One-year changes in sugar-sweetened beverage consumers' purchases following implementation of a beverage tax: a longitudinal quasi-experiment

Hannah G Lawman,[1] Sara N Bleich,[2] Jiali Yan,[3] Sophia V Hua,[3] Caitlin M Lowery,[4] Ana Peterhans,[3] Michael T LeVasseur,[3] Nandita Mitra,[5] Laura A Gibson,[3] and Christina A Roberto[3]

[1]Division of Chronic Disease and Injury Prevention, Philadelphia Department of Public Health, Philadelphia, PA, USA; [2]Department of Health Policy and Management, Harvard TH Chan School of Public Health, Boston, MA, USA; [3]Department of Medical Ethics and Health Policy, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA, USA; [4]Department of Health Policy and Management, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA; and [5]Department of Biostatistics, Epidemiology, and Informatics, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA, USA

ABSTRACT

Background: Few longitudinal studies examine the response to beverage taxes, especially among regular sugar-sweetened beverage (SSB) consumers.

Objective: This study aimed to examine changes in objectively measured beverage purchases associated with the Philadelphia beverage tax on sugar-sweetened and artificially sweetened beverages.

Methods: A longitudinal quasi-experiment was conducted with adult sugar-sweetened beverage (SSB) consumers in Philadelphia ($n = 306$) and Baltimore ($n = 297$; a nontaxed comparison city). From 2016 to 2017 participants submitted all food and beverage receipts during a 2-wk period at: baseline (pretax) and 3, 6, and 12 mo posttax (91.0% retention; data analyzed in 2019). Linear mixed effects models were used to assess the difference-in-differences in total purchased ounces (fl oz) of taxed beverages in a 2-wk period in Philadelphia compared with Baltimore. Secondary analyses: *1*) excluded weeks that contained major holidays at baseline and 12 mo (42% of measured weeks at baseline and 12 mo) because policy implementation timing necessitated data collection during holidays when SSB demand may be more inelastic, and *2*) aggregated posttax time points to address serial correlation and low power.

Results: There were no statistically significant changes in purchased ounces of taxed beverages in Philadelphia compared with Baltimore in the primary analysis. After excluding holiday purchasing, the tax was associated with statistically significant reductions of taxed beverage purchases at 3 and 6 mo (−157.1 ounces, 95% CI: −310.1, −4.1 and −175.1 ounces, 95% CI: −328.0, −22.3, respectively) but not 12 mo. Analyses aggregating all 6 wk of posttax time points showed statistically significant reductions (−203.7 ounces, 95% CI: −399.6, −7.8).

Conclusions: A sweetened beverage tax was not associated with reduced taxed beverage purchases among SSB consumers 12 mo posttax in the full sample. Both secondary analyses excluding holiday purchasing or aggregating posttax time periods found reductions in taxed beverage purchases ranging from −4.9 to −12.5 ounces per day. Larger longitudinal studies are needed to further understand tax effects. *Am J Clin Nutr* 2020;00:1–8.

Keywords: sugar-sweetened beverages, sweetened beverage taxes, nutrition policy, food policy, dietary interventions

Introduction

Sweetened beverage excise taxes are of increasing interest to public health practitioners and policymakers for their potential to raise revenue and discourage the consumption of sugar-sweetened beverages (SSBs) (1–3). Three longitudinal studies have examined the influence of beverage taxes on individuals. Using general population samples and self-reported consumption at baseline and 1-y later in Philadelphia, Pennsylvania, Cawley and colleagues (4) found selected declines including the frequency of soda consumption by adults (11 fewer times per month) and among children who were regular SSB consumers at baseline (22% less sugar or ∼15 g) but none

This study was supported by Bloomberg Philanthropies. Bloomberg Philanthropies had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Supplementary Methods and Results and Supplementary Ads and Surveys are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

Data described in the manuscript, code book, and analytic code will be made available upon request pending application and approval.

Address correspondence to HGL (e-mail: Hannah.Lawman@phila.gov).

Abbreviations used: MICE, multiple imputation by chained equations; SSB, sugar-sweetened beverage.

Received October 7, 2019. Accepted for publication May 28, 2020.

First published online 0, 2020; doi: https://doi.org/10.1093/ajcn/nqaa158.

overall, and Zhong and colleagues (5) found no changes. A study of Mexico's tax found larger reductions in objective taxed beverage purchases among households consuming >5 ounces (fl oz) of taxed beverages per capita per day (6). These studies indicate possible population-level improvements in SSBs following taxes but are limited by samples with low levels of SSB consumption (4–6), lack of data on low socioeconomic status groups or households without children (4, 5), low retention rates (4, 5), use of self-reported consumption (4, 5), lack of a control group (6), or use of an invalid control group that is affected by the tax (neighboring Philadelphia counties) (4, 5).

