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Group-based trajectories of maternal intake of sugar-sweetened beverage and offspring oral health from a prospective birth cohort study

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ABSTRACT

Objectives: To investigate the trajectory of maternal intake of sugar-sweetened beverages (SSB) during the first five years of their child's life and its effect on the child's dental caries at five years-of-age.
Methods: This is an ongoing prospective population-based birth cohort study in Adelaide, Australia. Mothers completed questionnaires on their SSB intake, socioeconomic factors and health behaviors at the birth of their child and at the ages of one, two and five years. Child dental caries measured as decayed, missing, or filled tooth surfaces was collected by oral examination. Maternal SSB intake was used to estimate the trajectory of SSB intake. The trajectories then became the main exposure of the study. Dental caries at age five years were the primary outcomes. Adjusted mean- and prevalence-ratios were estimated for dental caries, controlling for confounders.
Results: 879 children had dental examinations at five years-of-age. Group-based trajectory modeling identified three trajectories of maternal SSB intake: 'Stable low' (40.8%), 'Moderate but increasing' (13.6%), and 'High early' trajectory (45.6%). Multivariable regression analysis found children of mothers in the 'High early' and 'Moderate but increasing' groups to have greater experience of dental caries (MR: 1.37 (95%CI 1.01–1.67), and 1.24 (95%CI 0.96–1.60) than those in the 'Stable low' trajectory, respectively.
Conclusion: Maternal consumption of SSB during pregnancy and in the early postnatal period influenced their offspring's oral health. It is important to create a low-sugar environment from early childhood. The results suggest that health promotion activities need to be delivered to expecting women or soon after childbirth.

1. Introduction

Dental caries remains one of the most common chronic diseases in children [1], potentially leading to debilitating conditions (dental pain, infection, altered eating habits, sleep disturbances lower educational achievement), and negative impact on oral health-related quality of life [2]. Despite some improvement in preventing dental caries among children, a third of Australian children still experience dental caries by the age of five to six years [3]. Hence, it is important to identify early life factors that influence child oral health.

Intake of free sugars is a primary cause of dental caries [4–6]. The diets of toddlers and young children are dependent on their mothers/care-givers, making the home environment a particularly important influence on the development of their eating behavior and food preferences [7,8]. Several components of a child's home environment–such as socioeconomic position, home availability of sugars,

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parental dietary behaviors and parenting practices–are known to be associated with children's sugars intake [9–11]. We have reported earlier that 21% of young infants had been introduced to foods/drinks with added free sugars in their first year of life [12]. The home environmental factors influencing a child's diet have also been well studied [13–15]. However, there is a lack of research investigating patterns and timing of maternal dietary behavior in the early postpartum period, and whether those patterns affect their child's subsequent dental caries experience.

The Study of Mothers' and Infants' Life Events Affecting Oral Health (SMILE) is a prospective birth cohort study of children born in Adelaide, Australia started in the 2013 [16,17]. It offers an opportunity to investigate the trajectories of maternal free sugars intake from sugar-sweetened beverages (SSB) during the first five years of their child's life and their association with child dental caries experience measured at the age of five years. It was hypothesized that there would be an intergenerational effect of maternal health behavior on offspring oral health, expressed through differential trajectories of maternal intake of SSB.

2. Methods

2.1. Study design and data source

The conduct and reporting of this study follow the Strengthening the Reporting of Observational Study guidelines (STROBE). We used an observational population-based study design to follow a cohort of socio-economically diverse South Australian newborns and their mothers from birth. A detailed account of the study design and cohort profile have been published previously [16,17]. Briefly, SMILE is a single-center study established in Adelaide, the capital of the state of South Australia, a city with long-term water fluoridation. A cohort of newborns was recruited between July 2013 and August 2014 from the three main public hospitals offering maternity services in Adelaide and surrounding suburbs. A team of recruiters attended the three hospitals on various days of the week and invited all new mothers who could understand English to participate in the study. To achieve a socio-economically diverse and population-representative sample, a concerted effort was made to include mothers of children with different socioeconomic backgrounds from across all areas of Adelaide [16]. Written informed consent was obtained at recruitment and at each physical examination at later times.

Data available for the current analysis were sourced at recruitment (birth of the children) and from three waves (Waves 4, 5 and 6) of SMILE, when the children had turned one, two and five years of age, respectively. There were 1278, 1172 and 825 participating mothers in those waves, respectively (Appendix 1). A total of 879 children completed oral epidemiological examinations at the age of five years. SMILE had ethical approval from multiple Human Research Ethics Committees (HREC#50.13, 28/02/2013, HREC#13/WCHN/69, 07/08/2013, and HREC#H-2018–017, 16/10/2018).

2.2. Measurement of key variables and indicators

2.2.1. Characterization of trajectory of maternal intake of SSB

The major source of free sugars intake is from SSB in older children, teens and adults in Australia [18]. In this study, maternal consumption of SSB for each wave was assessed with the following items asking how frequently (every day, sometimes, never) they consumed SSB during the preceding week, including: (1) soft/soda drinks containing sugars (e.g., cola, energy drinks); (2) flavored milk; and (3) tea/coffee with added free sugars. These items were summed to form a composite score as a proxy of free sugars intake to rank the sample by the frequency of SSB intake. The three scores of maternal intakes of SSB were then used in group-based trajectory modeling (GBTM).

