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Exposure to sugar rationing in the first 1000 days of life protected against chronic disease

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We examined the impact of sugar exposure within 1000 days since conception on diabetes and hypertension, leveraging quasi-experimental variation from the end of the United Kingdom's sugar rationing in September 1953. Rationing restricted sugar intake to levels within current dietary guidelines, yet consumption nearly doubled immediately post-rationing. Using an event study design with UK Biobank data comparing adults conceived just before or after rationing ended, we found that early-life rationing reduced diabetes and hypertension risk by about 35% and 20%, respectively, and delayed disease onset by 4 and 2 years. Protection was evident with in-utero exposure and increased with postnatal sugar restriction, especially after six months when solid foods likely began. In-utero sugar rationing alone accounted for about one third of the risk reduction.

The first 1000 days since conception—from gestation until age 2 (early life)—is a critical window during which poor diet can negatively impact adult health (1, 2). Current dietary guidelines recommend zero added sugars during this period (3), but in the United States (US), the majority of children are exposed to excessive sugar through maternal diet in utero and while breastfeeding, and directly by consuming infant formula and solids (4). Pregnant and lactating women on average consume more than triple the recommended amount of added sugar, surpassing 80 g per day (5), and most infants and toddlers consume sweetened foods and beverages daily (6).

We estimated how restricting added sugar in the first 1000 days after conception affects the onset of type 2 diabetes mellitus (T2DM) and hypertension decades later. While ample causal evidence from rodent experiments demonstrated lasting adverse effects of excessive sugar intake in early life (7–9), rigorous evidence from humans is at best limited (10, 11). For humans, previous research on dietary shocks early in life was primarily focused on extreme in-utero caloric restrictions like famine (12) or on changes in risk factors for T2DM and hypertension like maternal gestational weight gain (13) and hyperglycemia (14). Thus, even though there is a broad agreement on the correlations between excessive added sugar and metabolic dysfunction generally (15–18), the lack of cohorts randomized to varying levels of added sugar early in life limits our understanding of the causal long-term effects of excessive sugar on human health.

This study leveraged a natural experiment: the end of a decade-long sugar and sweets rationing in the United Kingdom (UK) in September 1953, which led to quasi-experimental variation in sugar exposure in early life. During

rationing, the sugar allowance for everyone—including pregnant women and children—was comparable to today's dietary guidelines of around <40 g for adults or <15 g for children, and no sugar offerings to children under 2 years (3, 19–21). The cessation of rationing in 1953 led to an immediate, nearly twofold increase in the consumption of sugar and sweets (22).

To assess the effects of early-life sugar exposure on T2DM and hypertension, we used an event study approach to compare adults conceived shortly before rationing ended, with probable lower early-life sugar intake, to those conceived shortly after, with likely exposure to excessive sugar early in life. We hypothesized that exposure to sugar rationing in utero and early childhood reduced the risk and delayed the onset of T2DM and hypertension, with longer exposure having stronger effects.

Results

Dietary patterns during and after sugar and sweets rationing

Figure 1A describes percentage changes in average daily consumption of sugar in the UK from 1950 quarter (q) 1 to 1958 q4, compared to average consumption levels during rationing, along with the intake of produce (i.e., fruits, vegetables), and total protein and fats over the same period. A vertical line marks the end of sugar rationing in September 1953. For an average adult, daily sugar consumption sharply increased from 41 g in 1953 q1 to about 80 g by 1954 q3; this similarly high level was sustained for several years. These data are for adults, but others have shown that sugar intake for children more than doubled post-rationing and that their oral health deteriorated as well (21, 23). Relatively higher added sugar

consumption for those conceived post-rationing was maintained into the 6th decade of life (24).

After sugar rationing ended, total calorie intake sharply increased. Figure S1, A and B, shows quarterly fluctuations in sugar and total calorie consumption, and fig. S1C details their absolute changes relative to baseline levels during rationing (1950 q1–1953 q2). These data indicate that on average 77% of the calorie intake increase post-rationing is due to higher sugar consumption. The actual percentage is likely even higher: while data on sugar consumption exclude the intake of sweets purchased outside the home, total calorie consumption includes a 10% adjustment for potential wastage and food bought outside the home (25). Figure S2 describes annual changes in sugar and sweets sales, which increased sharply after rationing.

Although sugar was not the only food de-rationed during our study period, and all rationing ended in July 1954, the consumption of foods and nutrients other than sugar remained largely unchanged or showed minor changes during our study period (Fig. 1A). Butter was de-rationed in May 1954. This caused households to largely revert to butter from margarine, likely leading to only a minor adjustment in overall fats consumption (Fig. 1A and fig. S3A). Similarly, despite the end of cheese rationing in December 1953, fig. S3B shows a relatively constant consumption of cheese and milk including that provided to children in schools or on welfare. Figure S3C indicates a steady consumption of fresh fruits and vegetables but a notable increase in canned and dried fruit intake, especially after September 1953. This may have contributed to higher added sugar intake, as a 15 oz can of fruit in syrup contains 30–40 g of added sugars, and processed dried fruits often have added sugar (26). Cereals were de-rationed in July 1954, yet their consumption remained relatively stable (fig. S3D). We observed a minor decline in fish and only a gradual increase in meat consumption despite its de-rationing in July 1954 (fig. S3E). This is consistent with protein substitution, as protein intake remained steady throughout our study (Fig. 1A). Figure S4 shows a relatively constant food affordability over time proxied with food prices adjusted for general inflation and wage growth.

In summary, the sharp and quick response in sugar and sweets consumption and sales, unlike other foods, immediately after the de-rationing, strengthens our research design. We examined whether there are differences in outcomes among individuals born within a few months of each other—specifically, cohorts conceived or born just before compared to just after sugar and sweets rationing ended.

