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Abstract

Background:

Dental caries (tooth decay) is the most prevalent non-communicable disease globally and is a major public health challenge in children. Despite improvements in oral health over recent decades, substantial socioeconomic inequalities in childhood caries persist both between and within countries. Scotland historically experienced substantial levels of childhood dental caries, particularly among socioeconomically disadvantaged groups, prompting the development of the national child oral health improvement programme, Childsmile. Childsmile aims to reduce caries prevalence and narrow inequalities through a proportionate universalism approach to delivering national multi-sectoral interventions. However, important gaps remain in understanding how socioeconomic circumstances operate through family level factors and oral health behaviours at both individual and area levels to shape childhood oral health inequalities, and how large-scale public health programmes influence these patterns.

Aims:

This thesis aimed to investigate the influence of socioeconomic factors and early-life oral health behaviours on childhood dental caries in Scotland, and to evaluate the role of the Childsmile programme in shaping these relationships.

The specific aims were:

1. To analyse the association of early oral health-behaviours (cariogenic diet, toothbrushing, attendance at dentist) with caries experience at age 5 in Scotland, and how they are mitigated by family and community level factors; before and after early national roll-out of the Childsmile programme.

2. To evaluate the impact of Childsmile behaviour change interventions on early-life oral health behaviours, and whether effects differed by socioeconomic deprivation.

3. To investigate how early life socioeconomic circumstances contribute to child caries experience in Scotland at age 5, before and after early national roll-out of the Childsmile programme.

The thesis followed a staged analytical approach: first validating the caries experience outcome measure; second exploring associations between early-life oral health behaviours and caries; third evaluating Childsmile intervention effects; and finally examining the influence of early-life socioeconomic circumstances on childhood caries experience.

Results:

Parent/carer proxy-reporting of caries experience showed low sensitivity (42.3%, 95% CI: 39.0–45.7), decreasing with lower socioeconomic deprivation therefore the NDIP exam caries experience was used for outcome throughout thesis.

Aim 1:

Both pre-Childsmile (Birth Cohort 1 – BC1) and post-Childsmile (Birth Cohort 2 – BC2), higher cariogenic diet scores were the most highly associated oral health behaviour with increased caries risk (BC1: adjusted Risk Ratio (aRR) 1.19, 95% CI: 1.13–1.26; BC2: aRR 1.17, 95% CI: 1.10–1.26), while more frequent toothbrushing was protective (BC1: aRR 0.89, 95% CI: 0.81–0.97; BC2: aRR 0.81, 95% CI: 0.71–0.92), with broadly similar associations across cohorts. Dental attendance association with caries experience attenuated after adjustment for family and socioeconomic factors, particularly in BC2 (aRR 0.90, 95% CI: 0.79–1.04).

Aim 2:

Childsmile-related behaviour-change interventions targeting diet and toothbrushing were delivered by Dental Health Support Workers (DHSWs) and in primary care dental settings. The only evidence of an association with improved behaviour was for toothbrushing frequency following primary care dental interventions (1 contact aRR 1.05, 95% CI: 1.02–1.08; 2 contacts aRR 1.06, 95% CI: 1.02–1.11; ≥3 contacts aRR 1.10, 95% CI: 1.05–1.16). However, the magnitude of these associations was modest.

Aim 3:

Socioeconomic gradients persisted across both cohorts. Structural equation modelling showed socioeconomic circumstances had a direct effect on caries and indirect effects through parenting and oral health behaviours in both cohorts; where parenting styles were included due to their well-researched links to both socioeconomic circumstances and oral health behaviours.

Total mediated effects decreased from 58.8% in BC1 to 39.1% in BC2, driven mainly by diet (44.6% in BC1; 31.7% in BC2) and toothbrushing (9.5% in BC1; 4.0% in BC2), with minimal mediation via parenting pathways (4.8% in BC1; 3.5% in BC2). Longitudinal trajectory analyses showed highest caries risk in persistent poverty and deprivation, with elevated risk in children entering poverty (aRR 1.4, 95% CI: 1.1–1.8), exiting poverty (aRR 1.6, 95% CI: 1.3–2.1), and moving into more deprived areas (aRR 1.6, 95% CI: 1.2–2.2), whereas moving out of deprived areas was not associated with increased risk (aRR 1.1, 95% CI: 0.8–1.7).

Conclusions:

Child dental caries experience in Scotland is shaped by early-life behaviours and, more fundamentally, socioeconomic circumstances. While early-life oral health behaviours predict caries risk, they are strongly socially patterned and only partially explain observed socioeconomic inequalities. The persistence of substantial direct socioeconomic effects, alongside cumulative disadvantage, indicates that structural determinants exert a dominant influence on early childhood oral health, with behaviour change interventions in the early stages of the Childsmile programme implementation showing limited impact.

Equity impact depends on integration with wider early years services and alignment with upstream policies addressing child poverty, food affordability, and broader social determinants of health. As such, interventions targeting behaviours alone are unlikely to reduce inequalities without concurrent structural action.

Achieving meaningful and equitable improvements in child oral health will require further work on coordinated action across upstream, midstream, and

downstream levels, as current approaches are not delivering effective reductions in inequalities, with particular focus on upstream determinants. This may also include strengthening the role of Childsmile teams working in midstream and downstream settings, such as Dental Health Support Workers DHSWs and Extended Duty Dental Nurses (EDDNs), in linking families with community assets, local organisations, and wider support services through community linking or social prescribing approaches.

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Author's Declaration

This thesis has been submitted by alternative format. I declare that, except where explicitly stated, that this thesis is the result of my own work and has not been submitted, partly or in whole, for any other degree at the University of Glasgow or any other institution.

Research from this thesis was published to the following locations or presented at the following conferences:

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Generative AI tools (ChatGPT, OpenAI, https://chat.openai.com) version 3.5-5.5 were used during the preparation of this thesis for exploratory research, language refinement, and coding support. These tools were not used to generate the core academic arguments, analysis, or conclusions presented in this work, and all final content was reviewed and authoured by the researcher.

Abbreviations

aRR: Adjusted risk ratios
BASCD: British association for the study of community dentistry
CERT: Childsmile Evaluation and Research Team
CHI: Community Health Index
CHSP: Child Health Surveillance Programme
CHSP 6-8wk: Child Health Surveillance Programme 6 to 8 weeks
CI: Confidence intervals
CSDH: Commission on Social Determinants of Health
DHSW: Dental Health Support Worker
DMFT: Decayed, Missing, Filled Tooth (permanent dentition)
dmft: decayed, missing, filled tooth (primary dentition)
eDRIS: Electronic Data Research and Innovation Service
EPCC: Edinburgh Parallel Computing Centre
FV: Fluoride Varnish
HIC: Health Informatics Centre
HSC: Health and Social Care
ICDAS: International Caries Detection and Assessment System
MIDAS: Management Information & Dental Account System
NDIP: National Dental Inspection Programme
NHS: National Health Service
NRS: National Records of Scotland
NSTB: Nursery Supervised Toothbrushing
OR: Odds ratios
PBPP: Public Benefit & Privacy Panel
pH: Potential of hydrogen
PHS: Public Health Scotland
PIN: Personal Identification Number
RQ: Research question
RR: Risk ratios
ScotCen: Scottish Centre for Social Research
SEC: Socioeconomic circumstances
SEM: Structural Equational Modelling
SIMD: Scottish Index of Multiple Deprivation
SSBs: Sugar sweetened beverages
UK: United Kingdom
VPN: virtual private network
WHO: World Health Organization

Chapter 1

1 Introduction

This chapter reviews and synthesises the international literature relevant to early-life risk factors for dental caries in Scotland and the socioeconomic factors shaping inequalities in behaviours and outcomes. These issues are explored through the dual lens of the pre- and post-implementation phases of the national child oral health improvement programme, Childsmile.

Key themes and gaps in the literature are identified, establishing the foundation for the present study. Detailed literature search strategies are provided in Appendix A. The chapter begins by defining dental caries and examining its aetiology and explores the complex interactions between social, economic, and behavioural factors operating at the child, family, and community levels. The epidemiology, impact and wider burden of the disease are then considered; focusing primarily on children globally before narrowing to the UK and, more specifically, Scotland.

The chapter subsequently discusses the framework and strategies underpinning interventions to reduce the population burden and inequalities in the distribution of the disease. Finally, the background of the Childsmile programme will be presented, its theoretical foundation, design and implementation as well as evaluation will all be detailed.

1.1 Pathogenesis of Dental Caries

Dental caries is a chronic, biofilm-mediated disease characterised by the progressive destruction of the mineralised tissues of the tooth, including enamel, dentine and, in advanced stages, cementum. The disease arises from the metabolic activity of microorganisms embedded within dental plaque, a structurally organised biofilm adherent to the tooth surface (Kidd and Fejerskov, 2016). Within this biofilm, bacteria metabolise fermentable carbohydrates to produce organic acids, leading to a localised reduction in plaque pH.

Demineralisation occurs when the surrounding fluid becomes undersaturated with respect to tooth mineral. Although often cited as approximately pH 5.5, the critical pH below which enamel dissolves varies depending on the saturation of calcium and phosphate in saliva and plaque fluid, and is modified by fluoride availability (Featherstone, 2000; Larsen and Pearce, 2003). When pH falls below this dynamically determined threshold, hydroxyapatite crystals dissolve, releasing calcium and phosphate ions from the subsurface enamel.

This process is governed by the dynamic balance between demineralisation and remineralisation. Periods of acid challenge following sugar exposure promote mineral loss, whereas salivary buffering and the presence of calcium, phosphate, and fluoride facilitate mineral redeposition (Edgar and Higham, 1995; Pitts *et al.*, 2017). Caries develops when this equilibrium is disrupted over time, resulting in a net mineral loss and progressive structural breakdown of the tooth surface.

Importantly, caries is not attributable to a single exogenous pathogen but reflects a shift in the ecological balance of the resident plaque biofilm. Environmental changes—particularly frequent exposure to fermentable carbohydrates—select for acidogenic and aciduric microbial populations capable of sustaining low pH conditions (Marsh, 1994; Marsh, 2003). This ecological shift promotes prolonged mineral undersaturation at the tooth surface, reinforcing continued dissolution and lesion progression. Contemporary ecological perspectives further emphasise that metabolic activity and community function, rather than the presence of individual species alone, drive disease expression (Takahashi and Nyvad, 2011).

Clinically, the earliest manifestation of this process is a non-cavitated enamel lesion, often observed as a white-spot lesion reflecting subsurface mineral loss beneath a relatively intact surface layer. Because the surface layer remains preserved, early enamel lesions retain the capacity for remineralisation if ecological conditions are modified (Featherstone, 2000; Pitts *et al.*, 2017). This distinguishes dental caries from erosive tooth wear, in which surface mineral is irreversibly lost due to direct acid dissolution without subsurface lesion formation. If the cariogenic challenge persists, lesion progression extends into dentine, where lower mineral content and tubular architecture permit more

rapid spread. Advanced lesions may ultimately involve the dental pulp, resulting in inflammation, pain, and potential loss of tooth vitality (Fejerskov, Nyvad and Kidd, 2015). In epidemiological research, cavitated dentinal lesions are commonly used as the diagnostic threshold for "obvious caries experience" (Conway *et al.*, 2025).

1.1.1 Measurement and Assessment of Caries

The most common method for measuring dental caries experience is the Decayed, Missing, Filled Tooth Index - expressed as DMFT for permanent dentition and dmft for primary dentition. This index is sometimes referred to as the D_3MFT/d_3mft index (with the subscript "3" denoting dentinal level caries) and is widely used in large epidemiological surveys in the UK and across the world (Larmas, 2010).

Caries data are initially recorded at the tooth-surface level, with each tooth comprising up to five recordable surfaces, before being aggregated to the tooth level to produce the overall DMFT/dmft score. A tooth with a carious lesion is recorded as D/d, a tooth missing due to caries as M/m, and a tooth with a temporary or permanent filling as F/f. The maximum possible score is 32 for the permanent dentition and 20 for the primary (deciduous) dentition. A DMFT/dmft score greater than zero (DMFT/dmft > 0) indicates the presence of caries experience, whereas a score of zero indicates no caries experience. Caries assessment was conducted in accordance with British Association for the Study of Community Dentistry (BASCD) criteria (Pitts et al., 1997). In surface-based assessments, estimates may also vary depending on assumptions regarding the number of affected surfaces associated with missing teeth (Broadbent and Thomson, 2005).

An alternative and more detailed diagnostic system is the International Caries Detection and Assessment System (ICDAS), which classifies carious lesions on a six-point scale ranging from early enamel changes to extensive cavitation into dentine. Although ICDAS offers detailed detection of early carious lesions, its need for tooth cleaning, drying, examiner calibration, and detailed surface scoring makes it more time-consuming and resource-intensive for large epidemiological surveys compared with simpler indices (Gugnani *et al.*, 2011).

In Scotland, the National Dental Inspection Programme (NDIP) comprises both a Basic and a Detailed Inspection. The Basic Inspection is carried out at a majority population level in Primary schools annually in both Primary 1 (P1 – 84.0% coverage in 2025) and Primary 7 (P7 – 82.1% coverage in 2025) (Conway *et al.*, 2025); while the Detailed Inspection is conducted on a stratified random sample of children, with trained examiners performing a calibrated visual assessment of each tooth surface at the dentine (D_3) threshold; with annual cohort rotation between Primary 1 (P1) and Primary 7 (P7). The Basic Inspection, records obvious dentinal caries experience in all children using a simplified visual protocol, providing a pragmatic proxy for D_3MFT/d_3mft (Conway *et al.*, 2025). The basic inspection is used throughout this thesis to measure caries experience (detailed in Section 3.10.1).

1.2 Risk Factors of Dental Caries in Children

The risk factors of dental caries in children are extensive and complex, with many concomitant factors encompassing biological, behavioural, social, and environmental determinants. Numerous comprehensive reviews have catalogued a wide range of contributory factors (Fejerskov, Nyvad and Kidd, 2015; Harris *et al.*, 2004; Selwitz, Ismail and Pitts, 2007; Pitts *et al.*, 2017; Kirthiga *et al.*, 2019). The diversity of factors requires a conceptual framework to organise and interpret them systematically.

1.2.1 Conceptual Frameworks for Understanding Caries Risk Factors in Children

Several frameworks have been posited to understand childhood caries risk. The biomedical model emphasises biological and behavioural pathways, focusing on dental plaque biofilm, host susceptibility, diet, and oral hygiene practices (Selwitz, Ismail and Pitts, 2007). While this model is useful for explaining mechanistic pathways, it has been criticised for underemphasising the central role of sugar and for neglecting socioeconomic and environmental determinants (Watt, 2007; Sheiham and James, 2015; Watt, 2023).

In contrast, the Fisher-Owens *et al.* (2007) conceptual model situates risk factors within a multilevel ecological context, encompassing biological, child-level, family, community, and socioeconomic influences (Figure 1.1).

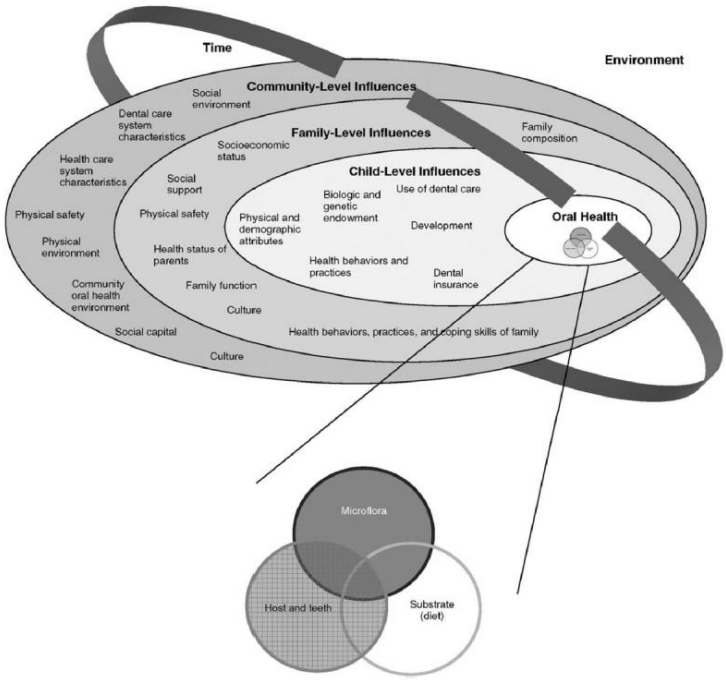


Figure 1.1 - Conceptual model depicting the multilevel influences on oral health - (Fisher-Owens *et al.*, 2007)

This model emphasises the interactions among these levels, highlighting how social determinants and family behaviours can shape biological susceptibility and child-level behaviours. Comparing these frameworks demonstrates the need to consider both mechanistic and social determinants, and for the purposes of this thesis, the Fisher-Owens model provides a robust structure for organising risk factors while maintaining awareness of their interconnections.

1.2.2 Evidence from Empirical Reviews

A seminal review, Harris *et al.* (2004) conducted a systematic search on studies between 1966 and 2002, high quality by the standard of the time but it lacks modern risk-of-bias tools and relied heavily on cross-sectional evidence. This review included 77 studies out of 1029 papers identified by the initial search and focused on children aged six years and under, identifying 106 factors reported as statistically significant in contributing to caries risk. These factors were grouped into sociodemographic influences, dietary patterns, oral hygiene practices, breast- and bottle-feeding practices, oral bacterial flora, and other factors, including sleep patterns and parental oral health.

Kirthiga *et al.* (2019) subsequently reviewed 89 studies (from 1215 unique records identified between 2005 and 2019), updating Harris's findings through a more rigorous multi-database search strategy, restriction to case-control studies, and meta-analysis of 29 included studies, strengthening the review by contemporary methodological standards. The review identified 123 factors statistically associated with caries risk, with enamel defects and high levels of *Streptococcus mutans* among the strongest predictors based on pooled effect estimates reported in the meta-analysis. However, these measures may have favoured more proximal biological and clinical risk factors, which are typically easier to quantify consistently across studies than broader social or structural determinants. Despite methodological improvements, the review remained limited by substantial heterogeneity, the predominance of cross-sectional studies, variable study quality, and inconsistent reporting that prevented synthesis of some risk factors. Both reviews also highlighted limited adjustment for confounding factors as an important limitation.

While these reviews catalogue many determinants, the Fisher-Owens *et al.* (2007) framework is necessary for better understanding how these factors interact and operate across biological, behavioural, family and socioeconomic levels. For clarity, throughout this thesis risk factors will be structured under the Fisher Owen's conceptual model; discussed in the following sections.

1.2.3 Biological Level Risk Factors for Dental Caries in Children

Biological factors influence individual susceptibility to dental caries by modifying microbial ecology, host defence, and tooth surface vulnerability. The composition and functional activity of the oral microbiota play a central role in determining susceptibility. Historically, *Streptococcus mutans* has been identified as a key biological risk indicator, with early colonisation associated with increased caries risk in children (Emilson and Krasse, 1985; Harris *et al.*, 2004). However, contemporary evidence indicates that risk is more accurately associated with dysbiotic microbial communities, characterised by increased proportions of acidogenic and aciduric taxa and enhanced carbohydrate metabolism, rather than the presence of a single pathogen (Philip, Suneja and Walsh, 2018; Tanner *et al.*, 2018; Zhang, Chu and Yu, 2022).

Microbiome research further supports the role of community-level dysbiosis as a biological susceptibility factor. A systematic synthesis screening 6034 unique articles and including 237 in their synthesis by Zhang, Chu and Yu (2022) reported that shifts in microbial composition, functional gene expression linked to acid production, and interkingdom interactions are associated with caries development and may precede clinical lesion formation. Nevertheless, heterogeneity in study design and limited control for confounders suggest these findings should be interpreted cautiously and considered risk associations rather than causal determinants.

Host-related biological factors also modify caries risk. Saliva is a critical protective determinant, providing buffering capacity, antimicrobial activity, and minerals necessary for remineralisation. Reduced salivary flow or altered composition impairs these protective functions, prolonging demineralisation periods (Dowd, 1999; Stookey, 2008). Variations in salivary proteins, enzymes, and immunoglobulins may further influence microbial colonisation and cariogenic potential (Zhang, Chu and Yu, 2022; Raja *et al.*, 2025); although a necessity for further high-quality recent studies is apparent.

Tooth-specific characteristics represent additional intrinsic risk factors. Developmental enamel defects, such as hypoplasia and hypomineralisation, increase plaque retention and susceptibility to acid dissolution, thereby accelerating lesion initiation and progression (Vargas-Ferreira *et al.*, 2015; Costa *et al.*, 2017). These systematic reviews and meta-analyses on enamel defects are robust due to their rigorous methodology, including representative population-based studies, comprehensive literature searches, quality assessment, and defect-specific analyses with subgroup and meta-regression evaluations. However, their weaknesses include reliance primarily on cross-sectional studies, variability in diagnostic criteria and clinical assessment of enamel defects, moderate heterogeneity, potential publication bias, and limitations in generalisability arising from differences in study populations, socioeconomic contexts, fluoride exposure, age ranges, caries diagnostic thresholds, and examiner calibration across countries and study settings.

Importantly, these biological factors do not act in isolation—they interact dynamically with dietary substrate. Fermentable carbohydrates provide the fuel

for acidogenic bacteria, with the resulting acid challenge modulated by saliva and enamel integrity. Frequent or excessive sugar exposure can overwhelm protective mechanisms, tipping the balance toward demineralisation and lesion progression. Thus, the biological environment sets the stage for child-level behavioural factors, including diet, oral hygiene, and feeding practices, to further influence individual caries risk (Fisher-Owens *et al.*, 2007; Selwitz, Ismail and Pitts, 2007).

1.2.4 Child Level Risk Factors for Dental Caries in Children

Child-level risk factors encompass behavioural, dietary, and genetic determinants that shape individual susceptibility to dental caries. Frequent consumption of free sugars—including added sugars, honey, syrups, and sugars naturally present in fruit juices—provides the primary substrate for acidogenic plaque bacteria, driving acid production and lowering local pH. Suboptimal infant feeding practices, such as prolonged bottle use, night-time feeding, or high-sugar formulas, exacerbate this effect by increasing both the frequency and duration of substrate exposure, particularly during periods of reduced salivary flow (Pitts et al., 2017; Moynihan et al., 2019; Peres et al., 2019b).

The frequency, timing, and physical form of sugar intake determine the intensity and duration of acid challenges, and repeated exposure can overwhelm salivary buffering and remineralisation, tipping the balance toward enamel demineralisation. Evidence for these associations is robust, drawing on high-quality literature which provide a rigorous synthesis of multiple studies (Pitts *et al.*, 2017; Peres *et al.*, 2019b). Frequent consumption of sugar-sweetened beverages, sweet snacks or any sugar sweetened snacks are consistently associated with greater caries experience due to the key role of free sugars in caries development, as supported by high-quality global evidence (Moynihan and Kelly, 2014; Sheiham and James, 2015; World Health Organization, 2025).

Infrequent or inadequate toothbrushing further compounds risk by allowing biofilm accumulation, promoting maturation of aciduric microbial communities, and prolonging demineralisation periods (Costalonga and Herzberg, 2014). This is supported by an array of systematic and Cochrane reviews, which argue fluoride exposure through toothpaste, water, varnish application or supplements

mitigates these effects by enhancing remineralisation and inhibiting bacterial metabolism (Iheozor-Ejiofor *et al.*, 2015; Peres *et al.*, 2019b; Walsh *et al.*, 2019b). Mechanistic and policy-focused reviews provide additional context for the central importance of sugar as a principal causal factor (Kearns, Glantz and Schmidt, 2015; Sheiham and James, 2015).

Host genetic factors may further contribute to individual susceptibility. Genetic variation may influence enamel structure, immune response, and oral microbiome composition, potentially modulating caries risk (Townsend, Aldred and Bartold, 1998; Vieira, Modesto and Marazita, 2014; Opal *et al.*, 2015). However, evidence remains limited and largely suggestive, as most studies are candidate gene approaches rather than large genome-wide association studies (GWAS). Existing GWAS demonstrate small polygenic effects, whereby numerous genetic variants contribute modestly to susceptibility, suggesting that genetics influences caries risk indirectly and in interaction with environmental and behavioural factors (Shaffer *et al.*, 2011). These findings indicate that genetics likely modulate risk indirectly rather than act as direct causal determinants.

These child-level behaviours and exposures are an integral part of the wider risk factor model. As well as interacting with biological risk factors detailed above, they are also heavily influenced by the socioeconomic, family and community factors detailed in the following section. Together, these factors create a multi-layered environment in which free sugar exposure, feeding practices, oral hygiene, and host susceptibility collectively determine whether carious lesions develop, progress, or are arrested.

1.2.5 Family and Community Risk Factors for Dental Caries in Children

Family and community factors are central determinants of child oral health within multilevel frameworks, operating as upstream influences that shape children's behaviours, exposures, and access to protective resources. These domains include parenting practices, family structure, cultural norms, neighbourhood characteristics, and access to health and social services. Importantly, family and community factors operate as distinct but interacting layers of influence, rather than simply acting as mediating pathways of other

determinants. As such, they function as structural “causes of the causes,” shaping behavioural risk and biological vulnerability from early childhood (World Health Organization, 2010). These domains are also the primary targets of population-level public health interventions aimed at reducing health inequalities.

Family-level influences play a foundational role in the development of early oral health behaviours and risk exposures. Parenting practices, parental oral health behaviours, household routines, and family dietary norms directly shape children’s toothbrushing habits, sugar consumption, and dental service utilisation (Duijster *et al.*, 2015). A systematic review of children aged 0-6 found 55 studies between 2006 and 2011 that identified consistent associations between parental psychosocial factors and childhood caries across diverse cultural settings and parenting-related factors; however, the authors noted a lack of research into parenting attitudes, knowledge and beliefs and limited longitudinal evidence, restricting causal interpretation (Hooley *et al.*, 2012). One influential framework for understanding these family processes is Baumrind’s parenting style typology, which characterises parenting according to the dimensions of responsiveness and demandingness (Baumrind, 1966). Responsiveness refers to parental warmth, emotional support, and sensitivity to a child’s needs, whereas demandingness refers to the extent to which parents set expectations, monitor behaviour, and enforce rules or discipline. Parenting styles are considered relatively stable throughout early childhood and are central to children’s emotional, behavioural, and social development. It has been further argued that parenting style operates as an emotional and behavioural context through which parental practices influence child outcomes, including the development of self-regulation and health-related behaviours (Darling and Steinberg, 1993). These dimensions are particularly relevant to oral health, where consistent parental supervision, dietary regulation, and reinforcement of toothbrushing behaviours are essential during early childhood. Parenting styles may therefore shape the extent to which preventive oral health practices are established and maintained within the home environment.

The family environment further influences oral health through broader structural and psychosocial factors. Parental stress, time constraints, and competing caregiving demands may reduce the capacity for consistent preventive practices,

particularly during early childhood when health behaviours are habitually established (Lawlor and Mishra, 2009). Such pressures are often more pronounced among families experiencing socioeconomic disadvantage and may also shape parenting approaches and caregiving practices. Consequently, the home environment influences the consistency of oral hygiene supervision, dietary regulation, and children's exposure to cariogenic diets, while broader family and socioeconomic characteristics have been associated with children's oral health-related quality of life (Kumar, Kroon and Lalloo, 2014). However, this systematic review noted considerable heterogeneity between studies and limited population representativeness, restricting the generalisability of findings. Nevertheless, much of the existing evidence examining family influences on oral health relies heavily on cross-sectional designs and self-reported behavioural measures, increasing the potential for reporting bias and limiting understanding of temporal relationships.

Community-level determinants encompass neighbourhood deprivation, access to services, local infrastructure, and broader environmental conditions that shape opportunities for health-promoting behaviours. Area-based deprivation has consistently been associated with lower utilisation of dental services, poorer preventive care uptake, and higher exposure to cariogenic food environments (de Aquino Goulart et al., 2025). This systematic review and meta-analysis identified 5,539 records (2000–2013), including 155 observational studies for qualitative synthesis and 92 studies that allowed for the calculation of odds ratios for quantitative meta-analysis across diverse global populations, with many focusing on children and adolescents. Risk of bias was assessed using a modified Newcastle–Ottawa Scale (NOS), evaluating selection, comparability, attrition, and outcome ascertainment (Wells *et al.*, 2000). Study quality was generally moderate, with 44 low-quality, 100 moderate-quality, and 11 high-quality studies. Publication bias was assessed using funnel plots and Egger's test (Egger *et al.*, 1997), indicating some asymmetry but no meaningful impact on pooled estimates. Despite heterogeneity and reliance on cross-sectional designs limiting causal inference, the large evidence base and consistent direction of findings support a robust association between socioeconomic disadvantage and dental caries. Overall, the review provides strong evidence that community-level

deprivation contributes to oral health inequalities, particularly in early life through differential access to preventive resources and services.