2.2.2. Dental caries experience

A small team of dental practitioners conducted oral epidemiological examinations under standardized conditions [17]. The examinations were visual only, aided by compressed air and two light sources. Examiners were trained and followed the standard protocol. Due to the young age of the children, repeated examinations were not conducted. To ensure consistency, the examiners conducted a number of examinations together, alternating between examination and data recording followed with relevant discussion.

Dental examination of each child was used to compute individual number of decayed, missing and filled surfaces (dmfs). Decay was defined as cavitated enamel or dentine lesions, or non-cavitated lesions with visible dentinal involvement. Examiners were instructed to distinguish between missing teeth and fillings due to dental caries vs missing teeth and fillings due to other non-carious reasons. Dental caries prevalence was determined as the percentage of children with at least one decayed, missing or filled tooth surface (dmfs). Caries experience was represented by the mean dmfs score.

2.2.3. Socio-demographic characteristics

These variables included child's age (months) at the date of child dental examination. All other sociodemographic variables used were measured at baseline. They included mother's age (years), mother's education attainment (High School, Vocational Training, Tertiary), mother's country of birth (Australia and New Zealand vs. Other), quartiles of household income, and parent household type (Single- or Two-parent household) and Index of Relative Socio-Economic Advantage and Disadvantage for Areas (IRSAD) developed by the Australian Bureau of Statistics at the postcode level [19]. The ISRAD index ranged from 1 (Most disadvantaged) to 10 (Most advantaged). These served as confounding factors in modeling the association between trajectories of maternal intake of SSB and child dental caries experience.

2.3. Statistical analysis

All analyses used Stata version 16 (StataCorp LLC, TX, USA). Two stages of analysis were adopted. In the first stage, trajectory analysis of mothers' SSB intake was undertaken. In the second stage, the identified trajectories were used as the main exposure for child dental caries prevalence and experience at age five (Fig. 1).

There were 1488 mothers with data on their SSB intake at one or more waves. There was 30.4% sample with completed data in all 3 rounds, 51.8% with at least two rounds of data and 66.6% with at least one round of data. Missing data was addressed with multiple imputation using chained equations (MICE). This approach is more advantageous than the other methods (including single imputation) because it involves creating multiple predictions for each missing value to account for the uncertainty in the imputations and to yield accurate standard errors [20]. Specifically, we used maternal socioeconomic factors (age, education level, IRSAD decile, country of birth, income, and indigenous status, and parent household) to impute the missing values for the maternal SSB intake. Each missing variable was imputed three times with a number of iterations to create 100 samples, imputed values of

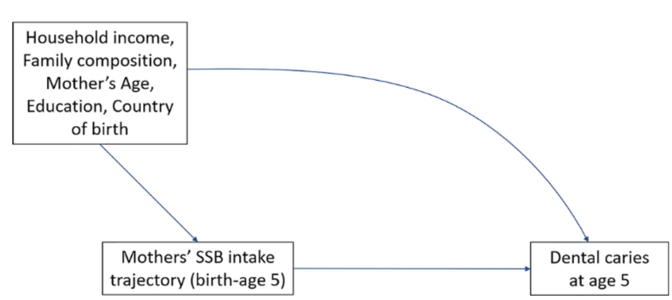

Fig. 1. Simplified directed acyclic graph of the study.

which were then averaged to create the final value for the variables [21]. We assumed that the missing values were missing at random, meaning that the missing and observed values were not systematically different due to differences the observed characteristics, not in the outcome, maternal SSB intake [22]. The descriptive summary for maternal individual sugars from SSB intake items before multiple imputation is presented in Table A2.1 (Appendix 2). The descriptive analysis in Table A2.2 (Appendix 2) showed that, except for the interquartile range (IQR) and sugar data in wave 6, the data related to maternal SSB intake was consistent before and after MICE, suggesting that MICE was valid.

Step 1: Trajectory analysis: We applied group-based trajectory modeling (GBTM) to identify maternal SSB intake trajectories [23,24]. We began by recoding those data in a manner that higher values reflect higher levels, such as every day, sometimes, and never as 2, 1, and 0, respectively, for all three items of maternal SSB intake. The three items of maternal SSB intake were then summed to form a composite score of maternal SSB intake at one, two and five years (Cronbach's α values for the three waves were 0.85, 0.87 and 0.90, respectively). These variables served as essential inputs for GBTM to identify a new latent variable, *trajectory group,* a statistical method for analyzing development trajectories of any outcome over age or time which is useful for statistical modeling, social policies and practices. Further details of the GBTM statistical methods are presented in Appendix 3.

We subsequently produced the individual-level estimates based on maternal SSB intake scales obtained from different waves of SMILE. All model estimates were undertaken using maximum likelihood, where the maximization was performed using a general quasi-Newton procedure. In the present article, for model section, we employed a number of criteria, including the Bayesian Information Criterion (BIC), probability of being assigned into the group, the 95% confidence interval (CI) of group trajectories and level of correspondence between observed and predicted trajectories. To avoid missing any possible models, we used all possible combinations and permutations of the relationships (including linear, quadratic, cubic and quartic) between age and maternal SSB intake indicators (in total, 16 models were performed, data not shown in the interest of space). Based on those criteria, we determined 3 as the optimal number of trajectory groups.

