A Sugar-Sweetened Beverage Intervention’s Effect on Non-Nutritive Sweetener Consumers and Consumption Patterns

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ABSTRACT

The overconsumption of added sugars leads to negative effects on health such as an increased risk for obesity, cardiovascular disease, and diabetes. With approximately 50% of added sugars in the American diet being attributed to sugar-sweetened beverage (SSB) intake, non-nutritive sweeteners (NNS) are recommended as potential replacements. The purpose of this secondary analysis of Talking Health, a 6-month SSB reduction intervention, was to explore 1) changes in NNS consumption patterns between SIPsmartER (n=101) and MoveMore (n=97) interventions, and 2) differences in demographics between three groups of various SSB-NNS consumption change patterns (Group 1: decreased SSB, increased NNS; Group 2: decreased SSB, no change in NNS; Group 3: increased SSB, regardless of NNS). Results showed that the SIPsmartER intervention significantly created more new NNS users than MoveMore after the 6 month intervention. There were significant between group over time differences for intake of aspartame, sucralose, and total NNS, with intake increasing for SIPsmartER participants as compared to MoveMore. However, when exploring demographics between the three SSB-NNS consumption change groups, no differences were found between those who successfully decreased SSB while increasing NNS and the other groups. While diet beverages were the most commonly consumed dietary source of NNS across groups over time, other sources such as tabletop sweeteners, yogurt, and meal replacement products contributed to total NNS intake. Future research is needed to identify those who would benefit most from using NNS as a tool to decrease SSB intake. This will help inform future interventions and provide appropriate strategies to decrease added sugars intake.
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GENERAL AUDIENCE ABSTRACT

The overconsumption of added sugars leads to negative effects on health such as an increased risk for obesity, cardiovascular disease, and diabetes. With approximately 50% of added sugars in the American diet being attributed to sugar-sweetened beverage (SSB) intake, non-nutritive sweeteners (NNS) are recommended as potential replacements. The purpose of this secondary analysis of Talking Health, a 6-month SSB reduction intervention, was to explore 1) changes in NNS consumption patterns between SIPsmartER \( (n=101) \) and MoveMore \( (n=97) \) interventions, and 2) differences in demographics between three groups of various SSB-NNS consumption change patterns (Group 1: decreased SSB, increased NNS; Group 2: decreased SSB, no change in NNS; Group 3: increased SSB, regardless of NNS). Results showed that the SIPsmartER intervention significantly created more new NNS users than MoveMore after the 6 month intervention. There were significant between group over time differences for intake of aspartame, sucralose, and total NNS, with intake increasing for SIPsmartER participants as compared to MoveMore. However, when exploring demographics between the three SSB-NNS consumption change groups, no differences were found between those who successfully decreased SSB while increasing NNS and the other groups. While diet beverages were the most commonly consumed dietary source of NNS across groups over time, other sources such as tabletop sweeteners, yogurt, and meal replacement products contributed to total NNS intake. Future research is needed to identify those who would benefit most from using NNS as a tool to decrease SSB intake. This will help inform future interventions and provide appropriate strategies to decrease added sugars intake.
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Chapter 1: Review of Literature

Obesity

Obesity is a serious public health concern worldwide. In the United States (U.S.), rates have followed world trends with a 40% prevalence of obesity in women and 35% in men.\(^1\) Although recent efforts have helped slow down obesity rates in adults and even reduce rates in children,\(^1\) more work must be done to ensure the effects of obesity on future generations are mitigated. Obesity is not only a concern due to its effect on cardiometabolic health, such as increased risk for type 2 diabetes mellitus (T2DM), heart disease, and some cancers,\(^1\) but also for the financial stress it puts on the country. Annually, obesity adds more than $150 billion in healthcare costs for the U.S.\(^1\)

Although science has not determined one specific etiology for obesity, as it is likely multifaceted, the World Health Organization pinpoints the underlying cause of obesity to be an imbalance between calories consumed and calories expended.\(^2\) The typical American diet exceeds the recommended amount of saturated fats, added sugars, sodium, refined grains, and consequently calories.\(^3\) Added sugars in particular have been one of the most closely followed targets by health professionals and food policy advocates who wish to reduce the excessive caloric intake in Americans’ diets.\(^4\)-\(^7\)

Nutritive Sweeteners

Nutritive sweeteners provide 4 kcal/g to the human diet. Nutritive sweeteners include sugars such as sucrose, fructose, galactose, lactose, and maltose, as well as products such as honey, molasses, high-fructose corn syrup, corn syrup, and agave syrup.\(^8\) Nutritive sweeteners like fructose can be found naturally in foods such as fruits,\(^9\) while others, such as high-fructose
corn syrup, are added to food or food products during processing to enhance their flavor or extend their shelf-life. These added sweeteners are commonly known as added sugars and from 2003-2010, made up 14% of total daily calories consumed for Americans aged 6 years or older.\textsuperscript{7}

In 2015, the Dietary Guidelines Advisory Committee’s report showed a strong correlation between added sugars consumption and increased overweight or obesity rates in all age groups, including children, adolescents, and adults.\textsuperscript{10} In response, the 2015-2020 Dietary Guidelines for Americans (DGA) recommend that added sugars comprise less than 10% of calories consumed daily.\textsuperscript{11} In a 2,000-calorie diet, a 10% consumption would equate to 200 calories or 50 grams of added sugars per day for adults. Unfortunately, these recommendations are not followed by the general public, with only 42% of Americans, 2 years and over, meeting this recommendation.\textsuperscript{12} Those who did meet the recommendation consumed an average of 28 g of added sugars, while those who did not consumed an average of 105 g.\textsuperscript{12} Approximately one half (40-50\%) of added sugars in the American diet are attributed to sugar-sweetened beverage (SSB) consumption.\textsuperscript{1} Furthermore, SSB provide the largest source of calories in the American diet,\textsuperscript{13} with about 50\% of American adults consuming at least one SSB per day.\textsuperscript{14} SSB include soft drinks, fruit drinks, sports drinks, energy drinks, sweetened milk, and tea and coffee with added sugars.\textsuperscript{15}

In addition to its link to obesity, increased consumption of added sugars has also been associated with chronic diseases such as diabetes, non-alcoholic fatty liver disease, and some forms of cancer.\textsuperscript{16} Public health organizations worldwide have also recommended a decrease in added sugars intake due to its role in nutrient displacement, dental caries, bone health, and excess energy intake.\textsuperscript{17} Due to the health impact of added sugars and SSB consumption, public health advocates have looked for ways to decrease intake of added sugars and SSB; one such method is
replacing added sugars intake with foods and beverages sweetened with non-nutritive sweeteners (NNS).

**Non-Nutritive Sweeteners**

NNS, also known as artificial sweeteners, provide little to no calories. One unique property of NNS is that they are much sweeter than sucrose, so a smaller amount is needed to sweeten a dietary item. Not only that, but some NNS, like saccharin and acesulfame potassium, are not absorbed by the human digestive system, so no actual energy is derived from the consumption of these NNS. These two properties allow NNS to sweeten foods and beverages to a level that is acceptable to the consumer, but that does not provide any additional calories to the diet. Besides their use in many beverages, NNS are also used in tabletop sweeteners (added to drinks like coffee and tea), toothpastes, desserts, chewing gum, and other items. At the moment, the approved types of NNS for use as food additives in the U.S. are acesulfame potassium, aspartame, saccharin, sucralose, neotame, and advantame. Stevioside and rebausioside A, which are both extracts from the *Stevia rebaudiana* Bertoni plant, and luo han guo (monkfruit) are “generally recognized as safe” (GRAS). The GRAS designation signifies the Food and Drug Administration, along with qualified experts, believe that no harm will come from consuming these products as intended and in their recommended quantity.

*Trends in NNS Use*

NNS are fairly new to the world of food science. Although saccharin has been around since the late 1880s and was used widely during World War II sugar shortages, it was not until the discoveries of aspartame, acesulfame potassium, and sucralose in 1981, 1988, and 1999,
respectively, that consumers became more interested in NNS.\textsuperscript{19} Recently, sucralose surpassed aspartame as the most popular NNS.\textsuperscript{22}

From 2005-2009, only 1.5% of over 85,000 food products available in the U.S. contained NNS, yet NNS was found in 15% of the volume of foods and drinks purchased.\textsuperscript{23} NNS were found in a large proportion of some product categories, including flavored waters (42%), yogurts (33%), and most diet beverages.\textsuperscript{23} Across the world, NNS was found in the largest proportion in carbonated diet beverages,\textsuperscript{19} and in the U.S., of all the beverages purchased by adults, 32% contained NNS.\textsuperscript{24}

A study conducted by Sylvetsky et al., which utilized data from the National Health and Nutrition Examination Survey (NHANES), found that NNS consumption increased from 26.9% in 1999-2000 to 32% in 2007-2008 in adults and from 8.7% to 14.9% in children.\textsuperscript{25} Despite the increase in NNS consumption, mean caloric intake was not found to be different for either adults or children.\textsuperscript{25} In order to be defined as a NNS consumer, subjects had to consume at least one food or beverage item that contained NNS within a single 24-hour dietary recall.\textsuperscript{25} A similar study using more recent 2009-2012 NHANES data, also conducted by Sylvetsky et al., found that NNS consumption had continued to increase with >41% of adults and 25% of children being considered NNS consumers.\textsuperscript{26} Both studies did not account for differences in consumption between types of NNS. In less than 10 years, consumption of NNS increased significantly, with a 54% increase in NNS consumption by adults (26.9% to 41.5%) and a >200% increase (8.7% to 25.7%) in children from 1999-2000 to 2009-2012.\textsuperscript{26} An interest in NNS in the general population has likely risen due to increased concerns on health and nutrition,\textsuperscript{19} as well as their increased availability in the food supply.\textsuperscript{26}
Demographics of NNS Users

Based on previous literature, NNS consumers were more likely to be older (55-74 years), \(^{19,26}\) non-Hispanic, white \(^{26}\) females. \(^{26,27}\) They were also found to be more educated, \(^{28-30}\) with a higher income, \(^{26}\) and more likely to be overweight or obese. \(^{28-30}\) A higher prevalence of obesity, T2DM, and abdominal obesity was also noted for NNS consumers. \(^{26,28,31}\) Lifestyle-wise, NNS users were likely to exercise more and be on a diet for weight loss. \(^{27}\) However, it is important to note that another study also found NNS consumption and minutes per week of moderate to vigorous physical activity to be negatively correlated. \(^{32}\)

Although the typical NNS consumer is described, prevalence of NNS consumption differs across ages, race, sex, and socioeconomic status. Sylvetsky et al., found that an increase in NNS intake has been observed in both children and adults of all socioeconomic statuses, as well as a more dramatic increase in use in females than in males. \(^{19}\) The most notable change related to age has been the increase in use by 6-11 year old children and adults older than 55 years. \(^{19}\) The increase of NNS consumption is likely related to the increase in intake of reduced-calorie drinks. \(^{19}\) Consumption of no-calorie beverages, however, has remained stable. \(^{26}\) Although an increase in NNS consumption in minorities has been observed, white Americans have the highest prevalence of NNS consumption when compared to non-Hispanic black Americans, Hispanic Americans, and other race groups. \(^{19}\) The most pronounced increase in NNS consumption by race has been observed in non-Hispanic black children. Consumption has also increased in non-Hispanic white and Hispanic adults. \(^{19}\)

Current research on the demographics and trends of NNS consumers is consistent, but this data is likely an underestimation of actual consumption due to the lack of accuracy and reliability in current NNS consumption evaluation methods. \(^{19}\)
Non-Nutritive Sweetener Intake and Health Outcomes

Weight Loss

NNS were originally created as substitutes for sugar with the goal of decreasing caloric intake and thus weight loss.\textsuperscript{33} Tate et al., analyzed the effects of replacing caloric beverages with either water or NNS beverages over a 6-month period.\textsuperscript{34} A control group, in which participants were not assigned any specific beverage and did not receive any education regarding beverages, was also used for comparison. Participants were encouraged to replace ≥ 2 servings of SSB with either NNS beverages or water. After the 6-month period, weight loss was observed across all groups (diet beverage: 2.5 ± 0.5% body weight loss, water: 2.0 ± 0.4%, control: 1.8 ± 0.4%), but the results were not significant for any of the groups.\textsuperscript{34} Although there was no significant weight loss, the study did find that the probability of losing 5% of body weight was twice as likely in the NNS beverage group than in the water group.\textsuperscript{34}

Peters et al., designed a similar but longer trial with 12-week active weight loss phase followed by a 40-week maintenance phase.\textsuperscript{35,36} The study sought to compare the differences between NNS beverages and water in weight loss. All participants attended weekly 60-minute group meetings led by registered dietitians and clinical psychologists that discussed topics such as portion sizes and food labels. Participants in the NNS group had to consume at least 24 fluid ounces of NNS and their water intake was not limited. Those in the water group had to consume at least 24 fluid ounces of water. The water group had to abstain from consumption of any NNS beverages for the full duration of the trial, but they were able to consume foods that contained NNS. There was no distinction between types of NNS consumed. At the end of the 12-week weight loss phase, weight loss was found to be more significant in the NNS group with 64.4% of participants in the group losing >5% of their body weight, while 43% of the participants in the
water group lost >5% of their baseline body weight. The 40-week maintenance phase of the study found that the NNS beverage group had 19% more subjects that had lost at least 5% of their body weight from baseline to week 52 when compared to the water group.