Wider environmental characteristics, including availability of green space, community cohesion, and local service provision, may also influence health behaviours through mechanisms such as stress reduction, social support, and opportunities for healthier lifestyles (Pearce *et al.*, 2007; Mitchell and Popham, 2008; Marmot *et al.*, 2010). However, reliance on area-based measures alone presents limitations, as they may mask within-area heterogeneity and fail to capture individual socioeconomic experiences (Shavers, 2007; McCartney *et al.*, 2023). This raises important methodological concerns when interpreting community-level effects on oral health inequalities.

Although family and community factors should be conceptually distinguished, socioeconomic circumstances (SEC) remain a pervasive structural determinant operating across both domains. Indicators such as income, parental education, occupation, and area-based deprivation are consistently associated with higher caries prevalence and severity across populations; as demonstrated across numerous systematic reviews and meta-analyses (Harris *et al.*, 2004; Schwendicke *et al.*, 2015; Kirthiga *et al.*, 2019; Elamin, Garemo and Mulder, 2021; Lam *et al.*, 2022). This persistent social gradient reflects broader structural inequalities in living conditions, access to resources, and health opportunities, supporting the conceptualisation of SEC as a fundamental cause of oral health inequalities rather than a distal covariate (Link and Phelan, 1995; Watt, 2023).

At the household level, socioeconomic disadvantage constrains material resources, health literacy, and caregiving capacity, while at the community level it shapes neighbourhood environments, service accessibility, and exposure to risk-promoting contexts (Schwendicke *et al.*, 2015; Peres *et al.*, 2019b). Crucially, much of the literature examining SEC and caries remains predominantly associative and cross-sectional, limiting causal inference and obscuring the dynamic and cumulative nature of socioeconomic exposures across early life. Focusing solely on proximal behaviours such as toothbrushing and diet risks obscuring these upstream structural drivers and may inadvertently

individualise what are fundamentally social inequalities (Watt, 2007; Marmot *et al.*, 2010).

Health behaviours relevant to dental caries, including toothbrushing, sugar consumption, and dental attendance, are established early and are strongly shaped by both family and community contexts (Lawlor and Mishra, 2009). These behaviours reflect broader social inequalities related to income, education, and employment, reinforcing the need to examine socioeconomic circumstances alongside, rather than instead of, family and community determinants when investigating childhood caries.

1.2.6 Life Course Epidemiology

The Fisher-Owens conceptual model incorporates a temporal dimension, recognising that influences on children's oral health operate and change over time (Fisher-Owens et al., 2007). This provides a useful basis for considering childhood dental caries within a life-course epidemiological framework. Life-course epidemiology examines how exposures at different stages of development may influence subsequent health, with particular emphasis on the timing and duration of exposures, the accumulation of risk, and changes in socioeconomic circumstances over time (Ben-Shlomo and Kuh, 2002; Kuh et al., 2003).

These concepts are particularly relevant to dental caries because caries experience accumulates over time, while oral health behaviours develop and change throughout childhood in response to evolving family- and community-level influences (Heilmann et al., 2015). A life-course perspective therefore extends the Fisher-Owens framework by considering not only the different levels at which risk factors operate, but also how exposures and their potential consequences develop over time. This is particularly important when examining socioeconomic inequalities, as a single measure of socioeconomic position may not distinguish between persistent disadvantage and temporary exposure. Longitudinal measures can instead identify patterns of socioeconomic stability, mobility and cumulative exposure, providing greater insight into the development of inequalities in childhood caries. The limited availability of longitudinal studies incorporating clinically measured oral health outcomes remains an important constraint on understanding how early-life socioeconomic

circumstances and behavioural exposures relate to subsequent oral health (Heilmann et al., 2015).

A life-course perspective therefore provides a theoretical basis for understanding how socioeconomic circumstances, family environments and oral health behaviours may interact over time to shape childhood dental caries. Examining both early-life exposures and changes in socioeconomic circumstances is important for distinguishing the potential effects of persistent disadvantage from those associated with socioeconomic mobility. This perspective highlights the need for longitudinal research that considers socioeconomic circumstances alongside behavioural and family influences, using clinically measured oral health outcomes to improve understanding of how inequalities in childhood caries develop and persist.

1.3 Global Burden of Dental Caries in Children

Dental caries is the most prevalent noncommunicable disease worldwide and has been described as a persistent global epidemic (Jin *et al.*, 2016; World Health Organization, 2022). While adults contribute substantially to the overall burden, childhood caries represents a distinct and prominent public-health challenge. Young children are more susceptible to dental caries with their own unique risk factors (Seow, 1998; Anil and Anand, 2017), this is due to their newly erupted teeth and their relatively immature immune system (Seow, 1998).

According to the Global Burden of Disease (GBD) Study 2021, untreated dental caries in permanent teeth remains the single most common health condition globally, affecting approximately 2.37 billion people; with over 510 million children experiencing caries in their primary (deciduous) teeth (World Health Organization, 2022). A systematic review estimated global prevalence at approximately 48% in children under five, with substantial geographic variation (Uribe, Innes and Maldupa, 2021).

A global meta-analyses report looking at prevalence of caries in child (1-9 years old) using multiple reputable search engines found a possible 2870 mostly high-quality cross-sectional observational studies from 1995 to 2019. Using the binomial distribution variance formula and weighted mean a weighted average

of all included studies suggest a prevalence of 46.2% (from 81 studies) in primary teeth and 53.8% (from 83 studies) in permanent teeth among children from birth to seven years (Kazeminia *et al.*, 2020). Broader global data for children aged 5–14 show a 15% increase in permanent-teeth caries incidence between 1990 and 2019, suggesting that older children carry a larger share of the burden (Huang *et al.*, 2024). It is important to note that new caries lesions will continue to develop at all ages (Fejerskov, Nyvad and Kidd, 2015), and caries experience increases with age as the disease is cumulative (Moynihan, 2016).

1.3.1 Global Economic Burden of Dental Caries in Children

In 2019, the five main oral conditions—caries of deciduous teeth, caries of permanent teeth, chronic periodontitis, edentulism, and other disorders (e.g., tooth, tongue, and jaw conditions)—were estimated to cost the global economy US $710 billion, comprising US $387 billion (range: US $327–404 billion) in direct treatment costs and US $323 billion (range: US $186–460 billion) in productivity losses (Jevdjevic and Listl, 2025); untreated caries specifically was attributed with $23.99 billion of the global productivity losses.

Childhood caries imposes substantial economic costs on families and health systems. In 2015, global productivity losses attributable to caries in primary teeth were estimated at US $0.90 billion (Righolt *et al.*, 2018). Given rising treatment costs and broader inclusion of data in recent estimates, these losses are likely higher today (Jevdjevic and Listl, 2025).

Treatment is often intensive, involving restorative care, extractions, and the use of general anaesthesia due to the young age of affected children (Righolt *et al.*, 2018). The economic impact underscores the importance of effective prevention to reduce both family burden and health-system costs.

1.3.2 Global Socioeconomic Inequalities in Dental Caries in Children

Oral health inequalities have persisted for decades across global, national, and subnational levels (Scottish Dental Epidemiological Co-Ordinating Committee, 2003; Macpherson *et al.*, 2010). Low-middle income countries bear a disproportionately high burden due to limited access to preventive care,

fluoridated products, and oral-health services (World Health Organization, 2022). Within countries, socioeconomic factors strongly influence prevalence: children from lower-income households experience higher rates of caries, less frequent toothbrushing with fluoridated toothpaste, and delayed or reactive dental attendance (Moynihan and Kelly, 2014; Peres *et al.*, 2019b; Maklennan *et al.*, 2024).

Globally, only 35% of children in low-income countries have access to oral-healthcare services, compared with 75% in upper-middle-income countries (Hosseinpoor, Itani and Petersen, 2012). These disparities in access and behaviours exacerbate inequalities in caries experience from early life, perpetuating a social gradient of oral disease.

International-level economic inequalities are starkly reflected in per-capita dental expenditures. High Income Countries spend an average of $260 per person annually, while low-income countries spend just $0.52, representing a nearly 500-fold difference (Jevdjevic and Listl, 2025). However, high expenditure does not automatically equate to good health outcomes or an equitable system. The United States spends the most per capita on healthcare (roughly twice as much as other high-income nations) yet frequently ranks low on life expectancy and has the highest prevalence of chronic diseases among other high-income countries (Rust, 2017).

1.4 Burden of Dental Caries in Children in the United Kingdom

Across the United Kingdom, epidemiological data on childhood dental caries are collected in line with guidance from BASCD (Pitts et.al, 1997), which has provided a coordinated framework for over 30 years to ensure consistent diagnostic criteria, particularly the DMFT/dmft indices, across NHS dental surveys. This standardisation supports some degree of national and local comparison of child oral health across England, Wales, Scotland, and Northern Ireland, although comparability is constrained by differences in service delivery following devolution and methodological differences in survey implementation, particularly the opt-in consent model used in England, which may introduce

selection bias and reduce representativeness relative to other UK nations employing alternative consent procedures.

BASCD-coordinated child dental health surveys began in 1985/86 in England and Wales, with Scotland joining in 1987/88 and Northern Ireland in 1993/94. Originally, identical school-based surveys examined children aged 5, 12, and 14 within a four-year cycle. Since 2003, survey programmes have diverged to reflect local priorities: Scotland surveys 5- and 12-year-olds annually; England and Wales examine these age groups in two years of a four-year cycle while using other years to survey additional populations; and Northern Ireland, although not conducting routine cycles, has used the same BASCD standards when surveys are undertaken.

Dental caries remains one of the most prevalent non-communicable diseases affecting children in the UK. Although overall prevalence has declined substantially over recent decades, a significant burden persists, particularly in primary teeth and in socioeconomically disadvantaged groups. Scotland will be detailed in the Section 1.5.

In England in 2023/24, the most recent National Dental Epidemiology Programme survey reported that approximately 23% of 5-year-olds examined (around 13% of the total population examined) had caries experience (Office for Health Improvement and Disparities, 2025). In Wales (2024/25), around 27.2% (95% CI: 26.3%–28.0%) of 5-year-olds examined (approximately 27% of the population examined) had caries experience in primary teeth—representing a marked improvement from nearly 50% twenty years ago (Cope, Barnes and Brocklehurst, 2026).

In Northern Ireland, although surveys are not conducted as routinely as in other UK nations, a prevalence of 36.5% was reported in 2019 among examined Primary 1 children (around 5% of the population examined), down from 61% in 2003 and over 90% in 1963 (Donovan, Sheehan and O'Sullivan, 2021; Crealey, Kelly and Donaldson, 2023). In Scotland, prevalence among 5-year-olds is reported at population level and is generally slightly higher than England but lower than Wales and Northern Ireland (Conway *et al.*, 2025).

Across England, Wales, and Northern Ireland, survey data are collected by trained and calibrated dental examiners using standardised visual diagnostic criteria in line with BASCD principles. England's National Dental Epidemiology Programme surveys representative samples of 5-year-olds biennially across local authority areas, while Wales conducts regionally sampled surveys across Dental Planning Areas coordinated by Public Health Wales. Northern Ireland follows the same protocol under the Public Health Agency. Rigorous calibration and standardisation procedures promote inter-examiner reliability and comparability; however, as these surveys are sample-based and vary slightly in administration and coverage, some underestimation of true population prevalence may occur.

Despite improvements in prevalence, the clinical burden remains substantial. Childhood caries continues to be the leading cause of hospital admissions for dental treatment among children in England, with tens of thousands of extractions performed under general anaesthetic each year—most attributable to decay (Knapp, Marshman and Rodd, 2017; Godson, Csikar and White, 2018). In the 2022–2023 financial year, NHS England recorded 47,581 tooth-extraction episodes among individuals aged 0–19 years, 66% of which were due to dental caries, with the national rate of decay-related hospital tooth extraction episodes among individuals aged 0–19 years was 229 per 100,000 population. (Office for Health Improvement and Disparities, 2024). Similar hospital-based burdens are reported in Northern Ireland (Donovan, Sheehan and O'Sullivan, 2021). These data underscore the continuing reliance on hospital-based interventions and highlight the importance of sustained preventive strategies across family, school, and community settings.

1.4.1 Economic Burden of Dental Caries in Children in United Kingdom

Childhood caries imposes substantial economic costs on the UK health system. For example, in 2022–2023, the total cost of decay-related tooth extractions under general anaesthetic in NHS England hospitals was estimated at £45.8 million, out of the £74.8 million for all child tooth extractions (Office for Health Improvement and Disparities, 2024). Intensive treatment needs, including restorations and general anaesthesia, contribute heavily to this cost. Although

comparable cost data are less routinely reported for the other UK nations, per capita expenditure is likely to be similar or potentially higher, given comparable NHS service structures and, in some areas, higher caries prevalence despite devolved healthcare systems.

A cohort simulation model was developed to estimate the lifetime direct costs of dental caries across socioeconomic groups in six high-income countries: the United Kingdom, United States, Germany, France, Australia, and Canada (Dunleavy *et al.*, 2024). The model simulated a population cohort over time, tracking individuals from early adolescence into older adulthood, and incorporated disease progression, treatment needs, and age-related mortality. Costs were estimated by applying the cost of treatment per affected tooth, multiplied by the number of teeth requiring treatment and adjusted for the probability of receiving treatment within each socioeconomic group. Population estimates for the 10–14-year age group were used as the starting point, with the cohort then projected forward to ages 60–64 years, accounting for general population mortality rates over time. The United Kingdom demonstrated the highest lifetime cost burden, totalling approximately £13 billion overall, or around £17,200 per person.

1.4.2 Socioeconomic Inequalities in Dental Caries in Children in the United Kingdom

Socioeconomic inequalities in childhood caries are consistently observed across the UK, with a clear and persistent social gradient in both prevalence and severity of disease. Children living in more socioeconomically deprived communities experience substantially higher levels of dental decay, poorer oral health behaviours, and a greater likelihood of requiring hospital-based dental treatment than those in more affluent areas (Donovan, Sheehan and O'Sullivan, 2021; Crealey, Kelly and Donaldson, 2023; Public Health Wales, 2024; Conway *et al.*, 2025; Office for Health Improvement and Disparities, 2025).

In England, five-year-olds living in the 20% most deprived areas are more than twice (32.2% vs 13.6%) as likely to have experienced dental decay compared with those in the least deprived areas (Office for Health Improvement and Disparities, 2025). A comparable if slightly less stark pattern is evident in Wales, where

caries experience prevalence among five-year-olds is 37.6% (95% CI: 35.4–39.7) in the most deprived quintile compared with 19.8% (95% CI: 18.1–21.6) in the least deprived. Children in the most deprived communities also experience greater disease severity, with a higher mean number of affected teeth (Office for Health Improvement and Disparities, 2025); and a retrospective cohort study using linked primary care and hospital electronic health records in London on 608,278 children aged 5–16 years born between 1 January 2001 and 31 December 2017 finding children in the most deprived areas have 4–5 times higher rates of dental general anaesthetic when compared to the least deprived. Although recent improvements have been observed overall, the overall inequality gap has remained largely unchanged since 2007/08.

In Northern Ireland in the 2018/19 school year, deprivation-related disparities are similarly pronounced. The prevalence of dental decay experience is 45.3% among children from the 20% most deprived areas compared with 16.3% among those from the least deprived areas, based on deprivation quintiles derived from home address (Crealey, Kelly and Donaldson, 2023). These findings are consistent absolutely with earlier evidence but relatively smaller still demonstrating substantial inequality (38% versus 10%) (Donovan, Sheehan and O'Sullivan, 2021).

Scotland demonstrates a comparable socioeconomic gradient in childhood caries prevalence and severity (Conway *et al.*, 2024); this is explored in greater detail in Section 1.5.2. Overall, while national prevalence of childhood caries has declined over recent decades, the burden of disease remains disproportionately concentrated in deprived populations across all UK nations.

These inequalities extend beyond just prevalence though. Children in disadvantaged households are also less likely to receive preventive care, brush regularly with fluoridated toothpaste, or attend routine dental appointments, and more likely to consume high-sugar diets (Moynihan and Kelly, 2014; Peres *et al.*, 2019b).

Marked geographical inequalities in hospital tooth extraction rates are evident across England. In 2023/24, the highest rate of decay-related tooth extraction episodes was reported in Yorkshire and the Humber at 454 per 100,000

population aged 0–19 years, compared with only 70 per 100,000 in the East Midlands (Office for Health Improvement and Disparities, 2024).

The cohort simulation model developed to estimate the lifetime direct costs of dental caries across socioeconomic groups for the 10–14-year to ages 60–64 years, found costs in the UK were unevenly distributed across socioeconomic groups (Dunleavy et al., 2024). With individuals in the two most deprived groups experiencing approximately 37% higher lifetime costs (≈ £21,400) compared with the least deprived groups (≈ £15,600), based on area-level deprivation measures.

The COVID-19 pandemic has further exacerbated inequalities by interrupting school-based oral health improvement programmes, which play a key role in equitable prevention (Gargano, Mason and Northridge, 2019; World Health Organization, 2022).

1.5 Burden of Dental Caries in Children in Scotland

Scotland has historically carried one of the highest burdens of childhood caries in the UK (Scottish Dental Epidemiological Co-Ordinating Committee, 2003; Macpherson *et al.*, 2010). Prevalence declined substantially from the 1970s through the 1990s, largely due to the introduction of daily fluoride toothpaste (Vos, 2020; Li, Yu and Chen, 2025). This progress plateaued in the early 2000s, prompting the national child oral health improvement programme: Childsmile (Section 1.9).

National data on caries experience prevalence are collected annually through the National Dental Inspection Programme (NDIP) at approximately ages 5 (Primary 1) and 11 (Primary 7), covering around 79.0% of population of P1 children in Scotland (Conway *et al.*, 2025). Among Primary 1 children, the percentage with no obvious caries experience rose from 45.0% in 2003 to 73.5% in 2020, slightly declining to 73.1% following COVID-19 disruptions, before increasing again to 76.5% by 2025 (Macpherson *et al.*, 2020; Conway *et al.*, 2022; Conway *et al.*, 2025). Despite these improvements, nearly a quarter of children still have caries experience, reflecting a persistent public-health burden.

Caries-related extractions under general anaesthesia remain the leading cause of elective hospital admissions among children in Scotland. In 2019/20 there were 7,291 admissions for dental extractions in children, with the rate of paediatric dental extractions under general anaesthesia being 652.8 per 100,000 children and young people (aged 0–17) by 2023 (Public Health Scotland, 2022a; Public Health Scotland, 2025c).

Poor oral health in childhood can affect children's school attendance and overall wellbeing. Children with caries experience tend to miss more school than their caries-free peers: on average, children without caries experience miss about 11 part-days per year, compared with around 16 part-days for children with caries experience. The number of absences rises among those requiring more intensive treatment—19 for children needing urgent dental care and 20 for those undergoing tooth extractions under general anaesthetic (Goulart *et al.*, 2025). These differences show that untreated dental disease can disrupt education and social development, extending its impact beyond clinical health.

1.5.1 Economic Burden of Dental Caries among Children in Scotland

Childhood caries imposes substantial costs on NHS Scotland. In the quarter ending June 2022, NHS General Dental Services delivered 219,245 courses of treatment to children under 18. Extrapolated annually, this equates to approximately 877,000 courses of treatment, up from the last pre-covid quota 471,000 in 2019/20 which had been on a steady decrease since 2013/14. Of the total 877,000 it is estimated 38% the annualised courses of treatment relate to restoration/extraction and other procedures likely to be associated with dental caries (Public Health Scotland, 2020; Public Health Scotland, 2022b). However, the steep rise in 2022 may be largely attributed to all child examinations being made claimable in February 2022.

Cost per registered child was £82 in 2019/20, slightly up from £81 in 2018/19, but has shown stable real-term expenditures over the decade (Public Health Scotland, 2020). This could suggest the overall economic burden of dental caries in children could have be decreasing since a possible peak of over £68 million in 2013/14, at least up until the pandemic (Public Health Scotland, 2020).

Hospital-based dental care under general anaesthesia is a significant contributor: in 2016, general anaesthetic dental extractions in children aged 0-18 across Dundee, Edinburgh, and Glasgow alone cost an estimated £1.7 million per year (NHS Scotland, 2017). These figures illustrate the ongoing reliance on high-cost interventions despite preventive initiatives.

1.5.2 Socioeconomic Inequalities in Dental Caries in Children in Scotland

Socioeconomic inequalities persist among Scottish children. NDIP data show that although the proportion of Primary 1 children with no obvious caries experience has increased across all levels of deprivation, a substantial gap remains: in 2020, 60.1% of children in the most socioeconomically deprived areas were caries-free compared to 83.9% in the least deprived areas — an over 20 percentage-point difference (Conway *et al.*, 2024).

These inequalities influence both access and behavioural factors. Children in Scotland from socioeconomically deprived communities are more likely to experience higher caries prevalence (Conway *et al.*, 2024) and more barriers with access to health care (Scottish Government, 2025d); including dental services (Scottish Government, 2025c). The COVID-19 pandemic amplified these disparities by disrupting preventive and routine care services (Conway *et al.*, 2022; Public Health Scotland, 2025c).

In 2023, there was a 15.7-fold variation in the age-sex standardised rate of hospital paediatric dental extractions under general anaesthesia across NHS Boards, ranging from 107.9 to 1,689.0 per 100,000 population (Public Health Scotland, 2025c). Extraction rates were consistently highest among children and young people living in the most socioeconomically deprived areas, highlighting the strong association between deprivation and severe dental disease.

Evidence indicates that children with poor oral health on average miss more days of school than their caries-free peers, with this effect exacerbated by deprivation, compounding existing educational and health inequalities (Goulart *et al.*, 2025). The children with dental caries living in 10% most deprived area experienced an increase of 6 part day absences when compared to their non-

caries experience suffering peer, whereas the least deprived only saw an increase of 3.8 absences on average. These socioeconomic variations were not present in more extreme caries cases; those that required urgent dental treatment or had undergone dental general anaesthetic, however this could be partially explained by the lower counts and wider confidence intervals.

These patterns highlight that childhood dental caries in Scotland remains both a preventable condition and a marker of broader social inequality, underscoring the importance of proportionate, population-level preventive programmes such as Childsmile.

1.6 Measuring Socioeconomic Determinants of Inequalities in Dental Caries

Socioeconomic circumstances (SEC) play a central role in shaping inequalities in dental caries among children, influencing exposure to risk factors, access to preventive care, and the resources available to support oral health. Consequently, many of the inequalities observed in childhood caries reflect social conditions that, at least in part, can be targeted by policy and public health intervention.

Historically, public health research has relied on a small set of core individual indicators—most commonly education, income, and occupation—because each captures a different facet of social advantage and has been shown to relate to key health outcomes through distinct pathways (Krieger, Williams and Moss, 1997; Braveman *et al.*, 2005; Cutler and Lleras-Muney, 2006). However, individual indicators alone may overlook contextual influences such as neighbourhood deprivation, housing conditions, access to services, and wider policy environments that also shape health outcomes (World Health Organization, 2010; de Aquino Goulart *et al.*, 2025).

Area-based measures of deprivation, such as those derived from Townsend's framework and later multidomain indices, capture neighbourhood-level conditions including housing quality, service access, environmental exposures and local labour markets, all of which shape opportunities independently of individual characteristics (Townsend, 1987; Noble *et al.*, 2006; Scottish

Government, 2020a). In the absence of individual-level measures of socioeconomic position, area-based measures may act as proxies for individual circumstances. However, while area-based measures provide valuable insights into contextual disadvantage, they have limited accuracy in identifying individual socioeconomic circumstances because they cannot capture variation between individuals living within the same area (McCartney *et al.*, 2023). In Scotland, the Scottish Index of Multiple Deprivation (SIMD) has been the primary tool for quantifying area-level disadvantage in research evaluating the child oral health improvement programme in Scotland, Childsmile, offering a practical, if imperfect, method for assessing socioeconomic inequalities (Scottish Government, 2020a).

Using both individual and area-level measures therefore provides a more comprehensive and theoretically grounded assessment of socioeconomic circumstances, reducing misclassification and strengthening the validity of analyses seeking to understand social inequalities (Conway *et al.*, 2019). However individual SEC and the inter-relationship with area-based SEC have thus far not been examined in relation to dental caries in Scotland.

1.7 Prevention and Tackling Socioeconomic Inequalities in Dental Caries

A mounting body of global research has consistently highlighted the patterns of oral health inequalities that persist across all stages of life. While considerable work has been done in developing theories and frameworks for prevention, much less progress has been made in the practical implementation and rigorous evaluation of policy interventions aimed at reducing these unjust and avoidable inequalities (Watt, 2023). This gap reflects a broader pattern observed in the social determinants of health, as emphasised in the work of Marmot et al. (2010), which demonstrates that health inequalities are deeply rooted in socioeconomic, environmental, and structural factors. Against this backdrop, there is a critical need for transformative reforms to oral health systems and policies, co-designed with communities and key stakeholders, to address these entrenched inequalities. Initiatives to tackle oral health inequalities can only be effectively developed when the underlying determinants and root causes of the problem are thoroughly identified and understood (Watt, 2007). Achieving this

understanding is essential for informing and guiding interventions that are appropriately targeted, evidence-based, and capable of promoting equitable oral health outcomes across populations.

1.8 Framework for Tackling Socioeconomic Inequalities in Dental Caries

The Conceptual Model of the World Health Organization Commission on Social Determinants of Health (CSDH) provides a multi-level framework for understanding the origin and perpetuation of health inequalities (World Health Organization, 2010). The framework conceptualises health inequities as the product of socially structured processes, whereby upstream political and socioeconomic forces shape individuals' living conditions and, ultimately, health outcomes. Determinants are categorised as structural, intermediate, and outcomes related. Structural determinants include the broader socioeconomic and political contexts, such as education systems, social protection policies, and power structures. Intermediate determinants encompass material conditions, behaviours, and psychosocial factors, which mediate the effects of structural determinants on health. Health inequalities represent the resulting inequalities in outcomes across populations.

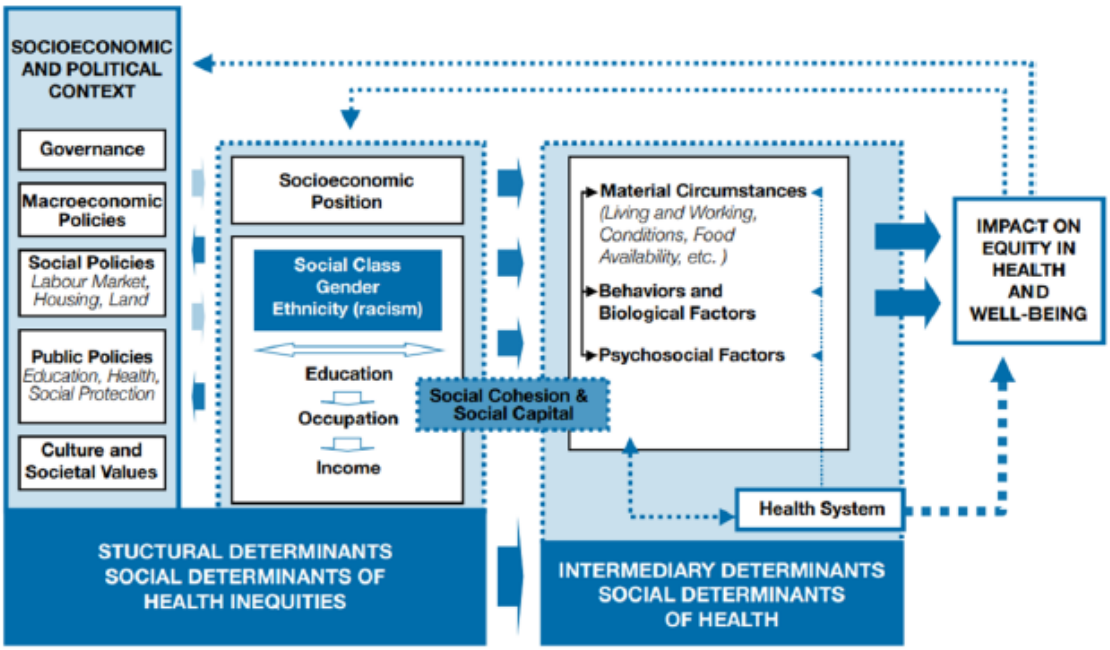


Figure 1.2 - Conceptual model of the WHO Commission on Social Determinants of Health (World Health Organization, 2010)

This framework is directly relevant for planning interventions, as it highlights that effective strategies must target determinants at multiple levels. Integrating the CSDH model with other frameworks, such as Fisher-Owens Conceptual Model of influences of children's oral health (Fisher-Owens *et al.*, 2007), enables an empirical examination of how contextual factors, such as area-level deprivation, interact with individual factors to produce oral health inequalities.