Step 2: Modeling: We modelled two main outcomes, dental caries prevalence as a binomial distribution, and the dmfs score as a negative binomial distribution. The exposure was maternal SSB intake trajectory. We used generalized linear regression models for a binomial distribution with log link for the prevalence outcome to estimate the prevalence ratio (PR) against the reference group [25,26]. For the caries experience (dmfs score, a count variable), we applied a generalized linear regression models for negative binomial distribution with log link to estimate the incidence risk ratio (or mean ratio, MR) against the reference group. For model diagnostics, we relied upon the Hosmer-Lemeshow Goodness-of-Fit indicator [27] and the lower Bayesian information criterion (BIC) for assessing model fit for the log-binomial and negative binomial models, respectively. Both of our final models satisfied these criteria. The models were built based on *a priori* assumptions of associations between the exposure variables and covariates with the outcome (Fig. 1). A total of 879 children who had a dental examination at age 5 years and their mother had at least one round of data on SSB intake were included in this analysis.

3. Results

The key characteristics of samples of mothers participating in at least one of three waves, when children were one, two and five years, and the sample of children having oral epidemiological examinations at the age of five years, are presented in Table 1. The two samples were relatively similar in key background variables. The mean age of mothers in both samples was just over 30 years. Most were Australians or New Zealanders (68.8% vs. 67.3%), in two-parent households (93.5% vs. 95.4%), tertiary educated (52.7% vs. 59.0%), or had incomes of >$AUD40,000 to 120,000 per year (84.7% vs. 87.9%), respectively. The samples used in this analysis were more likely to have tertiary education mothers than the baseline sample (59.0% vs. 46.0%). The proportion of low-income families was lower (12.1% vs. 19.6%), and more mothers born in other countries participated in this round (32.8% vs. 27.0%) than in the baseline sample.

The trajectories of maternal SSB intake identified from GBTM using the censored normal model are illustrated in Fig. 2. We obtained the optimal fit using a three-group model, in which 40.8% of mothers were classified as belonging to a 'Stable low' trajectory (group 1), 13.6% were

Table 1
Characteristics of the maternal and child samples.

Variables	Baseline sample (*N* = 2181)% (95%CI)	Maternal sample (*N* = 1488)% (95%CI)	Child's sample (*N* = 879)% (95%CI)
Mother's age, mean (95%CI)	29.8 (29.6–30.0)	30.3 (30.0–30.5)	30.7 (30.4–31.0)
IRSAD Decile, mean (95%CI)	5.3 (5.1–5.4)	5.5 (5.4–5.7)	5.7 (5.5–5.9)
Mother's highest education level			
High school	26.8 (24.9–28.7)	21.2 (19.2–23.4)	17.8 (15.4–20.5)
Vocational training	27.2 (25.3–29.1)	26.1 (23.9–28.4)	23.2 (20.5–26.1)
Tertiary education	46.0 (43.9–48.1)	52.7 (50.2–55.3)	59.0 (55.7–62.2)
Mother's country of birth			
Other	27.0 (25.1–28.9)	31.3 (28.9–33.7)	32.8 (29.7–35.9)
Australia or New Zealand	73.0 (71.0–74.9)	68.8 (66.3–71.1)	67.2 (64.1–70.3)
Household income (AUD)			
≤40,000	19.6 (17.9–21.4)	15.3 (13.5–17.3)	12.1 (10.0–14.5)
>40,000–80,000	34.3 (32.2–36.4)	33.0 (30.6–35.5)	33.5 (30.4–36.8)
>80,000–120,000	27.6 (25.6–29.5)	29.7 (27.4–32.2)	32.3 (29.2–35.6)
>120,000	18.5 (16.8–20.2)	22.0 (19.9–24.2)	22.1 (19.4–25.1)
Household composition			
Single-parent household	8.0 (6.8–9.2)	6.5 (5.4–7.9)	4.6 (3.4–6.2)
Two-parent household	92.0 (90.8–93.2)	93.5 (92.1–94.6)	95.4 (93.8–96.6)
Child variables			
Sex			
Female	46.3 (43.7–49.0)	46.5 (43.8–49.2)	45.8 (42.5–49.2)
Male	53.7 (51.0–56.3)	53.5 (50.8–56.2)	54.2 (50.8–57.5)

Baseline sample: Total sample at the recruitment.
Maternal sample: Mothers with completed dietary data at child age of one, two or five years.
Child's sample: Children with dental caries assessment at the age of five years.