Study population characteristics

The sample included 60,183 participants born between October 1951 and March 1956, and aged 51–66 when surveyed. Adults conceived in the 1000 days prior to September 1953

were defined as “rationed” (born October 1951 to June 1954, $n = 38,155$) and adults conceived after as “non-rationed” (born July 1954 to March 1956, $n = 22,028$). Figure 1B shows a timeline of exposure to rationing by calendar birth month. See table S1 for a sample distribution of births.

Table 1 shows balance in time-invariant characteristics between rationed and never-rationed cohorts, including sex (male 43.91% vs 43.73%), race (White 93.17% vs 93.16%), family history of diabetes (16.83% vs 18.03%), cardiovascular disease (62.69% vs 63.22%), and calculated genetic risk for obesity. Rationed adults were slightly more likely to be born in England (85.82% vs 85.09%, $p < 0.05$).

Association between early-life sugar-rich diet and risk for T2DM and hypertension

A total of 3,936 participants were diagnosed with diabetes, and 19,644 with hypertension. The risk of disease diagnosis increased with age for everyone, but it increased faster among adults with little or no exposure to rationing. Disease risk started to diverge when participants were in their mid 50s, and the largest differences were observed after age 60 (Fig. 2, A and B). See fig. S5 for estimated cumulative hazard. Unadjusted Kaplan-Meier survival curves (fig. S6) show that 92.2% and 65.4% of adults exposed to rationing in utero and postnatally had a higher chance of living without T2DM and hypertension to age 60, respectively, compared to those unexposed (89.1% and 61.4%). Log-rank tests confirmed significant survival curve differences at $p < 0.001$.

The risk of T2DM or hypertension decreased with the duration of exposure to rationing (Fig. 3). Each point on Fig. 3 is a hazard ratio (HR) estimate: the cohort’s HR relative to the reference group of never-rationed adults born July–December 1954. Compared to them, adults exposed to rationing only in utero had about a 15% lower risk of T2DM (HR 0.84 95%CI 0.75–0.95) (Fig. 3A and table S2, column 1). Risk was further reduced with longer exposure to rationing, particularly beyond 6 and 12 months postnatally. HRs remain relatively stable at around HR 0.62 (95%CI 0.55–0.69) for adults exposed for at least 19 months. A similar pattern was observed for hypertension, though with a smaller risk reduction. The HR decreased from 0.94 (95%CI 0.88–1.00) for adults exposed in utero only, to HR 0.79 (95%CI 0.74–0.85) if exposed from conception through at least 19 months postnatally (Fig. 3B and table S2, column 2).

The HR estimates for T2DM and hypertension in non-rationed adults remained constant after December 1954, with all post-rationing HRs statistically indistinguishable from 1 (p -value at 0.498 for T2DM, and 0.511 for hypertension) (Fig. 3). This supported our assumption of a similar disease risk trajectory between rationed and non-rationed cohorts independent of rationing. It also mitigated concerns about improvements in diagnostics or other events such as improved

access to medical care over time influencing the age of initial diagnosis, or regarding simultaneous exposure to sugar or other foods among adults who were never exposed to sugar rationing. For instance, butter went off-ration in May 1954. If fat rather than sugar alone affected these adults' health, we would expect that adults conceived after butter de-rationing (post-May 1954) would fare differently than adults conceived prior (October 1953–April 1954), and that disease risk would increase for younger cohorts. However, we find no significant differences in T2DM and hypertension risk among adults conceived at different points after sugar rationing ended.

We further addressed potential concerns about time trends influencing our findings by analyzing conditions unlikely to be affected by sugar intake: type 1 diabetes, trauma-triggered depression, menarche, and myopia/hyperopia. Despite having similar diagnostic requirements to T2DM or hypertension, these conditions showed no significant differences in HRs between cohorts (fig. S7).

Guided by HRs suggesting a similar disease risk between cohorts in the absence of rationing, and to increase statistical power, we combined non-rationed adults into one group and compared them to adults exposed to rationing in utero, in utero and up to age 1, and in utero and beyond age 1.

In-utero exposure alone explained about a third of the total reduction in T2DM and hypertension risk compared to exposure in utero and beyond age 1 (Table 2A). T2DM risk reduction due to in utero exposure (0.87, 95%CI 0.81–0.94) differed from in utero and postnatal exposure of up to a year ($p < 0.01$) and beyond ($p < 0.01$). Hypertension risk reduction due to in utero exposure (HR 0.92, 95%CI 0.88–0.97) differed from postnatal exposure of up to a year ($p < 0.001$) and beyond ($p < 0.001$). Table S3 shows that disease risk declines especially with exposure beyond 6 months postnatally (at $p < 0.001$ for T2DM and hypertension). Among those with more than one year of postnatal exposure to rationing, the T2DM risk reduction was significantly larger for women than for men ($p < 0.01$) (fig. S8).

Early-life exposure to sugar rationing increased the time to the first T2DM or hypertension diagnosis (Table 2B). Adults rationed in utero experienced a 1.46 (95%CI 0.45–2.48) year delay in T2DM onset and a 0.53 (95%CI 0.07–1.00) year delay in hypertension onset. Those exposed in utero and beyond 1 year postnatally experienced approximately a 4- and 2-year delay in diagnosis of T2DM and hypertension, respectively.

Figure S9 demonstrated a roughly 30% decrease in obesity risk from exposure to rationing in utero and beyond the first year (HR 0.69, 95%CI 0.60–0.80). Figure S10 and table S4 also show that adults exposed to in-utero and early postnatal rationing had about 2 percentage points lower prevalence of high waist-to-height ratios (WHR), with no meaningful differences in continuous WHR or blood pressure outcomes

between cohorts. The lack of differences may be due to improved disease management following long-standing diagnoses of T2DM or hypertension, and because sugar rationing delayed but did not prevent them.

Figure S11 and table S5 describe goodness of fit for parametric hazard models with Gompertz baseline parametrization and the criteria for these findings. Figure S12 presents a test of proportionality assumptions. Results remained robust across various model specifications (table S6) including adjusting models for changes in food affordability (fig. S13).