Madjd et al., tested the effectiveness of replacing diet beverages with water or the continued use of diet beverages in a 24-week weight loss program. A diet beverage (150 mL) was consumed once only during lunch (5 times/week). The other group consumed water during lunch, and both groups consumed water for the remainder of the day. The study found that while both groups had lost weight during the first 12 weeks and continued to slowly lose weight until week 24, the water group had a significantly greater weight loss than the diet beverage group (water: -8.8 ± 1.9 kg vs. diet beverages: -7.6 ± 2.1 kg). Along with that, both groups observed a significant decrease in body mass index (BMI), but the water group had a larger decline in BMI than the diet beverage group after 24 weeks (water: -3.4 ± 0.7 kg/m² vs. DB: -2.9 ± 0.8 kg/m²).

Many reviews and meta-analyses on this subject have been published. Miller and Perez found a modest reduction in BMI, body weight, fat mass, and waist circumference when added sugars were replaced with NNS. Azad et al., had varying results from randomized controlled trials in their review/meta-analysis. The paper studied five papers in regard to weight loss, but only two trials showed significant weight loss. The authors attributed the difference to the length of the trials (16-24 months compared to 6-month shorter trials). With that being said, the longer trials were also funded by industry, so it is harder to isolate the effects of the trial duration from any possible sponsorship bias.

Research on the effect of NNS intake and weight loss is mostly limited to diet beverages as a whole and does not usually include foods with NNS or differentiation between types of NNS consumed. However, one of the longest randomized controlled studies studying the relationship
between weight loss and NNS intake examined only aspartame. This study was conducted on 163 obese women and in 3 phases: a 16-week weight loss phase, a 1-year maintenance phase, and a 2-year follow-up. Participants were randomly assigned to either a group that consumed foods or beverages sweetened with aspartame or to a group where they were to abstain from consumption of aspartame during the full duration of the study. At the end of the weight loss phase, both groups lost an average of 10% of their baseline body weight, but at the end of the maintenance and follow-up phases, the aspartame group regained less of the weight lost than the non-aspartame group (aspartame: 2.6% and 4.6%, non-aspartame: 5.4% and 9.4% of body weight regained at weeks 71 and 175).40

Research showing the benefits of NNS consumption for weight loss have been varied, with some randomized controlled trials showing success in weight loss and weight maintenance,34-40 but results from other randomized controlled trials as well as meta-analyses do not fully support the benefit of NNS intake in weight loss.34,37,39 Studies vary in length, do not usually differentiate in differences in NNS type, exclude NNS foods, and are usually combined with exercise programs.

Weight Gain

NNS consumption has been linked with weight gain in mostly observational studies but also in a few randomized controlled trials.28,31,41 Several etiologies have been proposed to explain potential mechanisms leading to weight gain. One of these mechanisms is the possibility that the lack of energy provided by NNS might disrupt the link between taste responsiveness, appetite, and energy intake.42 This disruption is thought to increase appetite for sweet foods, decrease the ability to control this response, as well as decrease satiety, and thus lead to weight gain.42 To
date, this exact relationship has yet to be proven, but there are studies that continue to fuel this hypothesis.\textsuperscript{27,31,38,39,41}

Stellman and Garfinkel were the first to publish the association between NNS intake and weight gain in 1986.\textsuperscript{41} In 1982, American Cancer Society volunteers recruited subjects for a prospective mortality study. Potential subjects had to be at least 30 years of age and were not chosen at random so that volunteers would have easy and convenient access to them for the duration of the study. Questionnaires were filled out biennially until 1988. At baseline, some of the basic questions included age, current weight, weight one year ago, height, and if there had been a major diet change within the past year. Specific questions relating to NNS were then asked. These included: “Do you or have you ever added artificial sweeteners (saccharin or cyclamates) to coffee, tea, or other drinks or foods? (answers including yes, currently, formerly, or never)” and “If [you] ever used artificial sweeteners, indicate amount per day and for how long,” with a space to indicate the number of packets, drops, and tablets. Participants were also asked about the quantity and duration regarding both current and former use of diet soda and diet iced tea. Food frequency questionnaires (FFQ) were also utilized to determine food consumption patterns.

Of the original 1.2 million women and men recruited (685,748 women), only 78,694 subjects were chosen to avoid adjusting for potential confounding variables such as sex, age, socioeconomic status, etc. Characteristics of the chosen subjects included women, ages 50-69, with at least high school education, no history of chronic disease such as cancer, diabetes, heart disease, or conditions that may affect weight and dietary behavior. Subjects were included if they had never used NNS or were long-term users (answered “yes, currently” to the first question, and
had used packets, tablets, drops, and diet beverages for at least 10 years). Former NNS users were not included.

Besides the answers to the questions previously mentioned, there was no other specific quantity of NNS intake utilized to define a NNS user. The study concluded that users of NNS were more likely to gain weight than non-users. The FFQ utilized on participants did not show any differences in food intake between users and non-users. The study did not determine what specific NNS subjects may have consumed. Since cyclamate was banned in 1969 and aspartame was not widely available until after 1982, most of the results were based on saccharin consumption.

Since then, additional observational studies and meta-analyses have supported a relationship between NNS intake and weight gain, and increased BMI. In 2008, Fowler et al., published a study using data from the San Antonio Heart Study. This prospective study included 5,158 individuals aged 25-64 years old. The first cohort was studied from 1979-1982 and the second cohort from 1984-1988. Eight years later, 74% of the 4,998 surviving patients were included in a follow-up. At baseline, the cohorts were asked specific questions regarding intake of SSB. If SSB intake was reported, they were also asked if any sugar-free alternatives were also consumed. Sweeteners for coffee and tea were also included, and they were asked if they “usually” consumed sugar or sugar substitutes as well. Consumption of NNS from diet soda, coffee, and tea was summed, and NNS-sweetened beverage consumption was separated into four quartiles (NNS beverages consumed per week: <3, 3-10, 11-21, and 22+). The amount (in fluid ounces) of what was considered one NNS beverage was not specified.

A significant dose-response relationship was observed between NNS consumers and overweight/obesity, as well as for BMI increase. In the first cohort, NNS users in the fourth
quartile (22+ NNS beverages consumed/week) experienced a 78% greater increase in BMI than non-users. Similar results were observed in the second cohort. Overall, BMI change was 47% higher in NNS users than non-users (+1.5 vs. +1.0 kg/m$^2$, respectively)$^{27}$.

Chia et al.’s study utilizes data collected from the Baltimore Longitudinal Study of Aging (BLSA) during 1984 to 2012.$^{31}$ Subjects were considered NNS consumers when consumption of a food or drink containing NNS was noted via dietary records. However, no minimum quantity of NNS was needed to be consumed to determine a subject as a consumer. Results found that even when taking diet into account, NNS users gained more weight, had a greater incidence of abdominal adiposity, and increased their waist circumference as compared to NNS nonconsumers.$^{31}$ Of interest is the fact that weight gain was still observed even though the BLSA cohort was a highly motivated and health conscious group. During the follow-up period, only 17% of the cohort developed obesity, in comparison to the 38% prevalence in American adults in 2014.$^{31}$ Although there is no way to ascertain that NNS consumption was the sole cause of weight gain, it is interesting to see this increase in weight in NNS consumers despite being part of a group healthier than most Americans.

The studies discussed support a relationship between NNS consumption and weight gain, but most of these results come from observational studies. Results from these types of studies must be interpreted with caution, as even though some studies provide data over very long periods of time, it is difficult to establish a causal relationship between NNS consumption and weight gain. Not only that, but most studies also do not control for diet, so it is difficult to determine if weight gain is a direct cause from intake of NNS or from other unaccounted confounders.
Effects on Glucose Levels

Obesity is associated with many non-communicable diseases, one of them being T2DM. The relationship between added sugars consumption and T2DM is well established, and added sugars consumption is known as one of the biggest factors in the progression of the disease.\textsuperscript{13} Due to their low-caloric value, as well minimal blood glucose response, the consumption of NNS in both overweight and diabetic patients is common.\textsuperscript{44} However there is controversy regarding their impact on glucose levels.

Several observational studies have linked the consumption of NNS to abnormal glucose metabolism markers.\textsuperscript{44-46} A paper published on the Multi-Ethnic Study of Atherosclerosis by Nettleton et al., found that 30\% of participants who consumed at least one diet soda per day developed high fasting plasma glucose values ($\geq 126$ mg/dl) compared to those who did not regularly consume diet soda.\textsuperscript{45} Furthermore, the study also found that consumers of diet soda had a 67\% greater chance of developing T2DM than non-consumers.\textsuperscript{45} Using results from the European E3N study, Health Professionals Follow-Up (HPFS), and the European Prospective Investigation into Cancer and Nutrition (EPIC), an opinion paper published by Swithers et al., also suggested a link between NNS beverage intake and an increased risk for T2DM.\textsuperscript{46} Data from the EPIC study suggested that the risk for T2DM increased in those consuming at least one NNS beverage per day,\textsuperscript{47} and the risk for T2DM for participants in the European E3N study and HPFS more than doubled for those consuming NNS beverages in the highest quartile when compared to non-consumers.\textsuperscript{30,48} Kuk et al., focused on the associations between sucrose, fructose, aspartame, and saccharin consumption in 2,856 American adults participating in NHANES data collection (1988-1994).\textsuperscript{44} Results from this observational study found that only those who reported consumption of aspartame had a positive association with BMI and glucose intolerance as
compared to those who did not consume aspartame. In this study, consumption of aspartame was correlated with greater glucose impairment in obese individuals than leaner individuals. While these observational studies show a positive relationship between NNS consumption and risk for T2DM, higher fasting plasma glucose values, or glucose intolerance, none of the studies discussed controlled for dietary intake.