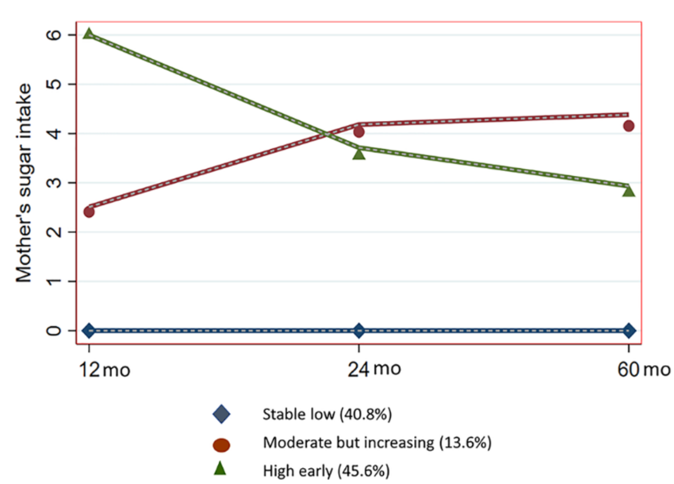

Fig. 2. Trajectories of maternal intake of sugar-sweetened beverages.

Table 2
Characteristics of maternal trajectories of sugar-sweetened beverages intake.

Variables	Groups		
	Stable low *N* = 608,% (95%CI)	Moderate but increasing N=176,% (95%CI)	High early N=704,% (95%CI)
Maternal variables (*N* = 1488)			
Mother's age (mean (95%CI)	30.9 (30.5 - 31.3)	30.4 (29.6 - 31.2)	29.7 (29.3 - 30.1)
IRSAD Decile (mean (95%CI)	6.00 (5.7 - 6.2)	5.21 (4.76 - 5.67)	5.23 (5.0 - 5.5)
Mother's highest education level			
High school	28.2 (23.5 - 33.5)	10.3 (7.3 - 14.1)	61.5 (56.0 - 66.8)
Vocational training	35.3 (30.6 - 40.2)	11.0 (8.2 - 14.5)	53.8 (48.8 - 58.7)
Tertiary education	49.2 (45.6 - 52.7)	12.5 (10.4 - 15.0)	38.3 (35.0 - 41.8)
Mother's country of birth			
Other	38.3 (34.0 - 42.8)	15.9 (12.9 - 19.5)	45.8 (41.3 - 50.4)
Australia or New Zealand	43.0 (39.0 - 54.1)	10.0 (8.3–12.0)	48.0 (44.9–51.1)
Household's income (AUD)			
≤40,000	27.8 (22.2–34.1)	11.1 (7.6–16.0)	61.1 (54.4–67.4)
>40,000–80,000	39.8 (35.4–44.3)	12.9 (10.1–16.3)	47.3 (42.8–51.9)
>80,000–120,000	44.6 (39.9–49.4)	12.9 (10.0–16.5)	42.5 (37.8–47.3)
>120,000	49.7 (44.1–55.2)	7.4 (5.0–10.9)	42.9 (37.5–48.5)
Household composition			
Single-parent household	33.3 (24.6–43.3)	7.3 (3.5–14.5)	59.4 (49.3–68.7)
Two-parent household	41.8 (39.2–44.4)	11.9 (10.3–13.8)	46.3 (43.6–48.9)
Child variables (*N* = 879)			
Sex			
Female	43.6 (39.7–47.6)	12.8 (10.4–15.7)	43.6 (39.7–47.6)
Male	48.6 (44.9–52.4)	13.0 (10.7–15.7)	38.3 (34.8–42.0)
Dental health			
Caries prevalence (%dmfs>0), (95%CI)	22.0 (18.8–25.7)	24.7 (18.7–31.9)	27.6 (21.3–35.0)
Mean dmfs (95%CI)	1.05 (0.77–1.33)	1.89 (0.85–2.94)	1.94 (1.14–2.75)
Median dmfs among children with dmfs>0	3.0	3.0	5.0
Overall caries prevalence (dmfs>0)	23.6 (20.9–26.5)		
Overall mean dmfs *(95%CI)*	1.37 (1.07–1.67)		
Overall median dmfs among children with dmfs>0	3.0		

dmfs: decayed, missing and filled surfaces. 95%CI: 95% confidence interval. IRSAD Decile: Area-level Index of Relative Socioeconomic Advantage/Disadvantage (1: Most disadvantaged; 10: Most advantaged).

grouped into a 'Moderate but increasing' trajectory (group 2), and the remaining 45.6% were assigned to the 'High early' trajectory (group 3). The 'Stable low' group comprised mothers who reportedly had little or no SSB intake across all three data collection points. The 'Moderate but increasing' group had a moderate level of SSB intake at the beginning, with a slight increasing trend over time. The 'High early' group had a high beginning and then a slightly declining pattern of SSB intake over the observation period.

Profiles of main socioeconomic and demographic characteristics of mothers by their membership of SSB trajectories are reported in Table 2. The group membership was associated with area-level SES (IRSAD index), mothers' education, country of birth, and household income. Those mothers who had high school only education, who were from the lowest income group, or were from single household were more likely in the 'High early' group than in the 'Stable low' group. The overall caries prevalence and the overall mean dmfs among the five-year-old children were 23.6% (95%CI: 20.9–26.5) and 1.37 (95%CI: 1.07–1.67), respectively. The prevalence and experience of dental caries were higher in the 'High early' (1.94; 95%CI: 1.14–2.75) and 'Moderate but increasing' (1.89; 95%CI: 0.85–2.94) groups than in the 'Stable low' (1.05; 95%CI: 0.77–1.33) group.

