Tapping into Correlates of Drinking Tap Water in the United States.

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A Dissertation submitted to

The Faculty of
The Milken Institute School of Public Health
of The George Washington University
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

August 31st, 2024

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Dedication

To Ryan, for insisting that I never forget what my strengths are or take the easy way out.

"From a certain point onward there is no longer any turning back. That is the point that must be reached." – Franz Kafka

Acknowledgments

First and foremost, I would like to acknowledge the exceptional mentorship of my dissertation chair, Dr. Allison Sylvetsky. I have spent the last four years learning from and looking up to your quick and helpful insight in problem-solving one thing after the next. I have learned so much from you that I will carry with me. Thank you for consistently being fully present (often at short notice) to see me through this arduous process.

To my committee members, thank you for your insight and support from the proposal to the final manuscript.

Dr. Colón-Ramos, I am particularly grateful for your availability and guidance as I worked through ideas about “what cake to bake”. You asked tough questions that strengthened my work by making me look at my research and analysis from different angles.

To my mother, father, aunt TM and uncle Naz, thank you for the love, support, and sacrifices that you have made to make sure I had the opportunities that led to the pursuit of this degree. I hope you know that I do what I can to show my gratitude and love for you, but I feel it will never be enough.

To Manon, thank you for being an exemplary role model, inspiring me to pursue research, and always being there for me when I needed your wise advice.

To the director of the PhD program, Dr. Jennifer Sacheck, thank you for giving me a chance to thrive in your program and the fellowship that made this possible.

To the faculty at the Milken Institute School of Public Health, particularly those in Department of Exercise and Nutrition Sciences, thank you for teaching me the fundamentals necessary to undertake and defend this research. Drs. David Huebner and Rob van Dam, thank you for the repeated feedback as I developed the proposal for this dissertation, which improved my proposed work substantially.

To my closest PhD peers and friends, thank you for always being there to dissolve even the most difficult times into laughter and sometimes tears.

Finally, thank you to all my close friends who have been by my side through the challenges and celebrations. Joya and Chloe, thank you for your wisdom and generosity as I set off to complete this manuscript. Joya, your voice reminding me of my options will never leave my mind. Chloe, allowing me to make your home in Paris my own, has been a gift I will cherish forever.

Abstract of Dissertation

Tapping into Correlates of Drinking Tap Water in the United States.

Approximately half of Americans do not drink water from the tap. Since less than 4-28% of the United States (US) population experiences a water safety violation in a given year, it is likely that many avoid tap water without having experienced a violation in their county of residence. National surveys indicate that lower tap consumption has unfavorable dietary correlates, including higher sugar sweetened beverages, which are a risk factor for weight gain and chronic diseases like diabetes and cancer.

The objectives of this research are to quantify the association between water safety violations and tap water consumption, water safety violations and sugary drink consumption, and to determine whether perceptions of the water utility may be associated with the choice to drink water from the faucet. These objectives were addressed with three specific aims. In the first two aims, we linked nationally representative water safety and dietary surveillance data to: 1) examine associations between previous water safety violations in an individual's county and self-reported tap water intake, and test race/ethnicity and income as moderators and 2) examine associations between previous water safety violations in an individual's county and self-reported sugary beverage intake, and test tap water intake as a mediator. In the third aim, we analyzed survey data from the state of Virginia on water beliefs and preferences to 3) describe the associations between self-reported water beliefs and tap water preference.

The results of this work informed us of the lack of alignment between both objective and perceived water safety and consumption of tap water among adults, which

is significant, because it determined for the first time, the proportion which individuals avoid tap water (50.5%), even when they reside in a county that has never experienced water safety violations. Among children, tap water avoidance is similarly high in those unexposed to previous water safety violations (48.9%), but among the exposed, the odds of tap water avoidance were significantly higher (adjusted odds ratio: 1.35, 95% confidence interval: 1.01-1.80).

Our findings from the water beliefs survey indicated that the odds of preferring tap water are considerably higher among individuals with the highest levels of the assessed water beliefs: trust in the water at their faucet, trust in the water utility company, perceived water quality, and perceived water safety. Nevertheless, there was still a gap between the proportion of the sample with positive water belief ratings (above 67%), and the proportion that prefer drinking from the tap (54%).

Both our national and state level findings indicated a strong association between higher levels of education and greater tap water intake and tap water preference in all models. Other demographic covariates such as race/ethnicity and urbanicity were also influential correlates of tap water intake and preference.

This research highlights the need for interventions to increase the trustworthiness of tap water, to reduce the disproportionate burden of low tap water intake on children, rural and minority health outcomes, and improve the health of all people living in the US.

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List of Abbreviations

SSB(s): Sugar sweetened beverage(s)

NHANES: National Health and Nutrition Examination Survey

SDWIS: Safe Drinking Water Information System

FNDDS: Food and Nutrient Database for Dietary Studies

OR: odds ratio

CI: confidence interval

SE: standard error

kcal: calories

mL: milliliters

PFAS: per- and polyfluoroalkyl substances

Glossary of Terms

Organoleptic: term used to describe aesthetic properties of water such as appearance, odor, taste, and smell.

Sugary drinks: term that includes both sugar sweetened beverages and 100% fruit juice.

Chapter 1: Introduction

To date, no country in the world has been able to reverse rises in obesity within their population (Swinburn et al.)**.** Sugar sweetened beverage (SSB) consumption is the number one source of sugar in the American diet and has been robustly associated with obesity, cardiometabolic diseases, and dental caries (Malik et al.). The mechanism by which sugar-sweetened beverages are thought to influence the development of obesity and cardiometabolic disease is primarily through weight gain from excess calories (Malik and Hu). There is also evidence that ingestion of the beverages leads to hyperinsulinemia, which over time may blunt insulin sensitivity, and that excess sugar stimulates increased production of fat in the liver (Malik and Hu), the organ primarily responsible for buffering blood glycemia. Sugar addiction is an additional proposed mechanism whereby high levels of sugar are highly rewarding much like addictive drugs, but this area of research is controversial and findings in humans have not been as consistent as in animals, or as with other mechanisms like weight gain and hyperinsulinemia (Malik and Hu; Westwater et al.). SSB consumption is of particular concern for youth, the highest consumers of SSBs in the US (*Get the Facts: Sugar-Sweetened Beverages and Consumption | Nutrition | CDC*), since children and adolescents with overweight or obesity are at high risk of retaining excess weight as adults (Gordon-Larsen et al.). Nationally representative data from the National Health and Nutrition Examination Survey (NHANES) indicates that there has been a decline in SSB consumption, which may result from continuing public health efforts to reduce SSB intake. However, SSB intake remain very high and continue to exceed recommendations (Dai et al.). For example, based on data collected during the 2017-18 cycle and NHANES, about three

quarters of children and adults reported having some amount of SSBs on a given day (Dai et al.). Concerningly, the COVID-19 pandemic may have reversed some of the improvements in reducing SSB intake, as children who were attending remote school during COVID-19 reported increasing their intake of sugary drinks (Sylvetsky, Kaidbey, et al.).

Water is often suggested as a replacement for SSBs, but only about half of Americans report consuming any tap water on a given day (Asher Y. Rosinger, K. A. Herrick, Wutich, et al.). Water is necessary for life (Daniels and Popkin) and essential for health (Asher Y. Rosinger, H. G. Lawman, Akinbami, et al.) but only about 40% of the US population is estimated to have adequate total water intake, which includes water from plain water, other beverages, and food moisture (Vieux et al., "Trends in Tap and Bottled Water Consumption among Children and Adults in the United States: Analyses of NHANES 2011-16 Data"). **Inadequate water intake has significant consequences for public health, which are further exacerbated by its pervasive consumption of SSBs**. It has been established that those who consume the most SSBs consume the least amount of plain water (Baraldi et al.). Vieux et al. conducted an analysis of water and SSB trends from 2011-16 to determine if recent declines in SSB intake are due to substitution of SSBs with water, as recommended by the dietary guidelines. There analysis determined that concomitant drops in SSBs and increases in tap water were only observed among non-Hispanic white adults (Vieux et al., "Opposing Consumption Trends for Sugar-Sweetened Beverages and Plain Drinking Water: Analyses of NHANES 2011–16 Data"). The same analysis also showed that non-Hispanic White participants had the greatest tap

and total water intake, whereas non-Hispanic Black participants had the lowest, and consumption among Hispanic participants fell in between. This result is supported by repeated findings – across time and distinct federal surveys – of racial disparities in plain water source in the US: only about a third of non-Hispanic Black (37.0%) and Hispanic (36.3%) adults consume any tap water on a given day as compared to 60% of non-Hispanic White adults (Brooks et al.). This finding is concerning because multiple analyses have found that those who drink the least amount of tap water often have the lowest plain water intake (Asher Y. Rosinger, K. A. Herrick, Wutich, et al.) and total water intake (Vieux et al., "Trends in Tap and Bottled Water Consumption among Children and Adults in the United States: Analyses of NHANES 2011-16 Data"). Furthermore, non-Hispanic Black and Hispanic individuals are more likely to consume bottled water compared to their white counterparts,(Asher Y. Rosinger, K. A. Herrick, Wutich, et al.) and perceive bottled water to be safer than tap water (Viscusi et al.). Estimates based on self-reported water intake have also been validated with a biological marker of hydration, urine osmolality: compared to non-Hispanic Whites, non-Hispanic Blacks and Hispanics had more than 40% higher odds of inadequate hydration(Brooks et al.). That analysis also found that the lower-income individuals had higher odds of inadequate hydration compared to higher-income counterparts. This aligns with findings that water intake follows a dose-response gradient with socioeconomic status (SES) (Vieux et al., "Trends in Tap and Bottled Water Consumption among Children and Adults in the United States: Analyses of NHANES 2011-16 Data"), where those of lower income consume less tap and total water as compared to higher income individuals (Asher Y. Rosinger, K. A. Herrick, Wutich, et al.). Untangling the relationship between

race and SES is complicated because even large surveys like NHANES may not be large enough to stratify by both characteristics simultaneously (e.g. low-income Black vs. high income Black) (Vieux et al., "Trends in Tap and Bottled Water Consumption among Children and Adults in the United States: Analyses of NHANES 2011-16 Data"; Rosinger and Young; Asher Y. Rosinger, K. A. Herrick, Wutich, et al.; Asher Y Rosinger et al.). Nonetheless, these findings highlight an economic burden of avoiding tap water that falls disproportionately on people of color and lower SES (Brooks et al.).

Disproportionately high occurrence of safety hazards in areas housing more low income and minority individuals may partially explain lower acceptability and consumption of tap water. Decades of environmental scholarship have documented "societal forces, policies and institutions that interact to produce and maintain racial and ethnic inequities"(Perry et al.) which is known as structural racism (Perry et al.; Hicks et al.). A prominent example is that people of color have much higher likelihood of living in hazardous, industrial areas which consequently increases their risk of exposure to pollutants (Hicks et al.; Perry et al.) due to discriminatory housing practices such as rezoning residential areas with high percentages of Black residents to commercial areas (Rouse et al.), lending fewer mortgages in Black neighborhoods, and devaluing Black-owned homes (Loh et al.). Although 99.7% of the people living in the US have access to piped water, it is critical to acknowledge that racial/ethnic minority and lower income communities have been systematically underdeveloped (Meehan, Jurjevich, et al.). For example, there have been cases of "under bounding" where the development of water systems intentionally circumvented black towns in Virginia and North Carolina (*Closing*

the Water Access Gap in the United States: A National Action Plan; Leker and Gibson), or water infrastructure was fraudulently promised and never delivered to Hispanic communities who bought land along the U.S-Mexico Border (Wutich et al.). Finally, although infrastructure is aging all over the US, this issue disproportionately burdens communities where there is less funding and investment for restoration or maintenance, such as those with greater proportions of rural, lower income, and racial/ethnic minority residents (Teodoro et al.; Condon).

Water safety violations are an example of the disproportionate burden of environmental hazards to black and Hispanic Americans. A national study of water violations (detection of a chemical or element above the lawful limit, or water treatment negligence) over the 1984-2015 period, found that 4-28% of the US population experiences a health-based violation in a given year.(Allaire, Wu, et al.) Although that study did not disaggregate their findings by race/ethnicity, another study of violations in 2013-2015 found that low socioeconomic status and proportion of black and Hispanic populations in communities were the strongest predictors of drinking water violations (Switzer and Teodoro). Other studies have replicated the finding that increasing proportion of minority races, as compared to White, increases the risk of water safety violations (Marcillo et al.; Mcdonald and Jones). Among the Black community, this has resulted in having more children exposed to lead than any other racial group(Perry et al.), and has consequently bred mistrust in public services (Javidi and Pierce) that predate the more recent crisis in Flint (Hicks et al.).

Growing attention to flagrant violations of access to clean drinking water in the US has called into question the notion of water security, defined as "the ability to access and benefit from affordable, adequate, reliable, and safe water for wellbeing and a healthy life"(Jepson et al.). The Household Water InSecurity Experiences framework conceives that there are four pillars to water security: availability, access, use, and stability of water(Young et al.). In this framework, use of water, is contingent on it being available and accessible. Electing not to use tap water (i.e. tap avoidance) even though it is available and accessible indicates that there may be a problem with or stability of acceptable water. Since over 99% of US households have piped water in their homes (Meehan, Jurjevich, et al.), this suggests that most common issue with tap water is not in its availability and accessibility, but rather its acceptability. Since water security measures in high income countries are still in their infancy, the self-reported avoidance of tap water is used as a proxy measure for water insecurity (Rosinger). A vast literature surrounding determinants of water acceptability demonstrates that an array of beliefs, demographic identities, and past experiences influence an individual's perceptions and choice of water source (i.e. bottled, unfiltered tap, filtered tap, etc.) (Grupper et al.; Anadu and Harding; Park, S. J. Onufrak, et al.; Onufrak, Park, Sharkey, and Sherry; Asher Y. Rosinger, K. A. Herrick, Wutich, et al.).

Trust, safety, and quality of the water are the most strongly correlated water beliefs that influence the decision of whether to consume tap or bottled water. Many surveys in adults across the US have shown that people who trust their water utility to provide them with safe water (Grupper et al.), rate their water quality as good or better (Mackey

et al.), and consider the water at their tap to be safe (Park, S. J. Onufrak, et al.; Onufrak, Park, Sharkey, and Sherry) are more likely to consume tap water. Conversely, people who consume more bottled water tend to think that their tap water is unsafe (Park, S. J. Onufrak, et al.; Javidi and Pierce), believe that bottled water is safer than tap water (Grupper et al.; Park, S. J. Onufrak, et al.), have less trust in the water utility to deliver safe water (Grupper et al.), and view their water quality as inadequate, either from an aesthetic -- like taste, odor, or color -- or from a contaminant perspective (Park, S. J. Onufrak, et al.; Mackey et al.; Anadu and Harding). Trust in the government has emerged as another important correlated of drinking water preference, which has critical implications for groups that have a historic legacy of marginalization by the government (Teodoro et al.). Since over 85% of water utilities in the US are owned by the government, the use of tap water has been described as a daily encounter people have with the government, and an individual's perceptions of the tap water is correlated with their trust in the government (Teodoro et al.).

Demographic characteristics are often related to water beliefs and choice of water source. Although estimates vary by survey, there are consistently race and class disparities in perceptions of tap water, with minorities and those with lower SES having less favorable appraisals (Hicks et al.; American Water Works Association). For instance, in the 2015 American Housing Survey conducted by the US Census Bureau, disagreement with the statement that tap water is safe for drinking or cooking was 5% among White adults, compared to 10% among Black and 16% among Hispanic adults (Javidi and Pierce). A Gallup poll in the same year found that while concern over tap

water was present for 55% of the overall sample, it jumped to 73% for those that did not identify as White (Hicks et al.). Data from a different national survey of US adults found that 11% of non-Hispanic White adults disagreed with the statement 'My local tap water is safe to drink', as compared to 20% of non-Hispanic Black and 16% of Hispanic adults (Onufrak, Park, Sharkey, and Sherry). The same survey also indicated disparate perceptions by income level. Compared to Individuals with higher income, those with lower income were more likely to disagree with statements that their tap water is safe, and agree with statements indicating that bottled water is safer. It is likely that both these surveys underestimate current negative sentiments about tap water, as they would not have fully captured the aftereffects of the massive failure in providing safe water to residents of Flint, Michigan which was not widely publicized until January 2016 when a state of emergency was declared by President Obama (Matsa et al.). Increases in negative perceptions about tap water have been documented more recently, such as in a mail-in survey study conducted over a 32-year period in the Pacific Northwest of the US, that showed that the percentage of residents who perceived their water at home as safe declined from 93% in 1988 to 79% in 2019 (Mahler). Education is another characteristic that is strongly related to both tap and bottled water perceptions, with an inverse relationship between years of education and negative tap water perceptions consistently documented. With very few exceptions (Hu et al.; Gholson et al.), those with higher educational attainment have higher odds of considering tap water to be safe and disagreeing that bottled water is safer than tap water (Onufrak, Park, Sharkey, and Sherry; Park et al.). In terms of age, older adults are more likely to perceive their tap water as safe (Junker and Carpenter; American Water Works Association; Mahler; Park

et al.) and less likely to consider that bottled water is safer (Viscusi et al.). Associations between gender and water perceptions are mixed; some investigations have found women have greater risk perceptions about their water than men (Anadu and Harding; Mahler) or that women were less likely to consider their local tap water as safe (Park et al.). Yet, others have not observed gender differences in perceptions of bottled or tap water safety (Onufrak, Park, Sharkey, and Sherry; Grupper et al.). Larger nutrition surveillance studies, such as NHANES, do not ask about water perceptions; however, gender differences in tap or bottled water consumption are not reported across gender in analyses using NHANES data since NHANES began distinguishing between bottled and tap water intake in 2005 (Asher Y. Rosinger, K. A. Herrick, Wutich, et al.; Vieux et al., "Trends in Tap and Bottled Water Consumption among Children and Adults in the United States: Analyses of NHANES 2011-16 Data").

To our knowledge, most studies that have focused on demographic correlates of tap water perceptions in the US, such as those reported here, have been conducted in adults. One exception is the 2010 Youth-Styles survey, which analyzed data from in 1,044 children 9-18 years old (Onufrak, Park, Sharkey, Merlo, et al.). In that study, both, children and one of their parents were asked whether they considered the tap water in their homes and schools to be safe. Consistent with demographic patterns described in adults, non-Hispanic Black, Hispanic, and lower income youth were the most likely to report their water as being unsafe. Furthermore, that study found that the agreement between parent and child perception was high, especially among kids who perceived their local tap water was safe (82% of their parents do as well), however, there were more discrepancies

among children who did not perceive their water was safe (only 56% of their parents did as well). Finally, the study also found that perceptions did not differ based on children's age (9-18) or sex. Another is a qualitative study done in a largely Hispanic community, which also reported that children have concerns about the safety of their tap water at home and at school, and these were expressed as perceived risk of getting sick from the water, and negative organoleptic properties (Barrett et al.).