Animal models have yielded similar results to those from observational studies. Collinson et al., looked at the effects of aspartame consumption on C57BL/6J mice beginning in utero through their first twenty weeks of life. At the conclusion of the study, impairment of insulin sensitivity (via fasting glucose levels) was observed in both male and female groups, but most notably in the male group. Swithers et al., published a study looking at a total of six experiments carried out in adult male Sprague-Dawley rats. Sample sizes in the experiments ranged from 16 to 72 mice. Although the experiments’ study designs varied slightly, the main aim of the study was to examine the effect of previous consumption of saccharin on body weight and glucose metabolism. Overall, results from the six experiments showed that mice with previous exposure to saccharin had higher blood glucose levels within eight to sixteen minutes after consuming either a glucose solution or novel sweet-tasting caloric test meal. Animals that were previously exposed to saccharin had impaired glycemic responses, but insulin release was not affected in either group in any of the experiments.

Some studies in animal models suggest that impaired glucose tolerance may be due to NNS altering gut microbiota. Studies by Suez et al., and Palmnäss et al., both explore this theory and show similar results. Of importance is Suez et al.’s study, which found a decrease in glucose tolerance without any weight gain in mice consuming either saccharin, sucralose, or aspartame. After observing this effect, the researchers carried out a fecal transplantation to see
if saccharin consumption directly affects gut microbiota. To test this, fecal matter from naïve mice was cultured under the presence of saccharin (5 mg ml$^{-1}$) or a control growth media. Nine days after incubation, the fecal transplants were performed on germ-free mice via gavage. Results showed that the mice which received the fecal matter cultured under saccharin had significantly higher glucose intolerance than those who received the control culture. Suez concluded that while NNS may not provide any calories to the human diet, it may affect the composition of gut microbiota, and thus affect physiological processes such as glucose metabolism.

Palmnäs et al., designed a similar experiment, this time focusing on the effect of a chronic low dose of aspartame in rats. The amount used (5-7 mg/kg/d) was supposed to be the equivalent of adults consuming 2-3 cans of diet soda per day and was scaled down to each rat’s weight. Four treatment groups (chow water, high fat water, chow aspartame, high fat aspartame) of diet-induced obese Sprague-Dawley rats (n = 10-12 per group) were used. Results from an oral glucose tolerance test administered at week 8 showed that fasting plasma glucose levels were higher in rats consuming aspartame in both chow and high fat diet. Blood glucose area under the curve was higher in the high fat diet than in chow, but aspartame consumption had no effect on this value. After week 9, an insulin tolerance test was administered. Results showed elevated blood glucose levels throughout the duration of the test for both chow and high fat diet aspartame groups. Palmnäs et al. concluded that the study observed elevated fasting glucose levels and an impairment of insulin-stimulated glucose disposal via an insulin tolerance test in rats consuming aspartame in both high fat and chow diets. Distinct microbiota changes in mice consuming aspartame were also observed. Although rodent physiology is different from human physiology, there is a possibility these results may be replicable in humans.
Randomized controlled trials in humans have varying results. Madjd et al., performed two similar studies looking at the effect on weight status by replacing diet beverages with water during lunch over a 24-week weight-loss intervention. The first study focused on overweight and obese women, while the second study focused on overweight and obese women diagnosed with T2DM. The first study observed significant improvements in both groups, however, the water group, as compared to the diet beverage group, demonstrated a greater significant improvement in fasting serum insulin concentrations (water: \(-2.84 \pm 0.77 \text{ mU/L}\), diet beverages: \(-1.78 \pm 1.25 \text{ mU/L}\)) and 2-hour postprandial glucose (water: \(-1.02 \pm 0.55 \text{ mmol/L}\), diet beverages: \(-0.72 \pm 0.27 \text{ mmol/L}\)). The second study had similar results, with significant improvements in both groups, but significantly greater improvements for those drinking water over diet beverages in fasting plasma glucose (water: \(-1.63 \pm 0.54 \text{ mmol/L}\); diet beverages: \(-1.29 \pm 0.48\)), 2-hour postprandial glucose (water: \(-1.67 \pm 0.62 \text{ mmol/L}\); diet beverages: \(-1.35 \pm 0.39\)), HOMA IR (water: \(-3.20 \pm 1.17\); diet beverages: \(-2.48 \pm 0.99\)), and fasting serum insulin (water: \(-5.71 \pm 2.30 \text{ m IU/mL}\); diet beverages: \(-4.16 \pm 1.74 \text{ m IU/mL}\)). While both studies showed a significantly greater improvement in glucose markers for those consuming water over diet beverages, improvements were still positive for the diet beverage group.

Suez et al., observed seven participants who did not usually consume NNS for one week. During days two through seven, participants were instructed to consume three daily doses of saccharin (120 mg per dose, which did not exceed the FDA’s maximum acceptable daily intake of 5 mg/kg). Results showed that four out of the seven participants developed significantly poorer glycemic response, determined via an oral glucose tolerance test five to seven days after consumption of the NNS, when compared to their own glycemic responses from days one through four. The other three participants saw no change in their glycemic response.
Analyses of the subjects’ microbiomes showed composition changes in those subjects that experienced changes in glycemic response, while those whose glycemic response was not affected had less pronounced changes.51

As previously mentioned, since NNS are used as substitutes for added sugars, it is important to assess that this substitution is beneficial. Observational trials as well as randomized controlled trials in rats have shown a relationship between NNS consumption and increased fasting plasma glucose,45,49,52 increased risk of T2DM,30,45-47,54 decreased glucose tolerance,44,51 increased blood glucose levels,50 and altered gut microbiota.51,52 Meanwhile, a couple of randomized controlled trials in humans have shown improved glucose measures in both patients drinking NNS or water during a weight loss trials, but the changes were more significant in the water group.37,53 A randomized controlled trial in humans has shown an effect between saccharin consumption, decreased glycemic response, and a change in gut microbiota.51 Although no energy is provided by the consumption of NNS, it does seem to alter gut microbiota composition and thus may affect metabolic markers as well.51,52 Further research is necessary on the specific effects of NNS consumption may have on gut microbiota, glucose metabolism, and other health markers that may be affected by the altered microbiota.

Blood Lipids

Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in American adults.55 Some of the risk factors for CVD include increased levels of blood cholesterol, increased triglyceride levels, increased low-density lipoprotein levels (LDL), low high-density lipoprotein levels (HDL), diabetes, and overweight/obesity.56 Several studies have shown a positive association between the consumption of sugary drinks and the risk of a heart
attack or an increased risk for heart disease.\textsuperscript{54,57} As NNS is used to replace added sugars, it is important for scientists to study the possible relationship between NNS intake, lipid levels, and heart health.

Studies focusing on the relationship between NNS and lipid levels are scarce, as most studies focus on the association between NNS intake, body weight, and glucose metabolism. A couple of studies show a relationship between NNS intake and increased blood lipid levels.\textsuperscript{58,59} von Poser Toigo et al., studied the effects of NNS consumption on the offspring of rats, who consumed various types of NNS.\textsuperscript{58} The mother rats were divided into four groups: control (water), sucrose, saccharin, and aspartame. They were then fed chow and water infused with the sweetener assigned to them for 30 days. Afterwards, they were placed with a male (3:1 ratio) to encourage mating. Twenty-one days after birth, the offspring were separated from the mother and divided by sex. The pups then had free access to chow and tap water and were sacrificed at 112 days of age for analysis.

When compared to the control group, a significant increase in triglyceride levels were observed in male sucrose and aspartame groups, as well as the female sucrose group. There was a significant increase in LDL levels for male sucrose and female sucrose and aspartame groups when compared to the control group. The male aspartame group was the only group that had a significant increase in LDL levels when compared to all groups. For triglycerides, only males in the sucrose and aspartame group had a significant increase when compared to the control. For both male and female groups, saccharin consumption led to no significant increases in any of the blood lipids measured. Both male and female groups observed significant increases in LDL levels with the consumption of aspartame, but only the male groups had significant increases in
multiple blood lipid levels (total cholesterol, LDL, and triglycerides) when compared to the female group.\textsuperscript{58}

Hess et al., found a positive relationship between both total NNS and aspartame intake and triglyceride levels, but not LDL, HDL, or total cholesterol in an observational study examining human adults.\textsuperscript{59} However, randomized controlled trials in humans have yet to support this observation as the current available research demonstrates a positive or null impact of NNS on lipid levels.\textsuperscript{37,53,60,61}

In a study conducted by Campos et al., no differences in post-prandial triglyceride concentrations were observed after a 12-week intervention that replaced SSB with NNS beverages in both patients with and without hepatic steatosis.\textsuperscript{60} Likewise, Madjd et al., carried out two studies with similar designs, just different subjects (overweight/obese women and overweight/obese women with T2DM).\textsuperscript{37,53} The first study observed the effects of replacing water with diet beverages or the continued use of diet beverages in a weight loss program with overweight/obese women.\textsuperscript{37} After the 24-week program, reductions in total cholesterol, LDL, and triglyceride levels, and increased HDL levels were observed in both groups, but there were no significant differences in between the groups over time.\textsuperscript{37} The same results were observed when this study was replicated on overweight/obese women with T2DM.\textsuperscript{53}

A study by Raben et al. highlights the strengths of replacing traditional sweeteners with NNS to help improve blood lipid levels.\textsuperscript{61} Comparing a diet made up of food and beverages sweetened with sucrose (2 g/kg/body weight) or with artificial sweeteners (type not specified), it was found that the consumption of a diet sweetened with sucrose for 10 weeks significantly increased postprandial triglyceride concentration as well as total fasting triglyceride concentration.\textsuperscript{61} However, once the results of postprandial triglyceride concentration were
adjusted for differences in fasting values, and changes in body weight, energy, and sucrose intake at week 10, the difference between groups lost its significance. Although total fasting triglyceride concentration was significantly higher at week 10 in the sucrose group, the changes from week 0 to week 10 were not significant between the sucrose and artificial sweetener (type not specified) groups. Over time, total fasting triglyceride concentration in the NNS group slightly decreased (sucrose: 1.48 ± 0.18 to 1.75 ± 0.24 mmol/l, artificial sweeteners: 1.07 ± 0.12 to 1.01 ± 0.14 mmol/l). Along with that, fasting cholesterol concentrations were not different between groups. This study concluded that consumption of a traditional sucrose sweetener resulted in significant postprandial elevations of lipidemia when compared to the use of artificial sweeteners.61 Although more research is needed, this opens the possibility of using NNS as a potential tool for blood lipid management in patients wishing to continue the use of sweetened drinks.

Literature studying the relationship between NNS consumption and blood lipids is limited, and the current research provides mixed results. In randomized controlled trials conducted on rats, the consumption of aspartame seems to increase triglyceride and LDL levels.58 An observational trial on humans showed similar results with a positive relationship between total NNS and aspartame intake, and triglyceride levels, but randomized controlled trials in humans have not confirmed these findings.37,53,60 Raben et al.’s work highlights the importance of continuing work on this subject as it shows the negative effects of continued sucrose use on blood lipids and the potential of NNS as an alternative sweetener source.61
Limitations to Non-Nutritive Sweetener Research

Although current NNS-related research is diverse, it does have its limitations. Much of the uncertainty surrounding NNS consumption lies on the study design, the lack of randomized controlled trials in humans, the difficulty of determining NNS consumption patterns, the use of diet soda as a proxy for NNS consumption, and the practice of combining all types of NNS into one variable.

The majority of studies showing a negative relationship between various health markers and consumption of NNS come from observational studies.\textsuperscript{28,31,41,44-46} Although observational studies are helpful in that they allow scientists to collect data over long periods of time, it is difficult to establish a causal relationship between NNS consumption and its possible negative effects on health. The minimal number of randomized controlled trials may be due to the difficulty of controlling several variables, such as diet, physical activity levels, accurate assessment of NNS intake, as well as expense. Randomized controlled trials in animal models have attempted to address some of the issues presented by randomized controlled trials in humans. Studies conducted on animals allow scientists to easily control what and how much of a food is consumed, as well as allow scientists to use specific types of NNS rather than diet soda. These studies are helpful in that scientists are able to fully control the dietary intake of the subjects, therefore enabling them to fully know how much NNS a subject consumes. Although helpful, this presents a problem as rodent physiology is different from human and not all results are applicable to the human population.