1.8.1 Proportionate Universalism

The CSDH model clarifies where to act, but a guiding principle is needed to ensure these actions reduce, rather than widen, inequalities. This is provided by proportionate universalism (Marmot *et al.*, 2010), which advocates for universal accessibility while tailoring the intensity of support according to levels of socioeconomic deprivation. Communities or individuals facing greater socioeconomic deprivation receive more intensive support, while universal strategies continue to benefit the wider population. This approach ensures that resources are allocated equitably along the socioeconomic gradient, preventing interventions from being disproportionately utilised by those with lesser need. It is the key to operationalising the CSDH framework effectively.

1.8.2 Multi-Level Intervention Strategies for Tackling Inequalities in Dental Caries

Guided by the principle of proportionate universalism, preventive interventions should be operationalised across upstream, midstream, and downstream levels, corresponding closely with the CSDH framework to effectively tackle health inequalities (World Health Organization, 2010; Peres *et al.*, 2019b; Watt, 2023).

Upstream interventions encompass structural changes such as policies implemented at a government or council level. These measures aim to address oral health inequalities at a broader societal level. Watt (2007) provided practical examples of local and national upstream actions to promote oral health in children. These include the development of oral health and nutrition policies in nurseries and schools, appropriate infant feeding policies, restrictions on television advertising of foods and drinks targeting children, tighter food labelling regulations, and fiscal measures such as the sugar tax. The fluoridation of water supplies is considered an effective upstream approach for reducing dental caries at a population level (McDonagh *et al.*, 2000), however there was a large anti-water fluoridation sentiment expressed by the public in a national consultation on oral health in early 2000s (Scottish Executive, 2002).

Midstream interventions focus on reducing social and environmental barriers that may hinder engagement with health and oral health services, placing responsibility on systems to improve accessibility rather than on communities to independently navigate complex services (Marmot *et al.*, 2008). These interventions aim to equip at risk communities with skills in areas such as self-empowerment, resilience, budgeting, cooking on a low budget, and access to healthy foods and services. Oral health can be incorporated into existing health services including antenatal classes, weaning clinics and universal early year health checks (Macpherson, Rodgers and Conway, 2019a). The Glasgow-based 'Pre-5-Year-Old Oral-Health-Gain Project' delivered supervised toothbrushing, distributed dental supplies, and ran parent workshops in deprived communities, specifically targeting the two most socioeconomically disadvantaged areas, working with nurseries and health visitors to embed routines locally (Blair *et al.*, 2004; Blair *et al.*, 2006). Public Health professionals collaborated with families and early years staff to improve daily oral hygiene and reduce sugar exposure,

which improved behaviours and reduced dental decay; while inequalities within Glasgow were not fully eliminated, child oral health in targeted areas was brought in line with the national average (Blair *et al.*, 2015; Ross *et al.*, 2023). The most effective elements — daily toothbrushing, fluoride toothpaste distribution, parent engagement, and professional collaboration — were carried forward into Childsmile, forming the core of its sustained, population-level approach and highlighting the value of proactive, embedded community delivery rather than placing responsibility solely on families (Marmot *et al.*, 2008; Blair *et al.*, 2015; Ross *et al.*, 2023).

Downstream interventions, by contrast, operate at a micro level and typically involve one-on-one interactions, concentrating on behaviour change and individual support. Caution is needed to ensure these approaches do not exacerbate inequalities, as families of higher socioeconomic status are generally more able to engage with and act upon educational messages (Watt, 2007; Thomson, 2012). This pattern is reinforced by the 'inverse care law', whereby those with the greatest oral health need are least likely to access services (Hart, 1971). Downstream strategies are often time-intensive, costly, and of limited effectiveness unless services proactively reach those most at risk. Nevertheless, preventive interventions delivered in clinical settings — including fluoride-based one-on-one measures — remain potentially important, and health professionals continue to provide behaviour change interventions on sugar reduction and toothbrushing; the challenge is ensuring that these services effectively reach and engage the populations that need them most (Macpherson, Rodgers and Conway, 2019a; NHS England, 2021).

Reducing dental caries prevalence and associated inequalities requires coordinated interventions across all three levels (Watt, 2007), with a mix of targeted and universal services and policies strategically calibrated to level the playing field and address the social gradient in health.

1.8.3 Common Risk Factor Approach for Effective Health Interventions

Complementing multi-level interventions, the Common Risk Factor Approach (CRFA) targets determinants that influence multiple health outcomes, rather

than focusing solely on dental caries (Sheiham and Watt, 2000). Despite strong theoretical support, empirical evidence largely comes from broader multifaceted programmes that incorporate CRFA principles indirectly, such as Childsmile (Briggs *et al.*, 2017). There have been empirical studies that demonstrate that population-level sugar-reduction policies can influence both obesity and dental outcomes, CRFA has however not been specifically evaluated as a discrete intervention targeting oral health (Briggs *et al.*, 2017; Rogers *et al.*, 2023). This means that isolating causal effects remains challenging due to complex intervention components and contextual variability. Integrating oral health into wider health initiatives allows interventions to address shared risk factors holistically, increasing efficiency, equity, and sustainability, while highlighting the systemic importance of oral health within overall well-being (Sheiham and Watt, 2000; Heilmann *et al.*, 2016)

1.8.4 An Integrated Framework for Action: Introducing Childsmile

Reducing dental caries prevalence and associated socioeconomic inequalities requires a cohesive strategy that integrates the multi-level structure of the World Health Organization Commission on Social Determinants of Health framework (Section 1.8), the equitable implementation principle of proportionate universalism, and the efficiency of the common risk factor approach. This integrated model ensures interventions are comprehensive (targeting upstream, midstream, and downstream determinants), equitable (calibrating support to need), and efficient (addressing shared determinants of disease). It is this powerful synthesis of concepts that provides the theoretical foundation for Scotland's national child oral health programme, Childsmile. Childsmile operationalises this very model, it is fundamentally structured on proportionate universalism, delivers multi-level interventions, and incorporates common risk factor strategies to address broader health outcomes (Shaw, Macpherson and Conway, 2009). Section 1.9 will provide a detailed examination of Childsmile's development, implementation, and ongoing evaluation, demonstrating how this theoretical framework is translated into practical, population-wide action.

1.9 Childsmile: A National Programme to improve child oral health and Tackle Child Oral Health Inequalities

Childsmile is a national, complex, and multi-sectoral programme funded by the Scottish Government, established as a direct policy response to stark and persistent oral health inequalities among children as highlighted by a key Scottish Executive policy document (Scottish Executive, 2005). Founded on the principle of proportionate universalism, the programme was designed with two core aims: to reduce the overall prevalence of dental caries and, critically, to narrow the socioeconomic inequality gap by targeting enhanced support to children in areas of highest socioeconomic deprivation while providing universal foundations for all (Macpherson, Rodgers and Conway, 2019a; Macpherson, Rodgers and Conway, 2019b).

By integrating scientific evidence, professional guidelines, and public health principles, Childsmile implements a comprehensive, preventive approach focused on early intervention to promote lifelong oral health and address the social gradient in dental outcomes (Ross *et al.*, 2023). Since its national roll-out in 2011, it has been recognised as a leading example of a policy-driven public health initiative (Ross *et al.*, 2023).

1.9.1 Founding Principles of Childsmile

Childsmile's foundations are explicitly rooted in addressing the social determinants of health and were informed by public health principles outlined in the Ottawa Charter (World Health Organization, 1986), the 2005 clinical guidelines from the Scottish Intercollegiate Guidelines Network (Healthcare Improvement Scotland, 2014), and contemporary evidence from systematic reviews available at the time (McDonagh *et al.*, 2000).

Piloted in 2006, the programme consisted of two distinct demonstration projects designed to test different strategies: one in the East of Scotland delivering nursery- and school-based clinical prevention for children aged three and over, and another in the West of Scotland that targeted children from birth through dental practices and community settings (Turner *et al.*, 2010). This dual-

pathway pilot reflected a commitment to finding effective, multi-level strategies to reach children across the socioeconomic spectrum.

Following the success of these pilots, Childsmile was rolled out nationally and was being delivered in all health board areas throughout Scotland by 2011, creating a unified yet adaptable national programme to tackle childhood dental caries and its underlying inequalities.

1.9.2 Evidence-Based Preventive Interventions

The design of Childsmile was informed by a body of evidence generated from earlier community and clinical oral health initiatives across Scotland. This provided a practical foundation of what worked in the Scottish context. Key learnings were drawn from several sources: the effectiveness of applying fluoride varnishes in primary care dental settings (Donaldson *et al.*, 1986); community projects that combined the distribution of fluoride toothpaste and toothbrushes with collaborative community engagement work to build local knowledge and capacity (Blair *et al.*, 2004; Blair *et al.*, 2006); and models for the early identification of caries risk in pre-school children by health visitors during routine checks (Ballantyne-Macritchie, 2000). To ensure clinical rigour, these practical experiences were formalised and standardised by aligning the programme's core activities with contemporary national evidence-based interventions/and recommendations as systematically reviewed by the Scottish Dental Clinical Effectiveness Programme (Scottish Dental Clinical Effectiveness Programme, 2010) and the Scottish Intercollegiate Guidelines Network (Healthcare Improvement Scotland, 2014).

1.9.3 Theory-Based Development

Alongside empirical evidence, Childsmile's framework was constructed using a theory-driven methodology for public health programme intervention (Macpherson, Rodgers and Conway, 2019b). This approach defined the change mechanisms at the start of the programme, namely the Childsmile interventions, and the context in which they would be delivered (Blamey and Mackenzie, 2007).

A cornerstone of the programme's framework was the systematic engagement of a wide spectrum of stakeholders, from policymakers to families, ensuring that strategies were both practically grounded and politically feasible for achieving sustained outcomes (Macpherson, Rodgers and Conway, 2019b).

Central to this theory-based framework was the development of a set of dynamic logic models mapping how evidence-based activities were expected to lead to short-, intermediate-, and long-term outcomes, including improvements in oral health and reductions in oral health inequalities (Childsmile, 2010; Macpherson, Rodgers and Conway, 2019b). Rather than existing as a single static diagram, these logic models function as an integrated framework guiding the delivery of interventions across multiple settings and stakeholders.

The logic models illustrate how programme inputs, activities, outputs, and intended outcomes are connected. They show how resources and intervention activities delivered across multiple levels and settings lead to key outputs, including behaviour change, service access and uptake, and intervention reach. These outputs are expected to contribute to improved health and social outcomes, particularly better oral health and reduced inequalities. In this way, the framework provides a structured basis for programme delivery and supports subsequent evaluation of both implementation and outcomes (Eaves and Gnich, 2013; Childsmile Central Evaluation & Research Team, 2019).

The synthesis of this evidence- and theory-informed approach resulted in a uniquely integrated, multi-agency programme. Childsmile was deliberately designed to connect professionals across the system—including health visitors, nursery and school staff, community workers, and dental teams—thereby enacting a coherent strategy in multiple settings and across upstream, midstream, and downstream levels of intervention (Macpherson *et al.*, 2010).

This multi-level system 1.8.2) is delivered through the overarching principle of 'Proportionate Universalism' (Section 1.8.1), ensuring that the intensity of support is responsive to the level of socioeconomic disadvantage (Macpherson, Rodgers and Conway, 2019b).

1.9.4 Components of Childsmile

The main components foundationally remain intact since Childsmile's inception. The Childsmile programme in Scotland is organised around three principal settings— primary care dental practices, community, and educational (nursery and school)—delivering a combination of universal and targeted interventions (Macpherson, Rodgers and Conway, 2019b):

- In the primary care dental setting, universal behaviour change interventions comprising of dietary guidance and oral hygiene instructions and demonstrations, as well as universal fluoride varnish (FV) application twice yearly from age two for all children attending. Higher-risk children may receive enhanced preventive care; such as more frequent fluoride varnish application, fluoride toothpaste provision, targeted dietary and oral hygiene behaviour change interventions, and referral to dental health support workers for ongoing follow-up.
- In the community setting, Dental Health Support Workers (DHSWs) operate alongside health visitors to support families with children at greater risk or poor oral health, providing dietary support, practical home-based oral health guidance, facilitating dental registration, and community linking (Fletcher, 2024).
- In the educational setting, nursery supervised toothbrushing is delivered universally, whereas primary school toothbrushing and fluoride varnish application in school and nursery are targeted to children in areas of higher deprivation, based on health board level Scottish Index of Multiple Deprivation measures (Public Health Scotland, 2024b).

A cross-cutting feature underpinning all settings is the national procurement and distribution system for dental packs. NHS National Services Scotland manages a national contract to supply toothbrushes and 1,450 ppm fluoride toothpaste, packaged into age-appropriate kits. These are distributed across all health boards across Scotland for use in the nursery and school supervised toothbrushing programme and distributed to families through health visitors, DHSWs, dental practices, and early years settings to maintain consistency across Childsmile's universal and targeted components to facilitate home toothbrushing (Karamat, 2023).

Overall, the programme can be broken down into four main components (Macpherson, Rodgers and Conway, 2019b):

- Tailored community support via DHSWs for targeted families at greatest risk of poor oral health- incorporates home based behaviour change interventions for diet and toothbrushing, facilitated registration with a dentist when appropriate and facilitated links to wider community services and resources.
- Universal prevention delivered in primary care dental practices (diet, toothbrushing and fluoride varnish applications)
- Supervised daily toothbrushing in all nurseries (universal) and some targeted primary schools
- Targeted nursery and school fluoride varnish applications.

These components integrate dental practice, community, and educational settings to improve oral health and reduce inequalities, detailed in Sections 1.9.4.1 - 1.9.4.4.

1.9.4.1 Dental Health Support Workers

Families requiring additional support are identified by Health Visitors between 6-8 weeks and five years old and referred to local DHSWs (Turner *et al.*, 2010). DHSWs provide age-appropriate behaviour change interventions, including practical home-based toothbrushing support, dietary guidance, and the distribution of dental packs. They also facilitate dental attendance and tailor interventions to each family's needs. DHSWs link families to wider community and third-sector services addressing social determinants of health. This includes financial or social support, illustrating that their role extends beyond health education into practical behaviour change support (Hodgins *et al.*, 2018; Macpherson, Rodgers and Conway, 2019b).

In 2024/25, 11,203 children in Scotland were newly referred to a DHSW, during the same period 12,270 children were successfully contacted, with some referrals carried over from previous years and some repeat contacts. Referrals predominantly came from Health Visitors (approximately 70%), with smaller contributions from clinics, dentists, NHS-24, self-referrals, and other sources.

Children from the most deprived areas were a focus: 37.1% of referred children (4,157/11,203) and 38.8% of children with at least one kept appointment (4,693/12,090) were from SIMD1, highlighting targeted support for higher-risk communities (Childsmile Central Evaluation & Research Team, 2025).

Previous work has suggested that aspects of DHSW involvement support earlier dental attendance using population-level routine data within a quasi-experimental natural experiment design (Hodgins *et al.*, 2018). Qualitative studies indicate that DHSWs may use motivational interviewing and other behaviour change techniques, but formal application of behaviour change techniques is not consistently documented (Ross *et al.*, 2023). With a previous thesis having reported that DHSWs only have the resources to support families who were identified at being low- to- medium-risk of caries instead of those at highest risk of caries (Young, 2017).

1.9.4.2 Dental Primary Care Component

Since 2011, within General Dental Services in Scotland, preventive behaviour change interventions and fluoride varnish applications have been offered universally twice yearly to all children attending dental practices from the age of two (Childsmile, 2011). Some evidence indicates that approximately 70 % of children access dental practice-based preventive services (Kidd *et al.*, 2020). However, the study was restricted to a single birth cohort from the national dental inspection programme, limiting it to children born within a narrow period. This introduces potential selection bias and constrains the generalisability of the findings to other cohorts and settings. There were also many potential confounding factors impacting dental attendance to consider.

All contacts within the dental practice provide opportunities for the whole dental team to share key behaviour change interventions with families. Formal interventions include dietary interventions, offering practical information on nutrition and drinks to foster good oral health behaviours and prevent decay. Toothbrushing interventions covers when to brush, appropriate brushes and toothpaste, the amount of toothpaste to use, and methods of brushing, including demonstrations and parental supervision for younger children to support skill acquisition (Macpherson, Rodgers and Conway, 2019a; Public Health Scotland,

2024a). The focus has shifted from standardised health education messages to more tailored messages embedded in behavioural and implementation science (Ross *et al.*, 2023). Fluoride varnish applications are delivered to all children twice yearly from the age of two, with medical histories reviewed to ensure there are no contraindications. These preventive activities in General Dental Service practice are now recognised in NHS dental payment arrangements in Scotland, supporting the delivery of this core preventive care (Scottish Government, 2023).

The initial appointment may be with an Extended Duty Dental Nurse (EDDN) to assess the level of support required, with follow-up visits either in conjunction with dentist appointments or independently, depending on the needs of the family. Interventions are tailored to the age of the child and the circumstances of the family, and the dental team works with parents to agree a key action plan to focus on until the next session (Public Health Scotland, 2024a).

Children at increased risk of caries, including those in the most socioeconomically deprived areas (20% SIMD), may receive a more intensive programme of care, either through longer appointments, more frequent visits, or more frequent fluoride varnish applications usually delivered by an EDDN, and practices are paid an enhanced capitation payment for this (Scottish Government, 2023).

In 2024/25 93.6% (973/1,040) of independent contractor General Dental Service practices were delivering Enhanced Preventive Advice & Treatment (including Childsmile) in the 2024/25 financial year, 42.1% (60,777/144,282) of zero to two years registered with an NHS dentist with 98.8% (60,062/60,777) of zero to two-year-olds who were registered with an NHS dentist in Scotland received one count of Enhanced Preventive Advice & Treatment. By age three to five, 78.7% (123,218/156,457) are registered with a dentist with 70.6% (86,970/123,218) of these three to five-year-olds receiving at least one count of these interventions (Childsmile Central Evaluation & Research Team, 2025).

This universal and targeted clinical approach complements home, community, and educational interventions, ensuring that all children in Scotland have access

to early preventive care, which contributes to reductions in both overall caries prevalence and oral health inequalities.

1.9.4.3 Nursery and Targeted Primary School Supervised Toothbrushing Programme

The Childsmile toothbrushing programme provides a structured approach to support oral health for children across Scotland. In nurseries, supervised toothbrushing is offered universally to all attending children, providing a consistent daily preventive routine. National standards govern infection control, product quality, and supervision protocols (Childsmile, 2023). Participation at the establishment level is high, with approximately 95.3% (2,469/2,591) of pre-school establishments taking part in 2024/25 (Childsmile Central Evaluation & Research Team, 2025). Individual exposure may vary due to staffing, logistics, and infection control practices, but the programme ensures access to resources, training, and support, providing a strong universal preventive foundation.

In primary schools, supervised toothbrushing is targeted to selected classes in areas of higher socioeconomic deprivation, guided by the Scottish Index of Multiple Deprivation (SIMD). In 2024/25, 58.0% (1,143/1,971) of primary schools participated, well above the 20% target (Childsmile Central Evaluation & Research Team, 2025). An early observational study found that participation of schools was higher in more deprived areas (Anopa *et al.*, 2015).

The Childsmile team ensures establishments are equipped and supported to meet these standards through the provision of resources, including sufficient stock between biannual visits and accessible standards documentation, alongside training for all relevant staff, with updates provided annually and prior to new staff participation (Public Health Scotland, 2023b). Establishments receive at least two monitoring visits per school year from NHS staff to review adherence, check supplies, distribute home packs, support related preventive activity such as fluoride varnish consent processes, and provide feedback. These visits are recorded on the Health Informatics Centre (HIC) system to evidence compliance and participation. The programme operates under a passive consent model, with opt-out registers maintained locally, and incorporates the Recycle and Smile initiative to promote sustainability.

To promote home toothbrushing, every child is also provided with a dental pack (containing a toothbrush and a tube of fluoride toothpaste) on at least six occasions by the age of five, initially by the health visitor and then via nursery and dental health support workers. Children also receive a free-flow feeder cup by one year of age (Macpherson, Rodgers and Conway, 2019b).

While participation indicates the school is engaged, it does not provide a measure of day-to-day adherence or effectiveness, emphasising the importance of monitoring and support visits. Economic evaluations suggest that supervised toothbrushing is likely cost-effective and may reduce future dental treatment expenditure, although attributing effect in a multi-component programme requires caution (Anopa *et al.*, 2015). Childsmile's supervised nursery toothbrushing programme has been shown to be cautiously clinically- and cost-effective in very early stages (Anopa *et al.*, 2015; Kidd *et al.*, 2020).

1.9.4.4 Fluoride Varnish Application in Nursery and School

FV is a highly concentrated topical fluoride preparation applied to the tooth surface to prevent dental caries (Marinho *et al.*, 2002; Marinho *et al.*, 2013). Within Childsmile, FV is delivered as a targeted preventive intervention for children at increased risk of dental caries. The programme uses 5% sodium fluoride varnish, applied twice yearly within targeted nurseries and primary schools by Childsmile dental teams. These teams typically comprise an Extended Duties Dental Nurse (EDDN) trained in fluoride varnish application and a DHSW. In addition to delivering fluoride varnish, EDDNs provide preventive care in nursery and school settings, while DHSWs support oral health promotion, encourage engagement with dental services, and assist families in accessing care, particularly in higher-need communities (Humphris and Zhou, 2014; Scottish Government, 2020c).

Participating nurseries and schools are selected by local Childsmile teams using indicators of socioeconomic deprivation. Establishments are prioritised according to the proportion of enrolled children living in the most deprived fifth using Scottish Index of Multiple Deprivation (SIMD), alongside information from the National Dental Inspection Programme and measures such as free school meal eligibility. Targeting occurs within each NHS Health Board, where establishments

are ranked by deprivation and included until approximately 20% of the local Primary 1 population is covered. Within selected settings, all eligible children are offered FV to avoid individual-level stigmatisation (Macpherson *et al.*, 2010). This approach improves the identification of settings serving children at highest risk, as schools located in relatively affluent areas may still enrol substantial numbers of children from deprived communities. Not without its critics this is believed within the programme to remain the most effective targeting method (Brewster, Sherriff and Macpherson, 2013).

In the 2024/25 academic year, the FV programme was delivered in 27.7% of nurseries (719/2,591) and 38.9% of schools (767/1,971), with participation varying massively across health boards from non-participation to full coverage. Among the 101,957 children aged 3–4 years in nurseries in this period, 28.2% (28,757/101,957) were targeted and 80.2% (23,063/28,757) of those had validated parental consent (parental/guardian consent reviewed and approved by a dentist to confirm the child is suitable for fluoride varnish application). Of those with validated consent, 82.3% (18,972/23,063) received at least one FV application and 48.0% (11,059/23,063) received two or more. Using local health board–level SIMD, 30.5% (6,898/22,856) of children in SIMD 1 received at least one application compared with 8.2% (1,596/19,536) in SIMD 5, while 17.6% (4,032/22,856) in SIMD 1 received two or more compared with 4.8% (943/19,536) in SIMD 5 (Childsmile Central Evaluation & Research Team, 2025).

In schools (P1–P4), the programme covered a population of 401,677 children, with 23.0% (92,380/401,677) targeted in participating schools. Of these, 83.7% (77,278/92,380) had validated consent, 94.4% (72,941/77,278) of whom received at least one FV application and 77.1% (59,553/77/279) received two or more. A similar deprivation gradient was observed: 53.5% (26,260/49,086) of children in SIMD 1 received at least one application compared with 9.5% (4,139/53,500) in SIMD 5, and 43.0% (21,094/49,086) in SIMD 1 received two or more compared with 8.1% (3,533/43,500) in SIMD 5. When compared with the national SIMD distribution for the same population, delivery appeared slightly more concentrated in the most deprived areas, although the differences were small (Childsmile Central Evaluation & Research Team, 2025). The numbers in school and nursery participation have stayed fairly consistent except for years affected by Covid-19 pandemic.

FV acts primarily by promoting enamel remineralisation and inhibiting demineralisation, thereby increasing resistance to acid attack. There have been regular systematic reviews on FV effectiveness at reducing dental caries, including in children, of varying quality over the past 25 years (Rozier, 2001; Petersson *et al.*, 2004; Azarpazhooh and Main, 2008; Carvalho *et al.*, 2010; Chou *et al.*, 2013; Marinho *et al.*, 2013; Mishra *et al.*, 2017; de Sousa *et al.*, 2019; Kumar *et al.*, 2026). The empirical evidence from the Cochrane review by Marinho *et al.* (2013) included 22 mostly moderate-quality trials involving 9,505 children from birth to adolescence, with follow-up periods ranging from several months to a few years. Across these trials, professionally applied FV appeared effective in reducing dental caries in children and adolescents., although trial quality and heterogeneity varied.

More recent evidence focused only on children up to 71 months, suggests that the magnitude of this effect may be smaller and less consistent, particularly when children are already receiving effective universal interventions such as supervised toothbrushing (de Sousa et al., 2019). This systematic review included 20 largely clinical trials drawn from an initial pool of 2,441 studies. The review also incorporated 10 new trials not included in the 2013 Cochrane review and performed an exhaustive bibliographical search and a thorough assessment of the risk of bias; most of studies were assessed as having medium to high risk of bias. Overall, it found that increasing exposure to professionally applied FV made little difference in the risk of developing new caries in young children.

The Protecting Teeth @3 (PT@3) trial, was conducted in Scottish nurseries instead of clinical setting, specifically evaluating FV delivered in school/nursery settings. This cluster-randomised study included 966 children in their first year of nursery and reported only modest, non-significant reductions in caries, indicating minimal incremental benefit in this context (McMahon *et al.*, 2020). A subsequent economic evaluation on a subset of these children (n=534) concluded that FV was unlikely to be cost-effective when delivered alongside existing Childsmile interventions, with the probability that it was cost effective at the assigned threshold of £20,000 per unit of quality-adjusted life years only 11.3% (Anopa *et al.*, 2023).

1.9.5 The Evaluation of Childsmile

Childsmile has incorporated ongoing evaluation from its inception to assess the processes and outcomes (Ross *et al.*, 2023), led by Childsmile Evaluation and Research Team (CERT) based at the University of Glasgow. The evaluation methods were developed following the Medical Research Council's guidance on developing and evaluating complex interventions (Craig *et al.*, 2008; Skivington *et al.*, 2021).

The programme is evaluated using a theory-based framework guided by the programme's logic models, which link resources and activities to outputs and intended outcomes (Section 1.9.3) (Childsmile, 2010; Macpherson *et al.*, 2010). These models outline how interventions such as supervised toothbrushing, fluoride varnish applications, and community-based family support are expected to influence behaviours and ultimately improve oral health outcomes while reducing inequalities.

Evaluation therefore encompasses both the implementation of interventions in practice and their effects on population oral health outcomes. The following sections describe the process evaluation of programme delivery (Section 1.9.5.1), and the outcome evaluation of programme reach and impact (Section 1.9.5.2).

1.9.5.1 Process Evaluation of Childsmile

Process evaluation provides insight into how, for whom, and under what conditions Childsmile interventions are delivered and work (Moore et al., 2015). It focuses on implementation fidelity, adherence to programme protocols, and operational challenges, rather than population-level reach, which is treated as an outcome. Mixed methods approaches combine routine monitoring data with qualitative exploration to understand delivery mechanisms across settings.

Early monitoring studies described the operational functioning of the programme, including the role of health visitors in infant risk assessment, supervised toothbrushing in nurseries and primary schools, and the activities of DHSWs (Turner *et al.*, 2010). These studies revealed regional and organisational variation in delivery, highlighting challenges in implementing a national

programme consistently. However, the largely descriptive nature of these analyses limits the interpretations of the findings.

Later evaluations integrated quantitative and qualitative methods to explore implementation in practice. For example, the DHSW component was assessed to understand how targeting and tailoring principles were operationalised (Hodgins, 2017). The DHSW evaluation was further extended using qualitative data understand the role of the DHSW and the difficulties they face day to day (Young, 2017). More recent work examined DHSWs' community-linking role using surveys, systematic review, and linked administrative data (Karamat, 2023), providing a comprehensive picture of operational processes. These studies demonstrate the complexity of delivering interventions across diverse contexts and highlight factors that may influence programme fidelity, consistency, and the likelihood that children will receive the intended interventions.