Discussion

We examined the impact of sugar restriction during the first 1000 days since conception on T2DM and hypertension, leveraging quasi-experimental variation from the UK's end of sugar and sweets rationing in September 1953. De-rationing nearly doubled sugar consumption. We found that early-life exposure to sugar rationing led to a reduction in T2DM and hypertension risk by about 35% and 20% and delayed the onset of these diseases by about 4 and 2 years, respectively. In-utero sugar rationing alone was protective, but most risk reduction occurred when rationing lasted beyond age six months.

Restricting early-life sugar intake could affect health by altering physiological programming in utero, supported by evidence from the “fetal origins hypothesis” (2, 11, 27). We found that exposure to in-utero rationing alone contributed to about one third of the overall reduction in T2DM and hypertension risk and accounted for approximately a quarter of the delay in disease onset. Our findings on in-utero sugar effects are consistent with animal studies demonstrating that high-sugar diets during pregnancy increase risk factors for T2DM and hypertension, such as insulin resistance and glucose intolerance in adulthood (8, 9), and with studies on humans demonstrating an association between sugar-rich diet during pregnancy and lactation with increased offspring's obesity risk (28).

Second, early-life sugar exposure may affect health by intensifying a lifelong preference for sweetness. Infancy and toddlerhood in particular are critical periods for developing a taste for sweets (or even addiction) that can elevate sugar consumption throughout life (24, 29–31). Over 70% of foods marketed to infants or toddlers contain added sugars in formula, foods, or beverages (4). By age two, many children consume the adult-recommended 7 teaspoons of sugar daily, nearly tripling it by their teens (6). We identified improved health from restricting sugar beyond gestation; postnatal rationing accounted for the majority of the reduction in disease risk, especially for T2DM. Its protective effects increased especially when extended past 6 months—a typical age for introducing solids (32). Women showed greater postnatal health benefits than men in reducing T2DM risk, reflecting

findings from animal studies that females in high-sugar settings are more susceptible to sugar addiction and disrupted glucose regulation, both of which elevate T2DM risk (33, 34). Postnatal rationing also reduced obesity risk and high WHR prevalence; known markers for increased cardiometabolic risk (35). Though not necessarily a primary cause (35), obesity suggests a biological pathway as it correlates with elevated sugar intake and metabolic disease (36, 37). Disease effects stabilized by age 1; the benefits of restricting sugar intake beyond age 2 remained uncertain.

Our findings provide insights beyond the context of rationing, since the sugar allowance then aligned with today's limits set by the US, World Health Organization, and American Heart Association dietary guidelines (17, 38). While we did not directly evaluate these guidelines, our findings imply that adhering to them early in life could provide substantial health benefits. Our results' magnitudes are comparable to the 2.8 year-long National Diabetes Prevention Program that decreased T2DM risk by 34% and delayed its onset by about 4 years (39), potentially extending life expectancy by about 1–1.5 years (40).

Dietary guidelines on added sugar intake have been criticized for relying on moderate-to-low-quality short-term evidence focused on obesity and dental health, on observational studies and on short-term clinical trials that studied T2DM or hypertension or their markers (17, 41). None were focused on the first 1000 days. As conversations intensify regarding policies like taxing sugar or sugar-sweetened beverages (42), or the regulation of added sugars in infant or toddler foods and their marketing (43), understanding the direct link between early-life sugar consumption and chronic disease is critical. Our results add to this discussion by not only linking sugar to health, but also by underscoring the importance of early-life diet in managing long-term metabolic disease risk.

This study has limitations, but we have taken various steps to ensure the robustness of our results. One concern was the potential for unobservable differences between cohorts conceived during and after rationing (except for early-life sugar exposure), particularly without a contemporaneous control group. We addressed this in several ways: first, we used a narrow time window around the end of rationing and observed similar early-life and parents' disease characteristics between cohorts. Second, we provided evidence that diet in the 1950s was similar between cohorts, except for sugar. Third, our results controlled for several early-life characteristics and food prices and are robust to excluding them. Additionally, we observed no differences in disease risk between cohorts for conditions likely unrelated to diet. Finally, equivalent to testing pre-trends in outcomes between rationed and non-rationed adults, HRs among older and younger non-rationed adults showed no significant differences irrespective of birth date.

Another limitation was that UK Biobank is not nationally representative and skews toward wealthier, healthier individuals, though it is useful for studying exposure-outcome relationships (44) and offers a larger sample than comparable surveys. The likelihood of volunteering for surveys was likely unrelated to the end of rationing as both the rationed and non-rationed cohorts were recruited using the same protocols. However, if sugar rationing improved economic well-being (24), wealthier adults might have received earlier disease diagnostics due to improved access to healthcare. The single-payer healthcare system in the UK helps lessen these concerns, as do our results showing no impacts on placebo conditions. A final limitation was right censoring and no pre-study mortality information; this concern is small given the similarly low mortality rates in rationed and non-rationed adults (45).

This study has several strengths. A quasi-experimental assignment to higher or lower early-life sugar exposure strengthens the likely causal nature of our findings. We accounted for confounding factors and consistently observed a protective effect of sugar rationing across various analytical specifications. We provided strong evidence that the health impacts observed were due to changes in sugar intake rather than shifts in overall calorie or other nutrient consumption. Last, our large sample enabled separate identification of in-utero and in-utero/postnatal effects while still using a narrow analytic window, and subgroup analyses by sex.

In conclusion, limiting exposure to sugar in utero and in early life can protect against T2DM and hypertension. Further research is needed to understand the optimal levels of added sugar consumption during pregnancy, lactation, and after the introduction of solids, as well as their pathways to influencing long-term health.