Perceptions of tap water are associated with the likelihood of using tap water filtration systems. There is literature to suggest that filtration improves aesthetic qualities of water, however, people who are concerned about the safety of their water may prefer to consume bottled water (Colburn and Kavouras). For example, a survey done in Jacksonville, Florida reported no association between perceived water safety and water filtration use, organoleptic qualities of water (in this case, smelly) were associated with filtration use (Triplett et al.). And while bottled water use was not sensitive to changes in income in that sample, filtration devices were (Triplett et al.), and this same finding has been replicated in another study (Levêque and Burns). It would appear, then, that more affluent individuals spend money on a filtration device as a luxury good[1], whereas individuals with lower income purchase costly bottled water out of perceived necessity. Just as we saw demographic characteristics correlate with tap water perceptions, it is also possible that demographics correlate with different reasons for filtering water. For example, in their 2020 Public Perceptions of Tap Water report, the American Water Works Association indicated that although both safety and taste are the

[1] a luxury good in economics is defined as one for which demand increases as income rises (Teodoro et al.).

top concerns among people who filter their water, respondents with incomes above one hundred thousand dollars, indicate that taste is the primary reason they filter their water, whereas those with lower incomes rate safety first. Unfortunately, the demographic characteristics of these respondents were not presented, precluding the ability to interpret the results from a more intersectional lens. Although NHANES does not ask about water perceptions, it introduced a question about whether participants used a water filter in their home for two cycles (2007-10). In an analysis of those two cycles, Rosinger et al. reported that higher income was directly associated with filter use, and they also found that higher education and being White were additional correlates (Asher Y. Rosinger, K. A. Herrick, Wutich, et al.). Furthermore, they found that even after controlling for filter use, non-Hispanic Black and Hispanic adults that were still less likely to consume tap water and more likely to consume bottled water compared with non-Hispanic white adults (Asher Y. Rosinger, K. A. Herrick, Wutich, et al.).

History with unsafe water is another factor that correlates with water intake, including both direct (first-hand) experiences as well as those that occurred to others with shared demographic characteristics. Political scientists have called the Flint water crisis a "focusing event", which describes how a high-profile event puts neglected issues back onto the public policy agenda (Teodoro et al.). Multiple sources of evidence show that the lead contamination of drinking water that occurred in the predominantly Black city of Flint, Michigan after the city switched its water source from Lake Huron to the 19-times more corrosive Flint River without making the required water treatment adjustments (Bellinger), had ripple effects near and far(Teodoro et al.).

One investigation, which studied low-income, mostly Black mothers in Michigan (none of whom were Flint residents), found that women who had friends or family in Michigan, were more likely to drink bottled water than mothers without connections to Flint (Bauer et al.). Another study showed how a city that had previously had lead contamination over a decade before Flint, had a massive uptick in residents ordering lead testing kits for their drinking water in the year following Flint(Teodoro et al.). But most striking, is a national surveillance analysis that aimed to estimate fluctuations in tap water use before and after Flint captured a staggering change. Based on the number of individuals who reported not drinking their tap water in the 2017-18 NHANES cycle (after the lead crisis in Flint), as compared to the cycle before it (2013-14), about 19 million more people (~5.6 million children and ~13.4 million adults) around the US reported that they did not drink water from the tap (Asher Y Rosinger et al.). Most alarmingly, these changes were only seen among people of color: 63% more non-Hispanic Black and 40% more Hispanic children and adults reported not drinking tap water, whereas there were no changes in tap water use among non-Hispanic Whites. This suggests that identifying with victims of government neglect or seeing how the government has neglected people who are not White, could be a powerful deterrent of consuming water from the tap water (Teodoro et al.). Targeted marketing of bottled water to Black and Hispanic families, strategically monetizes this distrust (Teodoro et al.), for example, using celebrity endorsements(Arumugam). One such example was Nestle's compelling marketing campaign "*La Promesa Nestle Pure Life*" which used featured a prominent Cuban-American talk show host, Cristina Saralegui, to challenge Latina moms to replace one

sugary beverage a day with a bottle of Nestle Pure Life, and used social media engagement to provide coupons for their products and entries into prizes(Arumugam).

Given substantial nutritional surveillance data indicating low consumption of tap water and considering widespread negative perceptions of tap water, efforts to increase water intake by promoting bottled water, instead of tap, might be considered. From a cardiometabolic perspective, consumption of any plain water from any source is preferable to consuming a caloric alternative such as SSBs. . However, encouraging bottled water instead of tap water consumption is disadvantageous for environmental, health, and equity reasons (Hu et al.; "One Bottle at a Time"; Asher Y. Rosinger, H. J. Bethancourt, et al.). First, the environmental impact of consuming bottled beverages is profound and far reaching (Jaffee). Briefly, if plastic bottles are littered or not properly contained in the landfill, they often turn into debris that disturb marine habitats, or their degradation in landfills releases microplastics into the ground which can contaminate water sources ("One Bottle at a Time"). Even in cases where consumers discard them bottles for recycling, a large percentage cannot be recycled (Javidi and Pierce). Although the more recent introduction of boxed water products may be favorable to bottled water, the production and transportation of these products require more resources compared to drinking water directly from the faucet (Teodoro et al.). Next, although bottled water consumers often cite safety and purity as a reason for their choice of water source (Mackey et al.; Javidi and Pierce; Grupper et al.; Teodoro et al.; Park, S. J. Onufrak, et al.), bottled water is not as stringently regulated as tap water (Teodoro et al.; Jaffee). Bottled water is regulated as a packaged food product, which falls under the

purview of the Food and Drug Administration (FDA). Technically, bottled water is subject to the same Safe Drinking Water Act rules that regulate water utilities, however, it has been shown that bottled water producers commonly fail inspections for maximum contaminant levels (Teodoro et al.; Hu et al.; Jaffee). Furthermore, unlike the water utility which is required by law to publicly report on its water quality performance (1) quarterly to the state government and (2) annually to its customers, both of which are public documents, bottled water producers are under no legal obligation to furnish such reports (Teodoro et al.). Finally, if bottled water were to be suggested as the optimal replacement for SSBs, this places a disproportionate burden on low-income families (Teodoro et al.), for whom buying bottled water may be diverting money from purchasing foods (Asher Y. Rosinger, H. J. Bethancourt, et al.). Alarmingly, research has already shown that food-insecure families spend more on bottled water (Bauer et al.), including one study that found that food insecurity is more prevalent in tap water avoiders, compared to those who consume tap water, even when controlling for income (Asher Y. Rosinger, H. J. Bethancourt, et al.). **Taking together data on water perceptions, intake, and violations all point to the same conclusion: tap water safety and avoidance is an urgent public health issue, which disproportionately burdens minority and low-income individuals living in the US.**

Whereas disparities in water safety violations and tap water consumption have been separately documented, the connection between safety and beverage consumption is understudied. To date, the only studies that have evaluated the effect of violations on water intake have used increased bottled water sales as a proxy for reduced tap water

consumption. These investigations of violations and bottled water sales among the US population, have shown that water safety violations are linked to increases of about 14-22% in bottled water store sales (Graff Zivin et al.; Allaire, Mackay, et al.), or making households about 25% more likely to purchase bottled water (Pape and Seo). Importantly, these investigations have found convergent findings despite analyzing bottled water purchases using distinct datasets, which increases confidence that there is a consumer response to water safety violations. Graff Zivin et al. used 2001-2005 sales data from an unnamed national grocery chain in Northern California and Nevada (Graff Zivin et al.); Pape & Seo used data from the 2006-2008 nationally representative Consumer Expenditure Survey diary which asks households to prospectively record all food purchases for 14 days(Pape and Seo); Allaire et al., used 2006-2015 Nielsen sales data which are estimated to account for 50% of retail purchases across the nation (Allaire, Mackay, et al.); and Hadachek uses 2010-2020 retail scanner data from Information Resources Inc (Hadachek). While these studies investigated bottled water purchases as an averting response to water safety violations, only one investigated purchases of beverages besides bottled water (Hadachek), leaving an important gap on this topic at the nexus of environment and health that has urgent public health implications.

Linking national water violations data to NHANES offers a powerful opportunity to move from an indirect estimate of intake -- bottled water sales -- to estimating how many individuals are avoiding tap water even in the absence of first-hand experiences with water violation. In doing so, it will be the description of how tap water intake differs among individuals living in communities with and without water violations.

Given that NHANES is nationally representative, some of these households have likely experienced first-hand experience with water violations and others have not since these violations typically affect 4-28% of the population on a given year (Allaire, Wu, et al.). NHANES would additionally facilitate investigation of another potential dietary correlate of water safety violations: sugary beverage intake. Clarifying the scope of the misalignment between water safety and tap water intake, and possible nutritional implications of this misalignment, has high public health significance.

Although NHANES provides robust dietary intake data, it leaves a gap in contextualizing reported water intakes with perceptions of water. As outlined herein, there is existing literature on beliefs and demographic characteristics associated with bottled or tap water consumption; however, the only surveys that ask about beliefs related to the water utility itself, do not investigate how those beliefs are associated with water intake or preference (Junker and Carpenter; American Water Works Association). Therefore, the third aim of the dissertation encompasses an analysis of survey data collected throughout the state of Virginia, that provides data on Virginians' preferred water source, and their beliefs about the water utility and the water at the faucet, along with demographic characteristics that are known correlates of water beliefs and water intake. To our knowledge, it is the largest survey in the state of Virginia on water perceptions and provides important baseline data for foundations such as the Virginia Foundation for Healthy Youth and the Virginia Health Catalyst, who are investing in campaigns and programs to improve the health of communities across Virginia.

The overarching objective of this dissertation is to examine cross-sectional associations among both objective and subjective measures related to drinking tap water with water intake or preference. In the first two aims, we investigate associations between legal violations of drinking water safety and beverage intake in a national sample, and in the final aim, we describe cross-sectional associations between perceptions of water with water preference. The specific aims are as follows:

Aim 1: Examine cross-sectional associations between previous water safety violations in an individual's county and self-reported tap water intake. **Sub-aim 1a:** Examine race/ethnicity and income as moderators of the association between previous water safety violations in an individual's county and self-reported tap water intake.

Aim 2: Examine cross-sectional associations between previous water safety violations in an individual's county and self-reported sugary drink intake. **Sub-aim 2a:** Examine tap water intake as a mediator of the association between previous water safety violations in an individual's county and self-reported sugary drink intake.

Aim 3: Examine cross-sectional associations between perceptions of water and the water utility and self-reported preferred drinking water source.

Chapter 2: A National Investigation of Water Safety and its Correlates to Beverage Intake.

Introduction

The importance of water for physiologic functions and overall health is uncontested, yet a variety of widely available sweetened beverages are often consumed instead of plain, unsweetened water (Brooks et al.; Vieux et al., "Trends in Tap and Bottled Water Consumption among Children and Adults in the United States: Analyses of NHANES 2011-16 Data"). Excess intake of sugar sweetened beverages (SSBs) has been linked to dental caries, excess weight gain, type 2 diabetes, cardiovascular disease, and cancer (Baraldi et al.; Malik and Hu; Malik et al.). While there are many factors that influence beverage choices, the role of water safety in beverage intake is often overlooked (Asher Y. Rosinger, H. J. Bethancourt, et al.; Miller et al.). Very limited data on coping behaviors in response to suboptimal water suggest that people may drink SSBs to cope with poor water quality and to avoid spending money on bottled water (Venkataramanan et al.).

Analyses of data from "What We Eat in America", the most extensive source of nationally representative nutrition surveillance in the United States (US), have consistently shown an inverse relationship between tap water intake and SSB consumption (Rosinger; Asher Y. Rosinger, H. Bethancourt, et al.). Qualitative research studies have explained that individuals may opt for SSBs instead of tap water when they believe their water might be unsafe (Hess et al.; Santillán Vázquez et al.), and interventions lend support to the potential for water to displace SSBs. For example, the

WaterUp study in Maryland found that providing families with a water filter at home resulted in both more tap water and less SSB consumption (Santillán Vázquez et al.).

Data from "What We Eat in America" have also shown that tap water consumption is rife with racial/ethnic and socioeconomic disparities: only about one-third of Hispanic and non-Hispanic Black adults consume tap water on a given day, compared with about 60% of non-Hispanic White adults (Brooks et al.). Numerous factors may contribute to racial/ethnic and socioeconomic disparities in tap water intake, including a legacy of intentional underdevelopment of infrastructure for these communities(Teodoro et al.). This has likely been a root cause for findings that communities with higher proportions of Black, Hispanic, and lower socioeconomic status residents have greater likelihood of water safety violations: failures to meet federal regulations that set standards for safe drinking water (Switzer and Teodoro). Violations are considered health-based if there is evidence that they could cause immediate harm to the health of individuals (Allaire, Wu, et al.). About 4-28% of the US population experience a health-based water safety violation in a given year (Allaire, Wu, et al.), indicating there may be a gap in the national rates of drinking water safety and tap water consumption.

To date, the studies that have evaluated the effect of violations on beverage intake have used increased bottled water sales as a proxy for reduced tap water consumption (Graff Zivin et al.; Pape and Seo; Allaire, Mackay, et al.; Alzahrani et al.). These studies have consistently shown that bottled water purchases increase after a violation. Although these studies support the notion that communities change their beverage consumption

behaviors in response to water safety violations, they have indirectly proxied tap water intake via bottled water sales, and have not investigated how violations could alter intake of beverages besides water.

Herein, we link data on water safety violations with demographic and dietary intake to estimate the association between experiences with water safety violations and beverage intake. To our knowledge, this is the first nationally-generalizable study investigating the extent to which tap water intake differs among individuals living in communities with and without water violations, whether violations correlate with sugary drink intake, and how these associations may differ across sociodemographic subgroups.

Methods

Data Sources

Water safety violations. Data on health-based water safety violations are publicly available from the Environmental Protection Agency's Safe Drinking Water Information System (*Safe Drinking Water Information System (SDWIS) Federal Reporting Services | US EPA*). The database compiles Safe Drinking Water Act (SDWA) violations that violate standards set by federal law in 1974. Reporting is required in every state in the US by all water systems that serve at least 25 people per day. Health-based SDWA violations (hereafter referred to as water safety violations) occur when exceeding maximum contaminant levels (e.g., nitrate, coliform, or lead), maximum residual disinfectant levels, or inadequate use of treatment techniques. These violations require notification to the public within 24 hours or within 30 days depending on the severity and acuteness of the health effects. The present analysis focused on community water systems, which are

systems that serve the same population throughout the year. Each utility in the SDWIS has information on the county served, which was used in conjunction with the state name, to determine its county FIPS code using the R package tidycensus (Walker and Herman).

Demographic and dietary data. Data from the National Health and Nutrition Examination Survey (NHANES) were used to estimate tap water and sugary beverage intake. NHANES publishes cross-sectional data every two years to assess nutrition and health among 10,000 adults and children from 30 counties that constitute a representative sample of the non-institutionalized, US population (NHANES – About the National Health and Nutrition Examination Survey, n.d.). NHANES is unique because it is nationally representative, assesses water intake using 24-hour dietary recalls, and provides information on relevant covariates, facilitating a robust analysis. The present analysis uses seven two-year cycles of NHANES, beginning in 2005 and ending in 2018. The study period was chosen to maximize the amount of data available for tap water intake (`DR1_330Z`), which NHANES started collecting in the 2005-06 cycle.

For the present analysis, Food and Nutrient Database for Dietary Studies (FNDDS) food codes were used to identify and categorize sugary drinks using a combined text-based and energy-based strategy, as previously described (Swithers et al.). Briefly, the `main food description` contains broad descriptions such as “chocolate milk” and the `additional food description` contains more specific information such as brand name. Sugary drinks were defined as: regular soda, fruit drinks (including sweetened bottled waters and fruit juices with added sugars), sports and energy drinks, sweetened

coffees and teas, flavored milk, and other sugary beverages (including horchata and sugarcane beverages), carbonated beverages (excluding plain, or unsweetened water), juice drinks (including 100% fruit juice and smoothies), and flavored milk-based beverages, unless otherwise specified as diet or low-calorie. Although the health effects of 100% fruit juice, compared to sugar-sweetened beverages, are more limited, less conclusive, and less adverse, these beverages are high in sugar, and have been associated with tooth decay and weight gain, therefore, were included in our characterization of sugary drinks (Auerbach et al.). If the main and additional food descriptions were not informative enough to distinguish whether the item was an sugary drink or low-calorie sweetened beverage, we used an energy-based classification method where beverages with fewer than 5 calories per 8-ounce serving were excluded (Swithers et al.). In order to avoid including instances where beverages, creamers (e.g. Coffee Mate), and whipped cream (e.g. Cool Whip) were used in food recipes, we used the NHANES variable for combination food codes (`DR1CCMTX`) to make sure that only food codes reflective of beverages or beverage additions were retained. The code to derive calories from sugary beverages for each participant has been published (placeholder for link to Github).

Participants' beverage consumption was estimated using the first day of 24-hour dietary recalls. NHANES collects two days of dietary recalls, but the first day is collected in-person, and the second is conducted over the phone (National Health and Nutrition Examination Survey (NHANES)). Day two was not used in the present analysis because (1) NHANES analytic guidelines stipulate that day one is sufficient for estimating population means, (*National Health and Nutrition Examination Survey: Analytic Guidelines,*

2011-2014 and 2015-2016) and (2) there is a higher non-response rate for the telephone dietary recall, which lowers the overall generalizability of the results (Bleich et al.; Dai et al.). Depending on the age of the child, a proxy (e.g. adult caregiver), either assists (6-11 years) or completes the entire interview (2-5 years) on behalf of the child (National Health and Nutrition Examination Survey (NHANES)). Children 12 and older are the primary respondents for their dietary interview (National Health and Nutrition Examination Survey (NHANES)).

Data linkage

The SDWIS and NHANES were linked by the county FIPS code, a unique identifier for each county in the US. This linkage was completed by a data analyst at the Research Data Center at the National Center for Health Statistics, after a review process concluded that there is no disclosure risk for NHANES participants from these results. All data analysis was conducted at the Research Data Center in Hyattsville, Maryland by the first author (JHK). Data collection for NHANES was approved by the National Center for Health Statistics (NCHS) Research Ethics Review Board (ERB). Analysis of de-identified data from the survey is exempt from the federal regulations for the protection of human research participants. Analysis of restricted data through the NCHS Research Data Center is also approved by the NCHS ERB.