1.9.5.2 Outcome Evaluation of Childsmile

A major strength of the evidence base evaluating oral health improvement programmes in Scotland is the use of routinely collected nationally linked administrative data. This approach has enabled robust population-level assessment of the reach and effectiveness of interventions delivered through the national child oral health programme Childsmile (Childsmile, 2010).

A key development in this field has been the establishment of the Childsmile Evaluation data linkage, which facilitates linkage between NHS dental service records, programme delivery data, national dental inspection outcomes, and educational datasets. This infrastructure has enabled detailed examination of both programme exposure and oral health outcomes at the individual level, while also allowing stratification by socioeconomic status using area-based deprivation measures such as the Scottish Index of Multiple Deprivation (SIMD).

Kidd (2019) extensively contributed to the development of the large population-based birth cohort using linked health, dental, and educational records to examine the reach and associations of the four core Childsmile interventions with caries experience at age 5, this utilised 50,379 children Primary 1 local authority schools 2014/15. Kidd *et al.* (2020) demonstrated that programme

implementation achieved high levels of coverage for universal interventions across all socioeconomic strata, particularly nursery-supervised toothbrushing (NSTB) and routine primary care dental practice attendance. In contrast, DHSW contacts were more strongly targeted towards children from more deprived areas, reflecting the intended proportionate universalism approach embedded within the programme design.

However, coverage was not complete, particularly among more marginalised groups, suggesting persistent challenges in achieving full population reach even within universal systems. Additional fluoride varnish application delivered in nursery and school settings showed comparatively lower reach and limited incremental impact on caries outcomes beyond existing fluoride exposure.

In terms of effectiveness, evidence from these linked analyses indicates that NSTB is the most consistently beneficial intervention, associated with reduced caries experience at age five, with particularly strong effects among children living in the most deprived areas. DHSW contacts demonstrate modest benefits among those successfully reached, although effects appear less pronounced in groups with the highest levels of need, potentially reflecting barriers in engagement intensity or continuity of support. In contrast, additional fluoride varnish provision appears to confer limited additional benefit in a context of widespread fluoride toothpaste use, raising questions about its marginal effectiveness at population level.

Overall, the linked evidence base highlights both the strengths and limitations of complex, multi-component public health programmes. While universal interventions demonstrate strong reach and measurable impact, targeted components show diminishing returns where engagement is incomplete, underscoring the importance of both implementation fidelity and sustained reach into hard-to-access populations.

Interpretation of these findings is constrained by limitations that continue to affect large-scale data linkage evaluations of Childsmile, including unmeasured family and behavioural factors, overlap between programme components, and the use of deprivation measures derived post-intervention, which complicates interpretation of socioeconomic influences. This analysis relied solely on the

Scottish Index of Multiple Deprivation (SIMD), an area-based measure of socioeconomic circumstances (SEC), which may misclassify children's true socioeconomic position, as disadvantaged families may reside in less deprived areas and vice versa. Consequently, observed socioeconomic gradients in programme reach and oral health outcomes may be diluted. Furthermore, area-based measures do not capture important household- or family-level influences, such as parental education, income, employment, health literacy, dietary practices, or oral health behaviours, limiting understanding of the mechanisms through which socioeconomic disadvantage may influence both intervention uptake and outcomes. Additional limitations include the exclusion of children attending private schools and the absence of detailed information on intervention intensity and home oral health practices. Strengths of the study include the use of high-quality population-level linked administrative data and adjustment for key confounding factors. Despite these limitations, Kidd (2019) provides robust population-level evidence regarding intervention reach, associations with oral health outcomes, and equity.

Stewart (2023), then examined the intersection of dental caries and obesity, utilising the Childsmile Evaluation data linkage to examine 335,361 children in Scotland in Primary 1 between 2011 and 2018. This study used line graphs and multivariable multinomial regression to show that children living in socioeconomic deprivation were disproportionately affected by both conditions and were less likely to receive certain targeted preventive interventions, despite comparable access to universal interventions. DHSW engagement was also lower in this group, highlighting persistent gaps in targeting the most vulnerable children. These analyses face similar limitations to Kidd (2019).

The Protecting Teeth @3 (PT@3) trial, detailed in section 1.9.4.4, provides complementary RCT evidence of nursery fluoride varnishes ineffectiveness. While not described here, it contextualises population-level outcomes alongside experimental findings, strengthening interpretation of programme effectiveness.

The programme's reach has also been examined among children with Additional Support Needs (ASN), linking data on ASN from Pupil Census (Sherriff *et al.*, 2023). This study used education data to provide high-quality population-level information on Primary 1 children with ASN and their peers (2016/17–2018/19; n

= 166,781), demonstrating that while many children with ASN were reached by universal interventions, coverage was not uniform. Limitations include potential under-ascertainment of children unable to attend school, lack of detail regarding the severity or type of additional support need, and exclusion of children attending private schools. Despite these constraints, inclusion of children with ASN as a sub-cohort is an important component of understanding programme reach and equity, helping to identify groups who may require additional support to ensure inclusive delivery.

Childsmile's outcome evaluation has also included a population-level economic analysis of the supervised nursery toothbrushing programme across all 14 Scottish Health Boards, drawing on national dental inspection data for approximately 62,000 five-year-old children examined between 1999/00 and 2009/10 (Anopa et al., 2015). The estimated annual cost of programme implementation was £1.76 million (2009/10 prices), with variation across Health Boards largely driven by staff salaries (49.1–90.4% of total costs), followed by toothbrush resources (4.4–49.4%), transport (2.7–17.4%), administration (0.2–12.4%), and training (0.5–3.5%). Unit costs of treatment were estimated at £8.84 per filling, £14.33 per extraction under local anaesthetic, £653.26 per extraction under general anaesthetic, and £36.28 per decayed tooth (baseline scenario). Population-level extrapolation of inspection data demonstrated substantial reductions in oral disease burden over time, including a 47.0% decrease in decayed teeth (107,925 to 57,167), alongside marked reductions in children with missing teeth (one missing tooth: 52.0% decrease, 1,615 to 776; two or more missing teeth: 56.2% decrease, 6,479 to 2,837) and a 42.7% reduction in filled teeth (19,030 to 10,909). Correspondingly, total costs of actual and anticipated dental treatment fell from £8.77 million in 2001/02 to £4.04 million in 2009/10, with extraction costs representing the largest component of expenditure. Area-based deprivation analyses using seven cohorts showed socioeconomic gradients: in the most deprived group, costs fell by £137,348 (49.9%) from baseline, compared with £30,174 (55.3%) in the least deprived group, with all deprivation categories experiencing declines in decayed, filled, and extracted tooth costs over time. Within three years of programme roll-out, estimated savings in dental treatment costs exceeded implementation costs, and by eight years savings were more than two and a half times programme costs. However, the evaluation is

limited by reliance on modelled “anticipated” treatment pathways rather than observed longitudinal outcomes, assumptions embedded in unit cost derivations and extrapolations, and the use of aggregated inspection data rather than individual-level follow-up, which may affect precision and causal attribution.

Moving forward, CERT have sought to address several limitations identified in earlier studies. A key development, and one central to this thesis, is the incorporation of the Growing Up in Scotland (GUS) longitudinal birth cohort data into the Childsmile evaluation data linkage. This analysis builds upon previous research by complementing routine administrative datasets with detailed information on behavioural, household and family-level factors. While administrative data provide high population coverage and allow robust assessment of programme reach and population-level outcomes, they contain limited information on the mechanisms through which interventions may influence oral health. This is particularly important because Childsmile’s theory-based logic models identify behavioural pathways, including toothbrushing practices, dietary behaviours and parental engagement, as key mechanisms through which programme activities are expected to improve oral health outcomes (Childsmile, 2010). The inclusion of GUS data therefore provides an opportunity to examine these pathways in greater detail and to better understand how Childsmile may influence oral health behaviours and outcomes over time.

Longitudinal birth cohorts such as Growing Up in Scotland provide rich prospective data on children’s health, development, family circumstances, and home environments, enabling a more comprehensive understanding of the wider determinants of oral health. Importantly, the two GUS birth cohorts include children born on either side of the implementation of Childsmile, creating a natural experiment that can be used to examine the programme’s impact (Craig *et al.*, 2012). Linking Childsmile evaluation data with GUS therefore allows investigation of how family, household, and broader socioeconomic factors interact with programme delivery and behavioural mechanisms, providing insight into programme pathways, equity, and differential effects that cannot be examined using administrative data alone.

1.10 Summarising Gaps in the Literature

Scotland has experienced substantial population-level improvements in children's dental caries since the early 2000s, with these trends likely reflecting, at least in part, the impact of the Childsmile programme. Despite these gains, marked socioeconomic inequalities in oral health outcomes persist, with children from more disadvantaged backgrounds continuing to experience a disproportionately high burden of disease.

The association between socioeconomic position and oral health is well established, with children from disadvantaged backgrounds consistently exhibiting poorer oral health behaviours and outcomes (Watt and Sheiham, 1999; Peres *et al.*, 2019b). However, much of the Scottish literature relies on area-based indicators of deprivation as a proxy for individual circumstances, most commonly the Scottish Index of Multiple Deprivation. While such measures are valuable for identifying population-level patterns, they do not adequately capture individual- and household-level socioeconomic circumstances, including parental education, income, material resources, and family behaviours (Galobardes, Lynch and Smith, 2007; McCartney *et al.*, 2023). These dimensions are critical for understanding how socioeconomic conditions shape children's exposure to cariogenic risk factors and influence oral health outcomes (Fisher-Owens *et al.*, 2007).

Behavioural determinants—including dietary habits, toothbrushing practices, and parental influences—play a central role in the development of dental caries (Harris *et al.*, 2004; Hooley *et al.*, 2012). However, these factors are infrequently measured within routine administrative datasets, limiting the ability of existing research to examine the pathways linking socioeconomic disadvantage to oral health. As a result, the mechanisms through which inequalities in oral health arise and persist remain insufficiently understood.

Despite growing evidence linking socioeconomic circumstances to childhood dental caries, limited research has examined parenting styles as a potential mediating mechanism within this relationship. Existing conceptual frameworks highlight the importance of family-level influences on children's oral health behaviours and outcomes (Fisher-Owens *et al.*, 2007). Parenting styles may

shape children's dietary habits, toothbrushing routines, dental attendance, and broader psychosocial environments, all of which are associated with caries risk. Families experiencing socioeconomic disadvantage may also face stressors and material constraints that influence parenting behaviours and household health practices. Previous studies have identified associations between parenting styles and childhood caries outcomes; however, the findings are mixed (Moya-López *et al.*, 2024).

A further limitation of the literature is the predominance of cross-sectional study designs, which provide only a snapshot of associations at a single point in time. Children's caries experience develops cumulatively and is shaped by dynamic changes in behaviours, parenting practices, and social conditions across childhood (Peres *et al.*, 2019b). Longitudinal approaches are therefore essential for establishing the temporal ordering of exposures and outcomes, identifying trajectories of risk, and examining how early-life circumstances influence later oral health (Ben-Shlomo and Kuh, 2002).

Prospective birth cohort studies offer a robust framework for addressing these limitations. By capturing detailed information on behavioural, biological, and psychosocial exposures over time, such designs enable a more comprehensive understanding of how risk accumulates and interacts across developmental stages (Grimes and Schulz, 2002; Cooper *et al.*, 2012). This is particularly important for identifying critical periods during which preventive interventions may be most effective (Lawlor, Andersen and Batty, 2009). Such data are available in Growing Up in Scotland providing a valuable opportunity to examine detailed cohorts before and after a complex public health intervention at multiple time points. This strengthens opportunities for causal inference in the absence of randomised controlled trials (Craig *et al.*, 2012; Hernán and Robins, 2020).

Although Scotland's national Childsmile programme has been recognised internationally as a leading example of a population-level oral health improvement intervention (Ross *et al.*, 2023), important gaps remain in understanding the mechanisms through which the programme influences oral health outcomes. Existing evaluations have demonstrated improvements in clinical outcomes while inequalities have remained; however, these analyses

have largely relied on routine administrative data sources (Kidd, 2019; Macpherson, Rodgers and Conway, 2019b). Consequently, key elements of the programme's logic model—particularly those relating to behaviour change, service uptake, and parental engagement—remain underexplored. Evidence on the programme's influence on behavioural determinants of caries, especially dietary practices and sugar consumption, is notably limited.

Methodologically, research in this field has often relied on traditional regression-based approaches, which may be limited in their capacity to capture the complex and interrelated pathways linking socioeconomic conditions, behaviours, and health outcomes. Large-scale longitudinal datasets containing rich measures of diet, family environment, and psychosocial factors remain underutilised, restricting opportunities to examine mediating and moderating mechanisms in greater depth (Peres *et al.*, 2019b).

Collectively, these gaps highlight the need for research that integrates individual- and household-level socioeconomic measures, detailed behavioural and dietary data, and longitudinal analytical approaches. Such work is essential for moving beyond descriptive accounts of inequality towards a more mechanistic understanding of how socioeconomic circumstances, family environments, and preventive interventions interact to shape children's oral health outcomes.

Chapter 2

2 Aim and Research Questions

2.1 Aims

The overarching aims of this thesis are:

a) To analyse the association of early oral health-behaviours (cariogenic diet, toothbrushing, attendance at dentist) with caries experience at age 5 in Scotland, and how they are mitigated by family and community level factors; before and after early national roll-out of the Childsmile programme (Chapter 5).

b) To evaluate the impact of Childsmile behaviour change interventions on early-life oral health behaviours, and whether effects differed by socioeconomic deprivation (Chapter 6).

c) To investigate how early life socioeconomic circumstances contribute to child caries experience in Scotland at age 5, before and after early national roll-out of the Childsmile programme (Chapter 7 and 8)

2.2 Rationale

To address these aims, this thesis adopts an epidemiological approach that combines longitudinal cohort data linkage with population-level analyses of childhood oral health outcomes. Given the multifactorial aetiology of childhood dental caries and its strong social patterning, the research questions were designed to examine caries experience from complementary perspectives, including measurement validity, early life behavioural risk factors, family and socioeconomic contexts, intervention effects, and life course socioeconomic influences.

Following a detailed description of the methodologies adopted in the thesis (Chapter 3), the research questions are structured to progress logically across the subsequent chapters.

Growing Up in Scotland (GUS) has parent/carer proxy reported caries outcomes- with other studies still using proxy reported caries (Skafida and Chambers, 2018). However, prevalence of caries experience from GUS proxy-report was lower than the matched National Dental Inspection Programme (NDIP) and therefore the first analysis was to investigate the reliability and bias of self-report (Chapter 4).

Chapter 5 looks at early life behaviours associations with caries experience using proximal behaviours of diet, toothbrushing, dental attendance from the Fisher-Owens conceptual model. This then introduces more distal factors associated with family and community, to assess their impact on these relationships. This is done across both GUS cohorts as a natural experiment to assess any changes brought about by the early implementation of the Childsmile programme.

Chapter 6 takes a more focussed assessment of the impact of Childsmile interventions designed to change the proximal behaviours of diet and toothbrushing in the early stages of programme implementation- and whether there was a differential impact according to socioeconomic circumstances.

The importance of the socioeconomic gradient in distal factors, proximal behaviours and caries experience and the complex inter-relationships not easily captured by previous linear models led to further exploration in Chapter 7 using Structural Equation Modelling causal pathway models. Key oral health behaviours and parenting styles were then introduced as mediating factors of socioeconomic circumstances and caries

Chapter 8 utilises the longitudinal nature of Growing Up in Scotland as well as the availability of multiple measures of socioeconomic circumstances better understand socioeconomic influences in the early years on caries experience.

Chapter 9 synthesises these findings and considers implications for policy, practice, and future research.

2.3 Research Questions

1. **What is the accuracy of parent/carer proxy-report of child caries experience when compared to clinician measured child caries experience; is this affected by socioeconomic deprivation level (Chapter 4)?**

   Research hypothesis: Parent/carer proxy-report of child caries experience is expected to have limited accuracy when compared with clinician-measured caries experience, with under-reporting of caries experience anticipated. The accuracy of proxy-report is also expected to vary according to socioeconomic deprivation.

2. **What is the association between early life behaviours (diet, toothbrushing, dental attendance) and child caries experience; have these associations changed before and after early national roll-out of the Childsmile programme (Chapter 5)?**

   Research hypothesis: More frequent consumption of cariogenic foods and drinks would be associated with a higher risk of caries experience, whereas more favourable toothbrushing behaviours and dental attendance would be associated with a lower risk of caries experience. The strength of these associations may decrease early post-roll-out cohort of Childsmile.

3. **To what extent do family and community-level factors influence the association between early life behaviours and child caries experience; have these changed before and after early national roll-out of the Childsmile programme (Chapter 5)?**

   Research Hypothesis: Family and community-level socioeconomic factors would contribute to the association between early-life behaviours and caries experience, with adjustment for these factors expected to attenuate the observed associations between proximal behaviours and caries. The extent of this attenuation may differ between the pre-Childsmile and early post-roll-out cohorts.

4. **What is the impact of diet and toothbrushing behaviour change interventions delivered by Dental Health Support Workers and in primary care dental settings on children's diet and toothbrushing frequency; are these associations affected by socioeconomic deprivation level? (Chapter 6)?**

   Research hypothesis: Receipt of Childsmile behaviour-change interventions is expected to be associated with minimal or no change in children's dietary and toothbrushing behaviours. Consequently, substantial differences in these associations according to socioeconomic deprivation are not expected.

5. **To what extent do parenting styles or oral health behaviours explain socioeconomic circumstances association with child caries experience; and how have these changed before and after early national roll-out of the Childsmile programme (Chapter 7)?**

   Research hypothesis: The association between socioeconomic circumstances and child caries experience is expected to be partly mediated through oral health behaviours and parenting-related factors, although these factors are not expected to fully explain socioeconomic inequalities in caries experience. The specific pathways and their relative contributions are not assumed a priori and may differ between the pre-Childsmile and early post-roll-out cohort.

6. **What is the longitudinal impact of changes in household income poverty and area-based socioeconomic-deprivation on child caries experience in early childhood (Chapter 8)?**

   Research Hypothesis: Children experiencing persistent household poverty or persistent area-based socioeconomic deprivation are expected to experience a cumulative increase in risk of caries experience. Upward socioeconomic mobility during the first five years of life is hypothesised to mitigate the increased risk.

Chapter 3

3 Methods

3.1 Overview

This chapter describes the data sources, linkage processes, quality assurance procedures, and analytical methods used throughout this thesis. It outlines the development of the Childsmile evaluation baseline cohort and its adaptation for each results chapter, including the integration of data from the Growing Up in Scotland (GUS) study. The chapter also defines the key variables used in the analyses and provides an overview of the statistical methods applied, with further methodological details presented in subsequent chapters. Previous work underpinning the large-scale data linkage is referenced (Kidd, 2019; Stewart, 2023).

3.2 Objectives

The primary objectives of this chapter are to:

1. Ensure ethical and information Governance compliance: provide details of the ethical approval and Information Governance approvals obtained for accessing and linking child-level datasets within a trusted research environment.

2. Define the baseline cohorts for the present study within the wider context of the overarching Childsmile evaluation and define any alterations to this for each subsequent results chapter.

3. Identify and describe datasets: specify the datasets and describe their origin, data collection and relevance to this thesis.

4. Assess data quality and completeness: summarise the quality and completeness assessments conducted on the datasets to ensure their suitability for analysis.

5. Define variables and outline analytical framework: define key variables for analysis and provide an overview of the primary statistical techniques employed.

3.3 Governance and Data Access Environment

This section outlines the ethical, legal, and infrastructural mechanisms that enable the secure and responsible use of individual-level data for this thesis. It includes approvals for data access and linkage, descriptions of data handling environments, and the technical setup for secure data analysis.

3.3.1 Ethical and Information Governance Approvals

Plans to link routine administrative datasets for evaluating the Childsmile programme were initiated in 2008. The evaluation examines child oral health trends, inequalities, and programme effectiveness and reach. Ethical oversight and data governance arrangements have been established and are described in detail elsewhere (Kidd, 2019; Stewart, 2023).

Following initial approval for data linkage by the Privacy Advisory Committee, governance approval transitioned to the Public Benefit and Privacy Panel for Health and Social Care (HSC-PBPP) after NHS Scotland restructuring (Project Code: 1516-0368). A comprehensive application formalising governance for the evaluation was approved in 2015. Subsequent amendments included: extension of the study period to 2025 (October 2018) (Appendix B – Section 11.2.1); approval to link the Growing Up in Scotland (GUS) dataset via a separate Statistics PBPP (S-PBPP) application (November 2021) (reference number: 200170146); and further approvals in 2023 to extend the study, add datasets and users, and incorporate more recent data. Final approval for these amendments was granted in February 2024, extending the study to November 2026 (Section 11.2.2).

An associated University of Glasgow MVLS non-clinical ethics approval (Phase II) was first granted in 2016 and updated subsequently (Project code: FM 04908); it now runs alongside HSC-PBPP and S-PBPP approvals, the acceptance of the latest amendment necessary for this this is shown in Section 11.2.3. NHS ethical

approval was not required as the work constitutes service evaluation using data collected as part of usual care (Kidd, 2019).

3.3.2 Data Access Infrastructure

To uphold the principles of legal, ethical, and secure data use, a structured data access environment has been established by Public Health Scotland in partnership with data custodians for approved researchers working on the Childsmile evaluation and related studies.

3.3.2.1 National Safe Haven

The Scottish Government's move towards secure data linkage coincided with increasing digitisation of administrative records. In 2012, NHS National Services Scotland launched the National Safe Haven—formally managed by the Edinburgh Parallel Computing Centre (EPCC) from 2015—as a secure, remote-access platform for research using linked administrative datasets.

All analyses in this thesis are conducted within this environment, ensuring rigorous adherence to data security protocols. Due to this any code used for analyses are not included in this thesis, but sections redacted are available upon request.

3.3.2.2 Electronic Data Research and Innovation Service Support

The electronic Data Research and Innovation Service (eDRIS), a unit within NHS National Services Scotland, supports researchers through the data access lifecycle. A designated eDRIS Research Coordinator guided the Childsmile evaluation team in:

- Navigating dataset suitability and consent requirements.
- Attaining 'approved researcher' and 'eDRIS user' status.
- Setting up National Safe Haven access.

All outputs from the National Safe Haven undergo eDRIS disclosure checks illustrated in Appendix C (Section 11.3.1) to prevent the release of potentially disclosive data.

3.3.2.3 National Records of Scotland

National Records of Scotland (NRS) serves as the trusted intermediary for data linkage, connecting datasets without direct release of raw data. Their protocols ensure privacy and uphold ethical standards, adding a layer of integrity to the data linkage process.

3.3.2.4 Access Setup and Security Protocols

Access to the National Safe Haven is restricted to approved institutions and users. Researchers must:

- Be affiliated with a recognised organisation (e.g., University of Glasgow).
- Complete GDPR/confidentiality training via Medical Research Council e-learning modules.
- Sign and submit the eDRIS User Agreement.

The author used remote access within the University of Glasgow for this study, facilitated by:

- **VPN Setup**: Cisco AnyConnect Secure Mobility Client installed by the University of Glasgow IT team.
- **Virtual Desktop**: Citrix Receiver software enabling a secure link to the National Safe Haven environment.
- **Two-Factor Authentication**: A one-time PIN sent via mobile to authenticate login.

The system automatically logs users out after inactivity. Passwords are rotated monthly to maintain security.

3.4 Childsmile Evaluation

The evaluation of Childsmile is underpinned by a comprehensive, population wide, child level linked dataset, designed to assess both the reach and effectiveness of the programme across Scotland. This data linkage, combined with a theory-based framework, enables rigorous evaluation and supports both outcome and aspects of the process analyses (detailed in section 1.9.5).

3.4.1 Purpose and Key Evaluation Questions

The linked datasets are made up of a variety of datasets (detailed in Section 3.5.2) based on a cohort of children (referred to hereafter as the "Childsmile evaluation baseline cohort") detailed in Section 3.5.1 has enabled a comprehensive evaluation of Childsmile by examining programme reach and association with key outcomes including caries experience, while exploring how these vary across deprivation groups. It has allowed analyses of which Childsmile components—such as nursery/school supervised toothbrushing, nursery/school and primary dental practice fluoride varnish application, dental health support worker visits/interventions and dental practice engagement—are associated with improved oral health, and whether these differ across Scottish Index of Multiple Deprivation Fifths (Childsmile Central Evaluation & Research Team, 2025).

3.5 Childsmile Evaluation Baseline Cohort Creation for Reach and Impact Analysis

A baseline cohort of children is required to establish a defined population for any analysis, providing a reference point to measure outcomes, evaluate exposure to Childsmile interventions, and examine inequalities over time.

The subsequent sections detail the creation of the baseline cohort underpinning the overarching evaluation and, by extension, this thesis. It proceeds as follows:

- Description of the overarching Childsmile evaluation baseline cohort set up to facilitate the evaluation of the whole programme underpinned by the programme theory and logic models.

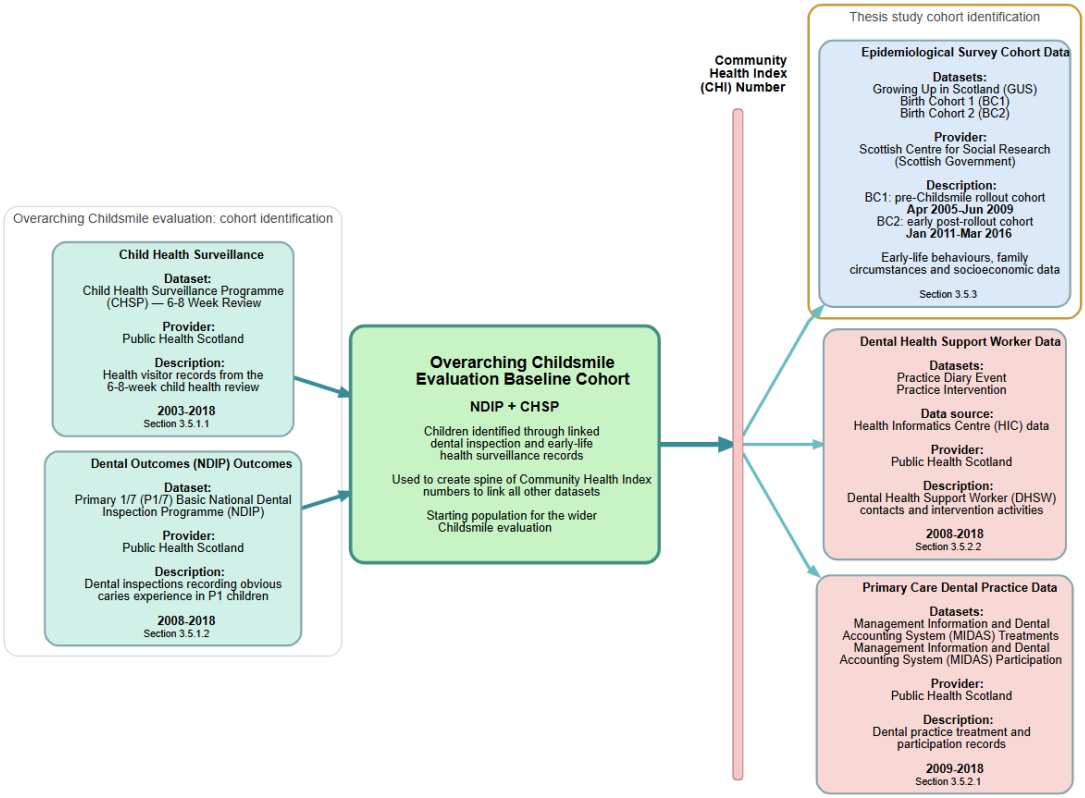
- Overview of datasets contributing to the overarching Childsmile evaluation and ones used in this current study.

- Explanation of the linkage of the Growing Up in Scotland (GUS) survey to the Childsmile evaluation baseline cohort.

- Detailed description of GUS design, measures, and response rates.

- Definition of the final analytic samples used in this thesis.

The creation of the baseline cohort for this thesis and data linkage of key datasets are introduced in Figure 3.1 and detailed further in the subsequent section.