REFERENCES AND NOTES

1. S. J. Schwarzenberg, M. K. Georgieff, AAP Committee on Nutrition, Advocacy for improving nutrition in the first 1000 days to support childhood development and adult health. *Pediatrics* **141**, e20173716 (2018). [doi:10.1542/peds.2017-3716](https://doi.org/10.1542/peds.2017-3716) [Medline](#)
2. P. D. Gluckman, M. A. Hanson, C. Cooper, K. L. Thornburg, Effect of in utero and early-life conditions on adult health and disease. *N. Engl. J. Med.* **359**, 61–73 (2008). [doi:10.1056/NEJMra0708473](https://doi.org/10.1056/NEJMra0708473) [Medline](#)
3. L. G. Snetselaar, J. M. de Jesus, D. M. DeSilva, E. E. Stookey, Dietary guidelines for Americans, 2020–2025: Understanding the scientific process, guidelines, and key recommendations. *Nutr. Today* **56**, 287–295 (2021). [doi:10.1097/NT.0000000000000512](https://doi.org/10.1097/NT.0000000000000512) [Medline](#)
4. R. W. Walker, M. I. Goran, Laboratory determined sugar content and composition of commercial infant formulas, baby foods and common grocery items targeted to children. *Nutrients* **7**, 5850–5867 (2015). [doi:10.3390/nu7075254](https://doi.org/10.3390/nu7075254) [Medline](#)
5. C. E. Cioffi, J. Figueroa, J. A. Welsh, Added sugar intake among pregnant women in the United States: National Health and nutrition examination survey 2003–2012. *J. Acad. Nutr. Diet.* **118**, 886–895.e1 (2018). [doi:10.1016/j.jand.2017.10.021](https://doi.org/10.1016/j.jand.2017.10.021) [Medline](#)
6. K. A. Herrick, C. D. Fryar, H. C. Hamner, S. Park, C. L. Ogden, Added sugars intake among US infants and toddlers. *J. Acad. Nutr. Diet.* **120**, 23–32 (2020). [doi:10.1016/j.jand.2019.09.007](https://doi.org/10.1016/j.jand.2019.09.007) [Medline](#)
7. A. J. Archibald, V. W. Dolinsky, M. B. Azad, Early-life exposure to non-nutritive