Although randomized controlled trials are the gold standard of research, one issue with current NNS research is the length of the studies, with studies in humans being as short as one week,\textsuperscript{51} or as long as three years.\textsuperscript{40} Longer randomized controlled trials are necessary to properly
assess the effects of long-term NNS consumption. Some studies are also combined with weight loss interventions, therefore some weight loss is expected in the results; thus, despite the intervention’s design, it may be difficult to extract the true impact of NNS intake. An additional issue with current randomized controlled trials in humans is the use of diet soda as a proxy for NNS consumption. This presents two problems. First, this may greatly underestimate the amount of NNS people consume as it is also found in many other food products. As Hess et al. points out, by considering subjects in their study as NNS users if they consumed the equivalent of NNS found in 1 fl oz of diet soda (3 mg acesulfame potassium, 17 mg aspartame, 12 mg saccharin, and 6 mg sucralose) from either foods or beverages, they had 50% of their subjects characterized as NNS users as opposed to 22%, had diet soda been used as the only proxy. Hedrick et al. also found that the top contributor of total NNS intake in a rural population was tabletop sweetener (37%), followed by diet tea (34%) and diet soda (27%). Therefore, by using diet soda as proxy for NNS, studies are excluding other sources of NNS such as tabletop sweeteners. The second problem is that there is not one single type of diet soda used in studies, therefore subjects could be consuming different amounts and types of NNS, thus possibly affecting the generalizability of results.

A similar problem in randomized controlled trials is the lack of differentiation between specific types of NNS. Due to the use of diet soda as a proxy for NNS consumption, NNS is usually studied as a whole rather than by its type. There are few studies in humans that focus on different types of NNS. Even in those few that did examine different types of NNS instead of NNS as a whole, only one study focused on multiple types of NNS (more than two), therefore making it difficult to compare the effects of various NNS on human health. This
presents an issue because the varying types of NNS are structurally different and metabolized in differing ways, therefore their effects on the body could be distinct as well.62

Other issues related to study design of randomized controlled trials in humans include the reliance on FFQ, 24-hour dietary recalls, and self-reported dietary records to assess dietary intake and the lack of control for subjects’ diets. While the only studies discussed that were able to fully control their subjects’ diets were those performed on rats, Raben et. al was able to control a great portion of their subjects’ diets. This, however, is rare on studies performed on humans.61 Both of these issues make it difficult to accurately assess the amount of NNS consumed by subjects. Although some studies have been able to compare more than one type of NNS, the current literature review did not find a study that comprehensively looked at the main four types.

One last limitation is the lack of community-based participatory research (CBPR) interventions in the U.S. focusing on NNS consumption and its effects. CBPR interventions are an equitable collaboration between researchers, organizational representatives, and, most importantly, the population being studied to help address any health or social inequalities.63 To date, there does not seem to be any CBPR interventions, that are also randomized controlled trials, that focus on NNS consumption. CBPR is helpful because it allows scientists to apply and test evidence-based practice to local communities that may benefit from the results.64 Along with that, CBPR interventions allow scientists see the effects of an intervention in a more realistic setting. Although lab-based randomized controlled trials allow scientists to control for more variables than community-based settings do, they do not represent a setting in which subjects are a part of every day. Although there are not any CBPR studies that focus specifically on NNS consumption, there are a few that focus on decreasing the consumption of SSB. Targeting
the decrease of SSB consumption presents the opportunity to study whether SSB-reduction interventions spontaneously increase NNS consumption to compensate for the decrease in SSB. Along with that, the demographic information of NNS consumers, both before and after the intervention, could be utilized to successfully target NNS as a possible tool for the reduction of SSB consumption for specific groups of people. The consumption of NNS might not be applicable to every person in the population, but it is important to know which demographics might be receptive to replacing SSB with NNS beverages as a SSB-reduction strategy in order to help inform future studies.

**Conclusion**

Current research has provided conflicting evidence for the impact of NNS intake on health by demonstrating a link between the consumption of NNS with weight gain and weight loss, improved and worsened glucose metabolism, and some improved blood lipid levels. However, the majority of the NNS investigations have various notable limitations. The main limitation being study design, with many studies either being observational studies in humans or randomized controlled trials in rodents. Randomized controlled trials in humans are few in numbers and are not without limitations as well. Some of the limitations with the human trials include the lack of control for subjects’ diets, the use of diet soda as the only proxy for NNS consumption and failing to compare the different types of NNS.

Future research must focus on randomized controlled trials in humans, as causality cannot be proven in observational trials. NNS should also be studied by type and compared, rather than as a whole, and studies must not rely on the use of diet soda as a proxy for NNS consumption. Although diet beverages are a popular method for people to consume NNS, it is
not the only method by which people consume them. A focus on CBPR interventions is needed
to help scientists mirror a more realistic setting in which consumers would be consuming NNS,
thus having results that are representative of a free-living population. Although the demographics
of the common NNS consumer are known, it is important to explore how the demographics of
consumers may change when exposed to an SSB-reduction trial. Exploring these possible
changing demographics can help target these individuals, who may be receptive to the
replacement of SSB beverages with NNS, in future studies. Addressing these limitations is
important to help strengthen current NNS research, expand upon it, and help reach out to specific
groups of people that may be more receptive to NNS consumption than others.
References


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Chapter 2: Changes in Non-Nutritive Sweetener Consumption Patterns in Response to a Sugar-Sweetened Beverage Intervention

Introduction

The typical American diet exceeds the recommended amount of saturated fats, added sugars, sodium, refined grains, and consequently calories. Consumption of added sugars in particular has been targeted by health professionals to help reduce the excessive caloric intake by Americans. In 2015, the Dietary Guidelines Advisory Committee’s report showed a strong correlation between added sugars consumption and increased overweight or obesity rates in all age groups. In response, the 2015-2020 Dietary Guidelines for Americans (DGA) recommended that added sugars comprise less than 10% of calories consumed daily. Unfortunately, less than half (42%) of Americans, 2 years and over, are meeting this recommendation.

The overconsumption of added sugars is linked to multiple negative health outcomes. In addition to its relationship with obesity, increased consumption of added sugars has also been associated with chronic diseases such as diabetes, non-alcoholic fatty liver disease, and some forms of cancer. Due to added sugars’ effect on health and their widespread consumption, public health advocates have searched other alternatives. One such method is the replacement of added sugars in food and beverage products with non-nutritive sweeteners (NNS), also more commonly known as artificial sweeteners to the general public.

Approximately half (40-50%) of added sugars in American diets can be attributed to the consumption of sugar-sweetened beverages (SSB). NNS are most commonly used in diet sodas as substitutes for added sugars. Because of this, consumers look to beverages sweetened with NNS as a substitute for SSB. NNS are an attractive replacement because they still provide a sweet taste but with little to no calories. Besides their popular use in diet beverages, NNS are
also used in tabletop sweeteners (added to drinks like coffee and tea), desserts, chewing gum, and other items such as toothpaste. Current, the NNS approved for use as food additives by the U.S. Food and Drug Administration include acesulfame potassium, aspartame, saccharin, sucralse, neotame, and advantame. Stevioside and rebaudioside A, which are both extracts from the Stevia rebaudiana Bertoni plant, and luo gan guo (monkfruit) are not approved as food additives, but rather have “generally recognized as safe” (GRAS) status.

Over time, consumption of NNS has increased. An analysis of National Health and Nutrition Examination Survey data, published in 2016, demonstrated that in less than 10 years, consumption of NNS increased significantly, with a 54% increase in the number of adult consumers (26.9 to 41.5%) and a >200% increase (8.7 to 25.7%) in the number of children consumers from 1999-2000 to 2009-2012. An interest in NNS in the general population has likely risen in conjunction with concerns on health and nutrition, as well as their increased availability in the food supply. However, research on the exact health benefits and/or detriments of NNS consumption is limited.

Results from research on the effects of NNS consumption are varied. Results range from desirable, such as weight loss and improved fasting serum insulin concentrations and 2-hour postprandial glucose, to undesirable such as weight gain or increased fasting plasma glucose levels. Results are not limited to the ones mentioned, but the variance in the results make it difficult for scientists to ascertain whether or not NNS are beneficial or harmful to human health. The inability to reach solid conclusions regarding the impact of NNS intake on health may be attributed to several limitations related to this area of research. These limitations include the use of observational studies rather than randomized clinical trials on humans, randomized controlled trials on rodents, the inclusion with weight loss
interventions, the use of diet soda as a proxy for NNS consumption, and the study of NNS as a whole rather than by specific type.

An additional area of research that has yet to be explored is the effect of a SSB intervention on self-imposed changes in NNS consumption, as well as the characterization of participants who became NNS consumers. This is significant because the characterization of NNS consumers after an intervention like this could be helpful in targeting specific people that are receptive to the replacement of added sugars with NNS. Additionally, it is important to look at specific dietary sources of NNS consumption as there are many varying sources that NNS are found in. This can further help design future interventions by knowing popular and preferred forms of NNS products.

**Aims and Hypotheses**

The purpose of this secondary analysis was to explore changes in frequency of NNS consumers, NNS consumption by specific type and total NNS, and dietary sources of NNS over a 6 month period for participants enrolled in a 6 month community-based SSB reduction trial known as Talking Health. Participants were either randomized into SIPsmartER (SSB reduction arm) or MoveMore (increased physical activity arm) intervention groups. Along with changes in NNS consumption patterns, demographics of SIPsmartER participants categorized into three SSB-NNS consumption change groups were compared.

**Aim 1**: To assess changes in NNS consumption patterns of an adult population in response to either the SIPsmartER or MoreMore intervention over the 6 month period. Variables to be explored include changes in the 1A) frequency of NNS consumers and non-consumers, 1B) amount of NNS consumed by specific types and total, and 1C) dietary sources of NNS.
**Hypothesis 1:** Minimal research has been conducted on this area. This was an exploratory aim to determine how NNS consumption patterns changed over time in response to changes in SSB; it was hypothesized that NNS beverage consumption would increase as it replaced SSB, as would packets of NNS for coffee and tea for SIPsmartER participants as compared to the MoveMore participants. It was also expected for the frequency of NNS consumers to increase over time in the SIPsmartER group as compared to MoveMore group.

**Aim 2:** To determine if there were significant differences in the demographic profiles of SIPsmartER participants who used NNS as a tool to reduce SSB intake and those who did not. Participants were categorized into three SSB-NNS consumption change groups: 1) decreased SSB with increased NNS, 2) decreased SSB but no increase in NNS, or 3) increase/no change in SSB, regardless of change in NNS.

**Hypothesis 2:** This area of research is unexplored. It is unknown which demographic profiles are more likely to use NNS as a tool to reduce SSB intake after a SSB intervention. Based on previous literature, NNS consumers are more likely to be older (55-74 years old), non-Hispanic, white, and female. They are also more likely to be more educated, with a higher income, and a higher prevalence of overweight or obesity.

**Methods**

*Study Design and Subjects*

This secondary analysis utilized data from Talking Health, a type 1 effectiveness-implementation hybrid randomized-controlled trial targeting community residents in rural southwest Virginia. The primary objective of Talking Health was to examine the effectiveness of a 6 month intervention trial aimed at decreasing SSB intake (SIPsmartER) when compared to a
matched-contact group targeting physical activity (MoveMore). In the original investigation, both SIPsmartER and MoveMore groups decreased their SSB intake over the six months, but only the SIPsmartER group did so significantly.