CHSP – Child Health Surveillance Health Programme; NDIP – National Dental Inspection Programme; HIC – Health Informatics Centre; MIDAS - Management Information & Dental Accounting System; GUS – Growing Up in Scotland; NHS – National Health Service Scotland

Figure 3.1 - Childsmile Data Linkage and Baseline Cohort Creation

3.5.1 Childsmile Evaluation Baseline Cohort

A child is part of the baseline cohort for the overarching Childsmile evaluation if they appear in the Child Health Surveillance Programme (CHSP) (6–8 weeks)

between the dates of 1st January 2003 to 30th June 2018 and appear in National Dental Inspection Programme (NDIP) P1/P7 between 1st July 2008 to 30th June 2018. The main aim was to capture children born in Scotland and stayed until the primary endpoint of caries experience in P1 was measured. Ensuring all analyses were evaluating Childsmile in children who were living in Scotland for the first five years where the programme was aimed. Anchoring the cohort on these datasets ensures representativeness, enables linkage to routine health and programme records, and provides the necessary outcome data for evaluating the impact of Childsmile across the population and within subgroups. Although this coverage varies over the years from 79.3% to 93.4% for CHSP 6-8 weeks (Public Health Scotland, 2025b), 84.9% to 91.5% for NDIP (Conway *et al.*, 2024).

3.5.1.1 Child Health Surveillance Programme 6–8-week review

The goal of the Child Health Surveillance Programme for 6 to 8 weeks (CHSP 6–8-week) is to review every child born in Scotland (79.5% in birth cohort 2004/05 and 91.2% in 2010/11 (Public Health Scotland, 2025b); these are the two birth cohorts used in this thesis).

The CHSP 6–8-week assessment is typically conducted by Health Visitors around six to eight weeks after birth and is used here to identify children born in Scotland for the Childsmile evaluation. The CHSP 6–8-week assessment is a thorough review that gathers detailed information about an infant's health, growth, and development during the early weeks of life. It covers key areas such as feeding difficulties, breastfeeding status, sleep patterns, and measurements of length, weight, and head circumference to monitor the baby's physical growth and wellbeing. The assessment also looks at early developmental progress and any concerns raised by parents. In 2011, the process was updated to include a section noting whether the child had been referred to a Childsmile Dental Health Support Worker (DHSW) (Section 1.9.4.1).

3.5.1.2 National Dental Inspection Programme

The National Dental Inspection Programme (NDIP) 'Basic Inspection' aims to assess the oral health of children in local authority and publicly funded primary schools, providing population-level data to inform parents/carers, health services, and government planning (Merrett *et al.*, 2008; Merrett *et al.*, 2009;

Conway *et al.*, 2022). Children are typically aged 5–6 years at inspection. Trained dental professionals conduct a brief, non-invasive visual examination using only a light, mirror, and ball-ended probe; no radiographs or treatment are performed. The inspection records visible decay, restorations, missing teeth, and overall dental condition.

Children are categorised into three clinical groups, and these outcomes are communicated to parents/carers via letters:

- Letter A: Severe dental disease (gross caries, abscesses, or obviously carious permanent teeth) requiring urgent dental care.

- Letter B: Evidence of caries experience (current or treated decay, missing or damaged teeth, restorations, or tooth wear), or poor oral hygiene/may require orthodontic assessment indicating the need to seek dental care in the near future.

- Letter C: No obvious caries experience; routine dental check-ups are advised.

The criteria for these categories have been refined over time to improve consistency. Until 2014/15, Letter B included indicators such as poor oral hygiene or possibly carious permanent teeth; from 2015/16, only clinically confirmed caries experience was coded, excluding subjective measures (Table 3.1).

Table 3.1 - National Dental Inspection Programme examination criteria for caries experience in Primary 1

Letter	2009/10 – 2010/11	2015/16 – 2016/17
A	Abscess or infection	Abscess or infection
	Gross caries	Gross caries
	Obviously carious permanent tooth	Obviously carious permanent tooth
B	Obviously carious primary tooth	Obviously carious primary tooth
	Possibly carious permanent tooth	
	Missing primary molar	Missing primary molar
	Evidence of restorations	Evidence of restorations
	Poor oral hygiene	
C	No obvious caries experience	No obvious caries experience

For the purposes of analysis, the outcome variable focuses on clinically confirmed caries (Letter A and all Letter B variables retained after update in 2015/16); further details are provided in Section 3.10.1.

Consent for the Basic Inspection operates under a 'negative consent' model; children are automatically included unless their parent or carer opts out. Coverage for the NDIP in the years analysed in this thesis was: 88.6% in 2009/10 (48,606/54,854), 85.6% in 2010/11 (47,712/55,763), 86.5% in 2015/16 (51,709/59,796), and 88.7% in 2016/17 (51,899/58,497)(Macpherson *et al.*, 2011; Macpherson *et al.*, 2012; Macpherson *et al.*, 2016a; Macpherson *et al.*, 2016b); these percentages do not substantially differ from the other years in the overarching evaluation (Macpherson *et al.*, 2018). Non-completion was mainly due to absence, refusal, or inability to participate. Denominators include only children in local authority schools, further excluding roughly 6% of the true population of 5-year-old children attending private or home schooling.

The NDIP Programme also runs a 'Detailed Inspection', which is a comprehensive assessment of each child's teeth, recording the status of every tooth surface and measuring obvious decay into dentine in a school setting. Inspections are carried out by trained and calibrated dental professionals. Approximately 20% of the target population is sampled each year, though coverage varies across health boards, rotating between Primary 1 and Primary 7 cohorts. The Detailed Inspection is more resource-intensive than the Basic Inspection, but outcomes from Basic produce very similar findings with detailed assessments, suggesting

that the simpler basic inspection reliably reflects population-level oral health patterns (Macpherson *et al.*, 2018). This allows Basic Inspection data to be used for full population surveillance while maintaining methodological rigor.

3.5.2 Datasets Linked to Childsmile Evaluation Baseline Cohort in the National Safe Haven Utilised in this Thesis

Numerous data sources within this National Safe Haven environment are linked to the Childsmile evaluation baseline cohort (Section 3.5.1), retaining children in each data set that are present in the Childsmile evaluation baseline cohort. The table below illustrates the datasets used in this thesis (Table 3.2) and then detailed in subsequent sections.

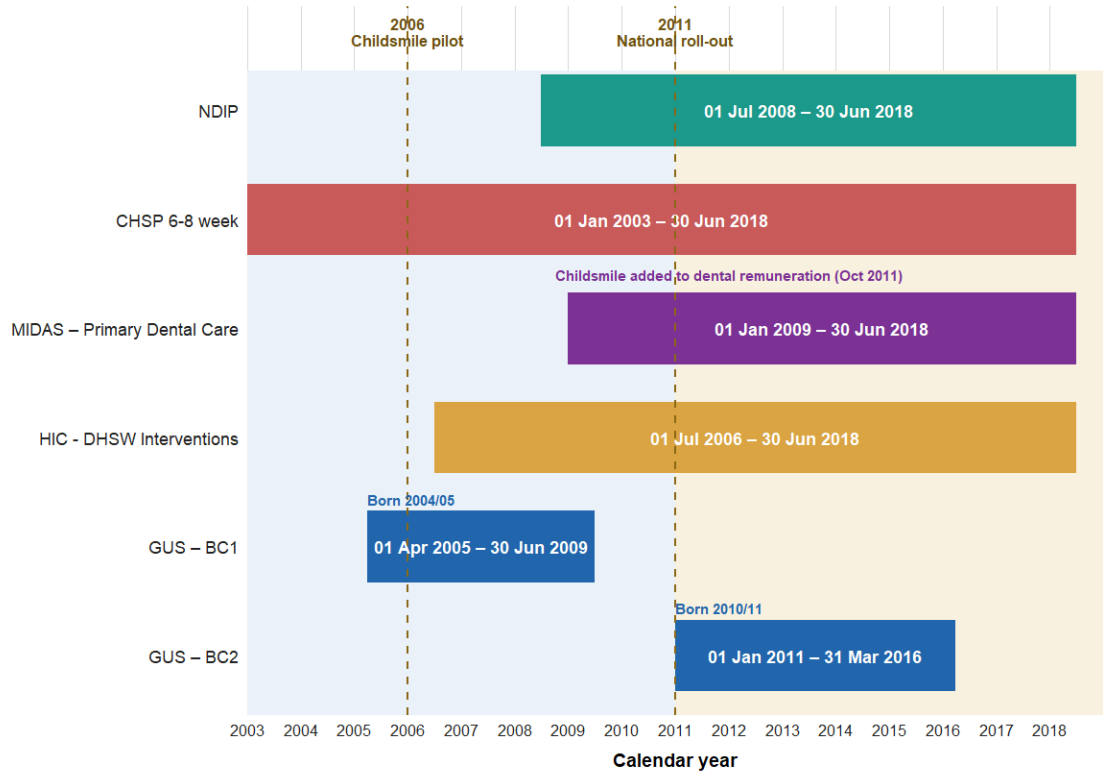
Table 3.2 - Childsmile evaluation datasets utilised in this thesis

Data Category	Datasets	Data Provider
Child Health Surveillance Programme	• 6–8 Week Review (Section 3.5.1.1)	Public Health Scotland
Primary Care Dental Practice Contact(s)	• Management Information and Dental Accounting System Treatments (Section 3.5.2.1) • Management Information and Dental Accounting System Participation (Section 3.5.2.1)	Public Health Scotland
Dental Health Support Worker Contacts (Health Informatics Centre Data)	• Practice Diary Event (Section 3.5.2.2) • Practice Intervention (Section 3.5.2.2)	Public Health Scotland
Dental Outcomes	• Primary 1 (P1) Basic National Dental Inspection Programme (NDIP) (Section 3.5.1.2)	Public Health Scotland
Epidemiological Survey Cohort Data	• Growing up in Scotland Birth Cohorts (Section 3.5.3)	Scottish Centre for Social Research (Scottish Government)

Additional datasets were available in wider Childsmile evaluation but not utilised for analyses presented in this thesis. These included birth records, further Child Health Surveillance reviews conducted at later ages, and additional National Dental Inspection Programme (NDIP) examinations, including the Primary 7 (P7) basic inspection and detailed NDIP examinations at both P1 and P7. Data on additional Childsmile interventions delivered within nursery and school settings, including fluoride varnish applications and supervised toothbrushing (not utilised in this thesis), were also available. Furthermore, administrative datasets such as

Scottish Morbidity Records (SMR) and Scottish Exchange of Educational Data (ScotXed) are also available and linked to the Childsmile evaluation baseline cohort.

Figure 3.2 illustrates the coverage periods of datasets used in this thesis, from programme inception to the end of the data approved by the PBPP. The end dates indicate the limits of approved data access, not the cessation of dataset use.



NDIP – National Dental Inspection Programme; CHSP – Child Health Surveillance Health Programme; MIDAS - Management Information & Dental Accounting System; HIC – Health Informatics Centre; DHSW – Dental Health Support Worker, GUS – Growing Up in Scotland; BC – Birth Cohort

Figure 3.2 - Thesis Datasets Gantt Chart

3.5.2.1 Management Information & Dental Accounting System Datasets

MIDAS, the Management Information & Dental Accounting System, is the administrative system through which dentists are remunerated for delivering NHS primary care dental services and recording patient registrations in Scotland (Public Health Scotland, 2019). The system comprises three key datasets available at the individual patient level: MIDAS Registration, MIDAS Participation, and MIDAS Treatment. The latter two are used throughout this thesis.

The MIDAS **Registration** dataset contains information on patients registered with NHS dental practices across Scotland. This dataset provides a snapshot of dental access, reflecting patient affiliation with individual dentists or practices and enabling assessment of population coverage and service capacity. It includes practice identifiers, geographic location, and patient registration information, providing a foundation for analysing patterns in dental service provision and population coverage.

The MIDAS **Participation** dataset complements the registration data by capturing contacts individuals have with NHS General Dental Services and Public Dental Services. This distinction between registration and participation is important for evaluating service utilisation, as not all registered individuals actively attend for care. Participation data therefore enables researchers and policymakers to assess engagement with dental services, measure continuity of care, and identify population groups that may be underutilising available services.

Finally, the MIDAS **Treatment** dataset provides detailed information on the nature and volume of dental care delivered in NHS primary care settings. It records treatment claims submitted by dental practitioners, including the type of procedure performed, treatment dates, anonymised patient demographics, and associated costs. As the dataset is based on treatment claims submitted for remuneration rather than detailed clinical records, it provides limited information on diagnostic status or disease severity. In addition, the dataset captures treatments delivered within NHS-funded care and therefore does not include dental treatments provided privately. Despite these limitations, the dataset supports a wide range of analyses, including evaluation of service delivery patterns, treatment trends, and prescribing behaviours.

Since October 2011, the MIDAS Treatment dataset has also incorporated records of Childsmile behaviour change interventions delivered in dental practices.

This dataset will be used in Chapter 5 for the assessment of regular dental attendance association with caries experience at age 5. In Chapter 6 it is used for the assessment of primary dental care Childsmile preventions association with early life oral health behaviours; and finally in Chapter 7 it is used to again

dental attendance but as part of the mediation analysis of socioeconomic circumstances and caries experience at age 5.

3.5.2.2 Health Informatics Centre Datasets

The Health Informatics Centre (HIC) housed at the University of Dundee provides the secure database infrastructure for routine data collection across several Childsmile programme components (Childsmile, 2026). These include Supervised toothbrushing in nurseries and schools (from 2006), Fluoride varnish applications in educational settings (from 2006) and the Dental Health Support Worker (DHSW) intervention (from 2011). This thesis uses these datasets for DHSW interventions (DHSW Practice Diary Events data and DHSW Practice Interventions data).

The DHSW Practice Diary Events dataset records information collected when a family is referred to a DHSW. It includes details such as the method of referral, date of referral, location of the health visitor, contact type, and start and end dates of the contact. The key variables are detailed further in relevant chapter (Chapter 6).

DHSW Practice Interventions documents the activities of DHSWs when families are referred to them. This dataset includes the method of referral, type of visit, result of the visit, details of oral health interventions delivered, and subsequent actions based on the visit's outcome (section 1.9.4.1).

These are used for the DHSW educational interventions in Chapter 6, to analyse their effect on early life oral health behaviours.

3.5.3 Growing up in Scotland Datasets

The overarching Childsmile evaluation integrates a wide range of datasets covering health, dental services, education, and Childsmile interventions. For the current PhD study with aims focussing on individual level socio-economic factors and early life behaviours associated with caries experience - the routine administrative datasets – detailed in Section 3.5.1 and 3.5.2 for the overarching evaluation of Childsmile- were inadequate. For the present study there was a

need to further link data from Growing Up in Scotland (GUS) to the Childsmile evaluation baseline cohort to answer the research questions.

Therefore, the data for children within GUS were linked to the Childsmile Evaluation baseline cohort in the National Safe Haven to create a sub cohort of children who had extremely detailed data including early life oral health behaviours (Cariogenic Diet and Toothbrushing), family factors and socioeconomic circumstances (Bradshaw *et al.*, 2011; Bradshaw, Knudsen and Palmer, 2018).

This meant that a subset of the Childsmile evaluation baseline cohort will be used throughout this study as GUS is made up of two longitudinal birth cohorts of approximately 5,000 children down from over 1.3 million unique children present in the Childsmile evaluation baseline cohort detailed in section 3.5.1.

For children to be eligible for the analyses in this thesis they have to have been present in one of the GUS cohorts and the Childsmile evaluation baseline cohort. The two birth cohorts timing made them particularly relevant to the Childsmile evaluation as one were born pre-Childsmile (2004/05) and one were born during early roll-out (2010/11).

3.5.3.1 Growing Up in Scotland Study Design

The GUS study is the key dataset underpinning the analysis in this thesis. The Growing Up in Scotland (GUS) study is a large-scale, longitudinal research project that has tracked the lives of children and their families since 2005 (Scottish Centre for Social Research, 2019). It provides a rich source of data on early-life risk factors relevant to children's oral health.

The study is commissioned by the Scottish Government, and the Scottish Centre for Social Research (ScotCen) is responsible for the design, implementation, and management of the GUS study. ScotCen oversees all aspects of data collection, processing, and quality assurance.

This thesis utilises two nationally representative cohorts of children, Birth Cohort 1 (BC1) and Birth Cohort 2 (BC2), with data used from 10 months to

approximately age of 5 from both. These two cohorts have been securely linked to the overarching Childsmile evaluation baseline cohort (section 3.5.1).

1. Birth Cohort 1 within GUS includes 5,217 children born between June 2004 and May 2005. Data were collected annually from when children were aged 10 months to just under 6 years, then biennially up to age 14 and with further data collection at age 17 and age 20. This current study uses data from the first five sweeps (age 10 months to approximately 5 years).

2. Birth Cohort 2 includes 6,127 children born between March 2010 and February 2011. Data were collected from when children were aged 10 months, approximately 3 years, and approximately 5 years. The final sweep took place in 2015, and no further data collection is planned for this cohort.

GUS used a clustered sampling design based on Primary Sampling Units (PSUs), which were created by aggregating Scottish Government data zones. Data zones are small geographical output areas covering the whole of Scotland and are commonly used for the dissemination of Census and neighbourhood statistics. For BC1, data zones were aggregated to produce areas with an average of approximately 57 births per year based on the mean number of births recorded in each data zone over the preceding three years. The resulting areas were sorted by Local Authority and Scottish Index of Multiple Deprivation (SIMD) score, and 130 areas were randomly selected as PSUs (Bradshaw *et al.*, 2011). Within each selected area, Child Benefit records held by the Department for Work and Pensions were used to identify eligible children based on date-of-birth criteria, with sampling conducted on a month-by-month basis to ensure coverage of the target population. Where more than one eligible child was present within a household, one child was selected at random. Prior to releasing the sample, the Department for Work and Pensions applied several exclusions, including cases considered sensitive and households that had participated in recent research.

A similar sampling framework was used for BC2, although 160 PSUs were selected and Child Benefit records held by His Majesty's Revenue and Customs were used to identify all eligible children within the sampled areas (Bradshaw, Knudsen and Palmer, 2018).

3.5.3.2 Data Collection

Interviews at each sweep were conducted primarily with the child's main carer, usually the mother (BC1 ≈ 98%; BC2 ≈ 97%) (Bradshaw *et al.*, 2011). The same respondent was encouraged to participate across sweeps: approximately 99% of BC1 interviews were with the same respondent as the previous sweep (Bradshaw *et al.*, 2011; Bradshaw, Knudsen and Palmer, 2018). The same respondent was also encouraged for BC2, but the figure is not reported and is likely lower due to the double-length timespan between sweeps. Fieldwork was conducted over a 14-month period, with the sample issued monthly to ensure all children were approximately the same age (in months) at interview; approximately 97% of interviews across all used sweeps in both cohorts were conducted within one month of the target age (Bradshaw *et al.*, 2011; Bradshaw, Knudsen and Palmer, 2018). The target age and what they are referred to in this study are shown in the Table 3.3.

Table 3.3 - Age of child at each Growing Up in Scotland sweep of data collection

Sweep – BC1 (Date)	Sweep – BC2 (Date)	Target Age	Name in study
1 (2005/06)	**1 (2011/12)**	10.5 months	10 months
2 (2006/07)	**N/A**	22.5 months	2 years old
3 (2007/08)	**2 (2013/14)**	34.5 months	3 years old
4 (2008/09)	**N/A**	46.5 months	4 years old
5 (2009/10)	**3 (2015/16)**	58.5 months	5 years old

BC1 – Birth Cohort 1; BC2 – Birth Cohort 2

Although GUS data is mostly gathered via parent/carer interviews, the questionnaire data have also been securely linked to health and school datasets throughout the data collection (Bradshaw *et al.*, 2011; Bradshaw, Knudsen and Palmer, 2018) (Table 3.4).

Table 3.4 - Growing Up in Scotland Data source overview

Source of Data	Child Age (Bold = BC1, otherwise both cohorts)				
	10m	***2***	3	***4***	5
Main Carer Interview	X	***X***	X	***X***	X
Parent/ Teacher Questionnaire		***X***			
Height and Weight		***X***		***X***	
Cognitive Assessments			X		X
Health Records	X	***X***	X	***X***	X
School Records			X	***X***	X

BC1 – Birth Cohort 1

GUS explores a wide range of topics including child development, health and wellbeing, education, parenting, family life, peer relationships, and participation in leisure activities. The study also considers the impact of

socioeconomic factors and neighbourhood environments. Data collected from parents and children over time helps inform Scottish policy and practice, with the aim of improving outcomes for children and reducing inequalities.

3.5.3.3 Response Rates

Initial Response Rates: For BC1, 63.5% of eligible children participated, and 71.9% of those issued were achieved. For BC2, these figures were 63.6% and 64.9%, respectively (Table 3.5). Differences in sampling frame mean that the issued sample response rates are not directly comparable between cohorts (Bradshaw *et al.*, 2007; Bradshaw and Corbett, 2013). However, the final achieved samples are similar enough in composition to allow valid comparison (Bradshaw and Corbett, 2013).

Table 3.5 - Growing Up in Scotland response rates

	Birth Cohort 1	Birth Cohort 2
All eligible children[1]	8218	9640
Child Removed[2] **(% of all eligible children)**	966 (11.8%)	202 (2.1%)
Children Sent Interview Invite	7,252	9,438
Children Responded	5,217	6,127
Response rate		
As % of all eligible children	63.5%	63.6%
As % of all issued	71.9%	64.9%
Total Number of Invites unable to collect data (% of total invites):	2,035 (28.1%)	3,311 (35.1%)
Non-contact	777 (10.7%)	1399 (14.8%)
Refusal	1,157 (16.0%)	1,696 (18.0%)
Other	101 (1.4%)	216 (2.3%)

1. Children Cross-sectional Survey weights are created using the children (section 3.14.2)
2. Children can be removed due to data errors, moving out of the country, removal of 'sensitive' cases by Department Work and Pensions or opting out

Longitudinal Response Rates: Not all children participated in every sweep. However, participants could return in later sweeps even if they had missed earlier ones, which led to some increases in later sweep numbers. These are illustrated in Table 3.6.

Table 3.6 - Participants available at each Growing Up in Scotland Sweep before data linkage

	Birth Cohort 1		Birth Cohort 2	
Responses at age (approximately)	In Sweep (% of total)	In all sweeps so far (% of total)	In Sweep (% of total)	In all sweeps so far (% of total)
10 months	5217	5217	6127	6127
2 years old	4512 (86.5)	4512 (86.5)	N/A	N/A
3 years old	4193 (80.4)	4120 (79.0)	5020 (81.9)	5020 (81.9)
4 years old	3994 (76.6)	3844 (73.7)	N/A	N/A
5 years old	4177 (80.1)	3815 (73.1)	4434 (72.4)	4260 (69.5)

Table 3.6 illustrates over two thirds of children present in first sweep were present in all sweeps for both cohorts.

3.5.4 Baseline Cohorts for this Thesis

The overarching Childsmile evaluation baseline cohort is detailed in Section 3.5.1. For the current study based on the Aims and Research Questions in Chapter 2 children are included if they are: participants of either Birth Cohort 1 or Birth Cohort 2 of the Growing Up in Scotland (GUS) study, have consented to data linkage, and are included in the overarching Childsmile evaluation baseline cohort. The numbers of children at each stage are shown in Figure 3.3.

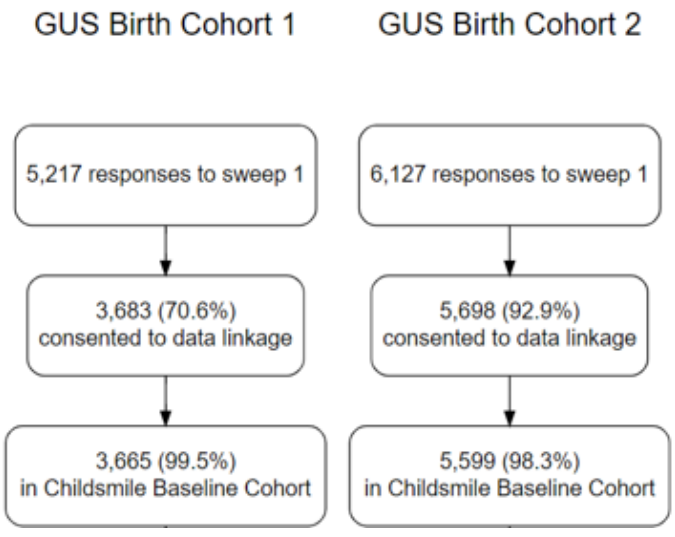


Figure 3.3 - Baseline cohorts for this thesis

More detailed numbers for each sweep of GUS for the number of children in the Childsmile evaluation baseline cohort are illustrated in Table 3.7. For BC1, this information was collected at sweep 4 (n = 3,994), by which point over 23% of the original sample had been lost to follow-up. Approximately 92% of those asked gave consent (3,683/3,994). However, because only three quarters of the original cohort were asked the question, the overall consent rate is lower. For

BC2, the data were collected at sweep 1, meaning the question was asked of the entire cohort. The 18 in BC1 and 99 in BC2 could have dropped out of GUS after agreeing to linkage, meaning BC1 children who had already survived attrition to sweep 4—were more likely to appear in the overall Childsmile evaluation baseline cohort.

Table 3.7 - Growing Up in Scotland participants in Childsmile Evaluation baseline cohort

	Birth Cohort 1			**Birth Cohort 2**		
Cases achieved at Age	In GUS Sweep (a)	In Childsmile evaluation baseline cohort (b)	% of (a)	In GUS Sweep (b)	In Childsmile evaluation baseline cohort (d)	% of (b)
10 months	5217	3665	70.3	6127	5599	91.4
2 years old	4512	3602	79.8	N/A	N/A	N/A
3 years old	4193	3553	84.7	5020	4659	92.8
4 years old	3994	3577	89.6	N/A	N/A	N/A
5 years old	4177	3422	81.9	4434	4136	93.3

GUS – Growing Up in Scotland

Adaptations to this cohort necessary for each subsequent results chapter will be explained in Section 3.12.

3.6 Data Linkage

Data linkage is the process of combining information about the same individual from multiple datasets to create a more complete record, enabling research questions that cannot be answered with a single dataset (Harron, Goldstein and Dibben, 2016). Linkage relies on unique identifiers or combinations of quasi-identifiers, and is typically performed using deterministic methods, which match exact identifiers, or probability matched, which estimate the likelihood that records correspond to the same individual (Zhu *et al.*, 2015). Deterministic linkage is highly accurate when identifiers are complete, whereas probabilistic linkage is more flexible and tolerates data errors but requires careful validation. Benefits of data linkage include richer datasets and increased statistical power, while limitations include potential linkage error, missing data, and privacy concerns, which can be mitigated through secure data environments (Harron *et al.*, 2017).

This section describes the principles and methods used to link the overarching Childsmile evaluation datasets by the National Records of Scotland (NRS) as well

as integrate the Growing Up in Scotland (GUS) datasets, with assistance from the data providers.

3.6.1 Linkage Methods and Principles

The Community Health Index (CHI) number serves as the fundamental unique identifier used for health data linkage (Public Health Scotland, 2025a). Each of the datasets are pre-populated with CHI or probability matched (Table 3.8). CHI numbers are deterministic when complete, allowing exact matches across datasets.