Statistical Analyses

Independent variable (exposure). Individuals were categorized as exposed to previous water safety violations depending on whether any water safety violations had

occurred in their county of residence prior to the year of their NHANES examination. Water safety violations were characterized dichotomously (presence of a violation within the county where the NHANES participant resides). Violations that occurred after December 31, 1990 were included. This timeframe was selected because a new law that increased regulation of the most common violation contaminant (coliform) became effective on that date (Allaire, Wu, et al.). Individuals were considered to be living in a county with a previous water safety violation if the violation occurred prior to the first year of the NHANES survey cycle they participated in. For example, for a 2005-06 participant, the violation must have occurred by December 31, 2004 in order for the participant to be counted as exposed; and for the participants in the 2017-2018 cycle (final NHANES cycle for the present study), the violation must have occurred by December 31, 2016. There were 176,387 health-based violations in community water systems between January 3, 1991, and December 31, 2016.

Dependent variables (outcomes). Four models were used to assess the beverage intake outcomes. Tap water was measured continuously in milliliters consumed on a given day (model 1), and dichotomously as absence or presence of tap water avoiders, defined as participants who reported 0 mL of tap water intake during their 24-hour recall (model 2). The NHANES dietary recall method does not distinguish between unfiltered (i.e. directly from the faucet) versus filtered tap water (National Health and Nutrition Examination Survey (NHANES)). Sugary beverage consumption was operationalized as total calories consumed on a given day (model 3), as well as percent of total calories from SSBs on a given day (model 4).

Covariates. Models were adjusted for relevant covariates including age, gender, race/ethnicity, examination season, urban or rural residency, housing status, body mass index (BMI) for adults and BMI percentile for children, state of residence, and total energy intake (sugary drink calories model only, to correct for systematic errors in reporting). Similar to other studies, socioeconomic status was proxied by adjusting for highest attained education in adult participants, and family income to poverty ratio in children/adolescent participants (Asher Y Rosinger et al.). Family income to poverty ratio is more appropriate for children, rather than their education level, because a child's education level is a proxy of their age rather than their socioeconomic status. Amount of physical activity (meeting the recommendation of 150 moderate activity minutes per week) was assessed for adults, but was not included in models for children because of inconsistency in youth physical activity variables over the course of the seven NHANES cycles, as previously documented (Omura et al.). Season and state (which are not publicly available variables) and were accessible at the NCHS Research Data Center and included to decrease the error in the model. Since temperature is a known correlate of water intake (i.e. drinking more water in warmer weather), knowing the exact examination date would be ideal to proxy temperature. However, the research data center does not release the examination date to researchers, and therefore examination season was the closest proxy for temperature available. State was requested to correct for potential systematic differences by state in SDWIS reporting accuracy or enforcement differences (Teodoro et al.). Multicollinearity was assessed for all regression models and only covariates with a

variance inflation factor (VIF) below 5 were retained. Survey year and state could not be included in our models due to multicollinearity (VIF >10).

Descriptive and multivariate analyses. All participants two years and older with a dietary recall were included (57,188), except participants with total energy intakes of 0 calories (0 adults, 33 children) or missing BMI (389 adults and 364 children). Survey weights were used for all analyses in accordance with the NHANES analytic guidelines (*National Health and Nutrition Examination Survey: Analytic Guidelines, 2011-2014 and 2015-2016*), which require the use of survey weights to make estimates for the whole sampling frame (i.e., the national population). Participant characteristics and beverage intake were summarized as weighted percentages with standard errors (SE), as appropriate. Generalized linear models were used for all multivariable analyses, with a logit-link function for our dichotomous outcome (tap water avoidance). Adjusted odds ratios (OR) and 95% confidence intervals (CI), or beta coefficients and standard errors were presented, as appropriate. To assess effect modification in the tap water models, we included an interaction term for race/ethnicity and violations, as well as for income and violations, separately. To assess mediation by tap water in the sugary drink models, we used causal mediation analysis to estimate the effect of prior violations on sugary drink intake that is mediated by tap water intake. All analyses were performed using R Statistical Software (v4.1.2; R Core Team 2021).

Results

Characteristics of 56,402 participants (21,486 children and 34,916 adults) that participated in NHANES between 2005 and 2018, are displayed in **Table 1,** stratified by

the exposure to water safety violations in the county of residence. Across all years, 10% of NHANES participants (N=5,744) lived in a county that had at least one water safety violation since 1990. The average percent of participants living in a county with a previous violation was 9% among children and adolescents, and 11% among adults. Percentage of participants exposed by survey year ranged between 3-20% among children (p-value = 0.42) and between 5-22% among adults (p-value = 0.4).

Most participants were born in the US (80%) and owned their homes (57.6%). The most common race/ethnicity was non-Hispanic White (37.4%), followed by Hispanic (28.6%), non-Hispanic Black (23.1%), Asian (5.9%); 5.0% of participants identified as other race/ethnicity. Approximately 24.6% of participants had not completed high school, 23.1% percent had high school diplomas, 29.5% completed some college or an associate's degree, and 22.8% had at least a college degree. NHANES participants living in counties with a history of violations had significantly fewer years of education (*p*-value = 0.02) and were more likely to reside in rural areas ($p<0.001$). Other demographic characteristics (e.g., age, race, sex) were similar among NHANES participants living in counties with and without a history of water safety violations.

Descriptive statistics on beverage intake between 2005-2018

Tap water avoidance in the sample occurred at similar rates in children and adolescents (49.7 ± 1.1%) and adults (47.3 ± 0.8%). Children and adolescents consumed an average of 352.6 ± 12.3 milliliters per day of tap water (roughly an 8-oz glass and a half), and adults consumed about twice as much (688.4 ± 17.0 milliliters per day). Tap

water intake varied by survey cycle in adults (**Supplemental Figure 1**) as well as children and adolescent (**Supplemental Figure 2**). Sugary drinks were consumed in any amount by 64.8 ± 0.5% of adults and 83.7 ± 0.5% of children and adolescents over the 14-year surveillance period. The mean percent of total energy intake from sugary drinks was 9.0 ± 0.1 for adults and 12.5 ± 0.2 for children, or about 198.1 ± 2.8 calories on a given day in adults and 241.5 ± 3.3 in children. Percent of total energy intake from sugary drinks declined from 9.3 ± 0.3% in 2005-06 to 8.4 ± 0.4% in 2017-18 for adults (**Supplemental Figure 1**), and 13.7 ± 0.5% to 10.7 ± 0.4% in children and adolescent for the same time frame (**Supplemental Figure 2**).

In unadjusted analyses of beverage outcomes, no differences in tap water consumption (neither in the milliliters, mL, nor proportion of the participants that avoid drinking from the tap) were observed between participants living in a county with versus without a prior water safety violation. The differences in mean volume of water (mL) consumed did not significantly differ among participants in counties with a history of water safety violations, (**Table 2** for adults and **Table 3** for children). There were no significant differences by exposure status in the unadjusted mean number of calories from SSBs, and results were similar in adults (**Table 4**) and children (**Table 5**). Calories and percent of total calories from SSBs did not significantly differ among participants living in counties where there had been prior violations (mean difference in adults: 10 calories, $p = 0.7$; in children and adolescents: 33 calories, $p=0.1$).

Associations between water safety violations and beverage intake among adults

i. Model A1: water safety violations and tap water intake volume

In multivariate analyses adjusted for participant characteristics, water safety violations were not associated with consumption of tap water among adults (**Table 2**). All covariates were independently associated with tap water intake, except there was no significant association for urbanicity (Urban resident: 50.5 ± 33.8, p = 0.1). Meeting the physical activity guidelines was associated with an average of 118 mL more tap water consumed on a given day (p<0.0001), which is roughly half an 8-ounce glass of water. Higher BMI, drinking water to lose weight, and higher levels of education were also positively correlated with intake. Compared with participants with no high school education, completing some college or an associate's was associated with an additional half glass of water (126.9 ± 26.4 mL, p<0.0001) and being college graduates was associated with more than a full additional glass (306.6 ± 29.4 mL, p<0.0001). Mean tap water intake estimates were lower for those with housing statuses other than homeownership, but the associations were not significant. Older age was also correlated with lower tap water intake: compared to those 20-39 years olds, those 40-59 years old drank about 131 mL less, and those 60 and older drank about 185 mL less on a given day (both p<0.0001). Mean tap water intake on a given day was also lower among non-White participants compared to non-Hispanic White participants. The largest association was seen among non-Hispanic Black participants (-314.9 ± 26.1 mL, p<0.0001), followed by Hispanic (-259.1 ± 31.6 mL, p<0.0001): both of these subgroups consumed more than a full glass less of tap water compared to non-Hispanic White participants. Tap water intake was not moderated by race (for Hispanic: -11 mL, 95% CI= -144,147, p =1.0; for

non-Hispanic Black= -1.9, 95% CI= -305, 283, p = 1.0) or by income (for FIPR >1 and <=3, -52.4 ± 92.9 mL, p = 0.6; for FIPR >3, -6.0 ± 113.0 mL, p = 1.0).

ii. Model A2: water safety violations and tap water avoidance

When tap water intake was assessed as a dichotomous outcome (those with 0 mL of tap water intake), there were no significant associations between water safety violations and avoiding tap water (OR = 1.18, 95% CI= 0.94-1.47, p = 0.2, **Table 2**). Most covariates were independently associated with the odds of avoiding tap water, the direction of the associations were consistent with the continuous model for tap water intake. For example, odds of avoiding tap water were higher among Black and Hispanic participants compared with White participants, as well as among participants older than 60 compared with those 20-39 years old. Again, years of education were associated with a large decrease in the likelihood of tap avoidance. Similarly, meeting the physical activity guidelines was associated with lower odds of avoiding tap water compared to those that were not as active. The odds of tap water avoidance were similar irrespective of BMI category or urbanicity, and tap water avoidance was not moderated by race or by income.

iii. Model A3: water safety violations and sugary drink calories

No associations between water safety violations and sugary drink intake were observed in adults (**Table 4**). No associations between water safety violations and sugary drink intake were observed in adults (Table 4). Although the associations were not statistically significant, previous water safety violations estimated 12 more calories from sugary drinks (12.0 ± 7.9, p=0.1). Older age was inversely associated with sugary drink

intake, as participants 40-59 years old and 60+ years old consumed fewer calories. Housing and race/ethnicity were also associated with increased odds of greater calories from sugary drinks for certain subgroups. Adults who rented their home consumed an average of 19.7 more calories from sugary drinks on a given day, compared to those who owned their homes. Non-Hispanic Black participants had about 46.1 calorie greater intake from sugary drinks, and Hispanic adults consumed about 14.2 calories more calories, compared to non-Hispanic White adults. Asian adults were the only subgroup that consumed fewer calories from sugary drinks than non-Hispanic White adults (-45 calories, $p<0.001$). Years of schooling were inversely associated with sugary drink intake; those with some college/associate's degrees and college graduates both reported 28 and 84 fewer calories from SSBs, respectively, compared to those who had not completed high school. Meeting the physical activity guidelines was not associated with calories from SSBs, but those who were attempting to lose weight by drinking lots of water consumed significantly fewer calories from SSBs compared to those not trying to lose weight by that method (-53 calories, $p<0.0001$). Given there that there was no association between sugary drinks and water safety violations, there was no mediation by tap water intake ($p=0.98$).

iv. Model A4: water safety violations and percent of total calories from sugary drinks

In our final beverage outcome model among adults, there continued to be no statistically significant association between previous water safety violations and total calories from sugary drinks (0.4 ± 0.4, $p=0.3$). The direction and significance of the relationships

between the covariates and calories from sugary drinks (model 3) were maintained in this model.

Associations between water safety violations and beverage intake among children and adolescents

i. Model B1: water safety violations and tap water intake volume

Among children and adolescents, water safety violations were also not associated with volume of tap water consumed (**Table 3**). Comparing mean tap water intake across race/ethnicity, non-Hispanic Black and Hispanic children consumed significantly less tap water on a given day compared to White children (both $p<0.001$). Children living in homes that were rented drank significantly less water than those living in homes that were owned ($p<0.0001$). As with the continuous model in adults, higher BMI percentile was associated with greater intake of tap water ($p<0.001$). Older children consumed significantly more tap water compared to the youngest age group, with those 12-19 years old consuming over a glass of water more compared to those 2-5 years old (249 mL, $p<0.001$). No differences in tap water intake were observed between rural versus urban residence ($p = 0.08$) and the association of water safety violations with tap water intake was not moderated by race or income.

ii. Model B2: water safety violations and tap water avoidance

In our tap water avoidance model (those with 0 mL of tap water intake), the odds of tap water avoidance were 34% higher among children and adolescents living in counties with a prior water safety violation (95% CI = 1.01-1.80, $p=0.04$). The odds of tap water avoidance varied by age group, with those 6-11 years old having significantly

less odds of avoidance (OR = 0.83, 95% CI = 0.75-0.92, p<0.001) and those 12-19 having significantly higher odds of avoidance (OR = 1.15, 95% CI = 1.03-1.28, p=0.01). Children living in the highest-earning households (federal income to poverty ratio greater than or equal to three) had significantly lower odds of tap water avoidance compared to those at or below the poverty level (OR = 0.77, 95% CI = 0.64-0.93, p < 0.001), as did children living in urban settings (OR = 0.77, 95% CI = 0.64-0.93, p=0.01). Finally, non-Hispanic Black and Hispanic children had about twice the odds of avoiding tap water compared to white children (both p<0.001), and children living in housing that was rented, had 1.5 times higher odds of avoiding tap water compared to those living in houses that were owned (p<0.001).

iii. Model B3: water safety violations and sugary drink calories

The associations between water safety violations and sugary drink intake observed in children and adolescents (**Table 5**), continued to be insignificant and in the same direction as seen in adults: more calories in children and adolescents who had experienced a violation (25 kcal, p=0.06). Likewise, there was no evidence of mediation of water safety violations and calories from sugary drinks by tap water intake (p = 0.93). Compared to children 2-5 years of age, 6-11 year-old children consumed about 15 fewer calories from sugary drinks (p=0.02), and those 12-19 years old had about 13 more calories from sugary drinks compared to the youngest children (p=0.04). Calories from sugary drinks were significantly associated with family income to poverty ratio, where those from households in the highest income category consumed about 28 fewer calories compared to those living in homes at or below the poverty level (p<0.001), and, children

who were urban residents consumed about 20 fewer calories from sugary drinks compared with children residing in rural settings (p=0.02). Although the direction of the relationship between housing and water safety violations remained consistent with that seen in adults -- those who lived in homes that were either rented consumed more calories from SSBs compared to children living in homes that were owned – the relationship was not significant in the sugary drink calorie model (p=0.07). Unlike for adults, no differences in calories from SSBs were observed among non-Hispanic Black or Hispanic children compared with non-Hispanic white children. However, children and adults who identified as Asian consumed fewer calories from sugary drinks compared to non-Hispanic White participants (-87.6, 12.5, p<0.0001).

iv. Model B4: water safety violations and percent of total calories from sugary drinks

When evaluating the association between water safety violations and percent of total energy intake from sugary drinks (**Table 5**, righthand side), the findings were mostly consistent, except for differences in age and housing status. Among the age subgroups, there was no significant difference in percent of calories from sugary drinks for children 6-11 years compared to 2-5 year olds (p=0.3), but those 12-19 years old continued to have greater intake (p = 0.002). While we found no significant relationship between housing and sugary drink intake in Model 3, there was significant increase in the estimated percent of sugary drinks calories among those who lived in rented, compared to owned, homes (p=0.03). Finally, given that was sugary drinks and water safety

violations were not associated, there was no mediation effect by tap water intake (p=0.93).

Discussion

This analysis of nationally representative data from NHANES demonstrates that living in a county with prior water safety violations was not associated with volume of tap water or caloric intake from sugary drinks. Findings were consistent across unadjusted and multivariate analyses, for both children and adults. We also find that children residing in counties with previous water safety violations were significantly less likely to consume any tap water at all (i.e. tap water avoidant), but the same pattern was not significant among adults.

Although there are many prior publications on tap water and/or sugary drink intake using data from NHANES, examining water safety violations in relation to beverage intake is novel. Prior to this study, it was documented that roughly half of Americans avoid water from the tap, and that roughly 4-28% have been exposed to a previous water safety violation, but the extent to which tap water avoidance was associated with water safety had not been evaluated. This study demonstrates a large gap between objective water safety and tap water avoidance, especially for adults, among whom there was no difference in tap water avoidance living in counties with or without prior water safety violations. Given that approximately 90% of NHANES participants were living in a county without any water safety violations since 1990, the relatively high percentage of NHANES participants that avoid consuming tap water (47% of adults and 49% of kids) is striking.

Our finding that children, but not adults, are more likely to avoid tap water when living in counties with a prior history of water safety violations, fits in with previous findings that even when adults may be more risk-taking with their own behavior, they are less likely to allow their children to do the same. In a New York Times article shortly after the Flint water crisis became national news, a 23-year-old Colorado resident, Maria Fuentes, explained that while she herself drinks from the tap, her two young children at home do not (Turkewitz). Ms. Fuentes made remarks illustrating her skepticism of the long-term stability of her tap water's safety: "We hear on the news: 'In such-and-such a state the water is contaminated,'…We think it's going to be that way here.", yet she consumes water from the tap. Nevertheless, she does not give it to her children, which suggests that she has assessed that while it seems safe enough for her, she still does not take that risk with her young children. This same gap in parent-child tap water avoidance was shown to be the case in a previous survey of a mostly Hispanic population in Utah: while 30% of parents never drank tap water, 41% never gave it to their children (Hobson et al.).