More broadly, cross-sectional studies and studies examining changes in beverage prices in-store and purchasing have shown that pass-through of beverage taxes has ranged from 42% to 120% (7–11), whereas purchases of taxed beverages have declined from 8% to 38% (7, 8, 11–13). One study of the Berkeley, California tax found a 52% reduction (0.55 times per day) in self-reported SSB consumption among low-income participants that persisted for 3 y following the tax (14, 15). However, consumption measured by 24-h beverage recall failed to detect a tax effect in a different Berkeley sample (7). In Philadelphia, a study based on objective sales data from 291 chain retailers found a 38% decline in sales after accounting for some increases in purchasing of taxed beverages across the border (8). Studies using cross-sectional data from purchases collected with exit interviews at stores in Philadelphia and neighboring counties or Baltimore have found significant reductions ranging from 5.8 to 8.5 ounces (39–62%) in taxed beverage purchases after 1 y (4, 16). Studies of consumption involving Philadelphia residents have shown mixed results, such that there were reductions in some subgroups or measures [e.g., frequency of soda consumption by adults (4), children that consumed SSBs regularly at baseline (4), odds of daily soda consumption at 3-mo posttax (17)], but not others [e.g., consumption frequency of all taxed beverages (4, 17)]. In addition, no prior studies have examined total food and beverage spending in individuals following beverage taxes, which is important for understanding possible substitution patterns and changes in taxed beverage spending as a proportion of total food and beverage spending.

Longitudinal studies with SSB consumers that incorporate objective measures (i.e., do not rely on self-reported consumption measures) are needed to further understand individual change following beverage taxes. The current study used a natural experimental design to study Philadelphia's 1.5 cents per ounce beverage excise tax on sugar-sweetened and artificially sweetened beverages among a cohort of regular SSB drinkers. The objective of the study was to examine changes in purchased ounces of taxed beverages in a longitudinal quasi-experiment in Philadelphia and a similar nontaxed comparison city (Baltimore, MD).

Methods

Policy intervention

The Philadelphia beverage tax applies to the distribution of nonalcoholic beverages (or nonalcoholic syrups or other concentrates used to prepare beverages for retail sale) listing any form of caloric sugar-based sweetener or artificial sugar substitute (e.g., aspartame) as an ingredient with certain exemptions (e.g., medical foods, beverages >50% milk by volume) (18). It was passed in June 2016 and began on 1 January, 2017 and applies to all distributors of sweetened beverages for retail sale in Philadelphia.

Participants

A convenience sample of residents of Philadelphia, Pennsylvania ($n = 306$), and Baltimore City, Maryland ($n = 297$), was recruited using print flyers disseminated outside food and beverage stores, advertisements on Craigslist, and paid advertising in free, local newspapers (**Supplementary Ads and Surveys**). Eligibility criteria included: *1*) resident of Philadelphia, PA, or the Baltimore area, *2*) self-reported SSB consumption ≥2–3 times per week, *3*) aged ≥18 y, 4) able to speak and read English, and *5*) successful completion of ≥2 out of 3 baseline study procedures (submitted first and second weeks of food/beverage receipts and completed questionnaire, described below).

Procedures

Baltimore was selected as the comparison city due to its similar demographic and SSB consumption profiles (8) and close geographic proximity without bordering Philadelphia. The 2 cities had similar SSB sales trends in large chain retailers in the year prior to the tax (8). Participants were asked to join a study about their food shopping and provided informed consent, including consent to have the specific study purpose (i.e., beverage tax evaluation) withheld until the study conclusion. Participants were debriefed at the end of the study and had an opportunity to withdraw their data (none did). A baseline run-in period (successful completion of baseline study procedures required for study enrollment defined as completing 2 out of 3 components including submitting the first and second weeks of receipts and an online survey) was used to improve retention and compliance, but likely reduced generalizability by selecting for compliant participants. Limited data were available to compare individuals who did not pass run-in to those who were enrolled. Available screening data for a subset of individuals ($n = 407$ Philadelphia, $n = 415$ Baltimore) indicated that the frequency of SSB consumption per week as reported in a single screening question was similar for those who enrolled in the study (mean = 5.99, SD = 2.39) compared with those who did not complete run-in (mean = 6.26, SD = 2.36), and was similar across study locations. Participants were recruited and completed baseline measures between September and 31 December, 2016 (166 participants in Baltimore completed measures by 23 January, 2017). Measures were collected again ∼3, 6, and 12 mo after tax implementation. Participants received $170 for full participation. The study was approved by the Philadelphia Department of Public Health Institutional Review Board (IRB) and was determined exempt by the University of Pennsylvania and Harvard University IRBs.