Table 3.8 - Methods for Community Health Index assignment to datasets

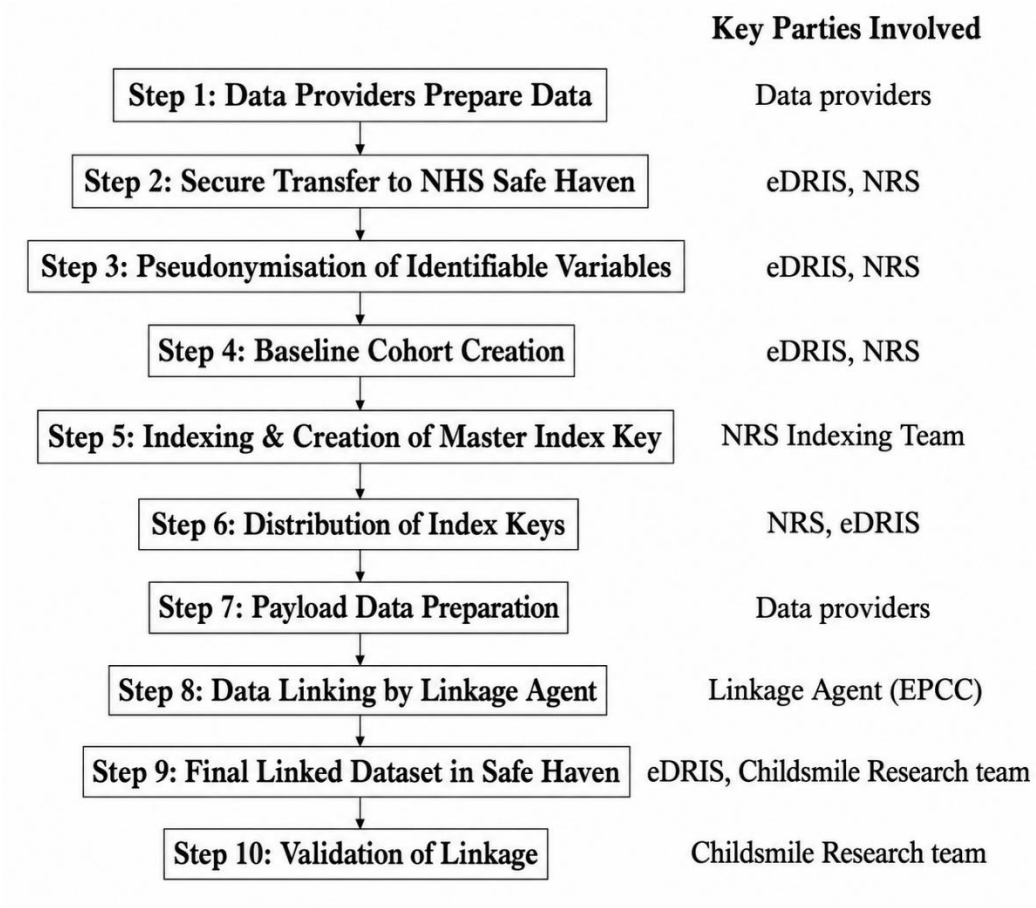
Dataset	Pre-populated
National Dental Inspection Programme P1	No
Child Health Surveillance Programme 6-8 week	Yes
Management Information Dental and Accounting System Participation/Treatment	Mixed
Health Informatics Centre DHSW Data	Mixed
Growing Up in Scotland	No

DHSW – Dental Health Support Worker

GUS datasets were linked to the Childsmile evaluation baseline cohort using unique GUS identifiers generated by ScotCen. GUS Birth Cohort 1 (BC1) used previously “CHI-seeded” pseudo-GUS IDs retained from previous project in 2014. For Birth Cohort 2, the Scottish Government commissioned ScotCen to provide personal identifiers to NRS for indexing. This generated read-through index keys, enabling secure linkage. The CHI methodology for the rest of datasets is detailed in previous work (Kidd, 2019).

3.6.2 Linkage Process

The wider data linkage process was detailed in previous work (Kidd, 2019; Stewart, 2023). The data linkage process for this specific study follows ten main steps illustrated in Figure 3.4 and detailed in the subsequent sections, ensuring secure, accurate, and confidential linkage of multiple datasets, including Childsmile evaluation health data and the GUS cohorts.



NHS – National Health Service; eDRIS – electronic Data Research and Innovation Service; EPCC – Edinburgh Parallel Computing Centre; NRS – National Records of Scotland; ScotCen - Scottish Centre for Social Research

Figure 3.4 - Summary of data linkage process

3.6.2.1 Data Providers Prepare Data

Health datasets, including the Child Health Surveillance Programme (CHSP) 6–8 Week assessments, the National Dental Inspection Programme (NDIP), the Health Informatics Centre (HIC), Management Information & Dental Account System (MIDAS), and GUS datasets from ScotCen were prepared for linkage. All datasets included unique personal identifiers, such as Community Health Index (CHI) numbers or GUS IDs, which were required for matching but protected throughout the process.

3.6.2.2 Secure Transfer to National Health Service National Safe Haven

All datasets were securely transferred to the NHS National Safe Haven. The health datasets were transferred by electronic Data Research and Innovation Service (eDRIS), while the GUS datasets were routed through National Records of

Scotland (NRS), acting as a trusted third party. This ensured that all data entered a controlled environment with robust access and security controls.

3.6.2.3 Pseudonymisation of Identifiable Variables

Direct personal identifiers, including names, addresses, CHI numbers, and pupil IDs, were replaced with pseudonymised codes. This allows datasets to be linked without revealing identifying information. Pseudonymisation is reversible only within secure environments via lookup tables held by NRS and eDRIS.

3.6.2.4 Baseline Cohort Creation (Overarching Childsmile Evaluation)

eDRIS created the baseline cohort for overarching Childsmile evaluation by compiling CHI numbers of all children who had either a Child Health Surveillance Programme (CHSP) 6–8 Week assessment or a P1/P7 NDIP inspection. These CHI numbers are securely transferred via Secure File Transfer Protocol to NRS. This Childsmile evaluation baseline cohort serves as the master list of individuals for all subsequent linkage efforts in Childsmile evaluation studies.

3.6.2.5 Indexing and Creation of Master Index Key

NRS matched each dataset to the baseline CHI spine and generated project-specific index keys for every dataset, as well as a master study index key linking all datasets together. At no point did personal identifiers leave NRS.

3.6.2.6 Distribution of Index Keys

NRS returned the study IDs to eDRIS, which then distributed them to the relevant data providers. This allowed data providers to append requested variables to the study IDs without accessing personal identifiers.

3.6.2.7 Payload Data Preparation

Data providers appended the requested variables to the study IDs and removed all direct identifiers. Only pseudonymised payload data was submitted to the linkage agent via secure transfer.

3.6.2.8 Data Linking by Linkage Agent

The University of Edinburgh's EPCC acted as a third-party linkage agent. EPCC received the pseudonymised datasets along with the master study index key from NRS. Using this key, EPCC replaced dataset-specific identifiers with a single master project ID and linked the datasets. EPCC had no access to personal identifiers.

3.6.2.9 Final Linked Dataset in Safe Haven

The fully linked dataset, containing only master study IDs and research variables, was securely uploaded to the National Safe Haven. Approved researchers accessed this dataset within the National Safe Haven, with no exposure to personal identifiers.

3.6.2.10 Validation of Linkage

Linkage accuracy was validated by Childsmile Researchers cross-checking distributions of key variables, reviewing consistency across datasets, and comparing with previous reports. This is to confirm that records are correctly matched and that the dataset was suitable for analysis.

3.7 Data Completeness and Linkage Checks

Before any substantive analysis was performed, extensive quality assurance was undertaken to verify the integrity, coverage, and quality of the linked datasets. Ensuring data completeness and validating linkage quality are critical steps to support the robustness of subsequent analyses.

Both quality and completeness checks have been systematically applied and documented in prior research using eDRIS-supplied datasets for Childsmile evaluation and linked cohorts, notably in previous theses by Kidd (2019), and Stewart (2023). The procedures described there formed the basis of the quality assurance framework used in this study. All previously established checks were rerun and meticulously revalidated. With the Growing Up in Scotland (GUS) checks within the National Safe Haven are shown in subsequent sections.

3.7.1 Growing up in Scotland Quality Checks

To check the validity of linkage processes that the right child in GUS was being linked with their correct record in the Childsmile evaluation baseline cohort, sex was checked from GUS with sex from the baseline cohort. Upon first linkage sex had been reversed, this was noted in the quality checks when agreement was as low as 0.2% and the data then re-linked, the new linked data sex check is shown in Table 3.9.

Table 3.9 - Growing Up in Scotland and Childsmile evaluation baseline cohort sex check

Sweep	Total	Males in Baseline	Mismatches: Females in GUS	Agreement %	Females in Baseline	Mismatches: Males in GUS	Agreement %
Cohort 1							
1	3665	1863	2	99.9	1802	3	99.8
2	3602	1833	2	99.9	1769	3	99.8
3	3553	1801	2	99.9	1752	3	99.8
4	3577	1813	2	99.9	1764	3	99.8
5	3422	1730	2	99.9	1692	2	99.9
Cohort 2							
1	5599	2837	2	99.9	2762	0	100
2	4659	2370	2	99.9	2289	0	100
3	4136	2091	1	>99.9	2045	0	100

GUS – Growing Up in Scotland

Table 3.9 shows sex agreement between GUS and the Childsmile evaluation baseline cohort across two cohorts and multiple sweeps. For Cohort 1, total linked records ranged from 3,422 to 3,665 per sweep. Sex mismatches were rare, with two male-to-female mismatches in GUS per sweep (three in females) in sweeps 1–4, and two mismatches for each sex in sweep 5. Agreement exceeded 99.8% in all sweeps.

For Cohort 2, linked records ranged from 4,136 to 5,599 per sweep. Across sweeps 1 and 2, two male mismatches and no female mismatches were observed, while in sweep 3 only one male mismatch occurred. Agreement was ≥99.9% for males and 100% for females across all sweeps.

Overall, fewer than 0.2% of records showed disagreement across cohorts and sweeps, indicating high linkage accuracy. In line with STROBE recommendations, remaining discrepancies were resolved by retaining the sex variable from the Childsmile evaluation baseline cohort, which has been previously validated (Kidd, 2019).

3.7.2 Growing up in Scotland Completeness Checks

Completeness checks are designed to confirm that the linked data corresponded to the published GUS study population (Table 3.10). This is essential to ensure that the linkage process has not introduced systematic exclusion of participants, which could bias subsequent analyses. Such checks are particularly important in longitudinal studies like GUS, where linkage quality underpins valid comparisons over time. The number of children in each birth cohort who consented to data linkage is compared across the full linked dataset and then separately within the Child Health Surveillance Programme (CHSP) 6–8-week records and the National Dental Inspection Programme (NDIP) P1 records. This evaluates both overall linkage coverage and the extent to which linked administrative datasets are available within the consenting cohort, rather than simply confirming data transfer into the secure National Safe Haven environment.

Table 3.10 - Growing Up in Scotland completeness checks

Data Set	Records with linkage consent (a)	Records in Linked Dataset (b)		Records in Linked Dataset and CHSP 6-8-week Assessment (c)		Records in Linked Dataset and NDIP P1 (d)	
	n	n	% of a	n	% of b	n	% of b
Birth Cohort 1 Sweep 1	3683	3665	99.5	2992	81.6	3501	95.5
Birth Cohort 2 Sweep 1	5599	5599	98.3	5289	94.5	5241	93.6

CHSP – Child Health Surveillance Programme, NDIP – National Dental Inspection Programme

The comparison demonstrates high levels of completeness for both cohorts. For Birth Cohort 1, 99.5% of consented records were successfully linked, and a large majority could be matched to both the CHSP 6–8-week assessment and the NDIP P1 data. Similarly, Birth Cohort 2 shows near-complete linkage (98.3%) with over

93% matched to both CHSP 6-8 week and NDIP P1. These results suggest that the linkage process did not materially reduce the representativeness of the GUS samples.

3.8 Cleaning of Childsmile Evaluation Datasets in the National Safe Haven

The following section describes the data cleaning process. Data cleaning procedures were based on existing Standard Operating Procedures (SOPs) developed in prior evaluation work and adapted and refined as required for the current analysis using the thesis baseline cohort (Section 3.5) (Kidd, 2019; Stewart, 2023). A SOP is a documented set of step-by-step instructions document created and held within the National Safe Haven that describe how to carry out a routine task or process consistently and correctly.

The steps, outputs and counts of key variables for the National Dental Inspection Programme (NDIP) (Section 3.7.1) SOP, the Management Information & Dental Account System (MIDAS) (Section 3.7.2) SOP, and the Health Informatics Centre (Section 3.7.3) SOP are shown in following sections, with extensive explanation and rationale detailed in work carried out prior to this study (Kidd, 2019; Stewart, 2023). Growing Up in Scotland data were cleaned and the process is described by the Scottish Centre for Social Research pre-data linkage (Bradshaw *et al.*, 2011; Bradshaw, Knudsen and Palmer, 2018).

3.8.1 National Dental Inspection Programme Standard Operating Procedure

There are 554,497 child records over a period of 11 birth cohorts from 2008 to 2018. This was linked to the Growing Up in Scotland birth cohorts; there are 3,501 in Birth Cohort 1 Sweep 1 pre-data cleaning, and 5,241 were in Birth Cohort 2 Sweep 1 after data linkage. The following NDIP cleaning process is illustrated in Table 3.11.

Table 3.11 - National Dental Inspection Programme data standard operating procedure

Cleaning Step	Birth Cohort 1 Count (cumulative % of total removed)	Birth Cohort 2 Count (cumulative % of total removed)
GUS Children pre-linkage at 1st sweep	total = 5217	total = 6127
Present in Childsmile evaluation baseline cohort	3665 (29.8)	5529 (9.7)
Had NDIP record in P1	3501 (32.9)	5241 (14.5)
Match Weight ≥ 30 (detailed below)	3489 (33.1)	5237 (14.5)
No Duplicates	3426 (34.3)	5114 (16.6)

GUS – Growing Up in Scotland; NDIP – National Dental Inspection Programme

Match weights are used only where deterministic identifiers are missing or unreliable—this happens in NDIP and occasionally primary dental care records, but not in the rest of the Childsmile evaluation datasets when CHI number is attached at data collection point. Match weights are numerical scores used in probabilistic record linkage to summarise how strongly two records are likely to belong to the same person. They are needed because real-world identifiers such as names, dates of birth, and postcodes are often incomplete or contain errors, meaning strict deterministic matching can miss true links. Match weights address this by quantifying the evidence from each identifier: for every field, the probability of agreement if the records are a true match (the m-probability) is compared with the probability of agreement occurring by chance (the u-probability). The weight is then calculated as the log-base-2 of the ratio of these probabilities, and the final match weight is the sum of the weights across all identifiers. Higher weights indicate stronger evidence of a true match, although there is no definitive cut-off, so thresholds are selected through review to balance sensitivity and specificity (Kidd, 2019).

As part of the NDIP SOP the variable ‘caries experience’ is defined as detailed in Section 3.10.1, as well as creating a ‘no exam’ count (BC1: n = 226 (6.3%), BC2: n = 344 (6.7%)) for children present in NDIP that did not get an exam on the day, reasons and counts for this stated in section 3.11.3.

3.8.2 Management Information and Dental Accounting System Standard Operating Procedure

The MIDAS datasets are very large, so the first step was to connect the MIDAS data to each wave sweep of the GUS study, keeping only MIDAS information for children who appear in GUS. The numbers remain large since some children in GUS have multiple records in MIDAS; with a different record for each attendance at Dental Services.

Two MIDAS datasets used are MIDAS Participation and MIDAS Treatment (Section 3.4.2.1). These are joined before the SOP is run (Table 3.12).

Table 3.12 - Management Information & Dental Account System Data standard operating procedure steps

Cleaning Step	Birth Cohort 1 Count (cumulative % of total removed)	Birth Cohort 2 Count (cumulative % of total removed)
Observations in Treatment or Participant (have attended dental practice) or GUS Sweep 1 in the Childsmile evaluation baseline cohort	91473	100377
Unique Child ID or Start Date of Visit or Dental Practice Location	59517 (34.9)	46632 (53.5)
Dental Attendance before age 7	24412 (73.4)	40124 (60.0)
Unique Children	3460 (96.3)	5366 (94.7)

GUS – Growing Up in Scotland

Post-cleaning, there were 3,460 unique children in Birth Cohort 1 who had attended a primary care dental services before the age of 7. This age threshold was used as a conservative proxy for attendance prior to a true Primary 1 inspection within the NDIP, as well as for Sweep 5 of GUS data collection. For NDIP Primary 1, this threshold allows for minor variation in the timing of inspections while excluding visits that clearly occur beyond the Primary 1 period.

Stricter age thresholds are applied in specific analyses. In chapters where caries experience is the outcome, attendance is restricted to before the date of dental inspection (Chapter 5). For GUS outcomes, attendance is restricted to before age 4.875 years for Sweep 5 and before age 2.875 years for Sweep 3. These stricter thresholds are applied within the broader cohort described above. Additionally, using an age-based cut-off ensured that attendance occurred after

Sweep 5 of the Growing Up in Scotland study (Chapter 6), which is why the NDIP inspection date itself was not used as the primary restriction during initial data cleaning.

Following the same cleaning process, 5,371 unique children were identified in Birth Cohort 2 as having attended primary care dental services before the age of 7.

3.8.3 Health Informatics Centre Data Standard Operating Procedure

This Standard Operating Procedure (SOP) uses the Diary (n = 277,298) and Practice HIC (n = 166,378) datasets (Section 3.5.2.2) as they are the two used in this thesis 3.5.2.2). These provide the data for the Dental Health Support Worker activity which is required to answer Research Question 4

Childsmile Interventions are only present in GUS Birth Cohort 2 (Table 3.13); as Birth Cohort 1 were born approximately 6 years before the national roll-out of Childsmile. The large drop down in numbers of children in HIC data for Dental Health Support Workers is expected due to it being a targeted intervention, compared to full GUS cohort.

Table 3.13 - Health Informatics Centre data standard operating procedure steps

Cleaning Step	Birth Cohort 2 Count (cumulative % of total removed)
GUS Children pre-linkage at 1st sweep	6127
Present in Overarching Childsmile evaluation baseline cohort	5529 (9.8)
Children in either Diary or Practice HIC data suggesting child was referred to DHSW	1218 (81.1)
Remove True Duplicates - where variable is identical across more than one row	1218 (81.1)
Delete children where family could not be contacted after referral	1218 (81.1)
Remove records with no date of intervention	1218 (81.1)
Remove Date of Intervention before Date of Birth	1187 (81.6)

DHSW – Dental Health Support Worker; GUS – Growing Up in Scotland; HIC – Health Informatics Centre

Table 3.13 shows that 1187 (21.46%) unique children of the 5529 children from Birth Cohort 2 Sweep 1 were contacted by Dental Health Support Worker which match the expected percent for a targeted part of the programme.

3.9 Measures of Socioeconomic Circumstances

This thesis examines socioeconomic circumstances associations with child dental caries experience. Socioeconomic circumstances operate through multiple, distinct mechanisms, with no single indicator sufficient to capture their full influence on health or social outcomes (Adler and Ostrove, 1999) (section 1.6). These can be described using individual or area-based measures, it is recommended, where possible, to use both types of metrics (Conway *et al.*, 2019). This study utilises the term 'socioeconomic circumstances' to capture the dynamic, environmental context of the participants' lives—including localised resources and immediate material challenges—thereby bypassing the potentially stigmatising connotations and deficit-based assumptions often embedded in traditional measures of social hierarchy using terms such as status.

All measures for this thesis are drawn from Growing Up in Scotland data using the two categories – area-based (Section 3.9.1) and individual level (Section 3.9.2).

3.9.1 Area-Based – Scottish Index of Multiple Deprivation

This thesis uses the Scottish Index of Multiple Deprivation (SIMD) as its measure of area-based deprivation (Scottish Government, 2020a). It is important to note when used without individual measure of socioeconomic deprivation it might act as a proxy for individual level circumstances.

3.9.1.1 Development and Components of Scottish Index of Multiple Deprivation

The SIMD was first introduced in 2004, based on a methodology developed by Oxford University to construct the Scottish Indices of Deprivation (Noble *et al.*, 2003). From 2004 to 2012, the SIMD evolved in both domain structure and indicator content:

1. SIMD 2004 included 31 indicators across 6 domains: Income, Employment, Health, Education/Skills/Training, Housing, and Geographic Access to Services.

2. From 2006 onwards, a seventh domain — Crime — was added. Other changes included updates to access indicators (e.g. drive time to secondary school) and revisions to the Income domain, such as the temporary removal and reintroduction of low-income tax credit indicators making a total 37 indicators in 2006 and 38 indicators 2009/2012.

Each version of the SIMD calculates a weighted score for each domain, which is then combined to produce a single overall deprivation score for each data zone. Data zones are small, geographically defined areas in Scotland, typically containing around 500–1,000 households, designed to provide consistent units for statistical analysis and policy planning. An individual's residential postcode is used to identify their corresponding data zone, and the SIMD score for that zone is assigned to the individual.

The overall SIMD score represents the relative level of deprivation in the area, with higher scores indicating greater deprivation. To facilitate analysis, data zones are ranked from most to least deprived and can be divided into quintiles (fifths) or deciles (tenths) to categorise areas for reporting or targeting interventions. The domains, indicators, and their weightings are detailed in Scottish Government technical reports (Scottish Government, 2004; Scottish Government, 2009; Scottish Government, 2012)

3.9.1.2 Utility of Scottish Index of Multiple Deprivation in this thesis

This thesis uses four SIMD versions: 2004, 2006, 2009, and 2012 (Scottish Government, 2004; Scottish Government, 2006; Scottish Government, 2009; Scottish Government, 2012). Guidance from Public Health Scotland) recommends using multiple SIMD releases when examining inequalities over time, to reflect time-specific deprivation and avoid interpreting methodological changes as true differences (Public Health Scotland, 2017; Public Health Scotland, 2023a).

For each cohort, a single SIMD measure per child was applied in each cross-sectional analysis, prioritising the earliest feasible sweep while ensuring compatibility with the availability of key covariates and exposures. The sweep used varied according to the outcome and analytical context, providing a stable baseline while maintaining temporal coherence and comparability across cohorts. Minor differences may arise due to updates in SIMD methodology between releases, but using the most appropriate sweep for each analysis ensures accurate estimation of area-level deprivation.

Each SIMD release was linked to participants in the Growing Up in Scotland (GUS) study via child's home postcode at the time of data collection. Postcodes were matched to one of 6,505 data zones, small areas of roughly equal population, created using natural boundaries and designed to capture homogeneity in social characteristics (Noble *et al.*, 2003). SIMD was supplied in GUS as a national rank (1–6,505) and was categorised into population-weighted fifths for analysis (SIMD 1 = most deprived 20%; SIMD 5 = least deprived 20%). Quintiles are constructed by ranking data zones and dividing them into groups containing approximately equal proportions of the Scottish population rather than equal numbers of areas, a population-weighted approach recommended for deprivation reporting in Scotland (Public Health Scotland, 2023a).

The concordance between SIMD versions in GUS and NDIP was high — 89.7% for Birth Cohort 1 at age five and 86.3% for Birth Cohort 2 at age five, supporting the robustness of the linkage.

Socioeconomic circumstances measured as early as possible in the life course were prioritised to reflect upstream determinants of child health, consistent with life course epidemiology (Ben-Shlomo and Kuh, 2002; Kuh *et al.*, 2003). SIMD from the earliest sweep was used for outcomes measured from birth, whereas later sweeps were employed when key covariates or exposures were available, ensuring consistency in baseline measurement and maintaining temporal coherence.

Table 3.14 outlines the SIMD version used at each sweep of GUS.

Table 3.14 - Scottish Index of Multiple Deprivation version used in each Growing Up in Scotland sweep

SIMD Collected		
	Birth Cohort 1	**Birth Cohort 2**
Sweep 1	2004	2009
Sweep 2	2006	2012
Sweep 3	2006	2012
Sweep 4	2006	
Sweep 5	2009	

SIMD – Scottish Index of Multiple Deprivation

SIMD enables comparison across small geographic areas, helping to identify patterns of disadvantage that may be obscured in broader administrative units such as health boards or council areas. It reflects area-level socioeconomic deprivation instead of individual socioeconomic circumstances and is therefore subject to ecological fallacy (Robinson, 1950; Morgenstern, 1995). Ecological fallacy occurs when assumptions about individuals are made based on group-level data, which is true for an area may not be true for every person in that area.

One theoretical criticism of SIMD is that because it includes a health domain, its use to study deprivation patterns in health is invalid because the SIMD and the health indicator being studied are not independent of each other. However, the health domain is weighted to account for a relatively small part of the overall SIMD (approximately 14%), and analyses of health inequalities using SIMD were found to give similar results whether the health domain was included or excluded, because that domain was so highly correlated with the overall index.

Where applicable, the use of SIMD at multiple time points also provides time-specific estimates of socioeconomic deprivation across early childhood, enabling a more comprehensive understanding of socioeconomic context in longitudinal or repeated cross-sectional analyses (Public Health Scotland, 2023a).

3.9.2 Individual Level Socioeconomic Measures

This study also uses household-level measures, specifically focusing on poverty, parental education, and employment status. This section will detail the key individual measure of socioeconomic circumstance and how they were derived.

3.9.2.1 Income Poverty

Income poverty in this study is defined according to the widely accepted threshold of 60% of the median equivalised household income (Hagenaars, de Vos and Zaidi, 1994; European Commission, 2004). Income of household is collected at each sweep of Growing Up in Scotland during the parent/carer interview, a standard used in both UK and European Union poverty statistics. Equivalised income adjusts raw income to account for differences in household size and composition, using the modified Organisation for Economic Co-operation and Development equivalence scale:

- First adult: weight of 1.0
- Additional adults (15+): 0.5
- Children (0–14): 0.3

This approach standardises income across households, allowing meaningful comparisons. The income data were collected at multiple GUS sweeps and processed into equivalised household income bands, from which a binary poverty indicator (below or above 60% of the median) was derived. This variable captures a core aspect of material deprivation: insufficient income relative to societal norms. This the most widely employed measure of poverty and while this approach has been critiqued for reflecting relative economic position rather than absolute need—capturing inequality and "economic distance" rather than material deprivation—it remains a standard in both UK and European research. (Spicker, 2012).

3.9.2.2 Highest Parental Education in Household

Higher Parental Education in Household at Age 2 to 5 years old: The maximum education of respondent or partner in the household categorised according to the National Vocational Qualifications (NVQ) and Qualifications and Credit Framework (QCF) levels. The levels are:

- No Qualification or Other

- GCSEs/Standard Grades/NVQ Level 2 or Below
- A Levels/Highers/NVQ Level 3 or Equivalent
- HNC, HND, NVQ Level 4 or Equivalent
- Degree/NVQ Level 5 or Equivalent

3.9.2.3 Highest Household Parental Occupational Class (Employment)

Highest Household Parental Occupational Class (Employment) is classified using the National Statistics Socio-economic Classification (NS-SEC), which includes fourteen categories based on employment relations, such as higher and lower managerial, professional, intermediate, small employers, own account workers, lower supervisory and technical, and semi-routine and routine occupations. For this study, categories were condensed into five groups, with a sixth category, 'never worked/unemployed', using the maximum value from the respondent and partner (Pevalin and Rose, 2002). The six groups are:

- Never worked/unemployed
- Routine
- Semi-routine
- Lower supervisory and technical
- Intermediate, small employers and own account workers
- Managerial and professional

3.10 Derivation of Key Variables

There are a variety of key variables that are used in multiple sections of this thesis. Some needed to be derived from the data available; the methodology for these is illustrated in this section. The creation of all these variables is explained extensively in previous work (Kidd, 2019).

3.10.1 Caries Experience (RQ1 – RQ5 – Chapter 4 to 7)

From the National Dental Inspection Basic P1 Examination Criteria is shown in Table 3.15 (also Table 3.1).

Table 3.15 - National Dental Inspection Programme examination criteria

Letter	Caries experience	No caries experience
A1	Abscess or infection	
A2	Gross caries	
A3	Obviously carious permanent tooth	
B1	Obviously carious primary tooth	
B2		Possible carious permanent tooth[1]
B3	Missing primary molar	
B4	Evidence of restorations	
B5		Poor Oral Hygiene[1]
C		No obvious caries experience

[1] Only option in Birth Cohort 1 National Dental Inspection Programme Examination

Thus, any child with one or more of 'A1', 'A2', 'A3', 'B1', 'B3' or 'B4' they would be classed as having 'obvious caries experience' referred to throughout thesis as simply 'caries experience'. If the child was marked as having 'B2', 'B5' or 'C', the would be classified as 'no obvious caries experience', referred to as 'no caries experience'. 'A1', 'A2' or 'A3' can be referred to as 'Severe caries experience' due to their more severe nature. Basic Examination was used due to its near population level coverage and high level of agreement with detailed examination (Conway et al., 2025).

3.10.2 Regular Dental Attendance (RQ2, 3 and 5 – Chapter 5 and 7)

Regular primary care (both General and Public Dental Service) Dental Attendance referred to as 'regular dental attendance' throughout the thesis, was defined using administrative data from the Management Information & Dental Accounting System (MIDAS) (Section 3.5.2.1). Public Dental Service counts are less consistently captured and therefore slightly undercounted. Children were considered to have regular dental attendance if they had attended a primary care dental service at least once per year in four out of the five years from birth up to their fifth birthday.

This variable was binary (Yes/No):

- Yes (Regular Attendance): Child attended primary dental care service 1 or more times per year in at least 4 of 5 first years.

- No (Irregular/No Attendance): Child did not meet the attendance threshold.

This threshold was used in preference to the number of dental visits alone, as visit counts do not necessarily distinguish between regular preventive attendance and repeated visits associated with dental problems and restoration. The binary measure therefore provided a more meaningful indicator of sustained engagement with primary dental care.