Although several studies have previously shown that people respond to health-based water safety violations by purchasing more bottled water, the estimated increases in spending on bottled water are quite small – as low as six cents per person affected (Allaire, Mackay, et al.; Graff Zivin et al.; Alzahrani et al.). Bottled water consumption is considered an "averting behavior", which implies that people avert from the tap to the bottle, and past studies have used bottled water as an outcome to proxy decreases in tap

water. To our knowledge, our study is the first to study associations between water safety violations and tap water consumption directly. There is a vast literature that could explain the lack of an association for between violations and beverage intake in adults. For example, surveys demonstrate that distrust in water is widespread in the United States (Teodoro et al.). Although most people do not have direct experiences with water safety violations in a given year (Allaire, Wu, et al.), identifying with others that have experienced water violations (e.g. due to shared race/ethnicity or socioeconomic status) can be conceived as an indirect experience (Teodoro et al.). Studies around the 2015 "Flint water crisis" (Asher Y Rosinger et al.; Teodoro et al.), a historic lead contamination crisis created by the city's negligence to adjust water treatment after switching its water source to save money (Bellinger), supports the hypothesis that trust operates through indirect experiences with water. Comparing the number of US residents that avoided tap water before and after the crisis, it is estimated that 19 million fewer people drank tap water after 2015-16. Most alarmingly, this decline was only observed among non-Hispanic Blacks and Hispanics with no changes in tap water use among non-Hispanic Whites (Asher Y Rosinger et al.). Another research finding in Providence, Maine, a city far away from Flint, continues to add support to how highly publicized events can have a far-reaching "ripple" effect (Teodoro et al.). In the years prior to the Flint lead-poisoning event, the city of Providence's voluntary lead testing kits were requested an average of 4-5 time per month by its residents. In the months following the Flint crisis, test requests soared to nearly 90 tests per month. It is important to note that Providence has had one of the highest poverty levels in the nation and is 16% Black and 43 % Hispanic. Higher rates of distrust in water among communities that are lower

income, and/or racial/ethnic minorities are based in discrimination and marginalization of these communities. It has been suggested that Hispanic individuals is that tap water avoidance is "culturally imported" (Teodoro et al.) from countries of origin where tap water is more likely to have been unsafe to consume (Javidi and Pierce). However, analyses have shown that even bottled water preference remains significantly higher among Hispanic, compared to non-Hispanic white, adults after controlling for immigration status or time since immigration (Teodoro et al.). Qualitative research helps shed light on how distrust in tap water is more likely to be tied to the state of the US water context rather than an "imported" belief: residents of low-income Hispanic communities in Maryland who expressed concern about the safety of their current homes' piping and water quality, used to consume tap water back home when the water sources were more visible (e.g. from nearby lakes or rivers) (Colón-Ramos et al.). Throughout history, Hispanic, Black, and low-income communities, have all been intentionally excluded from infrastructure investments to develop safe drinking water systems at times where more resourced and/or White communities were being developed (Teodoro et al.; *Closing the Water Access Gap in the United States: A National Action Plan*). For example, in the 1960s, as water lines were being laid out in Roanoke, Virginia, they excluded the largely Black town of Hollins (*Closing the Water Access Gap in the United States: A National Action Plan*). Another example can be drawn from Hispanic immigrants who were encouraged to immigrate to the US to work as underpaid laborers in the 1940-60s. When developers sold them land near the US-Mexico border (which came to be known as colonias) they fraudulently promised them that water infrastructure would be forthcoming – today nearly a million people are living in the colonias and many

lack access to safe drinking water (Wutich et al.). Taken together, discriminatory practices such as these contribute to a distrust in government services (e.g. utilities and tap water) and are exacerbated when events like those in Flint occur (Teodoro et al.).

In addition to this low trust that can result from shared identity with groups that have been underserved, there may also be insufficient agreement that the lengths that the utility goes through to ensure drinking water is safe are stringent enough for safe water. For example, in Paper 2 of this dissertation we find that among a group of 808 adults living across the state of Virginia, there was no relationship between awareness of testing and preferring to consume tap compared to bottled water. This may have roots in insufficient contact from the utility companies: in a national survey of 2,400 adults in 2001-2002, about two-thirds of participants were not aware of receiving any communication from the utility, even though by law every water utility in the US must send an annual report with information about their performance in meeting or missing standards set by the Safe Drinking Water Act (Mackey et al.). Similarly, the American Water Works Association (AWWA) surveyed 1,899 adults in 2020 and 2,200 adults 2021, and found that roughly 50-60% of participants report no memory of recent contact with their water utility (Junker and Carpenter; American Water Works Association). Although AWWA surveys find that people that recall hearing from their utility within the last year are more satisfied with their water quality and rate their water as safer compared to those who do not (Junker and Carpenter; American Water Works Association), it remains unclear whether this increased satisfaction correlates with higher tap water

intake, as these descriptive surveys did not analyze models of perceptions that included intake.

Despite the lack of an association between water safety violations and beverage intake volume (tap water) and calories (sugary drinks), the multivariate analysis confirms several known correlates of beverage intake. The relationship between education and health is well documented (Zajacova and Lawrence), and likely due to a combination of factors including greater income, cognitive skills and social connections that result from more years in school (Zajacova and Lawrence; Raghupathi and Raghupathi). While education should theoretically reduce inequity, educational institutions have perpetuated inequality by excluding people from opportunities based on the color of their skin, which has disproportionately burdened minority races and contributed to less schooling (Zajacova and Lawrence). Given the ubiquitous associations between suboptimal health behaviors with SES and race/ethnicity, low tap water consumption in these population subgroups is therefore unsurprising (Asher Y. Rosinger, K. A. Herrick, Wutich, et al.; Brooks et al.; Vieux et al., "Trends in Tap and Bottled Water Consumption among Children and Adults in the United States: Analyses of NHANES 2011-16 Data"; Bleich et al.; Hess et al.). The previous findings that tap and sugary drink intake vary by socioeconomic status and by race, combined with studies demonstrating that responses to violations differ among those of minority races and lower SES, was the impetus for testing the moderation of the association between water safety violations and tap water intake by both race and SES (which were not significant) in the present analysis. Similarly, given prior correlations between sugary drink and tap water intake, we examined tap consumption as mediator in the relationship between violations and sugary

drink consumption, but found no significant association. The present results are also consistent with those of other studies demonstrating that most children and adults consume sugary drinks on a given day (Dai et al.). Since the definition of sugary beverages included one-hundred percent fruit juice in this analysis, estimates of the percentage of youth consuming these beverages (84%) are slightly higher than in previous reports (~75%) (Dai et al.). Of particular concern, over the fourteen-year study period, children and adolescents consumed about 12.5% of their total calories from sugary drinks, which exceeds the dietary guidelines recommendation to limit calories from added sugars to 10% of total energy intake(*Be Sugar Smart: Limiting Added Sugars Can Improve Health | Nutrition | CDC*). Although that percentage has declined over time, sugary drink calories still comprised over 10% of total calories during the most recent cycle.

This study has several limitations, most notably, the likelihood of exposure misclassification, which may have occurred for several reasons. First, in cases where a person has moved residences, their exposure status will be based on the county where they were living at the time of the NHANES examination, which does not account for former residence outside the county that may or may not have had a violation history. Data from the US Census American Community Survey shows that geographic movement in the US is at a historic low (roughly 14-16% of the population moved during the present study period (Kerns-D'Amore et al.). Furthermore, those data show that more than half of people who move in the US stay in the same county of residence, therefore, this error is expected to be minimal. A second source of exposure misclassification is that

we did not have the exact date of the NHANES data collection, thus, only violations that occurred before the first NHANES survey year were included (i.e. 2005 for the 2005-06 cycle). Third, while aggregating violations at the county level was the most granular approach possible with the available data, this meant all participants in a given county were assigned the same exposure status, even though they might not have been serviced by the same water utility. Nevertheless, when violations occur, the law requires the utility to inform citizens by telephone, radio, and local news and this information is therefore likely heard by others in the geographic vicinity, even if their home did not receive water from the utility in violation, which may ultimately impact their tap water consumption. (Teodoro et al.). Fourth, although our study addresses the correlation between water safety violations and sugar sweetened beverages, it does not address the possible association with non-sugar sweeteners (e.g., diet beverages), for which the long-term cardiometabolic health outcomes are still uncertain (Sylvetsky, Rebolledo, et al.). Fifth, the dietary intake data from NHANES indicated that there were time-trends in consumption of tap water and sugary drinks, but we could not include survey year in our model due to multicollinearity. The error resulting from omitting this variable may have weakened our ability to find associations in our models which include all cycle years combined, and given the low percentage of participants that experience a water safety violation in some survey years, we were not able to do a sensitivity analysis for each two-year survey cycle.

The final set of limitations is related to the water safety data themselves. The US Government accountability office published a report in 2011 that documented inaccuracies in the reporting of water safety violations and made recommendations for

improvements (*Unreliable State Data Limit EPA's Ability to Target Enforcement Priorities and Communicate Water Systems' Performance*). Although some recommendations to improve data quality were implemented, this remains a likely source of error. Last, there are relatively new contaminants in modern water systems such as microplastics and per- and polyfluoroalkyl substances (PFAS), that are known to be harmful to human health, but have not yet had rules passed into law for their regulation and therefore could not be captured in our assessment of water safety violations.

This study also has several important strengths. First and foremost, this study is nationally generalizable to 90% of the non-institutionalized US population, the percentage of the population that uses water from a utility (US Environmental Protection Agency). Water intake is driven by an array of factors, which include temperature, and physical activity (Jéquier and Constant); to our knowledge, the present study is the first NHANES analysis of tap water intake that adjusted for these determinants (or appropriate proxies). Since we completed our analysis in the Research Data Center at the National Center for Health Statistics, we were able to use the NHANES examination season as a proxy for temperature. Rural/urban residency of participants -- another restricted variable -- is known to be predictive of worse cardiometabolic health outcomes for rural compared to urban communities (Hess et al.) and was also significantly associated with beverage intake in our analysis. Although the physical activity variable is publicly available, it likely has not been controlled for in previous tap water intake studies because NHANES has made changes to its physical activity questionnaires over time (Omura et al.). Another strength was inclusion of a survey question available in NHANES that asked

adults whether they were actively trying to lose or maintain their weight by drinking a lot of water, which to our knowledge, has not been included in prior publications on tap water intake. This variable was significantly predictive of higher tap water consumption and lower odds of avoiding tap water.

Conclusions

This study finds no association between water safety violations and tap water volume consumed or water safety violations and sugary drink calories, in neither children nor adults; however, it does find that children are more likely to consume no tap water at all, when living in counties that had previous water safety violations. Although consuming plain water and limiting calories from SSBs is recommended for all age groups, it is especially important for children to prevent excessive weight gain early in life. Our results illustrate a stark misalignment between the percentage of the US population that has previous experiences with water safety violations in their county of residence (~10%) and the percentage of the population that avoids consuming tap water (~50%). Despite the undeniable importance of laws to enforce drinking water standards, our findings demonstrate that having water free from violations is not sufficient to ensure tap water consumption. Furthermore, collecting robust information on tap intake in conjunction with tap perceptions are needed to obtain a more holistic understanding of beverage intake that integrates environmental, demographic, and perceptual factors. Designing initiatives to ensure safe water free of violations and position tap water intake as a trustworthy and appealing beverage are critical to promote healthier diets and prevent nutrition-related chronic diseases.

Tables and Figures

Table 1. Participant characteristics (weighted frequencies and standard errors), stratified by residence in a county with or without previous water safety violations. Unweighted n= 56,402. Data sources: NHANES 2005-2018 and SDWIS.

	No prior water safety violation(s)	Prior water safety violation(s)	Total Unweighted n (%)	p-value for difference
Age				
2-5 years	5.3 ± 0.1	5 ± 0.4	5140 (9.1)	
6-11 years	8.3 ± 0.2	7.7 ± 0.6	7285 (12.9)	
12-19 years	11.1 ± 0.2	11.9 ± 0.8	9061 (12.1)	0.06
20-39 years	28.1 ± 0.5	24.6 ± 1.4	11937 (21.2)	
40-59 years	27.9 ± 0.4	29.2 ± 1	11407 (20.2)	
60+ years	19.4 ± 0.5	21.4 ± 1.5	11572 (20.5)	
Gender				
Female	51.3 ± 0.3	50.1 ± 0.6	28583 (49.3)	0.07
Male	48.7 ± 0.3	49.9 ± 0.6	27819 (50.7)	
Born in US (% yes)	85.8 ± 0.6	86.8 ± 2.7	45098 (80.0)	0.7
Race/Ethnicity				
White	63.4 ± 1.4	70.7 ± 5.5	21105 (37.4)	
Asian	3.1 ± 0.3	2.9 ± 1.3	3335 (5.9)	
Black	12.3 ± 0.8	9.9 ± 2.3	13027 (23.1)	0.5
Hispanic	16.3 ± 1	12.8 ± 3.6	16138 (28.6)	
Other	4.9 ± 0.3	3.7 ± 0.8	2797 (5.0)	
Adult Education [+]				
Less than high-school	15.3 ± 0.6	19 ± 1.8	8576 (24.6)	
High-school graduate/GED or equivalent	23 ± 0.5	28 ± 2	8060 (23.1)	
Some college or Associate's degree	32.1 ± 0.5	28 ± 1.1	10298 (29.5)	0.005
College graduate or above	29.5 ± 0.9	24.8 ± 2.9	7950 (22.8)	
Family Income to Poverty Ratio				
≤1	16 ± 0.6	16.2 ± 1.9	13400 (23.8)	0.9
>1 and ≤ 3	33.9 ± 0.7	35.2 ± 1.9	21622 (38.3)	
Missing	[++]	[++]	4481 (7.9)	
Housing Status				
Own	65.3 ± 0.9	68.8 ± 3.8	32501 (57.6)	
Rent	31.4 ± 0.8	27.8 ± 3.6	21905 (28.8)	0.4
Other	1.9 ± 0.2	2.6 ± 0.4	1200 (2.1)	

% **Rural resident**	17.2 ± 1.4	39.4 ± 6.1	8016 (14.2)	<0.001
Trying to maintain or lose weight by drinking a lot of water [+] (% yes)	16.7 ± 0.4	13.7 ± 1	5267 (15.1)	0.3

[+]Only for adult participants (20 years and older).
[++] Not requested as part of restricted analysis at the Research Data Center

Table 2. Cross-sectional association of water safety violations with tap water intake and tap water avoidance in n= 34,916 adults.

	Tap water intake (mL)			Tap water avoidance (% with 0 mL intake)		
Unadjusted mean for those **with no prior** water safety violation(s)	690.9 ± 18.6			47.0 ± 0.09		
Unadjusted mean for those **with prior** water safety violation(s)	659.9 ± 62.0			50.5 ± 3		
	β	**SE**	**p-value**	**OR**	**95% CI**	**p-value**
Water safety violation (ref: none)	-20.6	57.5	0.7	1.18	0.94, 1.47	0.15
Age						
20-39	*Reference*					
40-59	-131.1	24.8	<0.001	1.05	0.97, 1.13	0.2
60+	-185.2	27.5	<0.001	0.76	0.69, 0.83	<0.001
Gender (ref: female)						
Male	30.4	16.7	0.07	1.05	0.98, 1.12	0.2
Education						
Less than high school	*Reference*					
High school graduate	25.5	29.7	0.4	0.89	0.80, 0.99	0.033
Some college or associate's	126.9	26.4	<0.001	0.69	0.63, 0.76	<0.001
College graduate or more	306.6	29.4	<0.001	0.41	0.37, 0.46	<0.001
Race						
White	*Reference*					
Asian	-80.7	37.6	0.03	1.02	0.88, 1.18	0.8
Black	-314.9	26.1	<0.001	2.0	1.81, 2.21	<0.001
Hispanic	-259.1	31.6	<0.001	1.84	1.62, 2.09	<0.001
Other	-139.5	44.4	0.002	1.4	1.19, 1.65	<0.001
Housing status						
Own	*Reference*					
Rent	-38.3	22.1	0.09	1.24	1.13, 1.35	<0.001
Other	-53.2	65.6	0.4	0.99	0.75, 1.30	>0.9
Urban resident (ref: rural)	50.5	33.8	0.1	0.93	0.82, 1.05	0.2
BMI (kg/m^2)	6.60	1.47	<0.001	1	0.99, 1.01	>0.9
Met physical activity guidelines (ref: did not)	117.5	20.7	<0.001	0.85	0.79, 0.92	<0.001
Drank a lot of water to lose weight (ref: did not)	154.8	33.0	<0.001	0.87	0.77, 0.98	0.02

Beta coefficients (β), standard errors (SE) and p-values are displayed for tap water consumption model.
Odds ratios (OR), 95% confidence intervals (CI) and p-values are displayed for the tap water avoidance model.
Dichotomously-coded variables have reference (ref) category in parenthesis.

Table 3. Cross-sectional association of water safety violations with tap water intake and tap water avoidance in n= 21,486 children and adolescents.

	Tap water intake (mL)			**Tap water avoidance (% with 0 mL intake)**		
Unadjusted mean for those **with no prior** water safety violation(s)	354.1 ± 13.2			48.9 ± 1.2		
Unadjusted mean for those **with prior** water safety violation(s)	347.0 ± 43.9			54.5 ± 3.9		
	β	**SE**	**p-value**	**OR**	**95% CI**	**p-value**
Water safety violation (ref: none)	-36.8	40.1	0.4	1.35	1.01, 1.80	0.04
Age						
2-5	*Reference*					
6-11	87.3	9.9	<0.001	0.83	0.75, 0.92	<0.001
12-19	249.0	16.6	<0.001	1.15	1.03, 1.28	0.012
Gender (ref: female)						
Male	66.0	16.2	<0.001	0.95	0.86, 1.05	0.3
Race						
White	*Reference*					
Asian	9.8	43.1	0.8	0.95	0.73, 1.24	0.7
Black	-179.3	22.9	<0.001	1.92	1.63, 2.27	<0.001
Hispanic	-185.9	21.8	<0.001	2.31	1.99, 2.67	<0.001
Other	-44.2	31.1	0.2	1.18	0.96, 1.43	0.11
Family income to poverty ratio						
≤1	*Reference*					
>1 and ≤3	5.0	18.6	0.8	1.01	0.89, 1.14	0.9
>3	6.8	21.7	0.7	0.86	0.74, 1.00	0.043
BMI percentile	1.0	0.2	<0.001	1	1.00, 1.00	0.5
Housing status						
Own	*Reference*					
Rent	-62.1	16.5	<0.001	1.56	1.39, 1.76	<0.001
Other	-65.5	41.8	0.1	1.37	0.96, 1.97	0.081
Urban resident (ref: rural)	52.8	29.9	0.08	0.77	0.64, 0.93	0.007

Beta coefficients (β), standard errors (SE) and p-values are displayed for tap water consumption model. Odds ratios (OR), 95% confidence intervals (CI) and p-values are displayed for the tap water avoider model. Dichotomously-coded variables have reference (ref) category in parenthesis.

Table 4. Cross-sectional association of water safety violations and sugary drink intake in n= 34,916 adults.