Measures

Overview of measures.

At each measurement period, participants were asked to submit 2 full weeks of all food and beverage receipts by texting pictures and mailing hard copies. Receipt collection protocols were adapted from previous studies (see **Supplementary Methods and Results** for details) (19, 20). Participants wrote in missing details (e.g., size, brand) of their beverage purchases on the receipt. Research assistants requested this information from participants when they failed to include it. Participants were provided with forms for missing receipts (e.g., vending machines, some small stores). Participants were recruited for a "food shopping study" and enrolled in weekly cohorts on a rolling basis at baseline and completed all measures during the same 2-wk period of the month for all follow-up periods to control for differences in food shopping patterns by time of month (e.g., weeks 3 and 4 of the month were used at each follow-up). At the end of the 2-wk receipt collection, participants completed an online survey (Supplementary Ads and Surveys) that included questions about demographics, SSB consumption, and beverage purchase locations.

Purchased ounces of taxed and nontaxed beverages.

Receipt data (which we refer to as objectively measured in contrast to self-reported consumption) were entered into a database, and all beverages were double entered. Two research assistants classified beverages by tax status (i.e., taxed or nontaxed) and resolved discrepancies with study investigators. The primary outcome was created by summing the total ounces of purchased taxed beverages across each person's 2 wk of receipts. The same was done for total ounces of purchased nontaxed beverages (secondary outcome).

Although self-reported beverage consumption in the past month was assessed with an existing 15-item questionnaire (21), it was not analyzed due to extensive data quality concerns suggesting it was not a valid and reliable measure of consumption (see Supplementary Methods). First, the questionnaire had low correlation with the more objective, receipt-based purchasing measure (r ranged 0.09–0.21 within time points). Further, in the comparison city, summer taxed beverage *purchasing* increased (as expected), whereas summer *consumption* assessed by this questionnaire declined (Supplementary Methods Table 1.3), which is inconsistent with well-established seasonal patterns that indicate beverage purchases and consumption increase in the summer months (7, 8, 22). In addition, the 12-mo consumption declines assessed by this questionnaire in Baltimore were very large (13.2 ounces/d or a 24.7% reduction), approaching the magnitude of change produced by intensive randomized-controlled behavioral trials (23, 24), which would be very unusual in the absence of treatment.

Purchasing patterns (secondary outcomes).

Receipt data were used to calculate: *1*) total amount spent on foods and beverages (this included any nonfood items also on the receipts), and *2*) proportion of total amount spent on taxed beverages. Purchasing of taxed beverages outside the taxed jurisdiction was examined by geocoding store addresses where receipts came from, summing ounces purchased inside versus outside the taxed jurisdiction, and calculating the proportion purchased outside. Participants also self-reported how often they traveled to neighboring counties to purchase sweetened beverages and the reason why at baseline, 6, and 12 mo. Research assistants coded these reasons into categories (e.g., avoid beverage tax, avoid sales taxes, because of travel for another existing purpose such as visiting family or for work). A reason could be assigned to multiple categories.

Distance to the Philadelphia border was examined to determine if the 254 Philadelphia participants with home addresses >0.5 miles from the border had different responses to the tax compared with control participants (n = 297; Supplementary Methods). This excluded 52 Philadelphia participants who lived close to the border and could theoretically more easily avoid the tax. Purchasing changes for 2 subsets of participants with self-reported taxed beverage consumption at least daily (>20 ounces per day; n = 430) or twice daily (>40 ounces per day; n = 250) for the 2-wk measurement period at baseline were examined separately to determine patterns of change in moderately high and very high consumers, respectively.

Data analysis

Purchase exclusions.

A total of 27,553 receipts were collected across time points. Receipts submitted outside participants' 2-wk collection windows were excluded (n = 1831, 6.6% of receipts). Receipts with missing dates (n = 359, 1.3% of receipts) were assumed to be within the collection windows. Two receipts in Baltimore contained extreme purchases of taxed beverages (>15,000 ounces) which influenced results and were therefore excluded as outliers. The final analytic sample included 25,720 receipts (93.3%). At the item-level, concentrates, syrup, alcoholic beverages, and meal replacements were excluded from the beverage analysis (n = 1933, 8.1% of 23,992 beverages) due to missing volume or small sample size. Beverages with missing or indeterminable volume, type, or tax status information were also excluded (n = 530, 2.2% of beverages). In the end, 21,529 beverages (89.7%) were analyzed.

Missing data.