For caries prevalence, the unadjusted analysis shows that maternal highest education level, country of birth and household income were associated with the outcome. Both unadjusted and adjusted models showed gradients of the prevalence of dental caries from the 'High early' and 'Moderate but increasing' trajectory groups to the 'Stable low' group. There was a strong gradient in the prevalence of dental caries across income groups with children among lower income families more likely to have dental caries.

Both unadjusted and adjusted analyses showed gradients in caries prevalence and experience across maternal trajectories of SSB intake (Table 3). Such gradients attenuated after adjustment for confounders. In the adjusted model, children of mothers in the 'High early' and 'Moderate but increasing' trajectory groups had MR of 1.37 (95%CI: 1.01–1.77) and 1.24 (95%CI: 0.96–1.60) times the dmfs score than that of children of mothers in the 'Stable low' group, respectively. Children of mothers in the 'High early' trajectory group had PR of 1.19 (95%CI: 0.85–1.64) than that of children of mothers in the 'Stable low' group. Household income measured at baseline was strongly associated with childhood dental caries, with children in the lowest income group having 6.67 times higher mean dmfs scores than children of highest income household (Table 3). Children of women born overseas had nearly two times greater dmfs scores than children of women born in Australia or New Zealand (MR 1.91 (95%: 1.51–2.42)).

4. Discussion

We have applied the group-based trajectory modeling technique to characterize temporal patterns in mothers' SSB intake during the first 5 years of their child's life and then examined its effect on child dental caries experience. Three distinctive trajectories of maternal SSB intake were identified, defined as being 'Stable low, 'Moderate but increasing' and 'High early' groups during the observation period. Importantly, the trajectories of maternal SSB intake affected their offspring's dental caries experience. Those effects were stronger when maternal SSB intake was high early during the observation period (infancy and toddler period). These findings indicate the important role of the home environment in which children grow up. This also provides evidence of an intergenerational relationship between maternal high SSB intake and their offspring's dental health. This constitutes intergenerational continuity in exposures to health risk factors, values, beliefs and behaviors towards health, and opportunities to maintain health, given young children were dependent on their mothers [28]. It is plausible that maternal free sugars intake, as an environmental proxy for role

Table 3
Regression models for caries prevalence and experience (dmfs) at age 5 years.

Variables	Models for the prevalence of dental caries [a]		Models for dental caries experience (dmfs) [b]	
	Unadjusted PR(95%CI)	Adjusted PR (95%CI)	Unadjusted MR (95%CI)	Adjusted MR (95%CI)
Maternal SSB intake trajectory groups				
High early	1.25 (0.93 - 1.68)	1.19 (0.85 - 1.64)	1.85 (1.48 - 2.31)	1.37 (1.01 - 1.77)
Moderate but increasing	1.12 (0.82 - 1.53)	0.96 (0.68 - 1.35)	1.80 (1.44 - 2.25)	1.24 (0.96- 1.60)
Stable low	Reference	Reference	Reference	Reference
Mother's country of birth				
Other	1.32 (1.04 - 1.68)	1.19 (0.88 - 1.61)	2.02 (1.69 - 2.41)	1.91 (1.51 - 2.42)
Australia or New Zealand	Reference	Reference	Reference	Reference
Household income (AUD)				
≤40,000	2.31 (1.48 - 3.59)	1.95 (1.19 - 3.20)	6.88 (4.92 - 9.63)	6.67 (4.39 - 10.15)
>40,000–80,000	1.69 (1.13 - 2.53)	1.38 (0.90 - 2.11)	2.82 (2.10 - 3.79)	2.49 (1.81 - 3.44)
>80,000–120,000	1.60 (1.06 - 2.41)	1.43 (0.95 - 2.18)	2.34 (1.74 - 3.16)	1.87 (1.36 - 2.57)
>120,000	Reference	Reference	Reference	Reference

95%CI: 95% confidence interval; PR: Prevalence risk ratio; MR: mean incidence rate ratio.
Multivariable regression models also adjusted for child age and sex, maternal education and age, Family composition, Area-level IRSAD.
[a] Log-binomial regression model for child caries prevalence.
[b] Negative binomial regression model for child caries experience (dmfs).

modeling and family food provision, influences child sugar consumption. We aimed to investigate the effect of maternal SSB intake because it can be collected early (during pregnancy and early infancy) when child sugars intake is not established. Also, it is evident that preventing early onset of child free sugars intake (through targeting maternal sugars intake) will have both early life and long-term effect on child health.

The developmental period investigated in this study is when young children are mostly dependent on their immediate home environment and their caregivers. The observed distinctive trajectories of maternal SSB intake exemplify important differences in sugars-related behaviors. Such differences were associated with household and maternal socioeconomic backgrounds. This finding is consistent with those of prior studies [29–31]. Hence, support is required for women who care for very young children to help them appreciate the potential detrimental health effects of free sugars. There were three distinctive levels of SSB intake by mothers early in the observation period, with an apparent convergence of the two trajectories with moderate or high initial intake toward the end of the follow-up period. These trends might be indication of some effect of early-life health and dental visits on maternal health behaviors or ongoing 'acculturation' of the mothers to their maternal role [32,33].