	Calories from sugary drinks			**Percent of total energy intake from sugary drinks**		
Unadjusted mean for those **with no prior** water safety violation(s)	197.3 ± 3			9 ± 0.01		
Unadjusted mean for those **with prior** water safety violation(s)	209.3 ± 8.7			9.5 ± 0.04		
	β	**SE**	**p-value**	**β**	**SE**	**p-value**
Water Safety Violation (ref: none)	12.0	7.91	0.13	0.4	0.4	0.35
Total Energy Intake (kcal)	0.1	0.0	<0.001	-	-	-
Age						
20-39	*Reference*					
40-59	-47.1	4.9	<0.001	-2.10	0.20	0.001
60+	-98.0	5.2	<0.001	-4.94	0.23	0.001
Gender (ref: female)						
Male	1.8	4.1	0.67	0.3	0.2	0.09
Education						
Less than high school	*Reference*					
High school graduate	-6.1	6.1	0.32	-0.2	0.3	0.4
Some college or associate's	-27.7	5.9	<0.001	-1.2	0.3	0.001
College graduate or more	-84.6	6.2	<0.001	-3.7	0.3	0.001
Race						
White	*Reference*					
Asian	-44.6	5.9	<0.0001	-2.6	0.3	<0.001
Black	42.9	4.7	<0.0001	2.3	0.2	<0.001
Hispanic	13.9	6.0	0.02	0.7	0.3	0.01
Other	-0.4	9.1	0.97	0.1	0.4	0.8
Housing status						
Own	*Reference*					
Rent	21.6	4.7	<0.001	1.2	0.2	0.001
Other	27.2	13.7	0.05	1.3	0.6	0.04
Urban resident (ref: rural)	-11.1	6.1	0.07	-0.5	0.3	0.09
BMI (kg/m^2)	0.7	0.3	0.04	0.03	0.01	0.04
Met physical activity guidelines (ref: did not)	-3.8	4.2	0.37	-0.3	0.2	0.14
Drank a lot of water to lose weight (ref: did not)	-53.1	6.3	<0.001	-2.5	0.3	<0.001

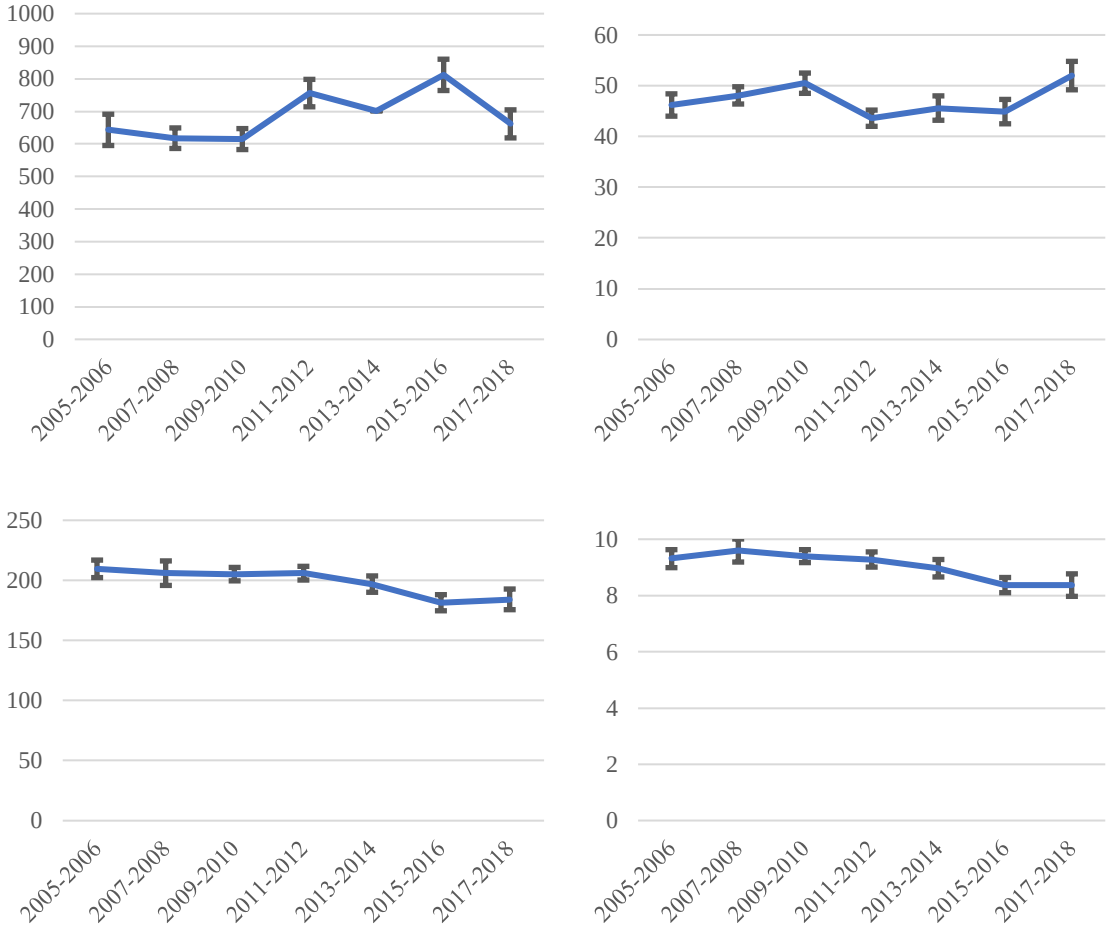
Beta coefficients (β), standard errors (SE) and p-values are displayed for both models.
Dichotomously-coded variables have reference (ref) category in parenthesis.

Table 5. Cross-sectional association of water safety violations and sugary drink intake in n= 21,486 children and adolescents.

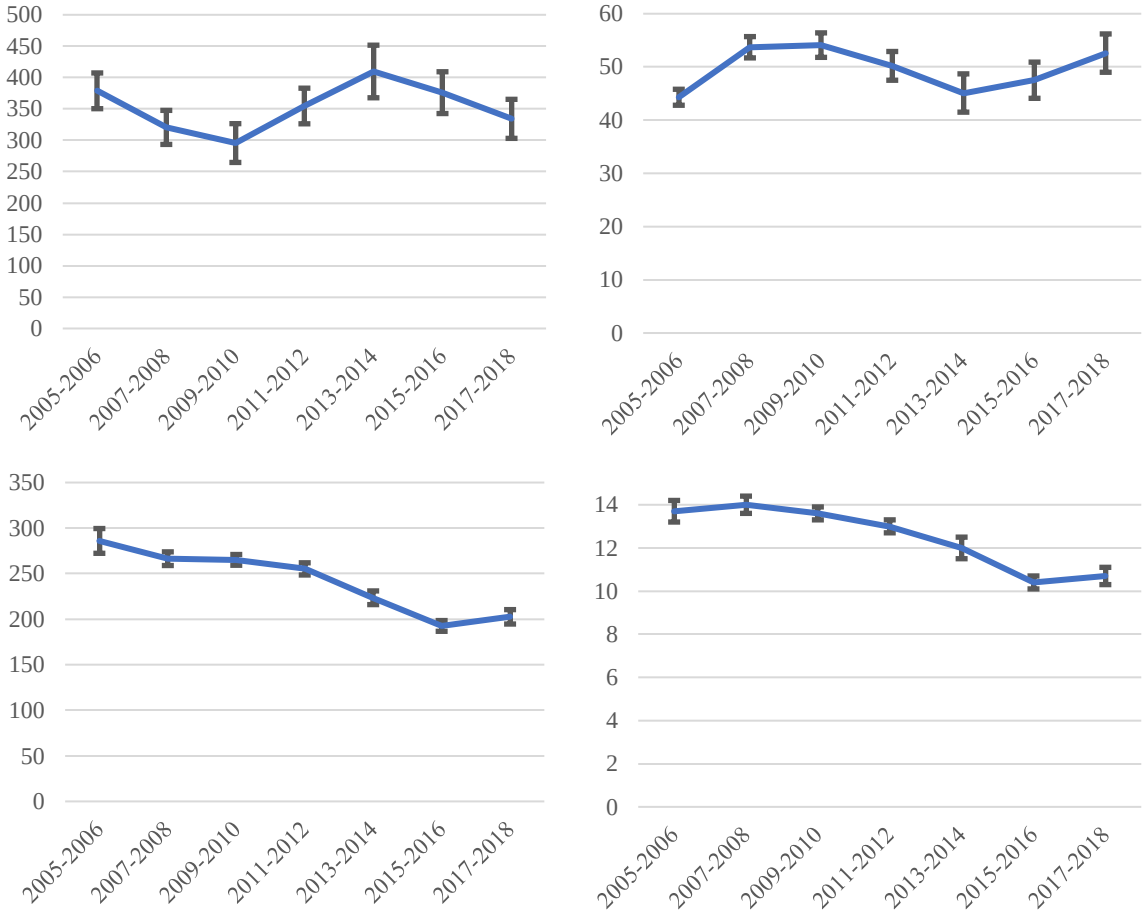
	Calories from sugary drinks			**Percent of total energy intake from sugary drinks**		
Unadjusted mean for those with **no prior** water safety violation(s)	238.3 ± 3.5			12.4 ± 0.2		
Unadjusted mean for those **with prior** water safety violation(s)	272 ± 13.6			13.7 ± 0.8		
	β	SE	p-value	β	SE	p-value
Water Safety Violation	24.5	12.7	0.06	1.2	0.8	0.1
Total Energy Intake	0.1	0.006	<0.001	-	-	-
Age						
2-5	*Reference*					
6-11	-14.5	6.3	0.02	-0.3	0.3	0.3
12-19	12.50	6.1	0.04	1.0	0.3	0.003
Gender (ref: female)						
Male	16.7	4.4	<0.001	0.8	0.2	<0.001
Race						
White	*Reference*					
Asian	-85.6	12.0	<0.001	-4.7	0.7	<0.001
Black	13.4	7.0	0.06	0.8	0.4	0.03
Hispanic	5.4	7.4	0.5	0.4	0.4	0.3
Other	-11.2	10.1	0.3	-0.8	0.5	0.1
Family income to poverty ratio						
≤1	*Reference*					
>1 and ≤3	2.8	6.0	0.6	-0.2	0.3	0.5
>3	-28.1	7.8	<0.001	-1.6	0.4	<0.001
BMI percentile	0.1	0.09	0.2	<0.1	<0.1	0.1
Housing status						
Own	*Reference*					
Rent	10.9	5.9	0.07	0.7	0.3	0.03
Other	9.0	17.9	0.6	0.8	0.8	0.3
Urban resident (ref: rural)	-20.1	8.6	0.02	-0.9	0.4	0.05

Beta coefficients (β), standard errors (SE) and p-values are displayed for both models.
Dichotomously-coded variables have reference (ref) category in parenthesis.

Supplemental Figure 1. Weighted means and standard errors for beverage outcomes for adult participants 20 years old and older (n= 34,916). Clockwise from top left: tap water intake (mL), Tap water avoider (% yes), sugary drink calories (kcal), and percent of total energy intake from sugary drinks (%).



Supplemental Figure 2. Weighted means and standard errors for beverage outcomes for children and adolescent participants 2-19 years old (n= 21,486). Clockwise from top left: tap water intake (mL), Tap water avoider (% yes), sugary drink calories (kcal), and percent of total energy intake from sugary drinks (%).



Chapter 3: Water beliefs as Predictors of Preferred Drinking Water Source: a Cross-sectional Study in Virginia, USA.

Introduction

Water is a physiological requirement for survival, yet numerous types of beverages, besides plain water, are widely available, some of which are associated with adverse health outcomes (*Be Sugar Smart: Limiting Added Sugars Can Improve Health | Nutrition | CDC*). Sugar sweetened beverages, which provide excess calories from added sugars with little to no additional nutrients and comprise the predominant source of added sugar in the American diet, often displace intake of healthier beverages (*Be Sugar Smart: Limiting Added Sugars Can Improve Health | Nutrition | CDC*). Because added sugar intake is robustly associated with obesity, tooth decay, type 2 diabetes, and other cardiometabolic risk factors (Malik and Hu; Laniado et al.; Bleich and Vercammen) the Dietary Guidelines for Americans, recommends limiting added sugars to no more than 10% of calories per day, and encourages replacement of sugar-sweetened beverages with unsweetened alternatives, such as plain water (U.S. Department of Health and Human Services and U.S. Department of Agriculture).

However, choosing a water source – that is, whether to drink water directly from the faucet, filtered water, or bottled water, is a complex behavior driven by several interconnected factors and historical experiences. At the individual level, it has been posited that individuals choose their water source depending on their 1) trust in the safety of water, 2) perceived risk and severity of an adverse event following the use of the water, 3) the salience of past events involving water, and 4) sensory evaluations of the

water such as its taste, odor, and appearance (Grupper et al.), and willingness to pay for alternatives (e.g. bottled water or filtration systems) (Javidi and Pierce). Systemic factors such as discrimination and marginalization that have led to underdevelopment of infrastructure, and higher exposure to unsafe drinking water also play a role in choice of drinking water source, particularly among lower income and racial/ethnic minority communities (Meehan, Jepson, et al., 2020; Switzer & Teodoro, 2018; Teodoro et al., 2022).

One of the hypothesized determinants of use of the tap water, is whether the individual trusts the water utility to provide them with safe water (Grupper et al.). Surveys have assessed Americans' attitudes and knowledge of their water utility (American Water Works Association; American Water Works Association Press Release), but there has been little research on how perceptions of the water utility relate to water source preferences. A survey of 352 adults from Roanoke, Virginia found that individuals who drink exclusively from the faucet had higher levels of trust in the water utility compared to individuals who drink exclusively bottled water (Grupper et al.). While this supports the notion that trust in the utility is positively associated with drinking from the tap, previous studies about trust in the water utility (Doria et al.) have not examined trust in the water; therefore, the relative impact of trust in the utility and trust in the water on choice of water source is presently unknown. Furthermore, there is limited understanding of how other dimensions related to the water utility, for example awareness of the frequency at which the water utility tests the water, may relate to water preferences. The purpose of this analysis is to cross-sectionally test whether perceptions

of water, both regarding the water itself as well as the water utility, relate to the preferred water source in a sample of adults across the state of Virginia. We specifically investigate whether trust in water and the water utility, perceived water quality and safety, and awareness of water testing, predict a preference for tap water.

Methods

Data source:

The data analyzed for this study were from the Water Beliefs Survey developed by the Virginia Foundation for Healthy Youth in collaboration with Virginia Health Catalyst. The survey was designed to assess water beliefs and drinking water behaviors among adults residing in the state of Virginia, with the goal of identifying factors that could encourage tap water consumption. Market Decisions Research, a commercial research company, recruited participants by address-based, mailed survey invitations and by an online panel assembled by Voxco, a market research company. The survey was administered in December 2022, and was completed by 1576 Virginia residents using an online survey tool (Voxco). However, only participants that had a water utility could answer questions about the water utility (described below); thus, 743 participants were excluded due to use of private wells or rainwater harvesting as their source of drinking water. An additional 24 participants were excluded due to incomplete responses to survey items used in this analysis.

Water Beliefs Survey Items:

The Water Beliefs Survey included questions about water perceptions, trust/awareness of water utility companies, water intake preferences, and demographic characteristics. For

the present analysis, we included six survey questions based on previously theorized determinants of tap water intake (Grupper et al.) were selected to investigate trust in water, the water utility, and the local government; awareness of water testing; and perceived quality and safety of the water. To assess trust, three questions were used: 1) “How much, if at all, do you trust the water at your faucet?”, and 2) “How much, if at all, do you trust your water utility company?”. Response options for these two questions were "A lot", "Some", "I don't know / I don't have an opinion", "Not too much", and "Not at all". Finally, participants were asked to select 3) whether the local government was a trusted for information about water. To assess quality rating of water, participants were asked 4) “How would you rate the quality of the water at your faucet?” with the response options of: “Excellent”, “Good”, “Just fair”, and “Poor”. To test awareness of water testing, participants were asked 5) “How aware are you, if at all, that utilities frequently test your water?”, with the options of: “Very aware", “Somewhat aware", “Not very aware", and “Not aware at all”. To assess perceived safety, participants were asked 6) “In your view, how safe or unsafe is the water at your faucet?”, with the following response options: “very safe”, “somewhat safe”, “I don't know/no opinion”, “somewhat unsafe” and “very unsafe”.

Statistical analyses:

Outcome. The outcome of this study was participants’ preference for tap water. Preferred source of drinking water was determined using the survey item “What is your preferred source of drinking water?”, which had the following response options: 1) “bottled water” 2) “a water filtering system (i.e., filtered pitcher, faucet mounted filter, fridge dispenser”,

and 3) “the water at your faucet”. Those who reported preferring any tap water (i.e., from a filtering system or from the faucet) were compared to those who drink bottled water.

Predictors. Water beliefs were used to predict preference for tap water. They were either characterized as multi-category factors based on their survey item responses or as a water beliefs score. The water beliefs score was created by assigning integer values to each of the water beliefs survey item responses. For the beliefs with Likert responses, we assigned integers ranging from 0 for the lowest response option (e.g. “not at all/not too much”) to 4 for the highest (e.g. “a lot”). Considering the local government as a trusted source of information on water (the only belief with a binary yes/no response), was recoded to 0 (did not trust the local government) and 4 (trusted the local government). The reliability of these survey items together was good (Cronbach alpha = 0.81).

Descriptive statistics. Survey items were summarized using frequencies (n) and percentages. For the five-point Likert scale responses (i.e., trust in water, trust in water utility, and safety of the water), the two lowest response options (e.g. “not at all” and "Not too much" for trust, and “very unsafe” and “somewhat unsafe” for safety) were combined into one category, due to small numbers. Contingency tables for each predictor and outcome were tested for an association using a chi-squared test.

Multivariate analysis. Logistic regression was used to generate the odds ratio (OR) and 95% confidence intervals (CI) of predicting tap water consumption, compared to bottled water consumption. We conducted seven logistic regression models. First, we conducted

one model for each water belief as an independent variable. Second, we used the water beliefs score, and third, we used included all the water beliefs in a single model (referred to as the multi-water beliefs model. All water beliefs were treated as factors in a model to predict choosing tap water (filtered or unfiltered), compared to bottled water, as the preferred source of water, except for the water beliefs score where they were a numeric variable. For the multi-water beliefs model, we further measured variable importance using two entropy-based measures with the R package randomForest, where agreement between the two indicates greater variable importance (Liaw and Wiener). Mean standard error summarizes the mean decrease in the model result accuracy from randomly shuffling observations of a certain variable; variables that create the biggest changes in the model results when they are randomly shuffled are considered the most influential. Mean decrease in node impurity is a measure of how well a variable performs at splitting observations into more homogenous groups on a decision tree; higher values of decreasing node impurity indicate that the variable is influential at distinguishing between respondent outcomes. Extreme observations, defined as those with a standardized residual greater than 3, were removed (n=1). A total of 808 participants remained and were included in this analysis. Variance inflation factors (VIF) were calculated to diagnose multicollinearity, but no variables with a VIF above 5 were detected. Covariates were selected based on previously demonstrated associations with water intake and included participants' age, sex, race/ethnicity, income range, education level, participation in benefit programs, household size, and housing status. All analyses were performed using R Statistical Software (v4.1.2; R Core Team 2021).