Talking Health targeted residents in an 8-county rural region in southwest Virginia. On the 9-point Rural-Urban Continuum Codes (1=urban, 9=completely rural) the targeted counties had an average rurality status of 6.1 ± 2.5 (ranging from 2 to 9). The location of this study, southwest Virginia, is of importance as low socioeconomic adults in rural areas have a higher risk of consuming more SSB. Likewise, rural, underserved communities have less access to healthcare and less exposure to research interventions they may benefit from. According to U.S. Census Bureau data, some characteristics of residents of these areas include Caucasian (95%) with ≤58% high school education, and 18% living below the federal poverty level.

Eligible participants for Talking Health were English-speaking adults ≥18 years of age, who consumed ≥200 SSB kcals/day, with no self-reported contraindications for physical activity, and with regular access to a telephone. Although not part of the inclusion criteria, recruiters targeted low socioeconomic individuals and those with limited health literacy. Recruitment methods varied per county. Extension Program Assistants were used for recruitment activities in several counties. Participants were recruited from organizations that served low resource populations, such as Free Health Clinics or Department of Social Services. Other recruitment methods included flyers posted in locations such as grocery or retail stores, newspaper advertisements, and/or recruitment postcards mailed directly to residents’ homes. Low income residencies were targeted by using either an existing Cooperative Extension database and/or mail source company.
Data was collected at baseline, 6 months, and 12 months post-intervention. Participants were either randomized into SIPsmartER (n=155) or MoveMore (n=146) at baseline. The goal of SIPsmartER was to decrease SSB consumption to the recommended level of ≤8 fluid ounces per day, while the goal of MoveMore was to increase physical activity to the recommended amount of 150 minutes of moderate-intensity and/or muscle strengthening activities per week. Over the 6 month period, both interventions consisted of 3 small group classes, 1 live teach-back call, and 11 interactive voice response calls. During the 1 of the 3 small group classes, SIPsmartER participants received information on the negative health effects of SSB overconsumption and potential replacements such as water and NNS. The controversy surrounding NNS consumption was addressed, and NNS was determined to be a healthy alternative to SSB if consumers wished to consume them. Meanwhile, MoveMore participants received no information on NNS during their small group classes.

For the purpose of this secondary analysis, participants who did not return at 6 months (n = 79), were pregnant at either baseline or 6 months (n = 5), or were considered an outlier (more than 3 standard deviations from the mean for total NNS consumption) at either baseline or 6 months (n = 12) were not included in this analysis. Additionally, 7 participants were removed for missing data regarding NNS consumption. A final sample for SIPsmartER (n = 101) and MoveMore (n = 97) was calculated. Furthermore, for aim 2, only SIPsmartER participants were analyzed.

Materials and Methods

Demographic characteristics (age, sex, ethnicity/race, income, education status) were collected at baseline. At baseline and 6 months, anthropometrics (height, weight, body mass
index [BMI]) and three 24-hour dietary recalls were collected. Weight was measured without shoes and light clothing using a calibrated digital Tanita scale (Model: 310 GS) at both time points, and height was only measured at baseline via a research-grade stadiometer.

Dietary intake was collected by trained researchers, supervised by a PhD-level Registered Dietitian Nutritionist, via three non-consecutive 24-hour dietary recalls within a two-week period, capturing two weekdays and one weekend day. Interviewer-administered methods were used to collect dietary recalls, with one completed at baseline in-person and the following two completed via unannounced telephone calls. Nutritional analysis software (Nutrition Data System for Research [NDS-R] 2011, University of Minnesota) was used to analyze the 24-hour dietary recalls.

Data Analysis

To characterize total and specific types of NNS, frequency of NNS consumers to non-consumers, and dietary sources, baseline and 6 month 24-hour dietary recalls were analyzed via NDS-R. The milligrams (mg) of NNS in NNS-containing food and beverage items were then extracted from the component/ingredient level of participants’ dietary intake. Categorization of NNS consumers and non-consumers in both SIPsmartER and MoveMore groups was determined based on the total mg of NNS from both foods and beverages in a participant’s diet. A participant was considered a NNS consumer if they consumed the equivalent of NNS found in 1 fl oz of diet soda from either foods or beverages. This corresponds to 3 mg acesulfame potassium, 17 mg aspartame, 12 mg saccharin, or 6 mg sucralose. This categorization ensured that NNS sources other than diet beverages were accounted for when determining NNS consumer status.
**Aim 1:** For this overall aim, SIPsmartER and MoveMore participants’ NNS consumption patterns were examined. 1A) Changes in NNS consumer/non-consumer frequencies over time within and between groups were analyzed. 1B) Changes in specific NNS types (aspartame, saccharin, acesulfame potassium, sucralose) and total NNS within and between groups were compared. Each group’s average daily NNS intake by mg content was also determined for specific types and total. 1C) Using only NNS consumers (at baseline, 6 months, or both) changes in the most commonly consumed NNS types were identified, along with major dietary sources (e.g., diet soda, packets, etc.) over time within and between groups. Dietary sources were analyzed by absolute total mg intake and number of instances. For example, if a participant consumed two bottles of diet soda and one packet of tabletop sweetener in a single day, this participant would have had two different instances of NNS intake. If a participant consumed three bottles of diet soda over a period of two days (one bottle on the first day, two on the second), the total instances of diet soda consumed over that period of time was listed as two.

**Aim 2:** Only SIPsmartER \((n = 101)\) participants were utilized for this aim. Comparison groups were determined via a continuum of changes in both SSB and NNS consumption (increase/decrease or no change, small decrease/increase, medium decrease/increase, and large decrease/increase) for a total of 16 groups. The groups of small, medium, and large changes were determined by dividing the participants into tertiles for both SSB and NNS intake. A fourth group was made for SSB and NNS that included increase/no change or decrease/no change, respectively. Similar groups were combined to create larger and more comparable groups for a total of 3 groups. They were categorized by amount of change and are as follows (See Table 1):

1) Group 1: decreased SSB consumption (i.e., 1.5-28.1+ fl oz) with increased NNS consumption (i.e., 3.0-235.0+ mg)
2) Group 2: decreased SSB consumption (i.e., 1.5-11.3 fl oz) but no change in NNS consumption (<2.99 mg)

3) Group 3: increased/no change in SSB consumption, regardless of NNS consumption

Demographic profiles (sex, age, race/ethnicity, weight, BMI, BMI category, educational level, household income, and mean income) between these three groups were compared at 6 months, along with changes in SSB consumption (fl oz), total NNS intake (mg), weight (kg), and BMI (kg/m²) over the 6 month intervention.

Table 1. Continuum of changes in sugar-sweetened beverage (SSB) and non-nutritive sweetener (NNS) consumption between three SSB-NNS consumption change groups

<table>
<thead>
<tr>
<th>Changes in Total NNS Consumption (mg)</th>
<th>Increase or No Change</th>
<th>Small decrease (1.5-11.3 fl oz)</th>
<th>Medium decrease (12.0-28.0 fl oz)</th>
<th>Large decrease (28.1+ fl oz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative or no change (&lt; 2.99 mg)</td>
<td>n = 15</td>
<td>n = 16</td>
<td>n = 14</td>
<td>n = 13</td>
</tr>
<tr>
<td>Small increase (3.0-91.0 mg)</td>
<td>n = 3</td>
<td>n = 5</td>
<td>n = 5</td>
<td>n = 3</td>
</tr>
<tr>
<td>Medium increase (91.0-199.0 mg)</td>
<td>n = 2</td>
<td>n = 1</td>
<td>n = 6</td>
<td>n = 4</td>
</tr>
<tr>
<td>Large increase (235.0+ mg)</td>
<td>n = 2</td>
<td>n = 4</td>
<td>n = 2</td>
<td>n = 6</td>
</tr>
</tbody>
</table>

Group 1 (blue): Decreased SSB with increased NNS (n = 36)
Group 2 (black): Decreased SSB consumption but no change in NNS (n = 43)
Group 3 (red): Increased or no change in SSB, regardless of change in NNS (n = 22)

a Met minimum threshold equivalent of 1 fl oz of diet soda (3 mg acesulfame potassium, 12 mg saccharin, 17 mg aspartame, or 6 mg of sucralose)
Statistics

Statistical analyses were performed using SPSS statistical software (version 25.0 for Macintosh, 2017; IBM). The significance level was set *a priori* at $p \leq 0.05$.

**Aim 1:**

1A) Changes between proportions of NNS consumers to non-consumers over time between groups (i.e., SIPsmartER and MoveMore) were analyzed via $X^2$ tests with adjusted standardized residuals.

1B) Changes in NNS intake (specific type and total) within groups (i.e., SIPsmartER and MoveMore) were analyzed via descriptive statistics (mean ± standard deviation, frequencies) and paired samples t-tests. Repeated-measures ANOVAs were used to assess differences in NNS consumption between groups (i.e., SIPsmartER and MoveMore) over time.

1C) Using only NNS consumers (baseline, 6 months, or both) for SIPsmartER and MoveMore, descriptive statistics (frequencies) were utilized to determine absolute mg intake for each type of NNS (acesulfame potassium, aspartame, saccharin, sucralose, and total NNS) per dietary source, as well as total instances for various NNS dietary sources.

**Aim 2:** The groups analyzed for this aim were the three SSB-NNS consumption change groups defined previously. Demographics were analyzed using descriptive statistics (mean ± standard deviation and frequencies). One-factor ANOVAs with Tukey’s post hoc test were used to evaluate differences in age, weight, BMI, and mean household income between groups at 6 months. $X^2$ tests with adjusted standardized residuals were used to evaluate differences in sex, race/ethnicity, BMI category, education level, and mean income category between groups. Descriptive statistics (mean ± standard deviation) were calculated for SSB consumption, total NNS consumption, weight, and BMI. Changes in SSB consumption, total NNS consumption, weight, and BMI were analyzed via paired sample t-tests within groups; differences between groups over time were analyzed via repeated measures ANOVA with Tukey’s post-hoc test.
Results

Aim 1A: Changes in Frequency of NNS Consumers and Non-Consumers Over Time

Table 2: Changes in frequencies of non-nutritive sweetener (NNS) consumers and non-consumers between SIPsmartER and MoveMore over 6 months

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>6 Months</th>
<th></th>
<th></th>
<th>Significancea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NNS Consumers n (%)</td>
<td>Non-Consumers n (%)</td>
<td>Became NNS Consumers n (%)</td>
<td>Remained NNS Consumers n (%)</td>
<td>Remained Non-Consumers n (%)</td>
</tr>
<tr>
<td>SIPsmartER (n = 101)</td>
<td>30 (30)</td>
<td>71 (70)</td>
<td>25 (25)*</td>
<td>21 (21)</td>
<td>46 (45)*</td>
</tr>
<tr>
<td>MoveMore (n = 97)</td>
<td>28 (29)</td>
<td>69 (71)</td>
<td>8 (8)*</td>
<td>13 (13)</td>
<td>61 (63)*</td>
</tr>
</tbody>
</table>

*a X² test with adjusted standardized residuals
* Indicates statistically significant difference between groups with absolute adjusted standardized residuals \( \geq 1.96 \)

There was a significant between group difference over time in the proportions of new NNS consumers and remaining NNS non-consumers for SIPsmartER and MoveMore (Table 2). SIPsmartER significantly created more new NNS consumers at 6 months than MoveMore, while MoveMore significantly had more non-consumers remain as non-consumers at 6 months than SIPsmartER.
Aim 1B: Changes in Non-Nutritive Sweetener Consumption Over Time

Table 3: Changes in mean non-nutritive sweetener (NNS) consumption between SIPsmartER and MoveMore by type and total NNS over 6 months

<table>
<thead>
<tr>
<th>NNS Type</th>
<th>SIPsmartER (n = 101)</th>
<th>MoveMore (n = 97)</th>
<th>Significance Between Groups Over Time&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline Mean ± SD</td>
<td>6 Month Mean ± SD</td>
<td>Mean difference ± SE</td>
</tr>
<tr>
<td>Aspartame (mg)</td>
<td>46.6 ± 107.5</td>
<td>83.8 ± 158.7</td>
<td>37.2 ± 13.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saccharin (mg)</td>
<td>0.6 ± 5.1</td>
<td>5.8 ± 32.9</td>
<td>5.2 ± 3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sucralose (mg)</td>
<td>5.0 ± 21.8</td>
<td>26.7 ± 108.7</td>
<td>21.6 ± 11.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acesulfame Potassium (mg)</td>
<td>8.1 ± 26.9</td>
<td>7.8 ± 22.1</td>
<td>-0.3 ± 2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (mg)</td>
<td>60.3 ± 127.3</td>
<td>124.1 ± 201.6</td>
<td>63.7 ± 18.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Paired samples t-test
<sup>b</sup> Repeated measures ANOVA

Over the 6 months, there was a significant increase in aspartame and total NNS consumption within the SIPsmartER group participants. Consumption changes for specific or total NNS were not significant within MoveMore participants, but there were significant between group over time differences for intake of aspartame, sucralose, and total NNS, with intake increasing for SIPsmartER participants over the 6 months as compared to MoveMore participants (Table 3).
Aim 1C: Changes in Proportions of Dietary Sources of Non-Nutritive Sweeteners

Aim 1C analyzes changes in various NNS dietary sources consumption (instances and absolute mg intake) using only NNS consumers from both SIPsmartER and MoveMore groups.