- sweeteners and the developmental origins of childhood obesity: Global evidence from human and rodent studies. *Nutrients* **10**, 194 (2018). [doi:10.3390/nu10020194](https://doi.org/10.3390/nu10020194) [Medline](#)
8. A.-M. Samuelsson, P. A. Matthews, M. Argenton, M. R. Christie, J. M. McConnell, E. H. J. M. Jansen, A. H. Piersma, S. E. Ozanne, D. F. Twinn, C. Remacle, A. Rowleson, L. Poston, P. D. Taylor, Diet-induced obesity in female mice leads to offspring hyperphagia, adiposity, hypertension, and insulin resistance: A novel murine model of developmental programming. *Hypertension* **51**, 383–392 (2008). [doi:10.1161/HYPERTENSIONAHA.107.101477](https://doi.org/10.1161/HYPERTENSIONAHA.107.101477) [Medline](#)
 9. E. E. Noble, T. M. Hsu, R. B. Jones, A. A. Fodor, M. I. Goran, S. E. Kinoski, Early-life sugar consumption affects the rat microbiome independently of obesity. *J. Nutr.* **147**, 20–28 (2017). [doi:10.3945/jn.116.238816](https://doi.org/10.3945/jn.116.238816) [Medline](#)
 10. K. A. Kaiser, J. M. Shikany, K. D. Keating, D. B. Allison, Will reducing sugar-sweetened beverage consumption reduce obesity? Evidence supporting conjecture is strong, but evidence when testing effect is weak. *Obes. Rev.* **14**, 620–633 (2013). [doi:10.1111/obr.12048](https://doi.org/10.1111/obr.12048) [Medline](#)
 11. D. Almond, J. Currie, V. Duque, Childhood circumstances and adult outcomes: Act II. *J. Econ. Lit.* **56**, 1360–1446 (2018). [doi:10.1257/jel.20171164](https://doi.org/10.1257/jel.20171164)
 12. D. Almond, J. Currie, Killing me softly: The fetal origins hypothesis. *J. Econ. Perspect.* **25**, 153–172 (2011). [doi:10.1257/jep.25.3.153](https://doi.org/10.1257/jep.25.3.153) [Medline](#)
 13. L. Poston, Gestational weight gain: Influences on the long-term health of the child. *Curr. Opin. Clin. Nutr. Metab. Care* **15**, 252–257 (2012). [doi:10.1097/MCO.0b013e3283527cf2](https://doi.org/10.1097/MCO.0b013e3283527cf2) [Medline](#)
 14. L. Hirsch, Y. Yoge, Impact of gestational hyperglycemia on maternal and child health. *Curr. Opin. Clin. Nutr. Metab. Care* **17**, 255–260 (2014). [doi:10.1097/MCO.000000000000030](https://doi.org/10.1097/MCO.000000000000030) [Medline](#)
 15. S. Basu, M. McKee, G. Galea, D. Stuckler, Relationship of soft drink consumption to global overweight, obesity, and diabetes: A cross-national analysis of 75 countries. *Am. J. Public Health* **103**, 2071–2077 (2013). [doi:10.2105/AJPH.2012.300974](https://doi.org/10.2105/AJPH.2012.300974) [Medline](#)
 16. G. A. Bray, B. M. Popkin, Dietary sugar and body weight: Have we reached a crisis in the epidemic of obesity and diabetes? Health be damned! Pour on the sugar. *Diabetes Care* **37**, 950–956 (2014). [doi:10.2337/dc13-2085](https://doi.org/10.2337/dc13-2085) [Medline](#)
 17. World Health Organization, *Guideline: Sugars Intake for Adults and Children* (World Health Organization, 2015).
 18. L. Te Morenga, S. Mallard, J. Mann, Dietary sugars and body weight: Systematic review and meta-analyses of randomised controlled trials and cohort studies. *BMJ* **346**, e7492 (2012). [Medline](#)
 19. D. F. Hollingsworth, "Rationing and economic constraints on food consumption in Britain since the Second World War" in *Nutrients and Energy*, vol. 42 of World Review of Nutrition and Dietetics, G. H. Bourne, Ed. (Karger Publishers, 1983), pp. 191–218.
 20. I. Zweiniger-Bargielowska, *Austerity in Britain: Rationing, Controls, and Consumption, 1939–1955* (Oxford Univ. Press, 2000).
 21. C. J. Prynne, A. A. Paul, G. M. Price, K. C. Day, W. S. Hilder, M. E. J. Wadsworth, Food and nutrient intake of a national sample of 4-year-old children in 1950: Comparison with the 1990s. *Public Health Nutr.* **2**, 537–547 (1999). [doi:10.1017/S1368980099000725](https://doi.org/10.1017/S1368980099000725) [Medline](#)
 22. R. Foster, J. Lunn, 40th Anniversary Briefing Paper: Food availability and our changing diet. *Nutr. Bull.* **32**, 187–249 (2007). [doi:10.1111/j.1467-3010.2007.00648.x](https://doi.org/10.1111/j.1467-3010.2007.00648.x)
 23. D. Jackson, Caries experience in English children and young adults during the years 1947–1972. *Br. Dent. J.* **137**, 91–98 (1974). [doi:10.1038/sj.bdj.4803244](https://doi.org/10.1038/sj.bdj.4803244) [Medline](#)
 24. P. Gertler, T. Gracner, "The sweet life: The long-term effects of a sugar-rich early childhood," NBER Working Paper 30799 (National Bureau of Economic Research, 2022); <http://www.nber.org/papers/w30799>.
 25. Department for Environment, Food and Rural Affairs, Official Statistics: Family Food historic reports: Historic National Food Survey reports from 1940 to 1984 (2016); <https://www.gov.uk/government/statistics/family-food-historic-reports> [accessed 19 August 2024].
 26. M. J. Sadler, S. Gibson, K. Whelan, M.-A. Ha, J. Lovegrove, J. Higgs, Dried fruit and public health - what does the evidence tell us? *Int. J. Food Sci. Nutr.* **70**, 675–687 (2019). [doi:10.1080/09637486.2019.1568398](https://doi.org/10.1080/09637486.2019.1568398) [Medline](#)
 27. C. Martyn, D. Barker, The maternal and fetal origins of cardiovascular disease. *Vasc. Med. Rev. vmr-5*, 129–137 (1994). [doi:10.1177/1358863X9400500205](https://doi.org/10.1177/1358863X9400500205)
 28. C. M. Whisner, B. E. Young, E. K. Pressman, R. A. Queenan, E. M. Cooper, K. O. O'Brien, Maternal diet but not gestational weight gain predicts central adiposity accretion in utero among pregnant adolescents. *Int. J. Obes. (Lond.)* **39**, 565–570 (2015). [doi:10.1038/ijo.2014.202](https://doi.org/10.1038/ijo.2014.202) [Medline](#)
 29. T. L. Fazzino, K. L. Kong, A new paradigm for investigating the etiology of obesity in early childhood: Exposure to added sugars and hyper-palatable foods in infancy and dysregulation of food reinforcement processes. *Obes. Rev.* **24**, e13526 (2023). [doi:10.1111/obr.13526](https://doi.org/10.1111/obr.13526) [Medline](#)
 30. C. M. Rose, L. L. Birch, J. S. Savage, Dietary patterns in infancy are associated with child diet and weight outcomes at 6 years. *Int. J. Obes. (Lond.)* **41**, 783–788 (2017). [doi:10.1038/ijo.2017.27](https://doi.org/10.1038/ijo.2017.27) [Medline](#)
 31. L. L. Birch, Development of food preferences. *Annu. Rev. Nutr.* **19**, 41–62 (1999). [doi:10.1146/annurev.nutr.19.1.41](https://doi.org/10.1146/annurev.nutr.19.1.41) [Medline](#)
 32. American Academy of Pediatrics, *Bright Futures: Guidelines for Health Supervision of Infants, Children, and Adolescents* (American Academy of Pediatrics, ed. 4, 2017).
 33. S. Wei, S. Hertle, R. Spanagel, A. Bilbao, Female mice are more prone to develop an addictive-like phenotype for sugar consumption. *Sci. Rep.* **11**, 7364 (2021). [doi:10.1038/s41598-021-86797-9](https://doi.org/10.1038/s41598-021-86797-9) [Medline](#)
 34. L. Dearden, S. G. Bouret, S. E. Ozanne, Sex and gender differences in developmental programming of metabolism. *Mol. Metab.* **15**, 8–19 (2018). [doi:10.1016/j.molmet.2018.04.007](https://doi.org/10.1016/j.molmet.2018.04.007) [Medline](#)
 35. I. Khan, M. Chong, A. Le, P. Mohammadi-Shemirani, R. Morton, C. Brinza, M. Kiflen, S. Narula, L. Akhabir, S. Mao, K. Morrison, M. Pigeire, G. Paré, Surrogate adiposity markers and mortality. *JAMA Netw. Open* **6**, e2334836 (2023). [doi:10.1001/jamanetworkopen.2023.34836](https://doi.org/10.1001/jamanetworkopen.2023.34836) [Medline](#)
 36. A. Drewnowski, The real contribution of added sugars and fats to obesity. *Epidemiol. Rev.* **29**, 160–171 (2007). [doi:10.1093/epirev/mxm011](https://doi.org/10.1093/epirev/mxm011) [Medline](#)
 37. J. M. Rippe, T. J. Angelopoulos, Added sugars and risk factors for obesity, diabetes and heart disease. *Int. J. Obes. (Lond.)* **40** (suppl. 1), S22–S27 (2016). [doi:10.1038/ijo.2016.10](https://doi.org/10.1038/ijo.2016.10) [Medline](#)
 38. M. B. Vos, J. L. Kaar, J. A. Welsh, L. V. Van Horn, D. I. Feig, C. A. M. Anderson, M. J. Patel, J. Cruz Munos, N. F. Krebs, S. A. Xanthakos, R. K. Johnson; American Heart Association Nutrition Committee of the Council on Lifestyle and Cardiometabolic Health; Council on Clinical Cardiology; Council on Cardiovascular Disease in the Young; Council on Cardiovascular and Stroke Nursing; Council on Epidemiology and Prevention; Council on Functional Genomics and Translational Biology; and Council on Hypertension, Added sugars and cardiovascular disease risk in children: A scientific statement from the American Heart Association. *Circulation* **135**, e1017–e1034 (2017). [doi:10.1161/CIR.0000000000000439](https://doi.org/10.1161/CIR.0000000000000439) [Medline](#)
 39. Diabetes Prevention Program Research Group, 10-year follow-up of diabetes incidence and weight loss in the Diabetes Prevention Program Outcomes Study. *Lancet* **374**, 1677–1686 (2009). [doi:10.1016/S0140-6736\(09\)61457-4](https://doi.org/10.1016/S0140-6736(09)61457-4) [Medline](#)
 40. Emerging Risk Factors Collaboration, Life expectancy associated with different ages at diagnosis of type 2 diabetes in high-income countries: 23 million person-years of observation. *Lancet Diabetes Endocrinol.* **11**, 731–742 (2023). [doi:10.1016/S2213-8587\(23\)00223-1](https://doi.org/10.1016/S2213-8587(23)00223-1) [Medline](#)
 41. J. Erickson, B. Sadeghirad, L. Lytyyn, J. Slavin, B. C. Johnston, The scientific basis of guideline recommendations on sugar intake: A systematic review. *Ann. Intern. Med.* **166**, 257–267 (2017). [doi:10.7326/M16-2020](https://doi.org/10.7326/M16-2020) [Medline](#)
 42. A. H. Grummon, B. B. Lockwood, D. Taubinsky, H. Allcott, Designing better sugary drink taxes. *Science* **365**, 989–990 (2019). [doi:10.1126/science.aav5199](https://doi.org/10.1126/science.aav5199) [Medline](#)
 43. J. L. Pomeranz, J. L. Harris, Federal regulation of infant and toddler food and drink marketing and labeling. *Am. J. Law Med.* **45**, 32–56 (2019). [doi:10.1177/0098858819849991](https://doi.org/10.1177/0098858819849991) [Medline](#)
 44. A. Fry, T. J. Littlejohns, C. Sudlow, N. Doherty, L. Adamska, T. Sprosen, R. Collins, N. E. Allen, Comparison of sociodemographic and health-related characteristics of UK Biobank participants with those of the general population. *Am. J. Epidemiol.* **186**, 1026–1034 (2017). [doi:10.1093/aje/kwx246](https://doi.org/10.1093/aje/kwx246) [Medline](#)
 45. J. Buxton, E. Tipping, S. Rozee, E. Morgan, "Mortality in England and Wales: past and projected trends in average lifespan" (Office for National Statistics, 2022); <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/articles/mortalityinenglandandwales/pastandprojectedtrendsinaaverage lifespan>.