Results

Demographic characteristics of adults (n=808) from across the state of Virginia who participated in the survey, are summarized in **Table 7**. Participants were mostly white (72%), with about a quarter of the remaining participants identifying as Black (19.6%), Asian (3.5%), Hispanic/Latino (1.7%), or Native/Pacific Islander (0.4%). About one third of the sample had educational attainment of a high school diploma or less, and about half had at least a college degree. More than half of the participants were female, homeowners, and had a household income of $50,000 dollars or more. The mean age was 46 years old, and the most common household size was 2-4 people.

The most common preferred water source was bottled water (N= 372, 45.5%), followed by filtered water (N=316, 38.7%). Only 129 people (15.8% of sample) indicated that water directly from the faucet (i.e., unfiltered) was their preferred drinking water source. Response frequencies for survey questions on trust in water at the faucet, trust in the water utility, awareness of water testing, and quality of tap water are presented in **Table 8**. The proportion of participants that had favorable responses (i.e. ratings above the midpoint of the Likert scale) was higher among those who reported a preference for tap water compared to those who preferred bottled water. The relationship between each of the water beliefs ratings and the preferred water source was significant (all $p<0.001$), except for awareness of the frequency of water testing (**Supplemental Table 1**). The resulting values from the water beliefs score that summed all the response frequencies, ranged from 2 to 21, with a mean of 13.15 and a standard deviation of 4.6.

Although only 15.8% indicated that unfiltered tap water was their preferred source for drinking, the majority of respondents indicated favorable water perceptions (e.g. selected somewhat safe or more, some trust or more, good quality or more, somewhat aware or more). Specifically, 67% had some or a lot of trust in their tap water, 78% had some or a lot of trust in their water utility, 69% rated the quality of their water as good or excellent, and 73% considered their water somewhat or very safe. When specifically examining those who selected the maximum Likert-scale value (i.e. 5 on a scale of 1 to 5) for each of the water beliefs, about a third of respondents trusted their tap water (N= 228, 28.2%) and water utility a lot (N= 291, 35.6%) and considered their water very safe (N=261, 31.9%). About a quarter of participants indicated being very aware that the water utility tests water frequently (N=200, 24.5%) and more than 19.6% of respondents rated the quality of their water as excellent. Finally, 49% of the sample considered the government a trusted source for information about water.

In the adjusted models of each water belief, all models showed the same pattern: participants with the highest value of water belief (e.g. “excellent” for quality, or “a lot” for trust in the utility) predicted higher odds of preferring tap water, compared to the reference category (**Supplemental Tables 2-6**). The largest increase in odds of drinking tap water was for those with the highest levels of trust in water at the faucet (OR: 3.20, 95% CI: 2.06-5.02, $p<0.001$), followed by those that rated their tap water quality as excellent (OR = 2.54, 95% CI:1.22-5.36, $p =.013$), those who rated their tap water as very safe (OR = 2.32, 95% CI: 1.42-3.82, $p<0.001$), those that had a lot of trust in the water

utility (OR: 1.85, 95% CI: 1.06-3.28, p= 0.03), and finally those who considered the local government a trusted source for information (OR: 1.56
95% CI: 1.14- 2.12, p =0.005). In all models of individual beliefs, no other levels were significantly different than the reference.

In the water beliefs score model (**Supplemental Table 7**), we found that each point higher was associated with a 10% increase in the odds of preferring tap water compared to bottled water (OR:1.10, 95% CI: 1.05-1.13, p<0.001). Finally, in the multi-water beliefs model, trust in the water at the faucet was the only water belief that significantly increased the odds of choosing tap as the preferred source of water (**Figure 1 and Supplemental Table 8**). Compared to those that reported no trust at all or not too much trust, those that had a lot of trust had significantly higher odds of preferring water directly from the faucet (OR: 2.34; 95% CI: 1.23-4.49; *p*= 0.01). No differences in odds of preferring water directly from the faucet were observed across the other response options (Some trust: OR: 0.88, 95% CI: 0.53-1.44, p=0.6; Don't know/No opinion: OR: 1.38, 95% CI: 0.69-2.79, p =0.3). The degree to which participants trust their water utility company, are aware of the water utility frequently testing their water, rate the safety, or rate the quality of their tap water were not associated with the odds of preferring water directly from the faucet. Furthermore, no significant differences in the odds of preferring tap water were observed based on whether participants considered their local government a trusted source of information (OR = 1.35, 95% CI: 0.97-1.88, p= 0.07). Results from the variable importance analysis resulted in the same order that we found of the largest odds ratios in our individual models. Trust in water at the faucet was the most influential

water belief in the model (mean standard error: 18.38, node impurity:15.27), followed by safety (13.97, 13.40), quality (13.63, 11.51), trust in the utility (1.65, 10.7) and finally, trust in the local government (1.11, 6.01).

Although exact values for odds ratios varied by model (Supplemental Tables 2-7), the patterns seen across the covariates remained constant. For race/ethnicity, non-Hispanic Black adults had significantly lower odds of preferring tap water, compared with non-Hispanic White adults, and no other subgroup differences were significant. Male participants had lower odds of preferring tap water compared to female participants, and post hoc analyses demonstrated that the proportion of White men in the sample was smaller compared to White women (44% vs. 26% of the total sample, respectively). Virginians living in housing situations besides renting and owning had lower odds of preferring tap water compared to home owners (the trend for those in rented housing was in the same direction but not significant for this subgroup). Older age and greater education were the two demographic characteristics associated with increased odds in preferring tap water. Participants with any educational attainment beyond a high school diploma, had much higher odds of preferring water from the tap compared to adults with a high school diploma or less. Finally, there was no association between the different regions of the state of Virginia and the odds of preferring tap water in any of the models.

Discussion

Our findings demonstrate that the odds of choosing tap water as the preferred source of drinking water are considerably higher among individuals with a lot of trust in the water at their faucet compared to those with not so much or no trust at all (over twice the odds

in the multi-water beliefs model and over three times when modeled alone). Upon examining perceptions of tap water in a model that adjusted for the known demographic correlates of tap water consumption, trust in the water at the faucet was the most influential perception in predicting tap water preference, although water quality, water safety, trust in the water utility and trust in the local government were also significant predictors when examined individually, or when examined cumulatively as a continuous water beliefs score. It has previously been shown that those who drink tap water trust the utility to deliver safe drinking water to them more than those that drink bottled water, although the cross-sectional design of that study precludes making conclusions on the directionality of that relationship (Grupper et al.). In the present analysis, by asking about trust in the water at the faucet and trust in the water utility separately, we were able to discern that these are two distinct constructs (VIF scores < 5). To our knowledge, these constructs have not been tested together in prior analysis of drinking water preferences, and the present findings emphasize the importance of discriminating between trust in the water at the faucet and trust in the water utility in future studies.

Tap water preference, the outcome of the present study, cannot solely be explained by trust in the water. In this study, favorable ratings of trust in the water were very common among participants (67% rated above the mid-point of the Likert scale), yet just over half of the participants (55%) indicated a preference for tap water. When looking at those who preferred unfiltered water straight from the faucet that gap drastically widens: only 16% reported a preference for unfiltered water. One explanation for the relatively low unfiltered tap use, despite the overall favorable responses for trust in the water, is that

most of the participants are filtering water to improve its organoleptic qualities (i.e. flavor, appearance, smell), however, these were not directly assessed in this study.

Differences in preferred water source even among people with similar feelings about the safety of tap water have also been previously reported (Grupper et al.). In that study, there were no differences in tap water safety ratings among individuals who drank tap water exclusively versus those who drank filtered water exclusively. Choosing different options at the tap (i.e. unfiltered or filtered) while holding similar views about water safety, supports the notion that water filters are commonly used to improve taste rather than due to concerns about safety. Taken together, these findings suggest that trust in water as being safe to drink is necessary, but not sufficient, to motivate people to drink from the tap; even when water is safe, filtration may be used for the purpose of improving the enjoyment from water. The finding that more Virginians in our sample prefer filtered compared to unfiltered tap water, even though they trust the water utility and trust the water at their faucet, points to an opportunity for utilities to improve upon their water's flavor.

Despite previous evidence that organoleptic properties (e.g. taste, smell, appearance) are powerful correlates of tap consumption, water quality ratings only significantly predicted a preference for tap water among those with the highest ratings ("excellent" compared to "poor"). The finding that quality was not a significant predictor of tap water consumption for participants with other positive beliefs (e.g. those that believed that the water was of "good" quality), may be consistent with blind taste-test studies that showed that people

might not always consume water that they most prefer (Teillet et al.). For example, highly effective marketing of bottled water could persuade people to choose bottled water despite high self-reported trust, quality, and safety of the water at the faucet (Jaffee).

In the present analysis among Virginians, higher education was strongly associated with preferences for tap water. Independent of trust, those with any higher education were more likely to prefer tap water compared to those that were high school graduates or less. Several theories may explain the strong positive correlation between education and trust. For example, social sorting (Borgonovi and Pokropek) posits that when someone with higher educational attainment faces negative consequences from misplacing their trust in someone or something, they have less to lose than someone with less education and fewer social "safety nets". Although being trusting within one's social circles is distinct from trusting strangers, institutions, and governments, the two types of trust are positively correlated(Borgonovi and Pokropek). It is important to consider that the sample surveyed in the water beliefs is highly educated (49% college educated), high earning (39% with annual incomes above 75,000), and mostly white (72%). Higher socioeconomic status and lower prevalence of racial/ethnic minorities have been linked to better water quality and water infrastructure (Switzer and Teodoro; Leker and Gibson). These same demographic characteristics of privilege (i.e. being non-Hispanic White and earning higher incomes) are also characteristic of those who have historically been afforded the privilege of higher education. This effectively compounds two important precursors of trust: those who have not been systematically discriminated against will have higher trust

in their government's ability to provide safe water to them, and those who have higher education and wealth live in better resourced communities with better water quality.

Another noteworthy and surprising correlate of preference for tap water in our analysis was gender; men were less likely to prefer water compared to women. Differences in tap water consumption by gender have not been observed in analyses of national survey data (Asher Y. Rosinger, K. A. Herrick, Wutich, et al.; Asher Y Rosinger et al.); and smaller non-nationally representative surveys have reported no association (Grupper et al.; Onufrak, Park, Sharkey, and Sherry) or found that men are more likely to prefer tap water to women (Güngör-Demirci et al.). A possible explanation for the difference in tap water preference across gender in this sample of Virginians is a different racial distribution by gender, as the proportion of White participants was smaller among men compared to women. There is a vast literature surrounding racial disparities in source of water intake. While 60% of non-Hispanic white adults consume any tap water on a given day, only about a third of non-Hispanic Black (37.0%) and Hispanic (36.3%) adults do (Brooks et al.). Furthermore, non-Hispanic Black and Hispanic individuals are more likely to consume bottled water compared to their white counterparts (Asher Y. Rosinger, K. A. Herrick, Wutich, et al.). Our present finding that Black adults had 41% lower odds of choosing tap water compared to White adults, was therefore consistent with results of multiple prior studies (Brooks et al., 2017; Rosinger et al., 2018). There is ample research that indicates that individuals from marginalized and/or historically oppressed communities have lower trust in tap water, which is typically rooted in systemic underdevelopment and discrimination, as explained in the discussion of Chapter 2.

A prior analysis demonstrated that negative perceptions of water safety are associated with lower tap water use and higher bottled water use but were not associated with filtration use (Triplett et al.). The authors of the study concluded that individuals who were concerned about their water safety forgo the tap altogether and consume bottled water. This suggests that, for some people, if water safety is a concern, a filter is perceived as ineffective in making it safe enough. Although 65% of bottled water in the United States is filtered municipal water rather than spring or well water, the "conventional wisdom" in the bottled water industry is that consumers may not know that (Jaffee). Opting out of public services (e.g. water from the tap) for commercial options (e.g. bottled water) has been linked to low trust in government, and in the US where about 85% of the population is served by a government-owned utility, this can have major implications on tap water consumption (Teodoro et al.). Geospatial studies linking survey data on trust in the local government with both bottled water sales and kiosk-water (private companies that market and sell "purified" water in bulk) abundance have shown that there is a inverse relationship between trust and consuming these tap water alternatives (Teodoro et al.). Our study aligns with that evidence by finding a direct association between trust in the government and tap water preference. Given that the government is responsible for the provision of public services, when the government has failed individuals from communities you identify with (either recently or historically), this lowers both the trust in the government directly as well as their services (Teodoro et al.). Communities with lower socioeconomic status and greater prevalence of racial minorities typically have much lower trust in government , due to confluence of injustices

including less government representation, less infrastructure development, and greater odds of living in environmentally hazardous areas, as described in Chapter 1 (Wutich et al.; Meehan, Jepson, et al.; Teodoro et al.).

Key strengths of our study include that the Water Beliefs Survey is, to our knowledge, the largest survey on water preferences in the state of Virginia. By collecting information on three critical areas – water perceptions, participant characteristics, and water preferences – it allowed us to construct a robust statistical model to predict preferred water source. Furthermore, in addition to the more established determinants of tap water consumption (e.g. trust and quality), this survey included questions such as awareness of water testing and trust in the government for information about water, which are less investigated as potential predictors of tap water choice. Nevertheless, the study was not without its limitations. First, the sample size and race/ethnic distribution of participants precluded the ability to explore important subgroup differences. For example, the present study population was only 1.7% Hispanic (14 of 808 individuals)—a small fraction considering that 10.5% of Virginians are Hispanic (*U.S. Census Bureau QuickFacts: Virginia*). Furthermore, the use of a panel for participant recruitment limits the external generalizability of the findings. Another limitation particular to the survey was that the question "How would you rate the quality of the water at your faucet" may not have been interpreted in the same way by all respondents. Previous research shows that some people consider it to probe the water's purity from contaminants or chemicals, whereas others interpret it to be about organoleptic properties such as taste, smell, and appearance (Anadu and Harding). In same vein, the acceptability of tap water may be influenced by

its temperature, and therefore not considering access to chilled tap water is another limitation in the Water Beliefs Survey (Mackey et al.). Finally, although people tend to consume one type of water the majority of the time (i.e. exclusively filtered, unfiltered or bottled) (Grupper et al.); consumption of multiple sources of water (i.e., sometimes tap and sometimes bottled) was not captured in the Water Beliefs Survey.

In summary, our results emphasize that trust in water at the faucet is an influential correlate of tap water preference. The finding that the majority of participants had favorable ratings of trust, quality and safety in this sample, may suggest that the utility could consider other areas that need improvement, such as the flavor of the water. The absence of an association between awareness of the frequency of water testing and preferring tap water may also represent an opportunity for the water utility to consider what other type of information it can provide to consumers to reflect their competence, reliability, and honesty, as these are the foundations of being trustworthy (Cerna; O'Neill). Efforts to strengthen the trustworthiness of tap water is a critical area for future investigation with the potential to improve public health outcomes both among Virginians and across the United States.

Tables and Figures

Table 6. Participant characteristics* (n=808) of the Water Beliefs Survey respondents.

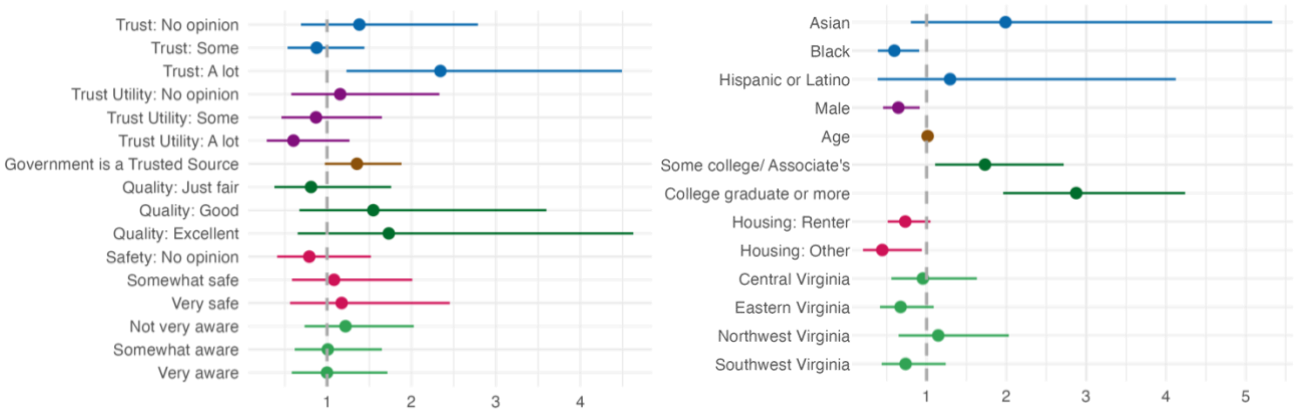
Race/ Ethnicity	
White	582 (72.0)
Black	158 (19.6)
Asian	28 (3.5)
Hispanic or Latino	14 (1.7)
Native American/Alaska Native/Native Hawaiian/Pacific Islander	3 (0.4)
Other/ Prefer not to answer	23 (2.8)
Education	
High school diploma or less	264 (32.7)
Some college or Associate's degree	147 (18.2)
College graduate or more	397 (49.1)
Gender	
Male	300 (37.1)
Female	481 (59.5)
Other	27 (3.3)
Age (Mean, Standard Deviation)	46.1, 17.1
Household size	
Live alone	112 (13.9)
2-4	581 (71.9)
5 or more	111 (13.7)
Missing	4 (0.5)
Region of Virginia	
Central	145 (17.9)
Eastern	214 (26.5)
Northern	166 (20.5)
Northwest	118 (14.6)
Southwest	165 (20.4)
Housing status	
Homeowner	492 (60.2)
Renter	285 (34.9)
Other/Prefer not to answer	40 (4.9)
Household income	
Under $24,000	132 (16.3)
$24,000 to $49,999	184 (22.8)
$50,000 to $74,999	176 (21.8)
$75,000 to $99,999	96 (11.9)
$100,000 or more	220 (27.2)

*All values are counts and percentages (n (%)) unless otherwise indicated.

Table 7. Response frequencies of water perception survey questions, stratified by the preferred source of drinking water.

