kcal/kg/d +/- 2
γ_l	Resting metabolic rate of lean tissue	22 kcal/kg/d +/- 4
P	Physical activity level	1.6 +/- 0.2

Abbreviations: NIH, National Institutes of Health.

Note. Values are from Hall et al.,[183] see also Basu et al.[41]

Table C.8. Details on key input parameters

Parameter	Conditioning Factors	Distribution & Modeling Parameters	Fixed or Variable	Source(s)
Baseline Characteristics				
Age	NA	Individuals assigned an age between 18-65	Variable	American Community Survey Public Use Microdata Sample (ACS PUMS)[218]
Sex	NA	Individuals assigned a sex (male vs. female)	Fixed	ACS PUMS[218]
Race/ethnicity	NA	Individuals assigned a race/ethnicity (non-Hispanic white, non-Hispanic black, or Hispanic/Mexican American)	Fixed	ACS PUMS[218]
Education level	NA	Individuals assigned an education level (some college or less vs. college degree or more)	Fixed	ACS PUMS[218]
Income level	NA	Individuals assigned an income level (185% of the Federal Poverty Level or less vs. more than 185% of the Federal Poverty Level)	Fixed	ACS PUMS[218]
Height and weight	• Age • Sex • Race/ethnicity • Education level • Income level	Assign height and weight by drawing from bivariate normal distributions defined by cohort-specific means, SDs, and covariances	Fixed (height) and variable (weight)	National Health and Nutrition Examination Survey (NHANES) 2005-2014 cycles[216]

Parameter	Conditioning Factors	Distribution & Modeling Parameters	Fixed or Variable	Source(s)
Usual SSB intake	• Age • Sex • Race/ethnicity • Education level • Income level	• Assign probability of any SSB consumption based on cohort-specific prevalence of SSB consumption • Assign amount of SSBs consumed given any consumption by drawing from gamma distributions defined by cohort-specific shape and scale parameters	Variable	NHANES 2005-2014 cycles[216]
Model Representations of Changes Over Time				
Change in SSB Intake due to Health Warning Policy				
Primary policy scenario: Smallest reduction (12.7%)	NA	• Assign proportional change in willingness to pay for SSBs in response to SSB health warning by drawing from a triangular distribution (min = -0.26469, mid = -0.10526, max = 0.05416) • Price elasticity of demand for SSBs: Assign all individuals an elasticity of -1.21	Fixed	Previous study of effect of health warnings on willingness to pay for SSBs;[21] systematic review of price elasticity of demand for SSBs[217]
Scenario 2: Smallest reduction + decreasing effectiveness over time (-10%/year)	NA	• Assign all individuals proportional change in SSB intake as in primary policy scenario. • Assign all individuals to a 10% per year reduction in this proportional change in SSB intake.	Fixed (change in efficacy over time) and variable (proportional change in SSB intake)	Previous study of change in cigarette warnings' effectiveness over time[204]

Parameter	Conditioning Factors	Distribution & Modeling Parameters	Fixed or Variable	Source(s)
Scenario 3: Smallest reduction + increasing effectiveness over time (+10%/year)	NA	• Assign all individuals proportional change in SSB intake as in the primary policy scenario. • Assign all individuals to a 10% per year increase in this proportional change in SSB intake.	Fixed (change in efficacy over time) and variable (proportional change in SSB intake)	Previous study of change in cigarette warnings' effectiveness over time[206]
Scenario 4: Medium reduction (14.7%)	NA	Assign proportional change in SSB intake by drawing from a triangular distribution (min = -0.23656, mid = -0.14773, max = -0.06024)	Fixed	Previous study of graphic health warnings' effect on SSB purchases[34]
Scenario 5: Largest reduction (22.4%)	NA	Assign proportional change in SSB intake by drawing from a normal distribution (mean = -0.2239, SD = 0.0875)	Fixed	Previous study of effect on SSB health warnings on SSB calories purchased[191]
Change in Total Energy Intake due to Change in SSB Intake				
Primary policy scenario: Sample from a distribution of possible values for caloric compensation	NA	Assign individuals a compensation factor by drawing from a uniform distribution (min = 0.63, max = 1.84)	Fixed	Range of estimates from previous studies[34,198–202]
Scenario 6: More conservative estimate of caloric compensation	NA	Assign all individuals a compensation factor of 0.63.	Fixed	Previous crossover trial examining caloric compensation after supplementation with SSBs or artificially-sweetened beverages[198]

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