Of 8 potential weeks of receipt data (2 wk at each of 4 time points), the majority of participants submitted all 8 wk (60.0%), 6–7 wk (23.1%), 3–5 wk (10.3%), or 1–2 wk (6.6%). For primary analyses, missing week-level data were addressed using multiple imputation by chained equations (MICE) (25) with 20 sets of imputations (Supplementary Methods, Table 2.5). To examine the robustness of imputations, 2 additional analytic samples were used. First, participants with all covariate data (described below) who submitted both weeks of receipts at any given time point (n = 559) were analyzed as 2-wk compliant cases. Unadjusted receipt- and purchase-level characteristics were examined in 2-wk compliant cases. Second, individuals with all covariate data who submitted either 1 or 2 wk of receipts at any given time point (n = 588) were included as 1-wk compliant cases. Missingness amounts and patterns were similar across study locations.

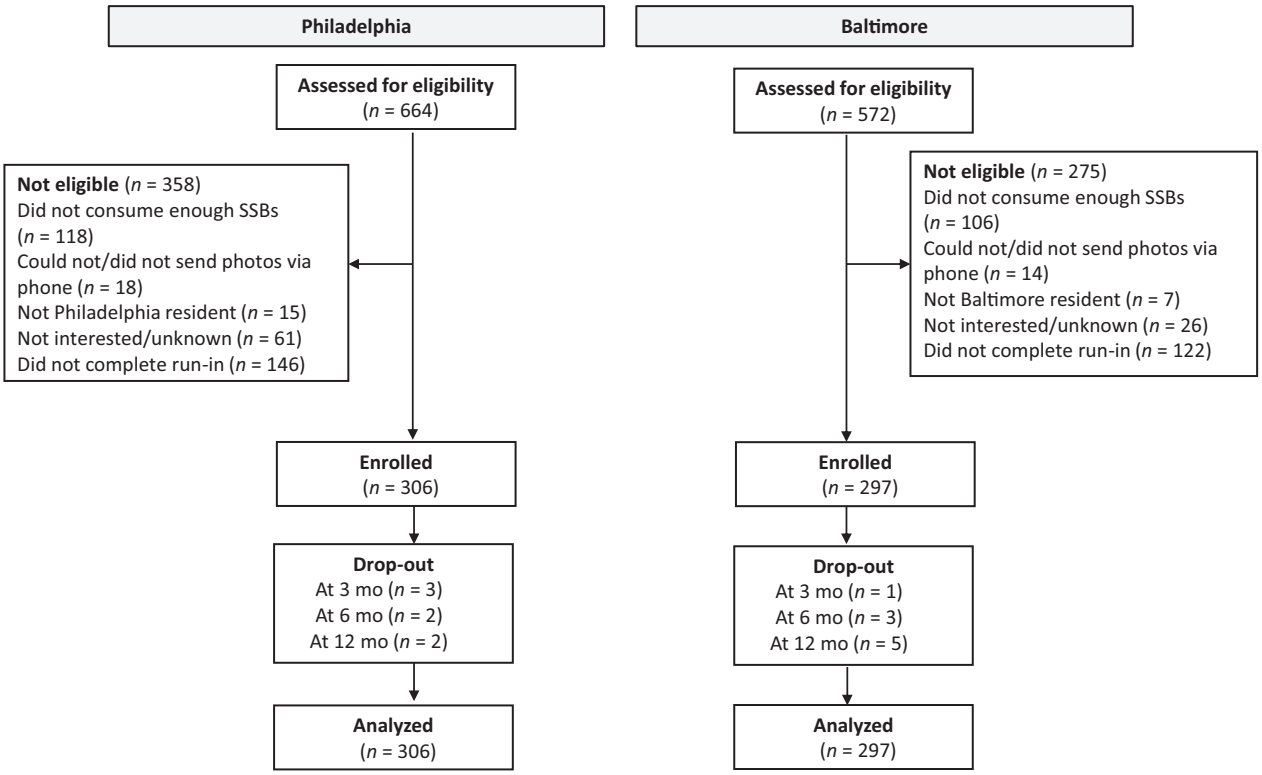

FIGURE 1 Participant enrollment flow. Note: completion of run-in for eligibility was determined by compliance with submitting ≥2 out of 3 requested baseline study measures including each of 2 wk of receipts and online survey completion. Eligibility for SSB consumption was defined as self-reported consumption of SSBs ≥2–3 times per week. SSB, sugar-sweetened beverages.

Analytic model.