It is important to note that children of women who had higher SSB intake early in the observation period when the children turned one year of age had higher dental caries experience than the other two groups. This difference was observed even though the 'High early' group converged with the 'Moderate but increasing' group when the children were older. This finding indicates the importance of the first year of life in forming children's preferences toward sugars [34]. Clearly, efforts must be made as early as possible to target free sugars intake among caregivers of young children.

Household income at childbirth and mothers' country of birth remained associated with dental caries experience, after adjusting for other variables. Such findings confirm the important role of socioeconomic determinants of child oral health. Addressing maternal behaviors only may not be adequate to prevent dental caries in young children.

The overall caries prevalence and experience among the five-year-old children in our study sample was 23.5% and 1.4 dmfs, respectively; which were comparable with caries prevalence and experience (25.3% and 1.4) among five-year-old South Australian children reported in the National Child Oral Health 2012–2014 [3]. This consistency supports our assertions about the population representativeness of our study sample.

The observed intergenerational association between maternal behavior and child dental caries experience can be explained by the dependence of young children on their immediate caregivers. This finding lends support for the integration of dental and general public health measures targeting mothers of young children through the Common Risk Factor approach [35]. Children of this birth cohort were born and grew up in fluoridated areas and hence were expected to receive its preventive benefits. Most other preventive programs target children through introducing and educating oral hygiene practices such as tooth-brushing with fluoridated toothpaste from an early age and reducing child consumption of foods and drinks high in free sugars. However, little has been done to investigate and address the role of maternal dietary practices in their offspring's dental health. It is noted that health education alone does not sufficiently lead to sustained behavioral change in individuals [36]. Oral health behaviors and oral health problems are enmeshed in more complex daily habits, which are largely determined by a broad set of psychosocial, economic and environmental factors [37]. In addition to focusing on children, we suggest strategically improving the environment in which children develop. It is crucial to recognize that maternal health attitudes and practices are likely to influence behaviors of children either through the direct provision of foods and drinks or role-modeling, and thus, play an important role in the uptake of favorable oral health practices. As has been highlighted, maintenance of child oral health starts with the mother [38,39]. Health promotion activities should be targeted to the mother's own SSB consumption to give them opportunity to embark on healthy dietary practices and oral hygiene practices, not only for themselves but also for their offspring. There should be concerted efforts to enhance a healthy environment at childcare and preschool facilities that directly influence young children and their mothers [40].

5. Strength and limitations

This study has capitalized on the advantages of a longitudinal design based on a population-representative sample [17]. The findings can be generalized to populations with similar socioeconomic characteristics. However, this study may have several limitations. As with other longitudinal studies, our study sample has been affected by attrition. Our multiple imputation technique helped to minimize that problem. Second, because we measured maternal free sugars intake using self-reports, social desirability bias was possible. However, we used the same tools and the same approach to collect data for different waves to ensure consistency. We collected information on only the three most commonly consumed SSB items, which, however, was adequate to rank relative frequency of intake to characterize maternal behavior toward sugars intake.

6. Conclusion

The effect of trajectories of maternal SSB intake on children's dental caries experience makes a strong case for public health programs that integrate dental preventive programs with general health promotion as an effective way to address oral health problems. Mothers should be given the opportunity and support to establish an environment suitable for their child's healthy development. Policy and regulatory initiatives that are specifically tailored to family socioeconomic background should also be anticipated. It is also clear that these promotion efforts tailored to the mother should be established as early as possible, even during the pregnancy and infancy.

CRediT authorship contribution statement

Diep H Ha: Conceptualization, Visualization, Data curation, Formal analysis, Writing – original draft. **Huy Nguyen:** Conceptualization, Visualization, Data curation, Formal analysis, Writing – original draft. **An Dao:** Conceptualization, Visualization, Writing – review & editing. **Rebecca K Golley:** Conceptualization, Visualization, Writing – review & editing. **W. Murray Thomson:** Conceptualization, Visualization, Writing – review & editing. **David J. Manton:** Conceptualization, Visualization, Writing – review & editing. **Sam D Leary:** Conceptualization, Visualization, Writing – review & editing. **Jane A Scott:** Conceptualization, Visualization, Writing – review & editing. **A. John Spencer:** Conceptualization, Visualization, Writing – review & editing. **Loc G Do:** Conceptualization, Visualization, Data curation, Formal analysis, Writing – original draft.

Declaration of Competing Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Supplementary materials

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References

[1] N.J. Kassebaum, A.G.C. Smith, E. Bernabé, T.D. Fleming, A.E. Reynolds, T. Vos, C.J. L. Murray, W. Marcenes, Regional Global, National Prevalence, Incidence, and disability-adjusted life years for oral conditions for 195 countries, 1990-2015: a systematic analysis for the global burden of diseases, injuries, and risk factors, J. Dent. Res. 96 (2017) 380–387, https://doi.org/10.1177/0022034517693566.

[2] P.S. Casamassimo, S. Thikkurissy, B.L. Edelstein, E. Maiorini, Beyond the DMFT: the human and economic cost of early childhood caries, JADA 140 (2009) 650–657.