Table 4. Changes in instances of dietary sources between SIPsmartER and MoveMore non-nutritive sweetener (NNS) consumers over 6 months

<table>
<thead>
<tr>
<th>NNS Dietary Sources</th>
<th>SIPsmartER</th>
<th>MoveMore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline Instances (n = 30)</td>
<td>6 Months Instances (n = 46)</td>
</tr>
<tr>
<td>Diet soda</td>
<td>37 (53)</td>
<td>60 (56)</td>
</tr>
<tr>
<td>Diet tea</td>
<td>8 (11)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Juice or flavored drinks</td>
<td>8 (11)</td>
<td>16 (15)</td>
</tr>
<tr>
<td>Tabletop sweetener</td>
<td>6 (9)</td>
<td>22 (21)</td>
</tr>
<tr>
<td>Yogurt</td>
<td>6 (9)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Popcorn</td>
<td>2 (3)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Cereal</td>
<td>1 (1)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Coffee creamer substitute</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Ice cream</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Hot cocoa mix</td>
<td>0 (0)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Meal replacement product</td>
<td>0 (0)</td>
<td>1 (1)</td>
</tr>
<tr>
<td><strong>Total number of instances</strong></td>
<td>70</td>
<td>107</td>
</tr>
</tbody>
</table>

a An instance was defined as follows: if a participant consumed two bottles of diet soda and one packet of tabletop sweetener in a single day, the participant would have two different instances of NNS intake. If a participant consumed three bottles of diet soda over a period of two days (one bottle on the first day, two on the second), the total instances of diet soda consumed over that period of time was listed as two.

b Percentages may not total to 100 due to rounding
Among SIPsmartER and MoveMore NNS consumers, there were a total of 70 and 66 unique instances of NNS dietary sources consumption at baseline, and 107 and 42 at 6 months (SIPsmartER and MoveMore, respectively) (Table 4). Diet soda had the largest number of instances of consumption at baseline and 6 months for both groups. Although percentages varied between groups and over time, other commonly consumed sources of NNS included juice or flavored drinks, tabletop sweeteners, and diet teas. Despite consumption instances of yogurt decreasing over time for both groups, it was another commonly consumed dietary source of NNS. Figure 1 illustrates the changes in percentages of instances of specific dietary sources to total instances.

Figure 1. Percent changes in dietary source instances over 6 months between SIPsmartER and MoveMore non-nutritive sweetener consumers
Table 5. Changes in the contribution of dietary sources to specific absolute non-nutritive sweetener (NNS) intake among SIPsmartER NNS consumers at baseline and 6 months

<table>
<thead>
<tr>
<th>Dietary Sources of NNS</th>
<th>Aspartame</th>
<th>Acesulfame Potassium</th>
<th>Sucralose</th>
<th>Saccharin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline mg (%)</td>
<td>6 Months mg (%)</td>
<td>Baseline mg (%)</td>
<td>6 Months mg (%)</td>
</tr>
<tr>
<td>Diet soda</td>
<td>3563 (76)</td>
<td>7671 (91)</td>
<td>291 (36)</td>
<td>593 (76)</td>
</tr>
<tr>
<td>Diet tea</td>
<td>596 (13)</td>
<td>77 (1)</td>
<td>288 (36)</td>
<td>22 (3)</td>
</tr>
<tr>
<td>Juice or flavored drinks</td>
<td>208 (4)</td>
<td>242 (3)</td>
<td>223 (28)</td>
<td>132 (17)</td>
</tr>
<tr>
<td>Yogurt</td>
<td>124 (3)</td>
<td>62 (1)</td>
<td>0 (0)</td>
<td>114 (22)</td>
</tr>
<tr>
<td>Tabletop sweetener</td>
<td>140 (3)</td>
<td>176 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Cereal</td>
<td>50 (1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Popcorn</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>22 (4)</td>
</tr>
<tr>
<td>Coffee cream substitute</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>8 (1)</td>
<td>6 (1)</td>
</tr>
<tr>
<td>Ice cream</td>
<td>17 (0)</td>
<td>85 (1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Hot cocoa mix</td>
<td>0 (0)</td>
<td>146 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Meal replacement product</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>26 (3)</td>
</tr>
<tr>
<td>Total (mg)</td>
<td>4698</td>
<td>8459</td>
<td>810</td>
<td>779</td>
</tr>
</tbody>
</table>

* Percentages may not total to 100 due to rounding

For SIPsmartER NNS consumers, the most commonly consumed NNS types at both baseline and 6 months in decreasing order were aspartame, sucralose, acesulfame potassium, and saccharin. Table 5 illustrates the relationship between the multiple dietary sources of NNS recorded for NNS consumers in SIPsmartER and the amount of absolute mg intake they provide to specific types of NNS. Diet soda made up a large portion of total NNS intake for all specific types of NNS for both baseline and 6 months. Tabletop sweeteners made up the majority intake for total sucralose intake at 6 months, and total saccharin consumption at baseline and 6 months. Diet teas and juice or flavored drinks also contributed to large proportions of total acesulfame and sucralose consumption at either baseline, 6 months, or both.
Table 6. Contribution of dietary sources to specific absolute non-nutritive sweetener (NNS) intake among MoveMore NNS consumers at baseline and 6 months

<table>
<thead>
<tr>
<th>Dietary Sources of NNS</th>
<th>Aspartame</th>
<th>Sucralose</th>
<th>Acesulfame Potassium</th>
<th>Saccharin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline mg (%)&lt;sup&gt;a&lt;/sup&gt; (n = 28)</td>
<td>6 Months mg (%)&lt;sup&gt;a&lt;/sup&gt; (n = 21)</td>
<td>Baseline mg (%)&lt;sup&gt;a&lt;/sup&gt; (n = 28)</td>
<td>6 Months mg (%)&lt;sup&gt;a&lt;/sup&gt; (n = 21)</td>
</tr>
<tr>
<td>Diet soda</td>
<td>2546 (83)</td>
<td>1742 (78)</td>
<td>56 (3)</td>
<td>80 (20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>167 (34)</td>
<td>104 (28)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>403 (100)</td>
</tr>
<tr>
<td>Tabletop sweetener</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1325 (74)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>144 (29)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Diet tea</td>
<td>293 (10)</td>
<td>393 (18)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>144 (29)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Juice or flavored drinks</td>
<td>68 (2)</td>
<td>77 (3)</td>
<td>222 (12)</td>
<td>165 (41)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>96 (20)</td>
<td>120 (32)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Yogurt</td>
<td>124 (4)</td>
<td>31 (1)</td>
<td>132 (7)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>32 (7)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Meal replacement product</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>38 (2)</td>
<td>115 (28)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>38 (8)</td>
<td>115 (31)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Cereal</td>
<td>50 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
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<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Coffee creamer substitute</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>10 (1)</td>
<td>37 (9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 (2)</td>
<td>37 (10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Ice cream</td>
<td>2 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Popcorn</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>8 (2)</td>
<td>0 (0)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Total (mg)</td>
<td>3083</td>
<td>2243</td>
<td>1783</td>
<td>405</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>489</td>
<td>376</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>403</td>
</tr>
</tbody>
</table>

<sup>a</sup> Percentages may not total to 100 due to rounding

For MoveMore NNS consumers, the most commonly consumed NNS types at both baseline in decreasing order were aspartame, sucralose, and acesulfame potassium. Saccharin was not consumed by MoveMore NNS consumers at baseline. At 6 months, the most commonly consumed NNS types for NNS consumers were aspartame, sucralose, saccharin, and acesulfame potassium. Table 6 illustrates the relationship between the multiple dietary sources of NNS recorded for NNS consumers in MoveMore and the amount of absolute mg intake they provided to specific types of NNS. Diet sodas made up large proportions of total intake for aspartame and acesulfame potassium at both baseline and 6 months. At 6 months, tabletop sweeteners contributed to a large proportion of total intake of sucralose and saccharin. Diet sodas, diet teas, juice or flavored drinks, and meal replacement products contributed to the total consumption of acesulfame potassium at both baseline and 6 months.
Table 7: Changes in absolute total non-nutritive sweetener intake per dietary source between SIPsmartER and MoveMore NNS consumers over 6 months

<table>
<thead>
<tr>
<th>Dietary Source</th>
<th>SIPsmartER</th>
<th>MoveMore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline mg (%)a</td>
<td>6 Months mg (%)a</td>
</tr>
<tr>
<td></td>
<td>(n = 30)</td>
<td>(n = 46)</td>
</tr>
<tr>
<td></td>
<td>Baseline mg (%)a</td>
<td>6 Months mg (%)a</td>
</tr>
<tr>
<td></td>
<td>(n = 28)</td>
<td>(n = 21)</td>
</tr>
<tr>
<td>Diet soda</td>
<td>4029 (66)</td>
<td>8432 (67)</td>
</tr>
<tr>
<td>Tabletop sweetener</td>
<td>189 (3)</td>
<td>3181 (25)</td>
</tr>
<tr>
<td>Diet tea</td>
<td>884 (15)</td>
<td>99 (1)</td>
</tr>
<tr>
<td>Juice or flavored drinks</td>
<td>637 (10)</td>
<td>444 (4)</td>
</tr>
<tr>
<td>Yogurt</td>
<td>238 (40)</td>
<td>62 (0)</td>
</tr>
<tr>
<td>Meal replacement product</td>
<td>0 (0)</td>
<td>52 (0)</td>
</tr>
<tr>
<td>Cereal</td>
<td>50 (1)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Coffee creamer substitute</td>
<td>16 (1)</td>
<td>12 (0)</td>
</tr>
<tr>
<td>Ice cream</td>
<td>17 (0)</td>
<td>85 (1)</td>
</tr>
<tr>
<td>Popcorn</td>
<td>22 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Hot cocoa mix</td>
<td>0 (0)</td>
<td>146 (1)</td>
</tr>
<tr>
<td>Total (mg)</td>
<td>6082</td>
<td>12513</td>
</tr>
</tbody>
</table>

* Percentages may not total to 100 due to rounding

Figure 2. Percent changes in total absolute non-nutritive sweetener intake over 6 months between SIPsmartER and MoveMore non-nutritive sweetener consumers