Outcomes were assessed with linear mixed effects models with random intercepts for participants' repeated measures over time. Models included indicators for city (Philadelphia compared with Baltimore) and follow-up periods (3, 6, and 12 mo) and their interactions (i.e., the effect of the tax), as well as prespecified covariates. Time was modeled categorically to allow for nonlinearity due to seasonality. Covariates for all models included age, sex, race/ethnicity, education, BMI, household size, and receipt collection week of the month [because distribution of federal food program benefits influences monthly purchasing patterns (26)]. Uncorrected *P* values are reported for taxed beverage purchases (primary outcome). Secondary analyses were adjusted using a Bonferroni–Holm correction of 2 for purchasing outcomes and 3 for total spending and survey outcomes. Sensitivity analyses (Supplementary Results) included: *1*) imputation robustness checks, *2*) testing a fixed effects model rather than a random effects model, *3*) consideration of additional covariates, and *4*) excluding time periods of receipt collection that included a major holiday (Thanksgiving, Christmas, or New Year's Day) between October and January. This was done because all of our baseline data had to be collected during this period due to policy timing, but beverage purchasing behavior may be atypical and relatively inelastic during these holidays. Weeks with 1 of these major holidays represented 42% of all measured weeks, some of which were at baseline ($n = 431$ wk) and some at 12 mo ($n = 332$ wk). All analyses were run in R (version 3.5.3).

Results

The sample demographic characteristics were similar to those of Philadelphia and Baltimore, but the sample included slightly higher representation of key subgroups of interest including non-Hispanic blacks (62.3–67.6%) and participants making ≤$25,000 per year (36.4–39.5%) compared with the citywide population data from the Census (44.1–62.8% black, 27.1–31.0% making ≤$25,000). Participant enrollment flow was similar across sites (**Figure 1**). The percentage of the sample that submitted ≥1 receipt for each of the 2-wk receipt collection periods and took the online survey was high and similar in Philadelphia and Baltimore (baseline = 92% and 93%, 3 mo = 75% and 79%, 6 mo = 77% and 78%, and 12 mo = 80% and 75%, respectively), and 91% of the sample submitted at least some data at 12 mo. The intervention and comparison city samples were demographically similar (**Table 1**). Philadelphia's sample had more females, fewer white respondents, and older respondents compared with Baltimore (Table 1).

Unadjusted purchase characteristics (Supplementary Results Table 2.2) over time by city showed that approximately one-third (range 34.7–40.7%) of receipts were from restaurants, most receipts contained a beverage (range 62.7%–70.5%), and $17–21 was spent on taxed beverages (ranging 9.8–12.7% of the total food budget).

Results (**Table 2**, Supplementary Results Figure 2.8) showed that overall, including purchasing during major holidays, there

TABLE 1. Baseline participant characteristics by city

	Philadelphia ($n = 306$)	Baltimore ($n = 297$)	P value
Age, mean ± SD	43.9 ± 13.4	41.7 ± 13.0	0.043
Gender, *n* (%)			0.033
Male	102 (33.3)	124 (41.8)	
Female	204 (66.7)	173 (58.2)	
Race/ethnicity, *n* (%)			0.010
Non-Hispanic white	49 (16.0)	78 (26.3)	
Non-Hispanic black	207 (67.6)	185 (62.3)	
Hispanic	17 (5.6)	9 (3.0)	
Other	33 (10.8)	25 (8.4)	
Income,[1] *n* (%)			0.183
≤$25,000	111 (36.4)	115 (39.5)	
$25,001–$50,000	102 (33.4)	79 (27.1)	
$50,001–$75,000	49 (16.1)	44 (15.1)	
$75,001–$100,000	22 (7.2)	19 (6.5)	
>$100,000	21 (6.9)	34 (11.7)	
Education,[1] *n* (%)			0.379
High school or less than high school	86 (28.2)	89 (30.6)	
Some college or 2-y degree	127 (41.6)	105 (36.1)	
College graduate or above	92 (30.2)	97 (33.3)	
Household federal assistance participation,[1,2] *n* (%)			0.638
Yes	163 (53.3)	152 (51.4)	
No	143 (46.7)	144 (48.6)	
Ever diagnosed as diabetic,[1] *n* (%)			0.070
Yes, currently	43 (14.1)	26 (8.8)	
Yes, I had it in the past, but no longer do	15 (4.9)	10 (3.4)	
No	248 (81.0)	260 (87.8)	
Primary food shopper for your family,[1] *n* (%)			0.473
Yes	262 (85.9)	243 (83.8)	
No	43 (14.1)	47 (16.2)	
Live within $\frac{1}{2}$ mile of city border, *n* (%)			0.038
Yes	52 (17.0)	33 (11.1)	
No	254 (83.0)	264 (88.9)	
Household size adults and children, mean ± SD	2.1 ± 1.9	2.0 ± 1.8	0.510
Total food and beverage spending, mean ± SD	220.3 ± 155.8	222.7 ± 171.2	0.860
Proportion spent on taxed beverages, mean ± SD	10.6 ± 9.8	11.8 ± 11.7	0.212

[1]Percentages do not sum to 100% due to missing values.