	Bottled (n=370)	**Tap** (n=438)	**All** (n=808)
Trust in water at the faucet			
None at all/ Not too much	121 (32.7)	83 (18.9)	204 (25.2)
Don't Know/ No Opinion	26 (7.0)	34 (7.8)	60 (7.4)
Some	163 (44.1)	153 (34.9)	316 (39.1)
A lot	60 (16.2)	168 (38.4)	228 (28.2)
Trust in water utility			
None at all/ Not too much	46 (12.4)	31 (7.1)	77 (9.5)
Don't Know/ No Opinion	54 (14.6)	50 (11.4)	104 (12.9)
Some	166 (44.9)	174 (39.7)	340 (42.1)
A lot	104 (28.1)	183 (41.8)	287 (35.5)
Rating of water quality			
Poor	27 (7.3)	19 (4.3)	46 (5.7)
Just fair	125 (33.8)	78(17.8)	203 (25.1)
Good	173 (46.8)	228 (52.1)	401 (49.6)
Excellent	45 (12.2)	113 (25.8)	158 (19.6)
Safety of water at the faucet			
Very/ Somewhat unsafe	66 (17.8)	49 (11.2)	115 (14.2)
I don't know/No opinion	63 (17.0)	42 (9.6)	105 (13.0)
Somewhat safe	160 (43.2)	167 (38.1)	327 (40.5)
Very safe	81 (21.9)	180 (41.1)	261 (32.3)
Local government is a trusted source of information about water			
Yes	148 (42.7)	251 (60.0)	399 (50.6)
No	222 (57.3)	187 (40.0)	409 (49.4)
Awareness that water utility frequently tests water			
Not aware at all	63 (17.0)	57 (13.0)	120 (14.9)
Not very aware	91 (24.6)	112 (25.6)	203 (25.1)
Somewhat aware	131 (35.4)	156 (35.6)	287 (35.5)
Very aware	85 (23.0)	113 (25.8)	198 (24.5)

Figure 1. Forrest plot of adjusted odds ratios (point) and 95% confidence intervals (bar) in the multi-water beliefs logistic regression model. Reference categories for water beliefs are: Not at all/ Not too much for trust in water utility company and trust in water at the faucet; poor for quality; very/somewhat unsafe for safety; and not at all for awareness. Reference categories for multi-category covariates are: non-Hispanic white for race/ethnicity, female for gender, high school or less for education, home-owner for housing, and northern Virginia for region of residence within the state.



Supplemental Table 1. Bivariate association between individual water beliefs and preferred source of drinking water.

Water belief	Chi-squared	p-value
Awareness that water utility frequently tests water	4.91	0.18
Trust in water utility	19.43	0.0002
Trust in local government as source of information	23.34	p< 0.0001
Water safety	38.97	p< 0.0001
Water quality	43.67	p< 0.0001
Trust in water at the faucet	54.28	p< 0.0001

Supplemental Table 2. Cross-sectional association between trust in water at the faucet and odds of preferring tap water compared to bottled water.

Characteristic	OR	95% CI	p-value
How much, if at all, do you trust the water at your faucet?			
Not at all/ Not too much	Reference		
No opinion/ Don't know	1.78	0.95, 3.39	0.074
Some	1.17	0.80, 1.72	0.4
A lot	3.20	2.06, 5.02	<0.001
Race/Ethnicity			
White	Reference		
Asian	1.99	0.81, 5.28	0.15
Black	0.57	0.38, 0.86	0.007
Hispanic or Latino	1.12	0.34, 3.60	0.8
Native American/Alaska Native	0.81	0.04, 8.82	0.9
Other/Unknown	1.53	0.60, 4.15	0.4
Gender			
Female	Reference		
Male	0.65	0.46, 0.91	0.013
Other	1.38	0.57, 3.47	0.5
Age	1.01	1.00, 1.02	0.015
Education			
High school diploma or less	Reference		
Some college or Associate's degree	1.70	1.10, 2.64	0.018
College graduate or more	2.93	2.02, 4.27	<0.001
Living Status			
Homeowner	Reference		
Renter	0.73	0.51, 1.03	0.070
Other	0.47	0.21, 0.97	0.046
Region of Virginia			
Northern	Reference		
Central	1.00	0.59, 1.69	>0.9
Eastern	0.69	0.43, 1.10	0.12
Northwest	1.13	0.65, 1.97	0.7
Southwest	0.75	0.45, 1.24	0.3

Adjusted odds ratios (OR) and 95% confidence intervals (CI) from logistic regression model.

Supplemental Table 3. Cross-sectional association between quality of water at the faucet and odds of preferring tap water compared to bottled water.

Characteristic	OR	95% CI	p-value
How would you rate the quality of the water at your faucet?			
Poor	Reference		
Just fair	0.78	0.39, 1.57	0.5
Good	1.63	0.85, 3.19	0.15
Excellent	2.54	1.22, 5.36	0.013
Race/Ethnicity			
White	Reference		
Asian	1.92	0.79, 5.08	0.2
Black	0.58	0.38, 0.87	0.009
Hispanic or Latino	1.28	0.39, 4.01	0.7
Native American/Alaska Native	0.69	0.03, 7.86	0.8
Other/Unknown	1.38	0.55, 3.67	0.5
Gender			
Female	Reference		
Male	0.69	0.50, 0.97	0.032
Other	1.23	0.51, 3.13	0.7
Age	1.02	1.01, 1.03	0.002
Education			
High school diploma or less	Reference		
Some college or Associate's degree	1.80	1.16, 2.80	0.009
College graduate or more	3.13	2.16, 4.55	<0.001
Living Status			
Homeowner	Reference		
Renter	0.77	0.55, 1.09	0.15
Other	0.47	0.22, 0.98	0.047
Region of Virginia			
Northern	Reference		
Central	1.04	0.62, 1.75	0.9
Eastern	0.74	0.46, 1.19	0.2
Northwest	1.18	0.68, 2.05	0.6
Southwest	0.78	0.47, 1.29	0.3

Adjusted odds ratios (OR) and 95% confidence intervals (CI) from logistic regression model.

Supplemental Table 4. Cross-sectional association between safety of water at the faucet and odds of preferring tap water compared to bottled water.

Characteristic	OR	95% CI	p-value
In your view, how safe or unsafe is the water at your faucet?			
Not safe at all/ not very safe	Reference		
Somewhat unsafe	0.95	0.53, 1.70	0.9
Somewhat safe	1.30	0.82, 2.06	0.3
Very safe	2.32	1.42, 3.82	<0.001
Race/Ethnicity			
White	Reference		
Asian	1.84	0.77, 4.77	0.2
Black	0.57	0.38, 0.86	0.008
Hispanic or Latino	1.12	0.35, 3.50	0.8
Native American/Alaska Native	0.73	0.03, 8.01	0.8
Other/Unknown	1.49	0.59, 3.97	0.4
Gender			
Female	Reference		
Male	0.69	0.49, 0.96	0.027
Other	1.41	0.59, 3.52	0.5
Age	1.01	1.00, 1.02	0.004
Education			
High school diploma or less	Reference		
Some college or Associate's degree	1.70	1.10, 2.65	0.017
College graduate or more	2.93	2.02, 4.27	<0.001
Living Status			
Homeowner	Reference		
Renter	0.75	0.53, 1.06	0.10
Other	0.47	0.22, 0.97	0.044
Region of Virginia			
Northern	Reference		
Central	1.03	0.62, 1.73	>0.9
Eastern	0.71	0.44, 1.13	0.15
Northwest	1.18	0.68, 2.04	0.6
Southwest	0.77	0.47, 1.27	0.3

Adjusted odds ratios (OR) and 95% confidence intervals (CI) from logistic regression model.

Supplemental Table 5. Cross-sectional association between trust in the water utility and odds of preferring tap water compared to bottled water.

Characteristic	OR	95% CI	p-value
How much, if at all, do you trust your water utility company?			
Not at all/ Not too much	Reference		
No opinion/ Don't know	1.33	0.70, 2.55	0.4
Some	1.33	0.78, 2.31	0.3
A lot	1.86	1.06, 3.28	0.030
Race/Ethnicity			
White	Reference		
Asian	1.70	0.71, 4.45	0.2
Black	0.55	0.37, 0.83	0.004
Hispanic or Latino	0.98	0.30, 3.06	>0.9
Native American/Alaska Native	0.61	0.03, 6.61	0.7
Other/Unknown	1.40	0.56, 3.74	0.5
Gender			
Female	Reference		
Male	0.72	0.51, 1.00	0.049
Other	1.36	0.57, 3.37	0.5
Age	1.01	1.01, 1.02	0.002
Education			
High school diploma or less	Reference		
Some college or Associate's degree	1.69	1.10, 2.61	0.017
College graduate or more	3.05	2.11, 4.42	<0.001
Living Status			
Homeowner	Reference		
Renter	0.74	0.53, 1.04	0.086
Other	0.47	0.22, 0.97	0.044
Region of Virginia			
Northern	Reference		
Central	1.05	0.63, 1.74	0.9
Eastern	0.74	0.47, 1.18	0.2
Northwest	1.19	0.69, 2.05	0.5
Southwest	0.76	0.46, 1.25	0.3

Adjusted odds ratios (OR) and 95% confidence intervals (CI) from logistic regression model.

Supplemental Table 6. Cross-sectional association between considering the local government as a trusted source of information about water and odds of preferring tap water compared to bottled water.

Characteristic	OR	95% CI	p-value
Local government is a trusted source of information (yes)	1.56	1.14, 2.12	0.005
Race/Ethnicity			
White	Reference		
Asian	1.64	0.68, 4.28	0.3
Black	0.55	0.36, 0.82	0.004
Hispanic or Latino	0.91	0.28, 2.85	0.9
Native American/Alaska Native	0.54	0.02, 6.06	0.6
Other/Unknown	1.52	0.61, 4.08	0.4
Gender			
Female	Reference		
Male	0.73	0.53, 1.01	0.061
Other	1.34	0.56, 3.36	0.5
Age	1.01	1.00, 1.02	0.006
Education			
High school diploma or less	Reference		
Some college or Associate's degree	1.67	1.09, 2.57	0.020
College graduate or more	2.94	2.04, 4.27	<0.001
Living Status			
Homeowner	Reference		
Renter	0.72	0.51, 1.01	0.057
Other	0.45	0.21, 0.92	0.032
Region of Virginia			
Northern	Reference		
Central	1.04	0.62, 1.73	0.9
Eastern	0.75	0.47, 1.19	0.2
Northwest	1.25	0.73, 2.16	0.4
Southwest	0.76	0.46, 1.25	0.3

Adjusted odds ratios (OR) and 95% confidence intervals (CI) from logistic regression model.

Supplemental Table 7. Cross-sectional association between water beliefs score and odds of preferring tap water compared to bottled water.

Characteristic	OR	95% CI	p-value
Beliefs Score	1.09	1.05, 1.13	<0.001
Race/Ethnicity			
White	Reference		
Asian	1.79	0.74, 4.71	0.2
Black	0.57	0.38, 0.85	0.006
Hispanic or Latino	1.09	0.33, 3.43	0.9
Native American/Alaska Native	0.57	0.03, 6.48	0.7
Other/Unknown	1.60	0.64, 4.30	0.3
Gender			
Female	Reference		
Male	0.66	0.47, 0.92	0.016
Other	1.25	0.52, 3.13	0.6
Age	1.01	1.00, 1.02	0.008
Education			
High school diploma or less	Reference		
Some college or Associate's degree	1.71	1.11, 2.66	0.016
College graduate or more	2.86	1.97, 4.16	<0.001
Living Status			
Homeowner	Reference		
Renter	0.77	0.55, 1.09	0.14
Other	0.49	0.23, 1.00	0.056
Region of Virginia			
Northern	Reference		
Central	1.05	0.63, 1.76	0.9
Eastern	0.76	0.47, 1.20	0.2
Northwest	1.24	0.72, 2.15	0.4
Southwest	0.82	0.49, 1.36	0.4

Adjusted odds ratios (OR) and 95% confidence intervals (CI) from logistic regression model

Supplemental Table 8. Cross-sectional association between water beliefs and odds of preferring tap water compared to bottled water.

Characteristic	**OR**	**95% CI**	**p-value**
How much, if at all, do you trust the water at your faucet?			
Not at all/ Not too much	Reference		
No opinion/ Don’t know	1.42	0.71, 2.86	0.3
Some	0.88	0.53, 1.44	0.6
A lot	2.34	1.23, 4.49	0.01
How much, if at all, do you trust your water utility company?			
Not at all/ Not too much	Reference		
No opinion/ Don’t know	1.15	0.57, 2.32	0.7
Some	0.88	0.46, 1.67	0.7
A lot	0.62	0.29, 1.29	0.2
In your view, how safe or unsafe is the water at your faucet?			
Very/ Somewhat unsafe	Reference		
I don't know/No opinion	0.78	0.40, 1.50	0.5
Somewhat safe	1.09	0.59, 2.03	0.8
Very safe	1.19	0.57, 2.49	0.6
How aware are you, if at all, that utilities frequently test your water?			
Not at all aware	Reference		
Not very aware	1.22	0.74, 2.03	0.4
Somewhat aware	1.01	0.61, 1.63	>0.9
Very aware	1.00	0.58, 1.71	>0.9
How would you rate the quality of the water at your faucet?			
Poor	Reference		
Just fair	0.80	0.37, 1.73	0.6
Good	1.53	0.67, 3.56	0.3
Excellent	1.71	0.64, 4.56	0.3
Consider the government a trusted source of information	1.35	0.97, 1.88	0.07
Race/Ethnicity			
White	Reference		
Asian	2.01	0.83, 5.39	0.1
Black	0.59	0.39, 0.91	0.02
Hispanic or Latino	1.31	0.41, 4.17	0.6
Native American/Alaska Native	0.72	0.03, 8.37	0.8
Other	1.62	0.62, 4.51	0.3
Gender			
Female	Reference		
Male	0.65	0.46, 0.92	0.02
Other	1.27	0.51, 3.27	0.6
Age	1.01	1.0, 1.02	0.008
Education			
High school diploma or less	Reference		
Some college or Associate's degree	1.73	1.11, 2.71	0.02

College graduate or more	2.91	1.99, 4.30	<0.001
Housing Status			
Homeowner	Reference		
Renter	0.73	0.51, 1.05	0.09
Unknown/Other	0.44	0.20, 0.93	0.04
Region of Virginia			
Northern	Reference		
Central	0.95	0.56, 1.63	0.9
Eastern	0.67	0.41, 1.08	0.1
Northwest	1.12	0.64, 1.99	0.7
Southwest	0.73	0.43, 1.23	0.2

Adjusted odds ratios (OR) and 95% confidence intervals (CI) from logistic regression model.

Chapter 4: Integrated discussion

Outline of this chapter:

In this integrated discussion chapter, the primary objective is to describe the emerging themes from each of the dissertation studies' main findings, describe the contributions and implications of this research, and conclude with critical future directions for the field of tap water consumption in the US.

Study summaries:

This dissertation research combined an *analysis* of national data on associations between health-based water safety violations and tap water and sugary drink intake among children and adults (Chapter 2: Paper 1), with data from a *statewide analysis* in Virginia on perceptions of water and their correlations to tap water preference among adults (Chapter 3: Paper 2). Paper 1 used a validated nutrition assessment tool (24-hour recall) to estimate beverage intake, and the Paper 2 used a survey to investigate latent perceptions and water preference. Two major themes tied the findings from this research together despite the different study designs: first, there were large gaps between rates of negative tap water experiences or perceptions and rates of tap water intake or preference. Second, the role of education among adults was consistently among the strongest demographic correlate of tap water consumption and preference.

The results of this dissertation show that previous water safety violations in the county of residence in a nationally representative sample were not associated with tap water or sugary drink consumption among adults, but tap water avoidance was significantly higher

among children who lived in counties with prior water safety violations. In the statewide analysis, awareness of the frequency of water testing was the only surveyed water belief that was not correlated with water preference; and trust in water at the faucet was the most strongly correlated belief to preferring tap water compared to bottled water. We also found that individuals with more overall positive beliefs (cumulatively), had higher the odds of preferring tap water compared to bottled water.

Part 1: Major Themes across the two research study findings

Theme 1: Low tap water intake and preference are largely unexplained by negative experiences and perceptions.

Although the two studies differ substantially in their outcome (tap water *intake vs.* tap water *preference*), both studies demonstrated that adverse experiences or beliefs (i.e. water safety violations for Paper 1 and poor water perceptions for Paper 2) were relatively infrequent compared to widespread prevalence of avoiding tap water on a given day, and preferring tap water to bottled water. If water safety violations were a strong determinant of tap water intake, high levels of tap water intake would have been expected in this sample, given that only 10% lived in counties with prior water safety violations. This was not the case: whereas about 10 percent of the sample in Paper 1 was exposed to water safety violations, nearly five times as many reported consuming no tap water (47.3 ± 0.8%). Similarly, in Paper 2, (water beliefs and preferences in adults in Virginia), over two thirds of participants had favorable ratings of perceived water safety (73%), trust (67%), and quality (69%), and yet only 54% reported tap as their preferred source of water. The gap is staggeringly widened when only considering those who reported drinking directly from the tap: a mere 16% of the sample.

Possible explanations for the mismatch

Several findings in the water literature shed light on the large gap between the 10% exposed to water safety violations, and the 47% who avoid any type of tap water based on analysis of NHANES data. Root causes for were discussed in the literature review in Chapter 1 and in the discussion of Paper 1; but briefly, this gap could be explained by (1) systemic inequities resulting in greater exposure to environmental hazards among communities with lower income and of color, and (2) identifying with individuals who experience unsafe water even when one's own communities is unaffected. Herein, another factor is described: skepticism that the treatment techniques that water utilities go through to comply with federal drinking water standards are sufficient to provide safe drinking water. Even though most water utilities effectively treat and test their water, that does not necessarily translate to enhanced trust in the utility's technical competence to treat water well. This could explain why in Paper 1, even though 90% of people live in a county that has not experienced water safety violations, nearly half avoid tap water. A previous survey on water perceptions found that the majority of their sample, which was demographically representative of the US, believed that drinking water regulations in the United States were not stringent enough (Apul et al.). This could mean that even if people are somewhat or very aware of water testing (as were 60% of the adults in the Virginia/Paper 2 sample), that awareness does not influence their decision to consume tap water. Indeed, among the Virginians surveyed in Paper 2, there was no association between awareness of the frequency of water testing and preference for tap water. Although it may be surprising that the awareness of frequency of testing was not related to drinking water preference, the notion that the regulations do not make people feel secure enough to prefer drinking from the tap is

consistent with the finding from Paper 1 that there was no association between violations and tap water avoidance among adults. This finding may be due to a perceived lack of stringency of regulations, which fits with other research indicating that when water violations occur, such as Flint, they can have widespread consequences. For example, the Colorado resident, Maria Fuentes, was quoted in Chapter 2 for saying "We hear on the news: 'In such-and-such a state the water is contaminated,'…We think it's going to be that way here."