For both SIPsmartER and MoveMore, diet sodas contributed to the largest absolute intake of total NNS intake at both baseline and 6 months (Table 7). Despite order varying
slightly across time and between groups, tabletop sweeteners, diet tea, and yogurt contributed large absolute intakes of total NNS. The contribution of yogurt to total NNS intake (40%) was the second largest at baseline for SIPsmartER consumers. **Figure 2** illustrates the changes in percentages of absolute intake from specific dietary sources to total NNS intake.
**Aim 2: Differences in Demographics Between SSB-NNS Consumption Change Groups**

Table 8. Differences in sugar-sweetened beverage (SSB), non-nutritive sweetener (NNS) consumption, body weight, and body mass index between SSB-NNS consumption change groups over timea

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group 1 (n = 36)</th>
<th>Group 2 (n = 43)</th>
<th>Group 3 (n = 22)</th>
<th>Significance Between Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline Mean ± SD</td>
<td>6 Months Mean ± SD</td>
<td>Mean difference ± Std. Error</td>
<td>t</td>
</tr>
<tr>
<td>SSB (fl oz)</td>
<td>34.4 ± 23.5</td>
<td>7.3 ± 10.7</td>
<td>-27.0 ± 3.4b</td>
<td>t = -7.89</td>
</tr>
<tr>
<td>Total NNS (mg)</td>
<td>63.0 ± 129.9</td>
<td>255.4 ± 216.8</td>
<td>192.3 ± 29.2c</td>
<td>t = 6.56</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>94.2 ± 28.9</td>
<td>94.8 ± 28.8</td>
<td>0.5 ± 0.4</td>
<td>t = 1.09</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>34.5 ± 9.0</td>
<td>34.5 ± 9.0</td>
<td>0.10 ± 0.2</td>
<td>t = 0.49</td>
</tr>
</tbody>
</table>

*a Group 1: Decreased SSB with increased NNS, Group 2: Decreased SSB consumption but no change in NNS, Group 3: Increased or no change in SSB, regardless of change in NNS.

*b Labeled means in a row without a common letter differ between groups. Significance determined by Repeated Measures ANOVA Tukey’s post hoc, P ≤ 0.05.

*c Significance determined by paired samples t-tests.

*d Significance determined by Repeated Measures ANOVA.

For group 1 (decreased SSB, increased NNS), there was a significant decrease in SSB consumption, as well as a significant increase in total NNS consumption over time. Group 2 (decreased SSB, no change in NNS) had a significant decrease in SSB and total NNS consumption, while group 3 (increased/no change in SSB, regardless of NNS change) only had significant increase in SSB.
consumption over time. There was a significant overall difference between groups for changes in SSB consumption, but post-hoc tests were unable to detect which mean differences differed between groups. Group 1 had a significant increase in total NNS consumption when compared to group 2’s decrease, while group 2’s decrease in NNS was significantly different from group 3’s increase. Both group 1 and group 3 increased NNS consumption, but post-hoc tests determined they were not significantly different from each other (Table 8).
Table 9: Demographic characteristics of SSB-NNS consumption change groups from SIPsmartER (n = 101) participants at 6 months

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group 1 (%)</th>
<th>Group 2 (%)</th>
<th>Group 3 (%)</th>
<th>Significance(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 36</td>
<td>n = 43</td>
<td>n = 22</td>
<td></td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>7 (19)</td>
<td>11 (26)</td>
<td>0 (0)</td>
<td>(X^2 = 6.60)</td>
</tr>
<tr>
<td>Female</td>
<td>29 (81)</td>
<td>32 (74)</td>
<td>22 (100)</td>
<td>(p = 0.037)</td>
</tr>
<tr>
<td><strong>Mean age ± SD (years)</strong></td>
<td>44.3 ± 12.9</td>
<td>43.3 ± 13.0</td>
<td>43.7 ± 13.2</td>
<td>(F = 0.058)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(p = 0.944)</td>
</tr>
<tr>
<td><strong>Race/Ethnicity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>34 (94)</td>
<td>42 (98)</td>
<td>21 (96)</td>
<td>(X^2 = 0.563)</td>
</tr>
<tr>
<td>African American</td>
<td>2 (6)</td>
<td>1 (2)</td>
<td>1 (4)</td>
<td>(p = 0.755)</td>
</tr>
<tr>
<td>Other</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>94.8 ± 28.9</td>
<td>87.7 ± 21.5</td>
<td>93.1 ± 25.5</td>
<td>(F = 0.830)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(p = 0.439)</td>
</tr>
<tr>
<td><strong>Mean Body Mass Index (BMI)</strong></td>
<td>34.53 ± 9.1</td>
<td>31.68 ± 7.8</td>
<td>35.1 ± 9.5</td>
<td>(F = 1.55)</td>
</tr>
<tr>
<td>± SD (kg/m(^2))</td>
<td></td>
<td></td>
<td></td>
<td>(p = 0.216)</td>
</tr>
<tr>
<td><strong>BMI Category</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underweight (&lt; 18.5)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>(X^2 = 4.53)</td>
</tr>
<tr>
<td>Normal (18.5-24.9)</td>
<td>4 (11)</td>
<td>11 (25)</td>
<td>2 (9)</td>
<td>(p = 0.338)</td>
</tr>
<tr>
<td>Overweight (25-29.9)</td>
<td>10 (28)</td>
<td>8 (19)</td>
<td>5 (23)</td>
<td></td>
</tr>
<tr>
<td>Obese (≥ 30)</td>
<td>22 (61)</td>
<td>24 (56)</td>
<td>15 (68)</td>
<td></td>
</tr>
<tr>
<td><strong>Education Level</strong></td>
<td></td>
<td></td>
<td></td>
<td>(X^2 = 0.097)</td>
</tr>
<tr>
<td>High school graduate or less</td>
<td>12 (33)</td>
<td>14 (33)</td>
<td>8 (36)</td>
<td>(p = 0.953)</td>
</tr>
<tr>
<td>Some college or more</td>
<td>24 (67)</td>
<td>29 (67)</td>
<td>14 (64)</td>
<td></td>
</tr>
<tr>
<td><strong>Mean household income ± SD ($)</strong></td>
<td>21,528 ±</td>
<td>23,547 ±</td>
<td>22,045 ±</td>
<td>(F = 0.162)</td>
</tr>
<tr>
<td></td>
<td>16,347</td>
<td>16,158</td>
<td>16,432</td>
<td>(p = 0.851)</td>
</tr>
<tr>
<td><strong>Mean income ($)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$≤14,999</td>
<td>18 (50)</td>
<td>16 (37)</td>
<td>10 (45)</td>
<td>(X^2 = 9.67)</td>
</tr>
<tr>
<td>15,000-34,999</td>
<td>10 (28)</td>
<td>16 (37)</td>
<td>8 (36)</td>
<td>(p = 0.289)</td>
</tr>
<tr>
<td>35,000-39,000</td>
<td>0 (0)</td>
<td>3 (7)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>40,000-54,999</td>
<td>6 (17)</td>
<td>2 (5)</td>
<td>2 (9)</td>
<td></td>
</tr>
<tr>
<td>$&gt;55,000</td>
<td>2 (6)</td>
<td>6 (14)</td>
<td>2 (9)</td>
<td></td>
</tr>
</tbody>
</table>

SSB, Sugar-sweetened beverages; NNS, non-nutritive sweeteners

\(^a\) Group 1: Decreased SSB with increased NNS, Group 2: Decreased SSB consumption but no change in NNS, Group 3: Increased or no change in SSB, regardless of change in NNS

\(^b\) \(X^2\) with adjusted standardized residuals for categorical variables, one-way ANOVA with post-hoc Tukey’s test for continuous variables

There were no significant differences between characteristics of participants who used NNS as a tool to reduce SSB consumption (group 1: decreased SSB with increased NNS) and those who did not (group 2: decreased SSB with no change in NNS) and those who were unresponsive to the SIPsmartER intervention (group 3: increased or no change in SSB,
regardless of change in NNS). Comparisons between the three groups found that the only significant difference in compared characteristics was the proportions of males to females, with participants in group 3 having significantly less males compared to group 1 and group 2 (Table 9).

Discussion

The aim of this study was to explore changes in frequency of NNS consumers, NNS consumption by specific type and total, and dietary sources of NNS over a 6 month period for participants enrolled in a sugar-sweetened beverage intervention with two intervention groups (SIPsmartER and MoveMore). This is the first investigation, that we are aware of, to examine this effect. Our findings suggest that the SIPsmartER intervention created significantly more new NNS consumers and significantly increased consumption of aspartame and total NNS after 6 months when compared to MoveMore. However, within the three SSB-NNS consumption change groups, no significant differences in demographics, with the exception of sex, were found for those who successfully decreased SSB by increasing NNS consumption, as compared to those who did not increase NNS but decreased SSB or were not successful at decreasing SSB. The only significant demographic characteristic was the proportion of males to females in group 3. Group 1 (decreased SSB with increased NNS) and group 2 (decreased SSB but no change in NNS) were 81% and 74% female, respectively, while females made up 100% of group 3 (increase or no change in SSB, regardless of NNS). The goal of this aim was to see if there were any differences in demographics between people who may use NNS as a tool to decrease NNS consumption. While there were no additional significant differences between groups, the demographics of all three groups mirror some common NNS-consumer trends: non-Hispanic, white females that are more educated and more likely to be overweight or obese.
Significant differences between groups were likely lacking due to the original sample’s homogeneity, as well as the small sample size of the three groups.

The hypothesis that the frequency of NNS consumers in SIPsmartER would increase over time when compared to MoveMore was supported by the results. At baseline, the proportion of NNS consumers to non-consumers between SIPsmartER (30% to 70%) and MoveMore (29% to 71%) were similar, with the amount of NNS consumers between both groups following the national trends of 33%. Over the 6 months, the proportion of NNS consumers increased by 16% for SIPsmartER, while the proportion of NNS consumers for MoveMore decreased 7%. Upon further analysis, it was found that SIPsmartER created significantly more new NNS consumers than MoveMore, while MoveMore had significantly more NNS non-consumers remain as non-consumers at 6 months than SIPsmartER.

Likewise, the hypothesis that consumption of NNS for SIPsmartER participants would increase when compared to MoveMore was also confirmed. Consumption of aspartame and total NNS increased significantly for participants in SIPsmartER over the 6 months, while MoveMore participants had an insignificant decrease in consumption of total and all types of NNS except saccharin. Between groups, SIPsmartER participants significantly increased their intake of aspartame, sucralose, and total NNS when compared to MoveMore participants. Studies focusing on NNS consumption usually focus on total NNS and few focus on different types of NNS. This study further strengthens the argument for the need of focusing on specific types as each type of NNS is different and may have differing effects on health outcomes.

Despite the analyses on dietary sources (instances and absolute mg intake) of NNS being descriptive, they provided valuable information that add to the current literature on NNS consumption. At both baseline and 6 months, for both intervention arms, the most commonly
consumed types of NNS for NNS consumers were aspartame, sucralose, and acesulfame potassium. This trend matches the prevalence of aspartame, sucralose, and acesulfame potassium in food and beverage products. Following patterns already found in the literature, at 6 months for SIPsmartER NNS consumers, the most commonly consumed dietary sources of NNS by instances mirror those consumed by absolute mg intake (diet soda, tabletop sweeteners, and juice or flavored drinks). For MoveMore participants at 6 months, the most commonly consumed dietary sources of NNS were diet soda, tabletop sweeteners, and juice or flavored drinks. However, the top contributors to absolute intake did not follow a similar pattern, with diet soda, tabletop sweeteners, and diet tea as the top three contributing dietary sources. Although they did not make up the majority of total NNS consumption, other sources recorded in SIPsmartER and MoveMore participants included yogurt, popcorn, cereal, coffee creamer substitutes, ice cream, hot cocoa mix, and meal replacement products. For SIPsmartER participants, intake of various NNS dietary sources (instances and absolute mg intake) increased over time, thus supporting the hypothesis that an increase in NNS beverages and tabletop sweeteners would be observed when compared to overall MoveMore participant trends.