3.10.3 Cariogenic Diet (RQ2, 3, 4 and 5 – Chapter 5, 6 and 7)

Cariogenic diet was derived from Growing Up in Scotland (GUS) food-frequency data collected through parent/carer interviews. Although the number and type of dietary variables differed slightly between cohorts, both provided detailed information on early life eating patterns:

- Birth Cohort 1 (BC1): 29 diet-related variables collected at age 2 or 5

- Birth Cohort 2 (BC2): 18 diet-related variables collected at age 3 or 5

Each candidate diet-related variable can be found in Supplementary Tables for Chapter 5 (ST 5.1). In these tables they are listed; first using frequency tables, then cross tables with ‘caries experience’ (Section 3.10.1) and then analysed using univariable adapted modified Poisson regression (Section 3.11.3) with the outcome ‘caries experience’. Area under the curve (AUC) was calculated for each model. Variables showing both strong predictive ability of caries experience and clear theoretical relevance to cariogenic dietary behaviour were retained (see Supplementary Tables for Chapter 5 – ST 5.2), ensuring that only indicators with robust and meaningful associations were carried forward.

Because dietary behaviours are often highly correlated, a confirmatory factor analysis (CFA) was used to reduce the data and quantify a single latent factor

representing cariogenic diet. CFA is a multivariate statistical technique that tests whether observed variables load onto a pre-specified latent construct, providing an estimate of the shared underlying pattern among related behaviours (Brown, 2015). Latent constructs were defined a priori based on theoretical and empirical evidence linking sugar-rich foods and beverages to dental caries (Moynihan and Kelly, 2014). Each observed variable was specified to load onto a single latent factor representing cariogenic diet. Only variables conceptually linked to cariogenic diet were included; all high in sugar or fermentable carbohydrates (Touger-Decker and Van Loveren, 2003):

- Sweet intake frequency (BC1: Age 2, BC2: Age 3)
- Sugar-sweetened beverages frequency (SSBs) (BC1: Age 2, BC2: Age 3)
- Crisps frequency (selected from BC2 to match BC1) (BC1: Age 2, BC2: Age 5)

These items have been consistently associated with dental caries risk in children, supporting their inclusion as indicators of the latent construct (Tahmassebi *et al.*, 2006; Sheiham and James, 2015). Using CFA allows the combination of multiple correlated dietary behaviours into a single, theory-driven measure, reducing measurement error and improving the validity of subsequent analyses. For latent variables made up from different sweeps of data children had to be present in both sweeps.

Each indicator was constrained to load onto a single latent factor, with residual variances assumed independent unless theory or modification indices indicated a need for correlation. Each of these items across both cohorts was assessed using frequency response categories ranging from: 1+ per day, 1 per day, 5-6 per week, 2-4 per week, 1 per week, 1-3 per month, and less often or never

Factor scores were subsequently standardised to a mean of 0 and a standard deviation of 1, with higher scores indicating more frequent consumption of cariogenic foods and beverages. This latent measure was employed as an exposure in analyses examining associations with dental caries. The distribution of the latent variables is illustrated in Figure 3.5.

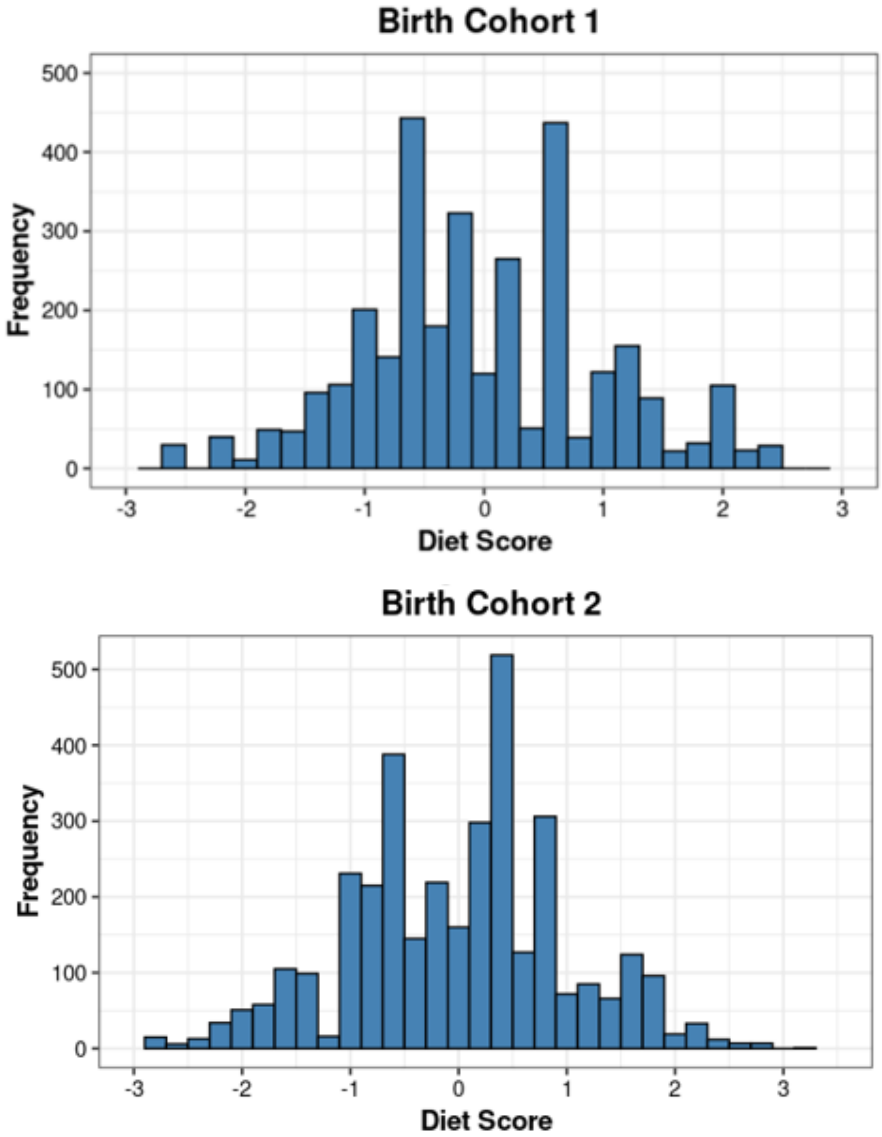


Figure 3.5 - Distribution of latent cariogenic diet variables

All CFA analysis is completed using the lavaan package in R (Rosseel, 2012), with the theory further detailed in subsequent Section 3.11.4.

3.10.4 Socioeconomic Circumstances (RQ 2,3,5,6, Chapter 5,7,8)

Socioeconomic circumstances during early childhood were represented as a single latent construct for each birth cohort, capturing multiple dimensions across four key family/community indicators described in Section 3.9:

- Area-based socioeconomic deprivation (Scottish Index of Multiple Deprivation fifths)

- Household income poverty (binary 60% median equivalised income threshold)

- Highest household education (five-level NVQ/QCF classification)

- Highest household occupational class (five-group NS-SEC category)

These indicators reflect distinct yet interrelated aspects of socioeconomic circumstances, encompassing material resources, parental human capital, occupational status, and neighbourhood-level deprivation – and collectively capturing socioeconomic circumstances. CFA was used to estimate the latent SEC factor, with WLSMV estimation applied to accommodate ordinal and binary data. Each observed variable was specified to load on the latent factor, and residuals were permitted to correlate only when theoretically justified. Factor loadings of 0.4 or greater were regarded as indicative of substantial contribution, though indicators with slightly lower loadings were retained to preserve the comprehensiveness of the construct.

The resulting latent SEC factor scores were standardised to a mean of 0 and a standard deviation of 1, with higher values representing more advantaged socioeconomic circumstances. This continuous latent measure integrates multiple facets of socioeconomic status into a single robust metric, providing a stable representation of early-life disadvantage for analyses of inequalities in child oral health and the effects of the Childsmile intervention. The distribution of the latent variables is illustrated in Figure 3.6.

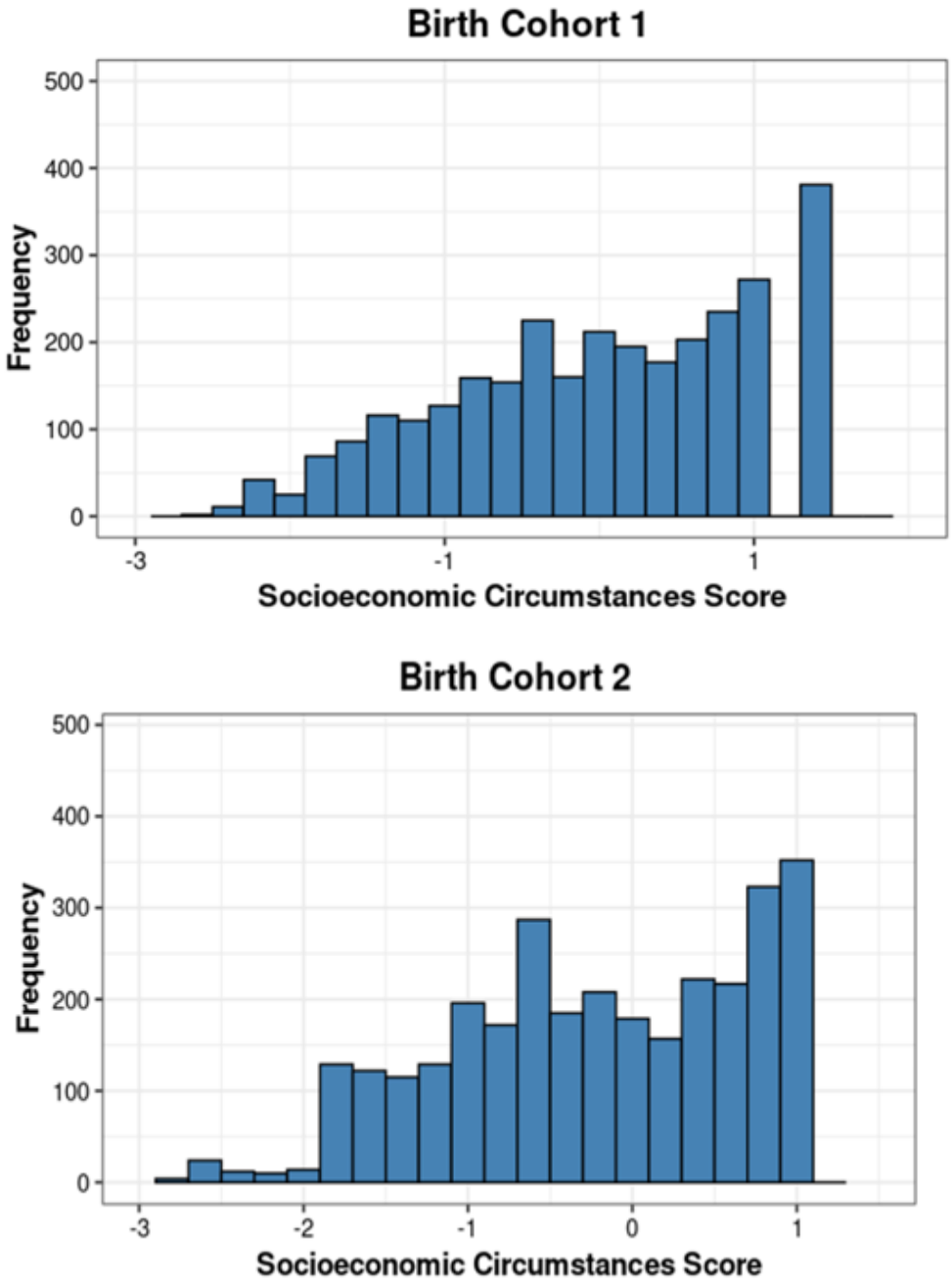


Figure 3.6 - Distribution of latent socioeconomic circumstances variables

The latent SEC distribution showed a modest ceiling effect, reflecting clustering of observations at higher levels of socioeconomic advantage. This likely arises from the categorical nature of the indicators and the relatively high proportion of households occupying advantaged education, occupational, and area-level categories. Consequently, the latent construct differentiates socioeconomic disadvantage more strongly than variation among highly advantaged households.

All CFA analysis is completed using the lavaan package in R (Rosseel, 2012), following the same procedure as the latent Cariogenic diet (Section 3.10.3) with the theory further detailed in subsequent Section 3.11.4.

3.11 Overarching Statistical Analyses

The following Section describes the overarching statistical methods used. Chapter specific analytical methods are described within each results chapter.

3.11.1 Software

Data cleaning and statistical analyses were completed using v4.2.0 of R (R Core Team, 2023).

3.11.2 Handling of Missing Data

Missing data arose through non-response at individual sweeps, attrition across successive sweeps and incomplete information on variables required for analysis. The Growing Up in Scotland (GUS) cohorts achieved generally good response levels, providing substantial information on children's early-life circumstances, family characteristics and health-related behaviours, although participation declined over successive sweeps. Analyses were conducted using complete-case data for the variables required in each model, without imputing missing values. This approach retained observed data without introducing the additional assumptions and modelling decisions required for multiple imputation, including the specification of appropriate imputation models across behavioural, socioeconomic and linked administrative variables. Given the substantial sample sizes and generally good response levels, complete-case analysis provided a practical approach to estimating the planned models. However, the choice of missing-data method should not be determined solely by the proportion of missing observations, as multiple imputation can be beneficial under appropriate assumptions even when missingness is limited (Sterne et al., 2009; Madley-Dowd et al., 2019). Complete-case analysis can nevertheless reduce statistical precision and introduce selection bias if inclusion in the analytical sample is associated with the exposure, outcome or relevant confounders (Hughes et al., 2019).

To account for the sampling design and differential participation, GUS survey weights were applied as appropriate to each analysis. Using complete-case data also simplified the application of the supplied GUS weights, as it avoided the additional methodological considerations involved in combining multiple

imputation with complex survey weighting. These weights incorporated adjustments for initial selection probabilities, non-response and calibration to the target population, with further adjustments for non-response and attrition at subsequent sweeps. Cross-sectional and longitudinal weights were available, with the appropriate weight selected according to whether analyses required data from a single sweep or multiple sweeps. The construction of these weights and their application in the present analyses are described below (Bradshaw et al., 2007; Bradshaw and Corbett, 2013; Bradshaw et al., 2011; Bradshaw, Palmer and Knudsen, 2018).

3.11.2.1 Cross-Sectional Survey Weights

Cross-sectional weights were generated by Scottish Centre for Social Research in three stages all detailed in GUS user guides (Bradshaw *et al.*, 2007; Bradshaw and Corbett, 2013).

The first stage accounted for selection probabilities. In households containing more than one eligible child, such as twins or multiple births, children were randomly selected, with each child having a probability of selection equal to one divided by the number of eligible children. The selection weight was the inverse of this probability. In households with children from different cohorts, cohort-specific selection probabilities were applied and inverted to generate the selection weight. No additional adjustments for age or sex were made beyond these household- and cohort-specific probabilities.

The second stage adjusted for non-response. Non-response was modelled using logistic regression to estimate the probability of participation based on baseline demographic, socio-economic, and household characteristics. Predictor variables included parental age, child sex, number of children in the household, method of benefit payment, area deprivation measured by SIMD, and urban or rural indicators. The selection weight from the first stage was multiplied by the inverse of the predicted probability of response, producing the non-response-adjusted weight. Each respondent's probability of response $\hat{p}_i$ was estimated, and then the weight was multiplied by $1/\hat{p}_i$

The third stage involved calibration to the population frame to ensure that weighted totals reflected the distribution of the eligible population in the Child Benefit register. Calibration variables included the age of the benefit claimant, child sex, month of issue relative to the child's birth, and, in Birth Cohort 2, the number of children in the household. This stage produced the final Sweep 1 cross-sectional weight, expressed mathematically as:

$$w_i^1 = \frac{1}{\pi_i} \times \frac{1}{\widehat{p_1}} \times c_i$$

- π_i = probability that child i was selected into the GUS sample (the design or selection probability).

- $\hat{p}_i$ = predicted probability that child i responded at Sweep 1 (from the non-response logistic regression).

- c_i = calibration factor ensuring that weighted totals match the Child Benefit sampling

At each subsequent sweep, the weight from the previous sweep serves as the starting point. Any additional non-response at the current sweep is modelled, and the resulting adjustment (the inverse of the predicted probability of response) is multiplied by the existing weight. This approach ensures that the calibration applied at the first sweep is retained in all subsequent weights, while also incorporating adjustments for attrition or non-response specific to each later sweep. In other words, all later cross-sectional and longitudinal weights inherit the Sweep 1 calibration to the Child Benefit population, and successive non-response corrections are accumulated as the study progresses.

For sweep t>1, the longitudinal or cross-sectional weight can be expressed as:

$$w_i^t = w_i^{t-1} \times \frac{1}{\widehat{p_t}}$$

3.11.2.2 Longitudinal Survey Weights

Longitudinal weights are used for analyses combining data across multiple sweeps, correcting for both initial selection probabilities and attrition over time. Only participants who contributed data at all relevant sweeps are assigned a longitudinal weight (Bradshaw *et al.*, 2011; Bradshaw, Palmer and Knudsen, 2018).

The cross-sectional weight from the first sweep was used as the base, and the probability of participation in each subsequent sweep was modelled using logistic regression, including baseline demographic, socio-economic, and household variables. Participants with lower predicted probabilities received larger weights.

The longitudinal weight is the product of the base cross-sectional weight, and the inverse predicted probabilities across all subsequent sweeps:

$$w_i^{long} = w_i \times \frac{1}{\widehat{p_{\iota,2}}} \times \frac{1}{\widehat{p_{\iota,3}}} \ldots \times \frac{1}{\widehat{p_{\iota,t}}}$$

3.11.2.3 Methodology Differences in Survey Weights between Birth Cohort 1 and Birth Cohort 2

Although the weighting principles were consistent across cohorts, minor methodological differences existed between Birth Cohort 1 and Birth Cohort 2.

Birth Cohort 2 included targeted oversampling of participants in the First-Time Mothers Programme, requiring a specific calibration adjustment, whereas Birth Cohort 1 did not. BC2 also separated respondents into those who participated in all sweeps and those who missed an intermediate sweep, applying separate adjustments, whereas BC1 applied attrition adjustments collectively. Calibration variables sometimes differed, with BC2 including the number of children in the household, and BC2 additionally applied trimming to extreme weights to improve sample efficiency, which BC1 generally did not.

3.11.2.4 Data-Linkage Dropout, Validation and Sample Efficiency

Original survey weights were not adjusted for non-consent or attrition related to linkage with administrative records, although exploratory adjustments were tested and did not materially improve representativeness.

Weighted estimates of key population variables, such as SIMD and household income, were compared with published statistics to validate representativeness.

Weight variability affects effective sample size, and trimming and scaling were applied as needed to maintain precision in weighted estimates.

3.11.2.5 Application of Survey Weights in Analyses

Weighted data were used for all frequency tables, cross-tabulations, and regression analyses, except where unweighted data are explicitly required (e.g., Chapter 4). Cross-sectional weights were applied to single-sweep analyses, while longitudinal weights were used for analyses spanning multiple sweeps.

3.11.3 Adapted Modified Poisson Regression models

Modified Poisson regression is a form of generalised linear modelling used to directly estimate risk ratios (RRs) for binary outcomes, in contrast to logistic regression, which yields odds ratios (ORs). The model is specified using a Poisson distribution with a log link function, allowing direct modelling of the log of the expected probability of the outcome.

Although Poisson regression is traditionally used for count data, it can be applied to binary outcomes as a modelling framework for estimating risk ratios. In this context, the Poisson distributional assumption is violated because the variance of a binary outcome depends on its mean, resulting in misspecification of the variance structure. However, regression coefficients remain consistent for the mean model (Zocchetti, Consonni and Bertazzi, 1995). To address this issue, robust (sandwich) variance estimation is typically used to obtain valid standard errors under variance misspecification (Zou, 2004). This approach is referred to as ‘modified Poisson regression’.

In this study, we extended this approach to account for complex survey design. RRs were estimated using survey-weighted generalised linear models with a log link fitted using the survey design framework in R (survey). This represents an adaptation of the modified Poisson approach of Zou (2004) for complex survey data, in which design-based variance estimation accounts for sampling weights, clustering, and stratification in place of conventional sandwich estimators. This will be called ‘adjusted modified Poisson regression’.

RRs were obtained by exponentiating regression coefficients. Confidence intervals were calculated on the log scale using standard errors and then exponentiated to return to the risk ratio scale ($\log(RR) \pm 1.96 \times SE$). This provides directly interpretable measures of association, where values above 1 indicate increased risk and values below 1 indicate reduced risk relative to the reference group.

Sensitivity analyses were conducted by fitting both Poisson and quasi-Poisson models for key variables of interest within this adapted method. These exploratory analyses produced no material differences in estimated RRs or confidence intervals, indicating that the findings were robust to the choice of distributional family.

RRs were selected as the primary measure of association due to easier interpretability over ORs. They quantify different measures of association and are not equivalent when the outcome is common (> 10%). ORs can be further from the null value than corresponding RRs and may overstate the magnitude of associations if interpreted as relative risks (Zhang and Yu, 1998). This led to the use of Modified Poisson regression provides a method of estimating RRs directly for binary outcomes, without relying on the approximation that ORs and RRs are equivalent when outcomes are rare (Zou, 2004).

3.11.3.1 Diagnostics of Adapted Modified Poisson Regression Models

Although Poisson regression models are traditionally designed for count data, they are frequently adapted for binary outcomes using modified Poisson regression with robust variance estimation, particularly when risk ratios are of interest. In this context, measures of discrimination such as the Area Under the

Receiver Operating Characteristic Curve (AUC) can be used in place of the concordance index to evaluate model performance in distinguishing cases from non-cases (Zou, 2004). This was applicable for the adapted method.

3.11.4 Lavaan Package

All latent variable modelling were conducted using the lavaan package in R (Rosseel, 2012). Given that a substantial proportion of observed indicators in Growing Up in Scotland were categorical or ordinal, model parameters were estimated using the Weighted Least Squares Mean and Variance adjusted (WLSMV) estimator. This estimator is particularly appropriate for non-continuous data, providing robust parameter estimates and standard errors by minimising the weighted squared difference between observed and model-implied correlation matrices while adjusting for both mean and variance. Error terms were allowed to vary independently unless modification indices indicated that correlations between residuals were theoretically justified.

Latent constructs were specified a priori based on theoretical and empirical considerations. Each observed variable was constrained to load on a single latent factor, and factor loadings were required to exceed 0.4 to ensure adequate representation of the underlying construct. Residual variances were assumed to be independent unless theoretical justification and modification indices indicated that correlations were warranted.

For each latent construct, factor scores were derived to represent individual positions on the underlying dimension and subsequently standardised to a mean of 0 and a standard deviation of 1. Higher scores consistently represented greater expression of the latent trait—for example, a more cariogenic dietary pattern or a more advantaged socioeconomic position.

Applicable model fit indices included the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardised Root Mean Square Residual (SRMR). However, the simplicity of the individual CFA models did not allow for meaningful use of these indices.

The lavaan package in R was selected for latent variable modelling because it provides a flexible and reproducible framework for confirmatory factor analysis and structural equation modelling, including support for categorical and ordinal indicators using the WLSMV estimator (Rosseel, 2012). Its use was also informed by the software available within the NHS Scotland Safe Haven, where access to alternative statistical packages was restricted; such as Mplus.

3.12 Analytical Baseline Cohorts for Each Research Question

Due to differences in the analyses, some results chapters use slightly modified versions of the baseline cohorts described in Section 3.5. These modifications reflect inclusion criteria specific to each research question, and each subset of the cohort is nested within the previous one:

- In overarching Childsmile evaluation baseline cohort and in Growing Up in Scotland Birth Cohorts ⟶ Children with valid National Dental Inspection Programme (NDIP) Primary 1 Examination ⟶ Children with a valid NDIP P1 caries experience outcome (for Research Question 6, only children present in every sweep of Growing Up in Scotland are included).

The four key inclusion criteria for all sub-cohorts are:

- Included in both overarching Childsmile evaluation baseline cohort and one of the Growing Up in Scotland birth cohorts

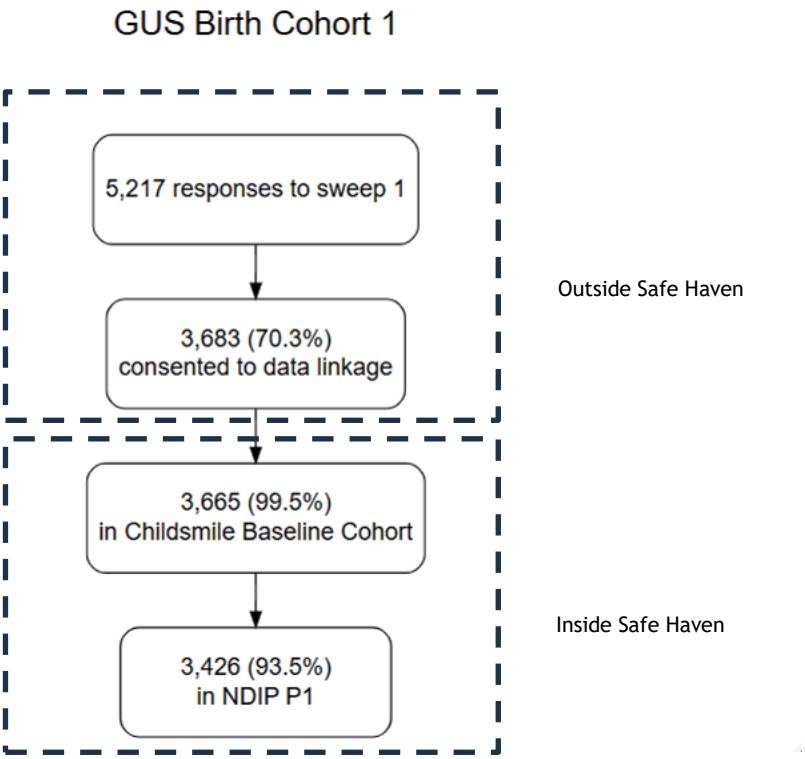
- Included in National Dental Inspection Programme (NDIP) Primary 1 data

- Having a valid NDIP P1 examination outcome (caries experience or no caries experience; excluding those that didn't get an exam coined 'no exam').

- Included in all Growing Up in Scotland sweeps used for longitudinal analysis

3.12.1 Research Question 1 – Chapter 4

For RQ1 cohorts- children were included who were in Birth Cohort 1 from the Baseline cohorts (Section 3.5.4) and were subsequently followed up in P1 when their primary school class underwent a NDIP exam (Figure 3.7).

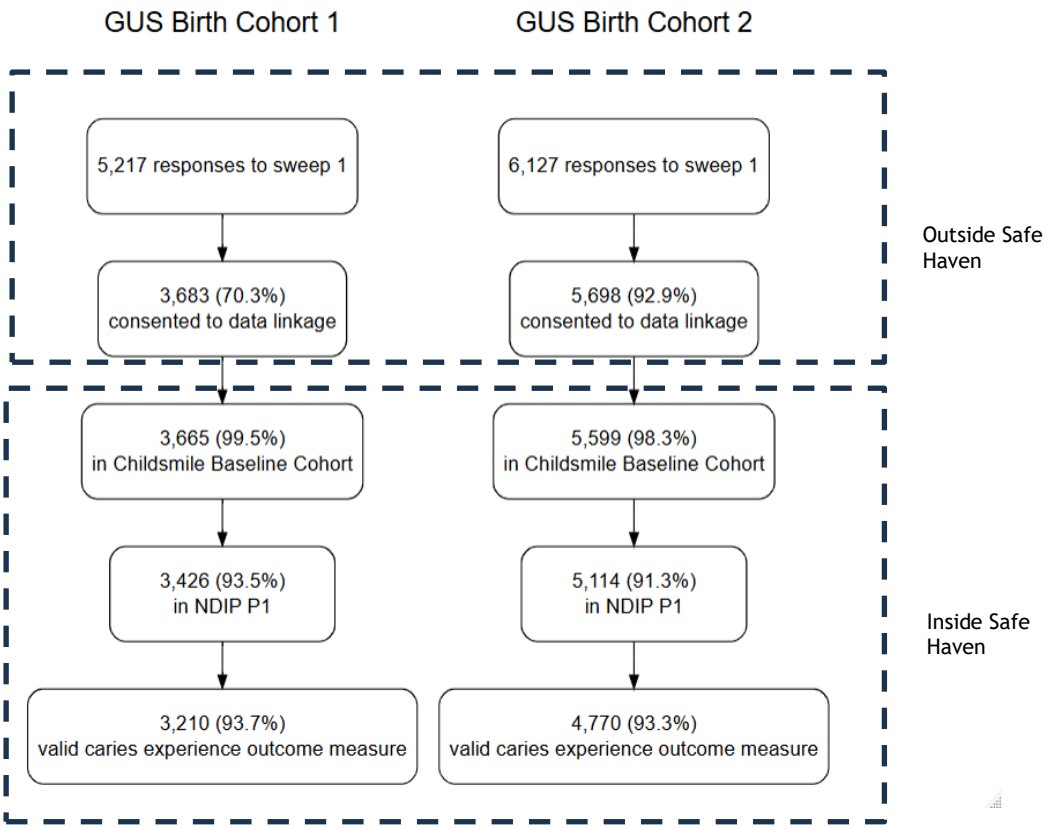


GUS – Growing Up in Scotland; NDIP P1 – National Dental Inspection Programme Primary 1

Figure 3.7 - Chapter 4 cohort

3.12.2 Research Question 2, 3 and 5 (Chapters 5 and 7) (Children that have valid caries experience Outcome)

For these research questions analyses all needed a valid 'caries experience' outcome. Therefore, all children from the baseline cohorts (Section 3.5.4) who were subsequently followed up in P1 when their primary school class underwent a NDIP exam and got a valid primary outcome measure of "caries experience (y/n) recorded were included (Figure 3.8).