[2]Federal Assistance Programs asked about include Supplemental Security Income, Social Security Disability Income, Supplemental Nutrition Assistance Program, and Temporary Assistance for Needy Families.

were no statistically significant declines in purchases of taxed beverages over a 2-wk period at 3 mo (−29.3 ounces; 95% CI: −123.3, 64.7), 6 mo (−47.3 ounces; 95% CI: −144.8, 50.3), or 12 mo (−10.1 ounces; 95% CI: −106.7, 86.6) in Philadelphia compared with Baltimore. Changes in nontaxed beverage purchases at 3 mo (62.1 ounces; 95% CI: −69.2, 193.3), 6 mo (−1.3 ounces; 95% CI: −124.3, 121.6), and 12 mo (75.0 ounces; 95% CI: −55.1, 205.0) in Philadelphia compared with Baltimore were not statistically significant (Table 2). Out of a concern for low statistical power in the full sample and to correct for serial correlation with a small number of groups (27), a posthoc analysis was done using all 6 wk of posttax purchasing data aggregated and compared with pretax purchasing in Philadelphia versus Baltimore. Ounces of taxed beverages purchased were statistically significantly lower posttax in Philadelphia compared with Baltimore (−203.7 ounces; 95% CI: −399.6, −7.8; $P = 0.042$. Data not shown in table).

After excluding weeks that contained major holidays (Table 2, Supplementary Results Table 2.4 and Figure 2.9), there were statistically significant declines in purchases of taxed beverages over a 2-wk period at 3 mo (−157.1 ounces; 95% CI: −310.1, −4.1) and 6 mo (−175.1 ounces; 95% CI: −328.0, −22.3) in Philadelphia compared with Baltimore, but 12-mo reductions were not statistically significant (−166.6 ounces; 95% CI: −350.0, 16.9, $P = 0.075$).

Patterns of results from sensitivity analyses using the 1-wk compliant and 2-wk compliant cases (Supplementary Results Table 2.5) were similar (difference-in-differences = −18.7 to −86.6 ounces). Results from fixed effects models were similar to the primary models (Supplementary Results Table 2.6).

There were no statistically significant changes in total food and beverage spending or the proportion of food/beverage spending on taxed beverages (Table 2). The proportion of ounces of taxed beverages purchased outside (versus inside) the city increased from ∼21% to 33% from baseline to 12 mo (12.5, 95% CI: 6.8, 18.2; Supplementary Results Figure 2.10, Table 2). Model-estimated means for secondary outcomes are shown in Supplementary Results Table 2.7. Before the tax, the top reasons people purchased beverages in neighboring counties were being there for another purpose or for convenience during travel. After

TABLE 2 Difference-in-differences regression results for changes in beverages purchased, total spending, and tax avoidance following implementation of a beverage tax ($n = 603$)[1]

	Difference-in-differences estimate	Lower CI	Upper CI	*P* value	Corrected *P* value
Primary outcome-purchasing					
Purchased taxed beverages (ounces)					
Tax effect at 3 mo	−29.3	−123.3	64.7	0.542	
Tax effect at 6 mo	−47.3	−144.8	50.3	0.343	
Tax effect at 12 mo	−10.1	−106.7	86.6	0.839	
Purchased taxed beverages excluding holidays (ounces)					
Tax effect at 3 mo	−157.1	−310.1	−4.1	0.044	
Tax effect at 6 mo	−175.1	−328.0	−22.3	0.025	
Tax effect at 12 mo	−166.6	−350.0	16.9	0.075	
Secondary purchasing outcomes					
Purchased nontaxed beverages (ounces)					
Tax effect at 3 mo	62.1	−69.2	193.3	0.355	0.355
Tax effect at 6 mo	−1.3	−124.3	121.6	0.983	0.983
Tax effect at 12 mo	75.0	−55.1	205.0	0.260	0.260
Percent of taxed beverages purchased outside border (%; Philadelphia only, $n = 306$)[2]					
3 mo after tax	6.6	0.9	12.3	0.025	0.049
6 mo after tax	10.0	4.4	15.6	<0.001	<0.001
12 mo after tax	12.5	6.8	18.2	<0.001	<0.001
Secondary spending/self-reported outcomes					
Total food and beverage spending ($)					
Tax effect at 3 mo	0.3	−27.6	28.2	0.983	>0.999
Tax effect at 6 mo	−4.0	−32.1	24.1	0.780	>0.999
Tax effect at 12 mo	17.0	−11.5	45.5	0.244	0.488
Percent spent on taxed beverages (%)					
Tax effect at 3 mo	−0.9	−3.8	2.0	0.560	>0.999
Tax effect at 6 mo	0.4	−2.5	3.4	0.784	>0.999
Tax effect at 12 mo	−0.5	−3.5	2.4	0.720	0.720
Self-reported frequency of cross-border shopping (Philadelphia only, $n = 306$)[3]					
6 mo after tax	0.12	−0.18	0.41	0.439	>0.999
12 mo after tax	0.25	−0.05	0.54	0.100	0.300