46. T. Gracner, C. Boone, P. J. Gertler, Exposure to rationing of added sugars in the first 1000 days of life protected against type 2 diabetes and hypertension [Software], Zenodo (2024); <https://doi.org/10.5281/zenodo.11243443>.
47. T. Gracner, C. Boone, P. J. Gertler, Exposure to rationing of added sugars in the first 1000 days of life protected against type 2 diabetes and hypertension [Database], Dryad (2024); <https://doi.org/10.5061/dryad.2v6wvwpzwm>.
48. C. Sudlow, J. Gallacher, N. Allen, V. Beral, P. Burton, J. Danesh, P. Downey, P. Elliott, J. Green, M. Landray, B. Liu, P. Matthews, G. Ong, J. Pell, A. Silman, A. Young, T. Sprosen, T. Peakman, R. Collins, UK Biobank: An open access resource for identifying the causes of a wide range of complex diseases of middle and old age. *PLOS Med.* **12**, e1001779 (2015). [doi:10.1371/journal.pmed.1001779](https://doi.org/10.1371/journal.pmed.1001779) [Medline](#)
49. N. J. Thomas, A. McGovern, K. G. Young, S. A. Sharp, M. N. Weedon, A. T. Hattersley, J. Dennis, A. G. Jones, Identifying type 1 and 2 diabetes in research datasets where classification biomarkers are unavailable: Assessing the accuracy of published approaches. *J. Clin. Epidemiol.* **153**, 34–44 (2023). [doi:10.1016/j.jclinepi.2022.10.022](https://doi.org/10.1016/j.jclinepi.2022.10.022) [Medline](#)
50. J. Becker, C. A. P. Burik, G. Goldman, N. Wang, H. Jayashankar, M. Bennett, D. W. Belsky, R. Karlsson Linnér, R. Ahlsgog, A. Kleinman, D. A. Hinds, A. Caspi, D. L. Corcoran, T. E. Moffitt, R. Poulton, K. Sugden, B. S. Williams, K. M. Harris, A. Steptoe, O. Ajnakina, L. Milani, T. Esko, W. G. Iacono, M. McGue, P. K. E. Magnusson, T. T. Mallard, K. P. Harden, E. M. Tucker-Drob, P. Herd, J. Freese, A. Young, J. P. Beauchamp, P. D. Koellinger, S. Oskarsson, M. Johannesson, P. M. Visscher, M. N. Meyer, D. Laibson, D. Cesarini, D. J. Benjamin, P. Turley, A. Okbay; 23andMe Research Group, Resource profile and user guide of the Polygenic Index Repository. *Nat. Hum. Behav.* **5**, 1744–1758 (2021). [doi:10.1038/s41562-021-01119-3](https://doi.org/10.1038/s41562-021-01119-3) [Medline](#)

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SUPPLEMENTARY MATERIALS

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Materials and Methods

Figs. S1 to S13

Tables S1 to S6

Referenes (48–50)