[3] D.H. Ha, K.F. Roberts-Thomson, K.G. Peres, P. Arrow, L.G. Do, Oral health status of Australian children, in: L.G. Do, A.J. Spencer (Eds.), Oral Health of Australian Children: the National Child Oral Health Survey 2012–14, University Press, Adelaide, 2016.

[4] P.J. Moynihan, S.A. Kelly, Effect on caries of restricting sugars intake: systematic review to inform WHO guidelines, J.Dent. Res. 93 (2014) 8–18, https://doi.org/10.1177/0022034513508954.

[5] A. Sheiham, W.P. James, A new understanding of the relationship between sugars, dental caries and fluoride use: implications for limits on sugars consumption, Public Health Nutr. 17 (2014) 2176–2184, https://doi.org/10.1017/s136898001400113x.

[6] WHO, Guideline: Sugars Intake for Adults and Children, Geneva, 2015.

[7] L.L. Birch, J.O. Fisher, Development of eating behaviors among children and adolescents, Pediatrics 101 (1998) 539–549.

[8] S. Scaglioni, V. De Cosmi, V. Ciappolino, F. Parazzini, P. Brambilla, C. Agostoni, Factors influencing Children's eating behaviours, Nutrients 10 (2018), https://doi.org/10.3390/nu10060706.

[9] K.M. Appleton, H. Tuorila, E.J. Bertenshaw, C. de Graaf, D.J. Mela, Sweet taste exposure and the subsequent acceptance and preference for sweet taste in the diet: systematic review of the published literature, Am. J. Clin. Nutr. 107 (2018) 405–419, https://doi.org/10.1093/ajcn/nqx031.

[10] D.S. Battram, L. Piché, C. Beynon, J. Kurtz, M. He, Sugar-sweetened beverages: children's perceptions, factors of influence, and suggestions for reducing intake, J. Nutr. Educ. Behav. 48 (2016) 27–34, https://doi.org/10.1016/j.jneb.2015.08.015, e1.

[11] N. Ranjit, A.V. Wilkinson, L.M. Lytle, A.E. Evans, D. Saxton, D.M. Hoelscher, Socioeconomic inequalities in children's diet: the role of the home food environment, Int. J. Behav. Nutr. Phys. Act 12 (Suppl 1) (2015) S4, https://doi.org/10.1186/1479-5868-12-s1-s4.

[12] D.H. Ha, L.G. Do, A.J. Spencer, W.M. Thomson, R.K. Golley, A.J. Rugg-Gunn, S. M. Levy, J.A. Scott, factors influencing early feeding of foods and drinks containing free sugars-a birth cohort study, Int. J. Environ. Res. Public Health 14 (2017), https://doi.org/10.3390/ijerph14101270.

[13] C. Bassul, A.C. C, M.K. J, Associations between the home environment, feeding practices and children's intakes of fruit, vegetables and confectionary/sugar-sweetened beverages, Int. J. Environ. Res. Public Health 17 (2020), https://doi.org/10.3390/ijerph17134837.

[14] S.M. Rex, A. Kopetsky, B. Bodt, S.M. Robson, Relationships among the physical and social home food environments, dietary intake, and diet quality in mothers and children, J. Acad. Nutr. Diet. (2021), https://doi.org/10.1016/j.jand.2021.03.008.

[15] P. von Philipsborn, J.M. Stratil, J. Burns, L.K. Busert, L.M. Pfadenhauer, S. Polus, C. Holzapfel, H. Hauner, E. Rehfuess, Environmental interventions to reduce the consumption of sugar-sweetened beverages and their effects on health, Cochrane Database Syst. Rev. 6 (2019), Cd012292, https://doi.org/10.1002/14651858.CD012292.pub2.

[16] L.G. Do, J.A. Scott, W.M. Thomson, J.W. Stamm, A.J. Rugg-Gunn, S.M. Levy, C. Wong, G. Devenish, D.H. Ha, A.J. Spencer, Common risk factor approach to address socioeconomic inequality in the oral health of preschool children-a prospective cohort study, BMC Public Health 14 (2014) 429, https://doi.org/10.1186/1471-2458-14-429.

[17] L.G. Do, D.H. Ha, L.K. Bell, G. Devenish, R.K. Golley, S.D. Leary, D.J. Manton, W. M. Thomson, J.A. Scott, A.J. Spencer, Study of mothers' and infants' life events affecting oral health (SMILE) birth cohort study: cohort profile, BMJ Open 10 (2020), e041185, https://doi.org/10.1136/bmjopen-2020-041185.

[18] P.M. Clifton, L. Chan, C.L. Moss, M.D. Miller, L. Cobiac, Beverage intake and obesity in Australian children, Nutr. Metab. 8 (2011) 87, https://doi.org/10.1186/1743-7075-8-87 (Lond).

[19] ABS, Census of Population and Housing: Socio-Economic Indexes For Areas (SEIFA), Australia, 2011, Australian Bureau of Statistics: Canberra, 2011.