[1] All purchasing and spending patterns estimates refer to a 2-wk period. Purchase, total spending, and taxed ounces purchased outside taxed jurisdiction models adjusted for age, gender, race/ethnicity, education, household size, BMI, and collection week of the month. The difference-in-differences effect of the tax was obtained by including interaction terms for location (Philadelphia compared with comparison) and time period (3, 6, or 12 mo) except for self-reported frequency of purchasing in neighboring counties. Secondary outcomes were adjusted using a Bonferroni–Holm correction for 2 tests for purchasing outcomes and 3 tests for spending and self-report outcomes.

[2] Model also adjusted for the distance from participants' home to Philadelphia city border and total ounces of taxed beverages purchased.

[3] Items on self-reported purchasing outside the taxed jurisdiction were measured on a 5-point scale. This question was excluded at 3 mo due to a survey error. The effect of the tax for this outcome was obtained by time period (6 or 12 mo).

the tax, those reasons were endorsed less often, whereas the beverage tax was endorsed most often (Supplementary Results Table 2.11).

Although not statistically significant, analyses with those living further from the Philadelphia border and those with at least daily SSB consumption showed patterns consistent with larger tax effects relative to the overall sample at 3-mo (−43.9, −61.4 ounces, respectively, compared with −29.3 overall), 6-mo (−66.9, −133.2 ounces compared with −47.3 overall), and 12-mo posttax (−18.8, −58.5 ounces compared with −10.1 overall), but twice daily SSB consumers showed contrary patterns (all increases) at all time points (range 4.1 − 87.9 ounces; Supplementary Results Table 2.12).

Discussion

This study examined the influence of a beverage tax among a longitudinal cohort of regular SSB consumers. There were no statistically significant changes in ounces of taxed beverages purchased 1 y after implementation of a beverage tax when purchasing during major holidays was included. There were, however, statistically significant reductions in cumulative taxed beverage purchases across the 3 posttax time points, inclusive of holidays, that corresponded to 4.9 fewer ounces per day. Further, reductions of SSB purchases in Philadelphia compared with Baltimore at 3 mo (spring) and 6 mo (summer) after tax implementation were large and statistically significant after excluding purchases during weeks that contained major holidays. Assuming no substitution, these difference-in-differences reductions translate to ∼11–13 fewer ounces purchased per day or roughly 160–189 calories. This may be both cost-effective and meaningful at the population level (28) and is similar to the size of SSB consumption reductions observed in intensive randomized controlled behavioral trials designed to reduce SSB intake, which have led to reductions in total energy intake (23) or BMI (24).

These results suggest that beverage taxes may have differential effects on purchasing, depending on time of the year, with limited influence during major holidays when demand may be more inelastic. In addition, results at 12-mo posttax were not statistically significant in either the full or holiday-excluded sample, which is in contrast to other studies in Philadelphia showing sustained reductions in sales of chain retailers at 12 mo (8), repeated cross-sections of purchases by individuals during exit interviews (4, 16), and some self-reported measures in some subgroups (4, 17) but not overall (4, 5, 17). A study in Berkeley demonstrated sustained reductions in self-reported consumption in low-income neighborhoods 3-y posttax (14, 15). The reasons for these discrepancies are unknown but could be due to differences in sample population (e.g., chain retailers, households with children, SSB consumers), measurement error, or reduced sample sizes due to exclusions of holiday purchasing.

It is important for future studies to examine heavy consumers (e.g., those who drink SSBs daily or twice a day). One longitudinal study, for example, reported greater reductions in household taxed beverage purchases among high ($\geq$ 150 mL/capita/d or 5.1 ounces) compared with low SSB consumers in the year following Mexico's tax (-7.5% to -8.6% compared with -0.5% to -3.4%) (6), but high consumption was determined using a median split rather than a clinically meaningful definition. For tobacco (29) and nonessential energy-dense food (30) taxes, heavy consumers have shown larger decreases following tax increases. For alcohol, taxes have been found to affect heavy drinking substantially, but compared with overall drinking reductions, the magnitude of effect is smaller (31).