MDAR Reproducibility Checklist

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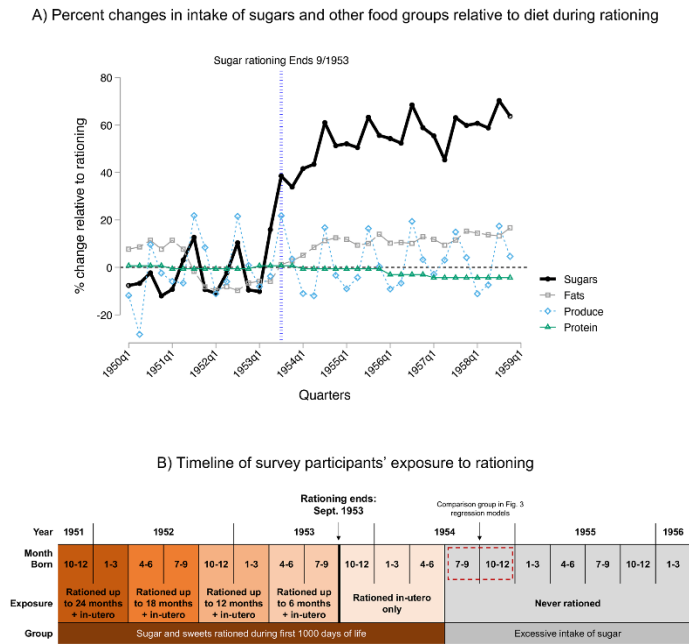


Fig. 1. Sugar and sweets rationing timeline and diet during and after rationing. (A) Calculations using NSF data. (B) Rationed groups are shown in shades of orange, and never rationed is shown in gray. The red dashed rectangle represents adults born between July and December in 1954, comprising the first group that never experienced sugar and sweets rationing. This group of adults serves as the reference or comparison group in regression models presented below.

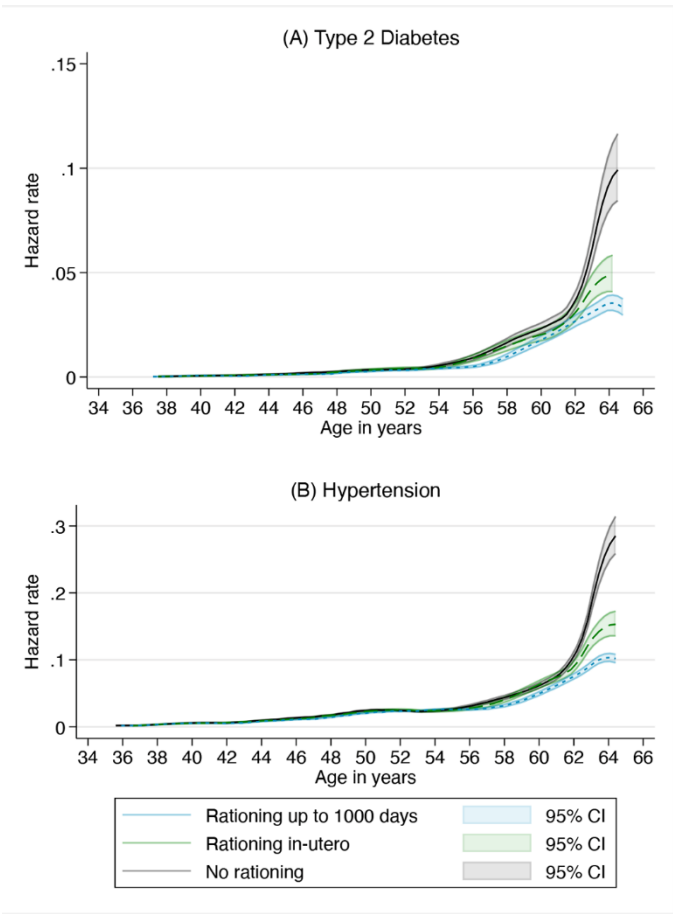


Fig. 2. Smooth hazard functions for type 2 diabetes and hypertension by exposure to rationing. Smooth hazard functions for (A) Hazard function for type 2 diabetes by rationed in-utero or more vs never rationed. (B) Hazard function for hypertension by rationed in-utero or more vs never rationed. Log-rank test confirmed significant difference between survival curves at $p < 0.001$. 95% confidence intervals reported.