[20] M.J. Azur, E.A. Stuart, C. Frangakis, P.J. Leaf, Multiple imputation by chained equations: what is it and how does it work? Int. J. Methods Psychiatr. Res. 20 (2011) 40–49, https://doi.org/10.1002/mpr.329.

[21] P.T. Hippel, How many imputations do you need? A two-stage calculation using a quadratic rule, Soc. Methods Res. 49 (2018), https://doi.org/10.1177/0049124117747303.

[22] J.A.C. Sterne, I.R. White, J.B. Carlin, M. Spratt, P. Royston, M.G. Kenward, A. M. Wood, J.R. Carpenter, Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls, BMJ 338 (2009), b2393.

[23] D.S. Nagin, Group-Based Modeling of Development, Harvard University Press, Cambridge, MA, 2005.

[24] H.L. Nguena Nguefack, M.G. Pagé, J. Katz, M. Choinière, A. Vanasse, M. Dorais, O. M. Samb, A. Lacasse, Trajectory modelling techniques useful to epidemiological research: a comparative narrative review of approaches, Clin. Epidemiol. 12 (2020) 1205–1222, https://doi.org/10.2147/CLEP.S265287.

[25] M.J. Knol, S.L. Cessie, A. Algra, J.P. Vandenbroucke, R.H.H. Groenwold, Overestimation of risk ratios by odds ratios in trials and cohort studies: alternatives to logistic regression, Can. Med. Assoc. J. (CMAJ) 184 (2012) 895–899.

[26] P.A. Ospina, D.V. Nydam, T.J. DiCiccio, Technical note, The risk ratio, an alternative to the odds ratio for estimating the association between multiple risk factors and a dichotomous outcome, J. Dairy Sci. 95 (2012) 2576–2584.

[27] D.W. Hosmer, S. Lemeshow, R.X. Sturdivant, Applied Logistic Regression, 3rd Ed., John Wiley & Sons, New Jersey, USA, 2013.

[28] D.M. Shearer, W.M. Thomson, J.M. Broadbent, R. Poulton, Maternal oral health predicts their children's caries experience in adulthood, J. Dent. Res. 90 (2011) 672–677, https://doi.org/10.1177/0022034510393349.

[29] V. Skafida, S. Chambers, Positive association between sugar consumption and dental decay prevalence independent of oral hygiene in pre-school children: a longitudinal prospective study, J. Public Health 40 (2018) e275–e283, https://doi.org/10.1093/pubmed/fdx184 (Oxf).

[30] S.M. Costa, C.C. Martins, L. Bonfim Mde, L.G. Zina, S.M. Paiva, I.A. Pordeus, M. H. Abreu, A systematic review of socioeconomic indicators and dental caries in adults, Int. J. Environ. Res. Public Health 9 (2012) 3540–3574, https://doi.org/10.3390/ijerph9103540.

[31] K. Larson, S.A. Russ, J.J. Crall, N. Halfon, Influence of multiple social risks on children's health, Pediatrics 121 (2008) 337–344, https://doi.org/10.1542/peds.2007-0447.

[32] D.L. Chi, J.M. Scott, Added sugar and dental caries in children: a scientific update and future steps, Dent. Clin. North Am. 63 (2019) 17–33, https://doi.org/10.1016/j.cden.2018.08.003.

[33] J. Hong, H. Whelton, G. Douglas, J. Kang, Consumption frequency of added sugars and UK children's dental caries, Commun. Dent. Oral Epidemiol. 46 (2018) 457–464, https://doi.org/10.1111/cdoe.12413.

[34] Pan, L., Li, R., Park, S., Galuska, D.A., Sherry, B., and Freedman, D.S., A longitudinal analysis of sugar-sweetened beverage intake in infancy and obesity at 6 years. Pediatrics, 134 Suppl 1 (2014): S29–35. 10.1542/peds.2014-0646F.

[35] A. Sheiham, R.G. Watt, The common risk factor approach: a rational basis for promoting oral health, Commun. Dent. Oral Epidemiol. 28 (2000) 399–406.

[36] M.P. Kelly, M. Barker, Why is changing health-related behaviour so difficult? Public Health 136 (2016) 109–116, https://doi.org/10.1016/j.puhe.2016.03.030.

[37] R.G. Watt, From victim blaming to upstream action: tackling the social determinants of oral health inequalities, Commun. Dent. Oral Epidemiol. 35 (2007) 1–11, https://doi.org/10.1111/j.1600-0528.2007.00348.x.

[38] L. Paglia, WHO: healthy diet to prevent chronic diseases and caries, Eur. J. Paediatr. Dent. 19 (2018) 5, https://doi.org/10.23804/ejpd.2018.19.01.01.

[39] L. Paglia, Oral prevention starts with the mother, Eur. J. Paediatr. Dent. 20 (2019) 173, https://doi.org/10.23804/ejpd.2019.20.03.01.

[40] L.A. Daniels, K.M. Mallan, D. Battistutta, J.M. Nicholson, J.E. Meedeniya, J. K. Bayer, A. Magarey, Child eating behavior outcomes of an early feeding intervention to reduce risk indicators for child obesity: the NOURISH RCT, Obesity 22 (2014) E104–E111, https://doi.org/10.1002/oby.20693 (Silver Spring).