Beverage tax studies have previously relied on self-reports of beverage tax avoidance behaviors and have not yet quantified broader food and beverage spending patterns. Objective store location data showed an approximate 6-point increase (21% to 27%) in the percentage of taxed ounces that regular SSB consumers purchased outside Philadelphia, which occurred at 3-mo posttax and then increased to a 12-point increase by 12 mo. Despite some tax avoidance, clinically meaningful reductions in purchased taxed beverages were still observed outside of major holidays, during spring and summer months, and cumulatively throughout the year. In addition, there were no changes to total food and beverage spending or to the proportion spent on taxed beverages specifically. These findings indicate that following a beverage tax, regular SSB consumers do not spend a greater share of their total food and beverage spending on taxed beverages and do not spend more money overall on food and beverages.

Published studies consistently show that taxes are associated with reductions in taxed beverage purchases and sales (6–8, 12, 16). A previous longitudinal study in Philadelphia using self-reported consumption showed significant reductions only in adults' soda consumption and may have had low statistical power and could not examine holiday consumption pattern differences (4). In addition, cross-sectional studies using measures of self-reported beverage consumption have found no significant changes (4, 7), mixed findings (17), or large reductions in low-income neighborhoods (14, 15). Self-reported consumption data in the current study were not reliable or valid. Discrepancies in purchasing versus consumption results in the published literature may be because self-reported SSB consumption studies are underpowered, requiring very large sample sizes due to high measurement error and the fact that many people do not drink SSBs. Although it is possible these discrepancies are because people increase their taxed beverage intake at restaurants or completely offset it by consuming these drinks outside the taxed jurisdiction, the findings of the current study suggest measurement error is more likely. In the current study, purchases from all sources were assessed, taxed beverage purchases from restaurants also declined, and tax avoidance behavior only partially offset declines in purchased taxed beverages. Significant net declines in taxed beverage sales of large chain retailers in Philadelphia also persisted after accounting for partial offset due to tax avoidance (8).

Limitations of this study include the use of only 2 wk of receipts per time point, which may not adequately capture typical purchasing behavior, and the use of a run-in period, which may limit generalizability because noncompliant respondents were not enrolled. However, 2-wk receipt expenditures have been shown to be strongly associated with 4-wk expenditures, particularly for SSBs ($r = 0.88$) (20). In addition, the timing of when the law was passed necessitated baseline data collection during the holidays, which may have resulted in atypical purchasing, increased measurement error, and reduced power in the full sample. It is possible that not all food and beverage receipts were submitted, which would result in under-representing beverage purchases. Although our numbers of receipts submitted and total food expenditures are similar to other studies using this method (20) and measurement error was not expected to vary by study site, receipt-based measures of free-living dietary patterns may still have measurement error. This study may have also been underpowered to detect changes in some secondary outcomes (e.g., daily and twice daily consumers, those living further from the border). Future studies of beverage excise taxes should include multiple time points and cities as more localities adopt such taxes to enable clustering SEs by location and/or use of methods like interrupted time series to improve causal inference. Difference-in-differences designs with a small number of groups may be at risk of downward biased SEs and increased risk of false positives (27, 32, 33). The study had a number of strengths including a longitudinal design with 4 measurement periods over 1 y, inclusion of taxed beverage purchases from all food retail sources (e.g., supermarkets, restaurants, vending machines), high retention and compliance, receipt-based measures of beverage purchases that may have lower levels of measurement error compared with self-reports, a diverse sample, and a focus on regular SSB consumers for whom the impact of beverage taxes is of particular public health interest. Future longitudinal research is needed with larger samples, longer-term follow-ups, and objective health outcomes.

In conclusion, this quasi-experimental study of the influence of Philadelphia's beverage tax on SSB consumers found no statistically significant changes to purchases of taxed beverages overall after 1 y when including purchasing during major holidays. However, reductions in taxed beverage purchases were statistically significant when collapsing posttax time points (amounting to 5 ounces per day) and in spring and summer months (amounting to 11–13 ounces per day) but not winter months after excluding purchasing during major holidays.

We would like to acknowledge Simone French and Lisa Harnack for their assistance with the receipt collection protocols. We are grateful to our research

assistants who assisted with coding all of the receipts and to Annaka Scheeres who supported the geospatial analyses.

The authors' contributions were as follows—HL: led the manuscript writing and had primary responsibility for final content; HL, CR, and SB: conceptualized and designed the study; JY, HL, and ML: contributed to study design and conducted statistical analyses; NM: oversaw the statistical analyses; LG: provided feedback on statistical analyses; SVH, CL, AP, ML, HL, CR, and SB: oversaw data collection and management; all authors provided critical feedback on manuscript drafts, and read and approved the final manuscript. The authors report no conflicts of interest.

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