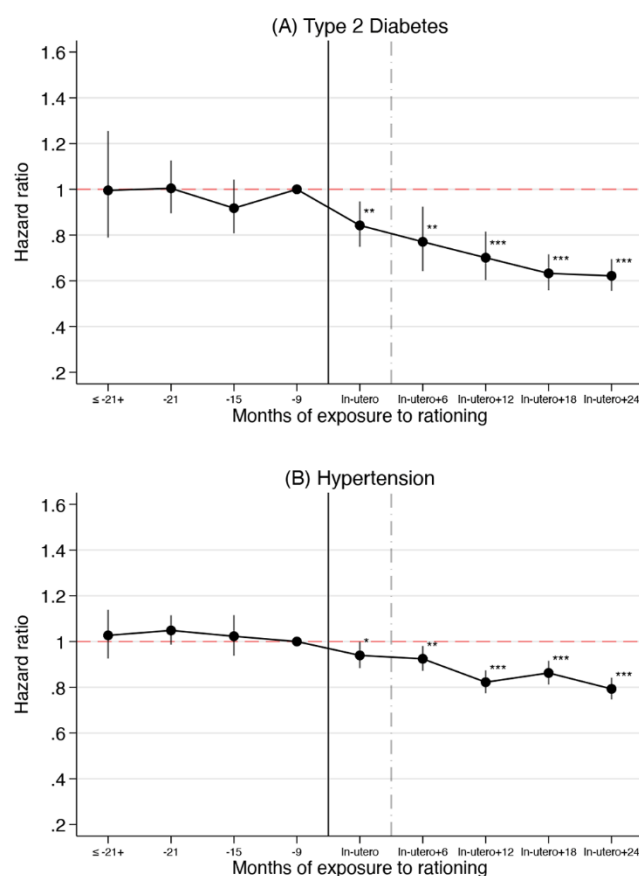


Fig. 3. Hazard ratios comparing the hazard rates at various levels of rationing exposure to the hazard rate of never-rationed adults born July–December 1954. (A) Hazard ratios at various durations of rationing exposure for type 2 diabetes. (B) Hazard ratios at various durations of rationing exposure for hypertension. Each point represents a hazard ratio, comparing the hazard rate of adults exposed to rationing in utero, in utero plus 6/12/18/24 months after birth, or not at all, to the hazard rate of the reference group (adults born July–December 1954). Adults never exposed to rationing were also those born between January–June 1955 (at least 15 months after rationing), July–December 1955 (at least 21 months after rationing), and January–March 1956. The HR estimates for adults born between January 1955 and April 1956, who were never rationed, were not individually nor jointly significantly different from the HR estimate of adults born in the reference group of July to December 1954 (at $p = 0.498$ for diabetes and $p = 0.511$ for hypertension). All regressions include indicators for calendar month of birth, survey year, birth place (England vs Wales vs Scotland), deciles of north and east place-of-birth coordinates, self-reported sex, race (white vs not), and parental cardiovascular disease (hypertension, heart disease, stroke), or diabetes indicator. +/*/**/*** indicates significance at p smaller than 0.1/0.05/0.01/0.001. See table S2 for results supporting this figure.

Table 1. Characteristics of survey participants born between October 1951 and March 1956. ¹Parents diagnosed with CVD (cardiovascular disease) is a self-reported indicator after respondents answered the question “Was your biological mother/father ever diagnosed with stroke/heart disease/hypertension.” 2,699 and 1,667 observations were missing for parental history of rationed and non-rationed adults, respectively; their calculations of n are adjusted accordingly. Differences in means were expressed in percentage points for all variables except age at the latest survey and were adjusted for parents being alive. */**/** indicates significant difference at p smaller than 0.05/0.01/0.001. Romano-Wolf step-down adjusted p-values. Reported percentages may not total 100 because of rounding.

Characteristic	Rationed (<i>n</i> =38,155)	Not Rationed (<i>n</i> =22,028)	Total <i>n</i> = 60,183
	<i>n</i> (Mean in %)	<i>n</i> (Mean in %)	Difference (percentage points)
Age at the latest survey	57.24 (SD=3.24)	55.04 (SD=3.37)	2.19*** (years)
Sex			
<i>Male</i>	16,754 (43.91)	9,633 (43.73)	0.19
<i>Female</i>	21,401 (56.09)	12,395 (56.28)	—
Place of birth			
<i>England</i>	32,745 (85.82)	28,744 (85.09)	0.73*
<i>Wales</i>	1,927 (5.05)	1,082 (4.91)	0.14
<i>Scotland</i>	3,483 (9.13)	2,203 (10.00)	—
Race/Ethnicity			
<i>Non-white</i>	2,606 (6.83)	1,507 (6.84)	−0.01
<i>White</i>	35,549 (93.17)	20,521 (93.16)	—
BMI polygenic z-score (SD)	0.000 (SD=1.003)	0.002 (SD=0.996)	−0.00
Parents diagnosed with CVD ¹	22,227 (62.69)	12,872 (63.22)	−0.53
Parents diagnosed with diabetes	5,967 (16.83)	3,671 (18.03)	−1.20

Table 2. The effect of rationing on disease risk and age of disease onset by duration of exposure to rationing.

A: Hazard ratios are expressed relative to the hazard rate of those never exposed to rationing (born after July 1954). Parametric hazard models in panel A were estimated using the Gompertz distribution, though results were not sensitive to the choice of the distribution function, like Weibull. B: Time-to-event models assume Weibull distribution and are estimated using the `stteffects, ra` command in STATA. */**/** indicates significance at p smaller than 0.05/0.01/0.001.

<i>A: Disease Hazard Ratio</i>	Type 2 diabetes (<i>n</i> =60,183)	Hypertension (<i>n</i> =60,183)
	1954 m7-1956 m3 (reference group)	1954 m7-1956 m3 (reference group)
<i>Rationing exposure:</i>		
In utero vs 0	0.87***	0.92**
SE	(0.03)	(0.02)
95% CI	0.81 - 0.94	0.88 - 0.97
<i>p</i> -value	(0.000)	(0.001)
In utero + up to 1 year vs 0	0.75***	0.85***
SE	(0.04)	(0.02)
95% CI	0.68 - 0.84	0.81 - 0.89
<i>p</i> -value	(0.000)	(0.000)
In utero + up to 2 years vs 0	0.64***	0.81***
SE	(0.02)	(0.02)
95% CI	0.60 - 0.69	0.77 - 0.84
<i>p</i> -value	(0.000)	(0.000)
<i>B: Delay in age of onset (years)</i>		
<i>Rationing exposure:</i>		
In utero vs 0	1.46*	0.53*
SE	(0.52)	(0.24)
95% CI	0.45 - 2.48	0.07 - 1.00
<i>p</i> -value	(0.005)	(0.028)
In utero + up to 1 year vs 0	2.80***	1.47***
SE	(0.61)	(0.28)
95% CI	1.61 - 4.00	0.93 - 2.01
<i>p</i> -value	(0.000)	(0.000)
In utero + up to 2 years vs 0	4.17***	2.12***
SE	(0.55)	(0.24)
95% CI	3.10 - 5.24	1.65 - 2.60
<i>p</i> -value	(0.000)	(0.000)
<i>Age of onset (95% CI)</i>		
No exposure to rationing	69.24 (68.57-69.90)	61.51 (61.16 - 61.85)
In utero exposure to rationing	70.70 (69.94 - 71.47)	62.04 (61.73 - 62.36)
In utero + up to 1 year of rationing	72.04 (71.05 - 73.03)	62.98 (62.56 - 63.39)
In utero + up to 2 years of rationing	73.40 (72.57 - 74.24)	63.63 (63.30 - 63.96)