Although the most commonly consumed dietary sources of NNS (diet beverages) are usually taken into account by most current studies, these results highlight the importance of accounting for other dietary NNS sources beyond beverages. Over the past few years, NNS have increased in the food supply as more NNS-containing products have become available to the public. As many studies rely on diet beverages as a proxy for NNS intake, it is important to include all these other NNS sources in studies in order to accurately measure people’s intake and ensure intake and number of NNS consumers are not underestimated.
An important thing to discuss is that while the SIPsmartER intervention had an increase in NNS consumers over time, as well as a significant increase in aspartame and total NNS consumption, the MoveMore intervention decreased in NNS consumers, as well as decreased consumption in various NNS dietary sources (e.g., yogurt). These results are not surprising since SIPsmartER was designed to encourage people to decrease their consumption of SSB, thus educating about alternatives to SSB, such as NNS, was a part of the curriculum. MoveMore participants received no information regarding NNS. A separate study highlighting focus groups prior to Talking Health in the same geographical area found that while some participants expressed positive feelings towards NNS, negative feelings such as “Diet sodas have aspartame and those showed to cause cancer,” were also expressed. It is likely that SIPsmartER participants were more likely to become or remain as NNS consumers than MoveMore participants since their misconceptions on NNS were addressed through the intervention. Likewise, dietary patterns (energy and carbohydrate intake) have been shown to improve when exercise is increased, so it is possible that the decrease in NNS consumption patterns in MoveMore is explained by this.

This study has its limitations. Data for this analysis was used from Talking Health, a 6 month intervention seeking to decrease participants’ consumption of SSB. A requirement for participants’ enrollment was the consumption of ≥200 kcals of SSB. Thus, by design participants had a higher intake of SSB; consequently, their familiarity with or consumption of NNS might have been different than consumers consuming less SSB. However, this level of SSB intake is comparable to SSB intake with this rural population. Similarly, our sample’s rate of NNS consumers at baseline (30% for SIPsmartER and 29% for MoveMore) was representative of national trends (33%).
Another limitation of the study is its rural locality. While this affects the generalizability of the results, research on SSB consumption in rural areas is important since residents in these areas are likely to consume more SSB than in other areas. Due to their high consumption of SSB, residents in rural areas might be more accepting of NNS than other people. An additional limitation is the possibility of 24-hour dietary recalls not being accurate enough for this study’s purpose. Talking Health’s original aims did not relate to NNS, therefore, it is possible that interviewers may have missed food items that could have contributed to total NNS intake. Similarly, misreporting is common when it comes to self-reporting dietary intake. To account for this, interviewers were supervised by a doctorate-level registered dietitian and the use of the U.S. Department of Agriculture’s automated multiple-pass method were utilized to reduce misreporting issues. Along with that, nutrition analysis software, NDS-R was utilized to analyze the nutrient content of 24-hour dietary recalls.

Despite its limitations, this study also had multiple strengths. This investigation addressed several identified limitations in the current literature: the use of diet soda as a proxy for NNS consumption and the study of NNS as a whole rather than by specific type. Many studies use diet soda as a proxy for NNS consumption. Although diet soda is one of the most popular NNS sources as shown by our results and past literature, our results also show that there are other dietary sources of NNS being consumed, many of which are not diet beverages. The inclusion of other dietary sources besides beverages helps ensure intake of NNS is accurately measured. Similarly, our study focuses on various types of NNS. This is important because not all types of NNS are metabolically equal. Likewise, various types of NNS are sometimes found in dietary sources. For example, in our results, diet soda was the most popular source of NNS. While it contributed mostly to the total mg intake of aspartame, it also
contributed to the total mg of the other three NNS types. Accounting for different types of NNS and dietary sources of NNS helps create a more accurate picture of NNS consumers and their intake patterns.

**Conclusion**

With the consumption of added sugars on the rise, it is important to study alternatives to help consumers improve their health while making sure they are consuming products they are satisfied with. Products sweetened with NNS are a potential alternative, but research on the effects of NNS on humans is limited. The present study focused on the changes in NNS consumption patterns after a 6 month SSB intervention trial in southwest Virginia. Results found that SIPsmartER significantly increased new NNS consumers over time when compared to MoveMore. Likewise, consumption of aspartame and total NNS increased significantly for SIPsmartER participants over the 6 months. The most commonly consumed dietary sources of NNS in SIPsmartER NNS consumers at baseline by instances were diet soda, tabletop sweeteners, yogurt, diet tea, and juice or flavored drinks. Meanwhile, when considering absolute mg intake, the top contributing sources for SIPsmartER at baseline were diet soda, yogurt, and diet tea. At 6 months for SIPsmartER NNS consumers, the top dietary sources, by instances and absolute mg, were diet soda, tabletop sweeteners, and juice or flavored drinks. At baseline for MoveMore NNS consumers, the most commonly consumed dietary sources by instances were diet soda, juice or flavored drinks, and yogurt, while for absolute intake, the top contributing dietary sources were diet soda, tabletop sweeteners, and diet tea. At 6 months for MoveMore, the top dietary sources contributing to total instances were diet soda, juice or flavored drinks, and coffee creamer substitutes. Meanwhile, the top dietary sources contributing to absolute mg intake
at 6 months for MoveMore NNS consumers were diet soda, tabletop sweeteners, and diet tea. Other reported dietary sources of NNS that were not beverages included yogurt, cereal, and meal replacement products. These non-beverage sources are not usually accounted for in NNS studies.

Research regarding the effect of SSB reduction trials on NNS consumption patterns is limited. This study highlights the need of taking into account the differing types of NNS, as well as different sources of NNS other than diet beverages. Results from this investigation can expand this part of the literature by helping future studies focus on different types of NNS and dietary sources of NNS. Likewise, this study shows the effectiveness of a SSB-reduction intervention in decreasing SSB consumption while increasing self-directed NNS consumption in rural Virginia. Further research on NNS consumption is needed to validate its potential as a tool to help decrease SSB consumption.
References


50. Sharkey JR, Johnson CM, Dean WR. Less-healthy eating behaviors have a greater association with a high level of sugar-sweetened beverage consumption among rural adults than among urban adults. *Food & nutrition research.* 2011;55.

Chapter 3: Future Directions and Conclusion

The 2015-2020 Dietary Guidelines for Americans recommend that added sugars contribute to less than 10% of calories consumed daily. In a 2,000-calorie diet, this equates to 200 calories or 50 grams of added sugars per day for adults. Unfortunately, only 42% of Americans, 2 years and over, meet this recommendation, with an average of 102 g per day for those who do not. The overconsumption of added sugars is worrisome due to its relationship to increased risk of chronic disease such as obesity, cardiovascular disease, diabetes, and non-alcoholic fatty liver disease. Other negative health outcomes linked to added sugars consumption include nutrient displacement, dental caries, bone health, and excess energy intake.

Although added sugars are found in a variety of food products, about one half (40-50%) of added sugars consumption in Americans’ diets can be attributed to sugar-sweetened beverages (SSB).

Due to the negative impact of added sugars and SSB on health, public health advocates have sought alternative methods to encourage people to decrease their consumption of added sugars. One such method is replacing added sugars with foods and beverages sweetened with non-nutritive sweeteners (NNS). NNS are desirable alternatives because they provide little to no calories while still having a sweet taste.

Over time, consumption of NNS has increased. A study utilizing National Health and Nutrition Examination Survey (NHANES) data found that NNS consumption increased from 26.9% in 1999-2000 to 32% in 2007-2008 in adults. A follow-up study utilizing 2009-2012 NHANES data found that NNS consumption increased to >41% in adults. It is likely that an interest in NNS in the general population has risen in conjunction with increased concerns on health and nutrition, as well as their availability in the food supply. With the majority of added sugars consumption coming from SSB, and the most popular dietary source of NNS being diet
beverages, this provides the opportunity to explore the potential of NNS as a tool to reduce added sugars intake.

In order to explore this question further, it is necessary to couple the study of NNS consumption patterns with SSB-reduction interventions. The study presented is the first, to our knowledge, to study changes in NNS consumption patterns in participants enrolled in a SSB-reduction intervention. Utilizing NNS as the focus in a SSB intervention in future studies would make it easier to test if SSB intervention participants are more accepting of NNS products as a replacements for added sugars. Likewise, proper education on NNS and their safety is paramount to ensuring people will be open to using them. Although there is not any conclusive evidence on whether or not consumption of NNS produces negative or positive health outcomes, the fear and misconception of NNS, especially aspartame, is widespread. A majority of the confusion comes from issues related to NNS research: research on animal models, observational studies on humans, the use of diet soda as a proxy for NNS consumption, and lack of studies focusing on specific NNS types in addition to NNS as a whole.

The results of this study help strengthen the body of current literature showing that the most common dietary sources of NNS include beverages such as diet soda, diet tea, and juice or flavored drinks. Along with that, the results illustrate the importance of taking other dietary sources of NNS besides beverages into account. Diet beverages are usually used as a proxy for NNS consumption; this is an issue because it lessens the accuracy of the measured consumption patterns as NNS are found in food items other than beverages. Other dietary sources of NNS reported in our study included tabletop sweeteners, yogurt, meal replacement products, cereal, popcorn, ice cream, hot cocoa mix, and coffee creamer substitute. Although they did not make a majority of the dietary NNS sources consumed by participants, they still
provided to the total dietary intake of NNS. Taking other sources of NNS besides beverages into account is important to help expand current NNS research, as well as to ensure NNS consumption patterns are accurately assessed.

This study also focused on changes in specific types of NNS (aspartame, acesulfame potassium, sucralose, and saccharin) as well as total NNS intake. Results showed that aspartame and sucralose were the most commonly consumed types of NNS between groups at both baseline and 6 months. Consumption of all specific types of NNS changed throughout the 6 months for both groups, and various dietary sources contributed to the total intake of each specific type of NNS. These results also strengthen the argument for including specific types of NNS in studies, rather than just total. As previously mentioned, this is important because the different types of NNS are metabolically different, so we cannot expect them to have similar effects on the body. These potential differing effects are illustrated by Higgins and Mattes, where sucrose and saccharin were found to significantly increase body weight when compared to aspartame, rebaudioside A, and sucralose in randomized controlled trial on adults. Likewise, no dietary source of NNS is exclusively tied to one specific type of NNS. For example, diet soda in our study contributed to total consumption of every single specific NNS type. Differentiating between types of NNS consumed is important to help isolate possible varying health effects.

The overconsumption of added sugars is worrisome, so it is reasonable for public health advocates to look for alternatives such as NNS to encourage consumers to decrease the consumption of added sugars. The Talking Health SSB intervention was successful in reducing SSB by increasing NNS intake for significantly more participants as compared to a match-contact physical activity intervention. However, within the SSB reduction group, no significant demographic differences were found for those who used NNS as a strategy as compared to those
who did not. More research is needed to identify those for who a NNS intervention to decrease SSB intake would be more effective. This will help inform future interventions and provide appropriate strategies to specific demographic groups.

The presented study highlights important gaps that must be addressed in current NNS research and can help guide future NNS studies. Future directions include: the focus on specific types of NNS, as opposed to simply total NNS intake, their possible health outcomes, and the inclusion of dietary sources other than beverages. Additionally, community-based SSB interventions can provide a unique opportunity for using proper NNS education to encourage consumers to replace added sugars with alternatives such as NNS. Although the replacement of SSB with water is the most desirable outcome, focusing on products sweetened with NNS could provide a stepping stone to reducing added sugars intake and improving health outcomes.
References