Another possible explanation for the lack of a correlation between water safety violations/negative water perceptions and tap water intake, is that people consume bottled water for reasons besides safety (American Water Works Association). Although safety is a top concern among bottled water consumers, people also drink bottled water for convenience or taste (American Water Works Association). In fact, in the "Public Perceptions of Tap Water" survey conducted by the American Water Works Association, convenience was the most frequently selected response to a survey question that asked respondents why they consumed bottled water, and taste was the second most selected response. While it is logical that people prefer to drink water that they like the taste of, marketing also plays an important role in promoting bottled water consumption. In a study that described underlying sensory attributes related to water preferences, people who habitually consumed specific brands of bottled water did not rate the tastes of those waters highest during a blind taste test that compared chilled bottled and tap water (Teillet et al.). The results from that blind taste test supports the notion that marketing drives people to form cognitive appraisals that bottled water is superior even if they

cannot tell the difference between bottled water and tap. Indeed, other research has shown that participants often fail blind taste test activities that ask them to distinguish between bottled and tap water, despite evidence that many Americans perceive bottled water as purer (Teodoro et al.). Ubiquitous bottled water consumption has been described to be the product of the "marketing trick of the century", as big beverage companies were able to convince people that bottled water was a healthier alternative to sugar sweetened beverages, when bottled water is an alternative to a much more-stringently regulated product: tap water (Jewell). Big beverage companies have substantial financial means to market bottled water, and the steady presence of bottled water as the largest beverage category by volume of the purchased beverages in the US for nearly a decade, reflects their success in making it highly desirable (*Bottled Water Reaches New Peaks in Revenue and Volume*). In sharp contrast to the vast budgets of the big beverage companies, the government's inadequate financial investment into drinking water infrastructure, has led to many high-profile failures to establish public water as trustworthy or appealing (Hughes). Although in public health, we traditionally view the rise of bottled water alongside the "fall of big soda", Teodoro, Zuhlke and Switzer offer an alternate perspective: that the precipitous rise in bottled water is occurring alongside a concomitant decline in trust in the government (Teodoro et al.). While highly effective marketing may persuade many people to choose bottled water despite high self-reported trust, quality, and safety of the water at the faucet that we found in the adults from Virginia, Teodoro et al., believe that marketing is not the root cause of why individuals consume more commercial water, but rather that marketing agencies appeal to consumers because of their distrust in the government (Teodoro et al.). As previously mentioned in the

discussion of Paper 2, marketing of bottled water often relies on portraying that the bottled beverage is purer and healthier than tap water (Jaffee). For example, Fiji ran an advertisement in 2006 with the headline "The label says Fiji because it's not bottled in Cleveland" (Figure 2). The advertisement further describes its water source as originating in "one of the most remote places on the planet, thousands of miles from the nearest industrialized continent", and stating that its water is "protected from external elements", "uncompromised" and a source of "life-essential minerals". The city of Cleveland responded to the advertisement by publishing laboratory tests that showed that their water utility has lower levels of bacteria and arsenic in their tap water compared to the bottled water giant (Jaffee). Beverage companies often market their products by stoking fear in the safety and healthfulness of tap water, but this can be deceptive because 65% of bottled water in the US is sourced from municipal utilities (i.e. it is tap water) rather than a spring or well. In his book "Unbottled", Jaffe describes this ubiquitous practice as "double dipping", where private companies profit from publicly funded municipal water, and further explains that the "conventional wisdom" of the beverage industry is that that they can get away with this because consumers are unaware of where their bottled water is sourced from (Jaffee). Teodoro et al. further explain how ultimately this creates a vicious cycle where citizen dollars are making private companies profitable instead of being reinvested back into local utilities which could allow for much needed operational and infrastructure updates (Teodoro et al.).

Figure 2. Fiji Water advertisement from 2006. Source: CNN Money (Horowitz et al.).

Theme 2: Education emerged as the strongest correlate of water source across contexts.

Educational attainment consistently emerged as the strongest predictor of tap water intake and preference, independent of all other variables -- in both the national (Paper 1) and the Virginia (Paper 2) samples. In the national sample, being a college graduate, was associated with about 313 mL more tap water a day compared to those who had not completed high school. This is roughly equivalent to consuming one and a third additional 8-ounce glasses of water per day. Having completed some college or an associate's degree was also strongly predictive of tap consumption, although this effect was roughly 133 mL, which is closer to just over half a glass. The only other correlate that had a comparable estimated effect was race/ethnicity – where, compared to non-Hispanic White adults, Hispanic adults consumed about 260 mL less tap water, and non-Hispanic Black consumed about 315 mL less tap water. Similar results were detected in

Virginia: those that were college graduates had 2.9 times higher odds of preferring tap water, compared to those with a high school diploma or less; and the next most predictive demographic correlate was race/ethnicity: those who were non-Hispanic Black had 42% lower odds of preferring tap water compared to non-Hispanic White.

Dissecting the link between education and beverage intake

Several reasons may explain why education has such a strong correlation to tap water consumption, as described in both Papers 1 and 2. On a systemic level, there is an overlap between those with the privilege of more years of education, those with historically better infrastructure, and those with less political marginalization and discrimination. Examples of discriminatory underdevelopment of water systems in Black and Hispanic communities were described in Papers 1 and 2. These communities also face barriers in accessing the same quality of educational resources (e.g. smaller class sizes, qualification of school teachers, quality curriculum), compared to their non-Hispanic White counterparts (Darling-Hammond). Yet, this type of inequitable access to resources has not solely marginalized individuals based on their skin color. An illustrative example of this is the case of Appalachia, a region that stretches from Mississippi to New York, with a history of discrimination and underdevelopment among a mostly non-minority, White population (Peterson). Appalachia (a quarter of which is rural), ranks worse off than the rest of the nation with respect to its poverty level, educational attainment, and median earned income ("Rural Appalachia Compared to the Rest of Rural America"). Appalachians, have been referred to as a "forgotten, invisible minority", stereotyped as "uneducated and incestuous", with their accent rather than their race being a source of

discrimination (Peterson). Similar to the disproportionate burden that minority races and lower income individuals face with respect to access to municipal water (Meehan, Jurjevich, et al.), Appalachians are more likely to lack complete plumbing in their homes compared to the rest of Americans (Teodoro et al.). But even among those who do have access to municipal water, surveys and qualitative research done in the region show that distrust in municipal water is high (Lakhani). In rural Martin county, Kentucky, where utility rates are among the highest in the state – a phenomenon that is common among rural communities that have less individuals to spread the cost of water treatment over (Condon)– a resident was quoted in a newspaper article saying "nobody drinks the tap water unless they have to, you can't trust it, and you can't trust the water department" (Lakhani). Some of this distrust may be rooted in the region's history of neglect, but there is also evidence that this county has longstanding issues with providing safe drinking water (Lakhani). Ultimately, many residents spend a large portion of their income on water utilities bills for tap water they do not even drink, or not until they have run out of bottled water and money for the month (Lakhani). Nonetheless, even in other parts of Appalachia, such as Morgantown, West Virginia, which has had a completely clean record (no water safety violation ever documented) a survey found that 37% of respondents there consumed bottled water, and that the odds of drinking bottled water decreased with higher education (Levêque and Burns). Indeed, consumption of bottled water is higher in Appalachian, compared to non-Appalachian, counties. Teodoro et al. found that residents of Appalachian counties spend about $0.38 more on bottled water annually after adjusting for socioeconomic status, percent Black and Hispanic residents, percent renters, and population size (Teodoro et al.). While the magnitude of this

differences seems small, it equates to an additional 9.5 million dollars for the bottled water industry, “disproportionately reaped by consumers with limited resources” (Teodoro et al.). Taken together, these examples show how the socio-political context of education, and more specifically, who has the privilege of educational opportunities, are linked to health behaviors like water intake (Zajacova and Lawrence).

Part 2: Contributions of this work and its implications for public health

The overarching findings of this dissertation are that tap water avoidance is widespread, even among people (1) living in areas without a history of water safety violations, and (2) that have positive perceptions of their tap water and their water utility. This highlights the pressing need to position tap water as a trustworthy and acceptable beverage that people choose to consume over a vast number of available alternatives, including bottled water and sugary drinks. While NHANES unfortunately does not assess reasons for not drinking tap water, trust was the most influential water belief on odds of preferring to consume tap over bottled water among adults in Virginia. Next, our findings highlight specific demographic subgroups that (1) have the highest odds of avoiding tap water, (2) have lower tap water intake and higher sugary beverage intake and finally (4) prefer bottled over tap water. These groups were: adults with an education of high school or less, Black and Hispanic adults and children, and children living in rural areas and/or areas with previous water safety violations -- implies a paramount need for resources in these populations. This is tremendously important, given that purchasing bottled water may exacerbate food insecurity, as discussed in Chapter 1, and that the prevalence of

household food insecurity is higher among Black, Hispanic, households with children, and rural households, compared with the national average (Rabbitt et al.).

When NHANES data were used to model the effects of replacing a single serving of sugar sweetened beverages with water, the associated energy reduction predicted a decrease in the total energy consumed from beverages by 14-33%, and a decline in the proportion of adults with obesity, from 35% to 32% (Duffey and Poti). Another notable implication of low tap water consumption together with high sugary drink consumption is a double-dose of cavity risk. Sugar sweetened beverages are well known risk factors of dental carries, whereas fluoridation of tap water is anti-cariogenic (Hobson et al.). Children are particularly vulnerable to dental carries, which are the most prevalent health condition affecting children. It is also well known that children who do not consume tap water are at higher risk for insufficient fluoride; and, evidence suggests that many parents are unaware that their children are missing out on the benefits of fluoridation by not consuming tap water (Huerta-Saenz et al.). Among youth in the US, Hispanic and non-Hispanic Black youth are the most likely to have dental carries (Fleming and Afful), and have the lowest intake of tap water (as seen in Paper 1 results) and highest intake of SSBs.

Distal goals: addressing systemic factors via policies that promote equitable access to education and improvements in the water utility.

Given preexisting evidence of the adverse nutritional correlates of low tap water intake (higher sugary drink consumption and/or ultraprocessed food), what do the present dissertation findings suggest may be the best course of action? Addressing systemic

factors related to more equitable access to education and better water systems in the US are critical for population health. There is a rich body of evidence that shows the relationship between education and health (Zajacova and Lawrence; Raghupathi and Raghupathi), and education and trust (Cerna; Borgonovi and Pokropek). Although a minor part of education's effect on health is mediated via income (Zajacova and Lawrence), education also supports the development of healthy coping mechanisms, social support networks, and problem-solving skills. But the benefits of education alone will not promote tap water consumption if the issues related to the current water infrastructure are not addressed to ensure equitable water access to all. Taken together, policies to support equitable access to education and water systems are urgently needed. Policies to improve access to education include more equitable access to the aforementioned factors that are disproportionately less common among minority and low incomes schools (class size, teacher qualifications, and curricular content). Policies to improve water systems would include consolidating small water systems which are the most likely to be out of compliance -- these water systems often lack the funding to attract and retain skilled employees with the technical skills required for water treatment, storage and distribution. Water system consolidation would also enable more stringent enforcement of safe drinking water act regulations: regulators tend to reluctant to fine small water systems even when they are out of compliance, because those fines are ultimately passed down to the people the laws are made to protect in higher water bills. Increased costs in larger systems allow costs to be spread out across more users, and ultimately when better regulatory compliance results in better tap water in the long term, choosing tap over bottled water will lower drinking water costs for individuals. Next,

water utilities need to be incentivized to prioritize water aesthetics, which are not currently required by the Safe Drinking Water Act. Consumers that are more satisfied with the organoleptic properties of water are more likely to consider it safe as well as trust the government. Finally, investment into both drinking water infrastructure as well as human capital (the water workforce) are necessary to support improvements to America's aging infrastructure and increasingly complex work of maintaining water systems.

Proximal goals: interventions for education and access to healthy and safe beverages

Downstream from systemic factors influencing tap water perceptions and intake, knowledge about the health risks of sugary beverages reduces their consumption. Among adults and adolescents, there is cross-sectional evidence that being aware of the adverse effects of SSBs is associated with lower consumption of these beverages (Park, Lee, et al.; Park, S. Onufrak, et al.), and many educational interventions are effective in lowering SSB intake, although findings are mixed (Vézina-Im et al.; Irwin et al.; Avery et al.). Furthermore, effects of educational interventions on beverage intake are complicated by several factors. One issue is that parents are sometimes misinformed about sugary drinks that are homemade, made with fruit, or contain vitamins – and perceive these as "healthy" (Sylvetsky, Hoang, et al.), despite being high in sugar, similarly to commercially-available sugary beverages. This is further complicated by the fact that scientific consensus about the healthfulness of 100% fruit juice is still evolving and less conclusive than that of sugar-sweetened beverages (Auerbach et al.). Replacement of sugary drinks with non-sugar sweeteners is even less conclusive, though scientists are

increasing advising caution with regard to consuming non-sugar sweeteners. The lack of transparency about the presence/quantities of non-nutritive sweeteners in foods has challenged the investigation of their health effects (Sylvetsky, Rebolledo, et al.). Similarly, another factor associated with the success of sugary beverage reduction interventions is when an alternative is provided to study participants. For example, the Water Up intervention provided an educational curriculum its participants along with a filter certified to reduce lead (A. C. Reese et al.) and the findings showed that sugary drink consumption decreased concomitantly with an increase in tap water consumption. In that study, the arm that received education about healthy beverages in addition to the filter, did not experience significantly better outcomes compared to the arm that received a filter only.

Education about water is trickier than sugary drinks. Whereas detrimental effects of SSBs are well-established (note, the term SSB excludes 100% fruit juice), a blanket recommendation that tap water is always the healthiest option is simply not possible. There are situations where tap water is unsafe, and it is healthier (i.e. safer) to consider a tap water alternative like bottled water. Furthermore, even in a context where water is free from violations this does not mean - it meets the current criteria for being considered safe, as briefly mentioned in the discussion for Paper 1 regarding PFAS. These man-made industrial byproducts are present in the blood of almost everyone living in the US (Fleury et al.). Alarmingly, children tend to have more concentrated exposure to PFAS than adults for a variety of reasons including touching their mouths more often and larger food and water intake when adjusting for body size (Fleury et al.). It has taken decades of

activism and scholarship to introduce legislation to start monitoring and limiting PFAS in water. In April 2024, the Environmental Protection Agency finalized a law that establishes legally enforceable limits for six PFAS that would result in water safety violations if exceeded (Per- and Polyfluoroalkyl Substances (PFAS), 2024). Nevertheless, Americans will not actually see any of the regulations go into effect for many years. For example, it is not until the year 2029 that utilities can be legally held accountable for water safety violations such as those studied here, if they do not comply with maximum contaminant levels of PFAS. Furthermore, there is a precedent for new administrations that come into to roll back deadlines of timelines such as these (Friedman).

Future work and important considerations

Future work would ideally combine gold-standard nutrition assessments (such as a food frequency questionnaire, which is the nutrition assessment most correlated to doubly labeled water intake (Chang et al.) with contextual assessments about participant beverage perceptions and choices. For example, if NHANES were to create a questionnaire that probes perceptions related to water, much like their questionnaires for consumer behavior, this could provide a context for why individuals avoid tap water, which was not possible in the present research. Despite the need to invest in developing and implementing such surveys on a national level, there are several notable caveats to consider: (1) participation in national surveys has been declining for decades, and (2) the topics surveyed are still leaving important populations understudied. For example, many of the most widely used federal surveys like NHANES and the National Health Interview Survey (NHIS), among many others, have seen steep declines in respondent participation in the last few decades (Czajka and Beyler). For example, in 2000, the responses rates

were 81.9% and 76.3% for the NHANES interview and examination, respectively, and in 2014 these numbers dropped to 71.9% and 68.5%. Although these large federal surveys are not our only option, the scale of these surveys is largely unmatched. Nonetheless, other prominent research organizations, such as the non-profit and non-partisan, Pew Research Group, have seen participation in their telephone surveys decline even more dramatically: from 36% in 1997 to 9% in 2018 (Kennedy and Hartig). In regard to the gaps that nutrition surveillance has left unfilled, two major issues are: first, the need to use an intersectional lens, and second, the need to study key populations in more robust ways. Although surveys like NHANES oversample minority populations, NHANES does not visit sovereign, Native American reservations, and Native Americans are not oversampled despite being a community that is well known to be at higher risk for cardiometabolic disease risk factors (J. A. Reese et al.), and also have higher risk for barriers to access to safe water that were discussed in this dissertation for Hispanic, Black, and Appalachian communities (*Closing the Water Access Gap in the United States: A National Action Plan*). NHANES is a critical source of information for the surveillance of nutritional intake among Americans, but expanding its questionnaires to include context about water, more oversampling of Native Americans, and strategies to tackle declining participation rates are critical to ensure that this survey stays nationally representative and relevant for as many Americans as possible.

Concluding remarks

I set off on this research as a student investigating the nutritional correlates of tap water consumption, and the resulting work led me to appreciate a wide and complex

network that situates water consumption at the nexus of equitable access to resources such as infrastructure and education. In the first research study, the most important contribution to the field is the extent to which tap water avoidance is widespread, even without a history of water safety violations. The second research study's most salient contributions were that trusting water is necessary but not sufficient for tap water preference, and that awareness of testing does not improve the odds of tap consumption (Paper 2).

Previous research has shown that educating individuals about tap water safety (when water is safe, which it is for the majority of Americans) and providing filters can help reduce sugary beverage intake, and I believe these are important resources that can be quickly deployed to address the public health issues of low tap water intake and high sugary drink consumption. This will be particularly critical for the most vulnerable groups among whom beverage intake disparities were highlighted by this research: children, rural/urban residents, low income, and minority individuals. In tandem, the existing literature that has helped me contextualize my dissertation results indicates that there remains a major role for the US government to address a long history of discriminatory practices, by supporting investments and policies that strive to make water excellent (that means safe and palatable) for everyone, everywhere. Even so, it will not be easy to rectify a historic legacy that has left so many unjustly behind. As a resident of rural Martin County, Kentucky said: "The easiest thing is fixing pipes, the hardest will be getting peoples trust back" (Lakhani). It is only after the work to make tap water trustworthy on a systemic level, that we can expect future interventions to improve trust in tap water effectively at a population level.

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