GUS – Growing Up in Scotland; NDIP P1 – National Dental Inspection Programme

Figure 3.8 - Chapter 5 and 7 cohort

The cleaned NDIP steps are detailed in section 3.8.1. The reasons and number of children removed for no exam are listed in Table 3.16; this is the removal of children that are present in the NDIP data but did not get an exam. This is necessary for any research question where 'caries experience' was the primary outcome for these analyses.

Table 3.16 - Reasons for 'no exam' at National Dental Inspecion Programme examination

Reason for no examination	Birth Cohort 1 (% of total)	Birth Cohort 2 (% of total)
Total	216	344
Absent	157 (72.7)	256 (74.4)
Child Refusal	8 (3.7)	30 (8.7)
Not Attending[1]	17 (7.8)	21 (6.1)
Parental Refusal	31 (14.4)	26 (7.6)
Remove from list[2]	0 (0)	8 (2.3)
Missing	3 (1.4)	1 (0.3)

[1]Not attending: Children who were scheduled for examination but did not attend on the day.
[2]Remove from list: Children removed from the NDIP sampling frame prior to the examination (e.g., moved out of the area).

Similar distribution of reasons across both cohorts for children not getting exams with approximately 6% of children not getting exams and over 70% of those children being due to absence.

3.12.3 Research Question 4 (Chapter 6)

This represents Birth Cohort 2 children from the overall baseline cohort described in Section 3.5.4 (Figure 3.9).

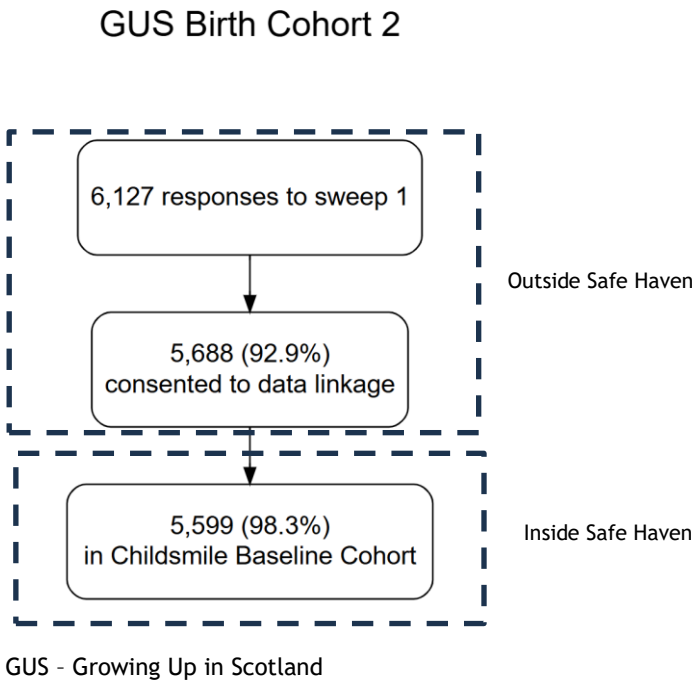
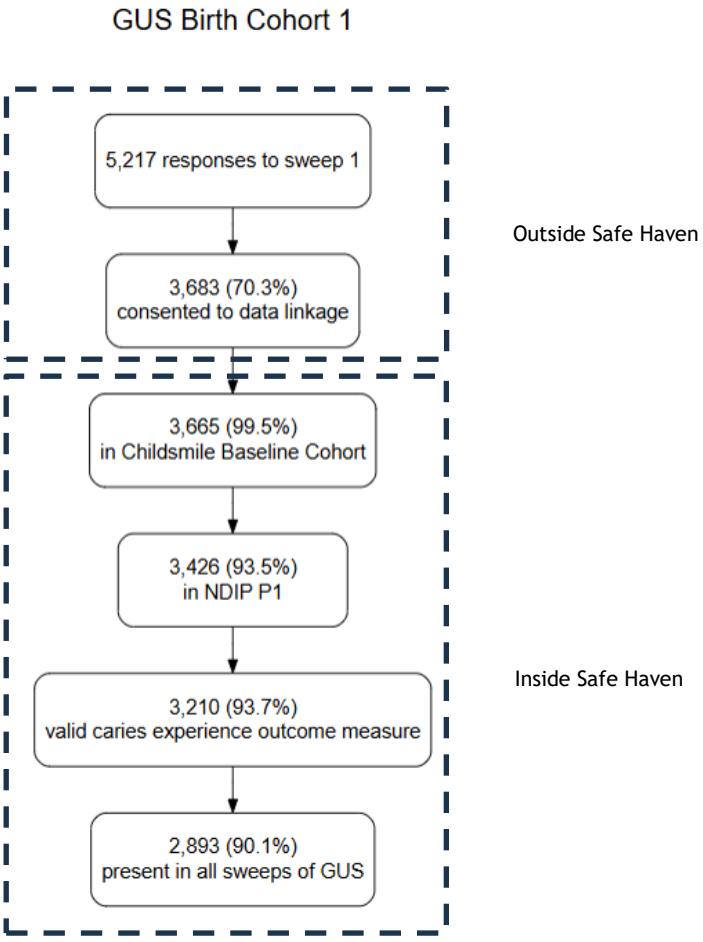


Figure 3.9 - Chapter 6 cohort

This is the largest cohort of children at 5,599. This cohort is used for Research Question 4, where the oral health behaviour (Cariogenic Diet and Toothbrushing) questions in GUS Birth Cohort 2 are the primary endpoints.

3.12.4 Research Question 6 (Chapter 8)

For this research question outcome, children who were present in baseline cohorts (Section 3.5.4) and had a P1 NDIP exam, got a valid primary outcome measure of “caries experience (y/n)” recorded and were subsequently in every other sweep of GUS used in analysis (Figure 3.10).



GUS – Growing Up in Scotland;
NDIP P1 – National Dental Inspection Programme Primary 1

Figure 3.10 - Chapter 8 cohort

Results (Chapter 4 – 8)

Chapter 4

4 Accuracy of Parent/Carer Proxy-Reporting of Caries Experience in Children and Association with Socioeconomic Circumstances

The contents of this chapter were published to the journal Community Dental Health on the 29th of July 2024. This results chapter answers research question 1.

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Keywords: *epidemiology, socioeconomic factors, dental caries, self-report, child health, medical record linkage*

4.1 Preface

Monitoring children's oral health remains a vital public health priority in Scotland, with the National Dental Inspection Programme (NDIP) providing a well-established clinical standard for population-level assessment. Meanwhile, the growing availability of parent/carer-reported information from surveys and administrative data—often linked across sources—presents a valuable opportunity to explore how these data might contribute to oral health surveillance.

This chapter takes advantage of the availability of both parent/carer-reported assessments and clinical outcomes from the NDIP to investigate the accuracy of parental reporting. Given that conditions such as dental caries are often negatively perceived, reporting accuracy may be influenced by various social and cognitive factors. Understanding this relationship is important to consider whether parental reports might be limited in utility, serve as useful complements, or even act as proxies for clinical data in certain contexts.

Additionally, the chapter examines whether the accuracy of parental reporting varies by socioeconomic circumstances by stratifying results using the Scottish Index of Multiple Deprivation (SIMD). This stratification allows for a more

nuanced consideration of how social background might shape the reliability of parent-reported data.

4.1.1 Author Contributions to this Manuscript

I led the development and conduct of this study, including the research questions, study design, data analysis, interpretation of findings and preparation and writing of the manuscript. Andrea Sherriff contributed to the initial development of the research idea and study design, provided guidance throughout the study, and reviewed and provided feedback on the manuscript. David Conway and Paul Bradshaw reviewed the manuscript and provided feedback.

4.2 Research Question

1. What is the accuracy of parent/carer proxy-report of child caries experience when compared to clinician measured child caries experience; is this affected by socioeconomic deprivation level?

4.3 Abstract

Objectives: To compare parent/carer proxy-reported dental caries experience of their 5-year-old child with epidemiological survey clinician examination of caries experience in the same children. To determine any differences in the accuracy by area-based socioeconomic group.

Methods: A cross-sectional data linkage study linked data from the Growing Up in Scotland (GUS) study and the National Dental Inspection Programme (NDIP) school epidemiology survey. Parent/carer proxy-reported caries experience was compared with clinician-measured caries experience on n=3008 children, and data were stratified by home-residential area-based socioeconomic deprivation levels (Scottish Index of Multiple Deprivation (SIMD)). Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were calculated overall and stratified by SIMD.

Results: Overall, parent/carer proxy-reporting had low sensitivity (42.3% 95%CI: 39.0, 45.7) that decreased with decreasing deprivation (SIMD-1(most deprived):

49.4% to SIMD-5 (least deprived): 37.2%). Specificity remained consistently high overall and across area-based socioeconomic deprivation levels (overall=96.2%, 95%CI: 95.3, 97.0; SIMD-1: 94.4% SIMD-5: 97.8%). In children whose parents/carers reported them to have caries experience (GUS) a high percentage were found to have caries experience (NDIP) (PPV=81.8%, 95%CI: 78.2, 84.9).

Conclusion: Parent/carer proxy-reporting of caries experience in 5-year-old children had very low sensitivity and was lowest in children from the least deprived areas. In contrast, parents/carers who reported their child had caries experience did so reasonably accurately. This study concludes that proxy reporting caries experience is not sufficiently sensitive to replace clinician examination in assessing dental caries experience in surveys of child populations and highlights the importance of data linkage to routine datasets.

4.4 Introduction

Dental caries affects 530 million children globally (World Health Organization, 2019) and in higher income countries, almost a third of these children have untreated decay with large and persistent inequalities. In Scotland, caries experience in children has improved over the past 20 years although inequalities remain stubborn. Annual data on caries experience in 5- and 11-year-olds in Scotland are obtained from the National Dental Inspection Programme (NDIP), a school-based population-wide oral health survey that covers almost 95% of all children in these age groups. Caries experience is recorded by teams of trained dentists using a standardised protocol and the data are used to assess individual child treatment need and local area service delivery and for epidemiological purposes. The need for these large and costly epidemiological surveys has been debated previously (Silman *et al.*, 2018) with some arguing that parent/carer proxy-reporting of caries experience in children may be less onerous and costly (Fleming and Afful, 2018).

Parent/carer proxy reporting whereby the parent/carer reports health or behaviours on behalf of the child necessitates them to understand behaviours, feelings, and experiences of the child, as well as being able to communicate this accurately. This form of proxy reporting can firstly be beneficial due to the varying levels of a child's ability to report on their own health (Mpundu-

Kaambwa *et al.*, 2021; Paul *et al.*, 2023). Moreover, proxy-reporting can capture information that is not easily accessible through clinical examinations alone, such as pain perception and treatment preference. It is also generally seen as less invasive and more cost-effective than many other methods. Despite these possible advantages however, proxy-reporting in the context of child oral health is expected to exhibit limitations. Errors are an inherent part of scientific research in all disciplines and are even more apparent in studies that involve extra levels of subjectivity such as proxy reporting. Validity and accuracy concerns may arise in these findings due to a plethora of possible errors, mainly social desirability, and memory concerns (Upton, Lawford and Eiser, 2008; Mack *et al.*, 2020). This all needs to be considered before utilising proxy-reporting as a means of collecting information. The optimal goal for subjective reporting as with any study is to minimise the total study variance and bias without impacting the generalisability of the study (Sica, 2006).

A secondary analysis comparing maternal proxy-reporting of child caries experience against clinician assessed caries experience was carried out across 774 local government areas in Nigeria using 1549 children under the age of 6 years (Folayan *et al.*, 2020a). This study used the decayed-missing-filled teeth (dmft) index (Pine, Pitts and Nugent, 1997) to define dental caries experience and found that parents under-reported the prevalence in their children in the study population. They also explored the socioeconomic impact through mothers age, mother income, mother educational status, and mothers' ability to act independently. They found that the higher the income and higher the mother's ability to make more independent decisions had a statistically significantly higher level of accurate proxy-report. Both factors are believed to be key to high utilisation of dental services in Nigeria. Conversely, an increase in education saw a decrease in the accuracy of the reporting, however, the reason for this is not explored in the paper. Studies comparing the accuracy of parent reporting to the child self-report equivalent are more commonplace usually for subjective outcomes such as health related quality of life, such as Ooi *et al.* (2020) with regards to obesity and Blake *et al.* (2020) with sickle cell disease. Another example paper comparing parent reporting and child self-reporting is Mack *et al.* (2020) exploring the level of agreement between symptoms and functioning children going through cancer treatment. All three of these papers found that

parents couldn't consistently agree with the child self-report, and concluded the elicitation of child's own report should still be pursued wherever possible. The final paper examined explored this type of comparison in the field of oral health (Reissmann *et al.*, 2017). This looked at correlation between child and parent ratings and diagnostic accuracy of the parental rating cross-sectional study of 140 children in Cologne aged 7–17 years and was assessed with the 19-item Child Oral Health Impact Profile (COHIP) (Broder, Wilson-Genderson and Sischo, 2012; Sierwald *et al.*, 2016). Their findings were like the previous papers mentioned with the concordance among individual scores minimal, and the diagnostic precision of the parent ratings deemed inadequate.

The potential time and cost advantages of proxy-reported caries experience over clinician measured caries experience are posited, however a direct comparison between the two measures in young children is necessary. The availability of robust data, especially valid outcome measures is critical to research and evaluation in the field of child oral health and is important to inform policy makers where to concentrate efforts and financial resources.

4.5 Methods

This was a data linkage, cross-sectional study comparing proxy-report of caries experience with clinician examination measured caries experience among children in the Growing Up in Scotland (GUS) cohort study who were born in 2004/05 *and* who underwent a basic dental inspection in Primary 1 (aged ~ 5 years) between 2009 and 2011 as part of the National Dental Inspection Programme in Scotland.

Growing Up in Scotland (GUS) is a cohort study tracking all aspects of a child's life from birth onwards in two separate nationally representative birth cohorts and a child cohort. For this study, data are analysed from the first birth cohort of children born between 01/06/2004 – 31/05/2005 (n = 3833) at ~ 5 years old in the 5th sweep of data collection (Bradshaw *et al.*, 2011). The National Dental Inspection Programme P1 was an annual survey of caries experience in children in their Primary 1 school year (approximately 5 years old) attending local authority and some public schools. The dental inspection involved a simple assessment of the mouth and teeth of each child by trained and standardised

primary care dental teams within primary schools. For this study GUS records were linked to the NDIP in school years 2009/10 and 2010/11.

Data Linkage used the Electronic Data Research and Innovation Service (eDRIS), with a strict disclosure protocol. The data were linked at an individual level to Scotland's list of unique patient identifiers, the Community Health Index (CHI) number, using probabilistic matching on key variables using date of birth, sex, and postcode. The linkage agent pseudonymises study specific identifiers allowing individuals to be linked across both data sets stored within the National Safe Haven. The NDIP dataset and the GUS dataset have both been subject to data cleaning and quality assurance using standard operating procedures (SOPS).

GUS caries experience was a derived binary variable coded as "1" if the child's parents/carers reported that their child had tooth fillings, had a decayed tooth extracted, or had some or a lot of decay, and "0" otherwise. The questions used for this can be found in the GUS data documentation (Bradshaw et al., 2011).

NDIP caries experience (yes/no) is illustrated in Table 4.1 by any category defined in section A or the first, third or fourth categories in section B (Macpherson et al., 2020). A secondary measure of Gross Caries was considered to allow for the fact parents/carers may identify gross caries more readily. This is only the most extreme cases and is only defined as yes for anything defined in section A of Table 4.1.

Table 4.1 - National Dental Inspection Programme examintaion criteria

NDIP Examination (Up to 2014/2015)	
Letter	
A	Abscess or infection Gross caries Obvious caries permanent tooth
B	Obvious caries primary tooth Possibly carious permanent tooth Missing primary molar Evidence of restorations Poor oral hygiene
C	No obvious caries experience

The Scottish Index of Multiple Deprivation (SIMD) 2009 was used as an area-based deprivation measure (Scottish Government, 2009). It is based on 38 indicators in seven individual domains of current income, employment, housing, health, education, skills and training, geographic access to services and crime. SIMD is

calculated at data zone level, enabling small pockets of deprivation to be identified. The data zones are ranked from most deprived (1) to least deprived (6,505) on the overall SIMD index. The ranked data zones were then categorised into fifths.

Caries experience (and gross caries) (as measured by NDIP) was cross tabulated with proxy-reported caries experience (as measured in GUS). Sensitivity, specificity, positive predictive value, and negative predictive value were calculated (Altman and Bland, 1994; Trevethan, 2017).

The study received ethical approval (College of MVLS, University of Glasgow) and approval from the Public Benefit and Privacy Panel - Health and Social Care (PBPP- Public Health Scotland) and the Statistics- PBPP (Scottish Government) (reference number: 200170146). Reporting used the STROBE guidelines (von Elm et al., 2008).

4.6 Results

There were 3833 children in the GUS Birth Cohort 1 in the school year 2009/10 (Sweep 5 – Aged 4 – 6 years) of which 3422 (89.3%) are present in the National Safe Haven. Those missing (n=411) did not give consent for their survey data to be linked to routine administrative data.

There were 51,074 Primary 1 children who had a NDIP record in the same timeframe. Of the 3422 children who had proxy reported caries experience in GUS, 3214 (93.9%) had a corresponding NDIP record. Those not in the NDIP database are likely to have attended the ~5% of schools who did not participate in the dental inspection. Four children present in GUS data set had missing data for all three proxy-reported questions. Of these 3210 children, 202 attended NDIP participating schools but did not receive a dental inspection on the day of the dental inspection for various reasons (child was absent or refused) leaving 3008 children with both measures of caries experience. Of the 3008 children included 1518 (50.5%) were male and 1490 (49.4%) were female. In this group, 526 (17.5%) of the children lived in the 20% most deprived areas of Scotland (SIMD1), 541(18.0%) in SIMD2, 587 (19.5%) in SIMD3, 685 (22.8%) in SIMD4 and 669 (22.2%) children lived in the 20% least deprived areas of Scotland (SIMD5).

The comparison of the proxy-reported caries experience from the GUS survey with the clinician measure of caries experience and gross caries from the NDIP is presented in Table 4.2.

Table 4.2 - Comparison of caries experience/gross caries (Nation Dental Inspectioon Programme) with Growing Up in Scotland proxy-report

		NDIP				
		No caries experience (%)	caries experience (%)	No Gross Caries (%)	Gross Caries (%)	**Total**
GUS	No Caries experience	2067 (96.23)	496 (57.67)	2449(87.71)	114 (52.53)	2563
	Caries experience	81 (3.78)	364 (42.33)	342(12.29)	103 (47.47)	445
	Total	2148	860	2791	217	3008

NDIP - National Dental Inspection Programme; GUS - Growing Up in Scotland

Based on the NDIP, 28.6% (860/3008) of children had caries experience, whereas only 14.8% (445/3008) had caries experience based on the parent/carer proxy-report. Gross caries was reported in 7.2% of children (217/3008).

Table 4.3 presents Sensitivity and Specificity for caries experience overall, then partitioned by SIMD fifths. For those with caries experience in the NDIP only 42.3% (364/860) proxy-reported caries experience (sensitivity) in GUS. In contrast specificity was high with 96.2% (2067/2148) of those with no caries experience (NDIP) reporting correctly via proxy report in GUS. The sensitivity did improve slightly for gross caries (47.5%), while the specificity decreased to 87.7% (2449/3008) as children without gross caries could still report to having caries (GUS caries experience v NDIP gross caries only). In parents/carers who reported their child to have caries experience (GUS), almost 82% (364/445) had clinician verified caries experience (PPV).

Table 4.3 presents the Sensitivity, Specificity, PPV, NPV, Overall Accuracy and Caries Prevalence comparison between caries experience (NDIP) and parent/carer proxy-report caries experience (GUS) in all children and then partitioned by area-based deprivation fifths (SIMD).

Table 4.3 - Sensitivity, specificity, positive predictive value, negative predictive value, overall accuracy and prevalence for caries experience (National Dental Inspection Programme) vs Growing Up in Scotland proxy-report partitioned by area—based deprivation

SIMD	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Ovr Accuracy (95% CI)	Prevalence (95% CI)
ALL	42.33 (39.00, 45.71)	96.23 (95.33, 96.99)	81.80 (78.16, 84.94)	80.65 (79.73, 81.53)	80.82 (79.36, 82.21)	28.59 (26.98, 30.24)
1-most deprived	49.37 (42.87, 55.89)	94.43 (91.10, 96.78)	88.06 (81.83, 92.35)	69.13 (66.33, 71.80)	73.95 (69.98, 77.66)	45.44 (41.12, 49.80)
2	43.01 (35.79, 50.46)	95.77 (93.13, 97.62)	84.21 (75.98, 89.99)	76.23 (73.86, 78.45)	77.63 (73.88, 81.08)	34.38 (30.38, 38.55)
3	42.14 (34.36, 50.21)	96.96 (94.86, 98.37)	83.75 (74.54, 90.07)	81.85 (79.78, 83.76)	82.11 (78.77, 85.13)	27.09 (23.53, 30.88)
4	34.53 (26.68, 43.06)	95.42 (93.31, 97.02)	65.75 (55.14, 75.00)	85.13 (83.52, 86.61)	83.07 (80.04, 85.50)	20.29 (17.34, 23.50)
5- least deprived	37.23 (29.13, 45.89)	97.75 (96.10, 98.83)	80.95 (69.99, 88.57)	85.83 (84.18, 87.34)	85.37 (82.47, 87.96)	20.45 (17.15, 23.70)

PPV - Positive Predictive Value; NPV - Negative Predictive Value; Ovr – Overall; SIMD – Scottish Index of Multiple Deprivation

Sensitivity was lowest in children living in the top 40% least socioeconomically deprived areas of Scotland. (SIMD4: 34.5%; SIMD5: 37.2%) and highest in children living in the 20% least deprived areas (49.4%). In general sensitivity decreased as levels of deprivation decreased. Specificity remains consistently high, ranging from SIMD1: 94.4% to SIMD5: 97.7%. The PPV follows a similar pattern as the sensitivity with the 40% least deprived areas having the lowest PPV (SIMD4: 65.8%; SIMD5: 81.0%) and highest in children living in the 20% least deprived areas (88.1%). There is a notable PPV outlier at SIMD 4; more than 15% lower than any other SIMD fifth.

4.7 Discussion

This study compared the proxy-reporting of caries experience against a standardised clinician examination on a cohort of children approximately 5-years-old. The findings reveal that parental/carer proxy-reporting for caries experience identified in the NDIP, has very low sensitivity (<50%) even when only

considering gross caries experience which should be visibly obvious. The sensitivity decreased even further in respondents from less deprived areas of Scotland, however in contrast specificity remains consistently high across all SIMD fifths. The GUS proxy-report only identified around half the amount of caries experience as the clinicians (15% to 29%), however the positive predicted value was high, indicating that parents/carers report of decay, fillings or missing teeth in their child were reasonably accurate.

The findings of low sensitivity of parental/carer report of child caries experience aligns with previous research (Folayan *et al.*, 2020a) and indicates that parental/carer reporting may not be suitable as a valid tool to measure child caries experience. It is worth noting that the that the PPV of caries experience identified by GUS is reasonably high (81.80%) but also follows similar socioeconomic pattern to sensitivity when using SIMD.

The impact of socioeconomic factors on reporting accuracy was seen in this study through the decrease in sensitivity in the least deprived SIMD fifths (SIMD1 = 49.37% vs SIMD5 = 37.23%), however which and how many of the 7 SIMD domains had impact is unclear. The importance of understanding this is illustrated by the findings from Folayan *et al.* (2020a). They concluded maternal income as a significant factor in increasing sensitivity, inversely sensitivity decreased as maternal education levels increased. Folayan *et al.* (2020a) study used a wide age range of children (under 6) with various stages of dentition compared to this study which took place at 5 years old. Their study also had a much lower prevalence of caries (4.50% vs 28.59%) and a smaller sample size (1155 and 3008) when compared to this study. It is also important to consider cultural, social, and environmental differences between to the two countries the studies are set in and the constraints that places on the comparability of the findings.

Looker (1989) asserted that education is a pivotal socioeconomic indicator in proxy reporting, suggesting its potential significance as a key driver in the socio-economic patterns observed in this study. These findings were reinforced in a community-based, cross-sectional epidemiologic study in North Carolina which compared dental caries using the dmft index against a dichotomised oral health question (fair/poor vs. excellent/very good/good). This study linked lower

education levels with higher levels of parental reporting of sub-optimal oral health across the 6328 children aged 3-5 in the study. However, although it did compare clinician untreated caries outcome and parental reporting or oral health accuracy it did not explicitly do this across the socioeconomic factors included in their study (Imes *et al.*, 2021). Their study had a sample that emanate from a low-income, high-risk child population meaning the findings may not be transferable to more affluent strata. Their oral health question asked was more ambiguous than the ones included in this study which could have attributed to its notably lower sensitivity than this study (24.54% v 42.33%). Imes *et al.* (2021) study was also multi-ethnic and refers to ethnicity as a key factor in the differences in reporting; while there are other studies that report an improvement in health reporting from minority ethnic groups (Bombak and Bruce, 2012; Mindell *et al.*, 2014). The potential confounding impact of ethnicity in this study, however, will be minimal due to the low proportion of minority ethnic groups present in the cohort (approximately 3%). This effect is complicated further by the complex relationships between ethnicity, socioeconomic position and health in Scotland (Walsh *et al.*, 2019a). The effect of parental education levels on proxy-reporting has also been explored in a wider health setting. Cullinan and Cawley (2017) conducted a cross-sectional cohort study on 8568 9-year-old children which were sampled from 910 schools Ireland. They examined reporting of child obesity and found obese parents with higher levels of education saw lower levels of concurrence.

The accuracy disparities across SIMD may be attributed to social desirability bias, which includes a fear of judgment, social stigma, and the desire to present oneself positively. Specific to education; higher educated individuals may be more susceptible to social desirability bias due to their heightened awareness of medical recommendations, public health messaging, and the health implications associated with certain conditions or behaviours (Cullinan and Cawley, 2017). These are all applicable to dental caries (Imes *et al.*, 2021) and could cause it to be underreported (Pitiphat *et al.*, 2002).

This study underscores the limitations of solely proxy-reporting for recording dental caries experience prevalence and suggests an influence of socioeconomic factors on subjective reporting. These findings provide valuable insight suggesting the necessity to continue with large population wide epidemiological

studies such as NDIP to report on outcomes such as dental caries. This study is believed to be the first in a high-income country that has directly compared parental/carer proxy-reporting accuracy against a standardised clinician reporting of dental caries in children using robust data linkage between a national survey and routine population-wide dental inspection data.

Finally, the strengths and limitations of this study need to be considered. Firstly, the linkage process between the datasets was robust with a high linkage rate, which did not exclude many records. The cohort for this study slightly overrepresented families from less deprived areas, as is common for opt-in studies however the relatively large sample size allowed thorough comparisons within each SIMD group. This study was cross-sectional, and therefore the impact of age of the child on proxy-reporting accuracy could not be assessed, with reporting accuracy believed to alter depending on the age of the child (Parsons *et al.*, 2012; Imes *et al.*, 2021). Another limitation of this study was that exact dates (day/month) of GUS survey responses were not available due to information governance constraints, and it is possible that some parents/carers completed the survey at an earlier time point than their child underwent the NDIP, albeit in the same school year. It is unlikely that a large percentage of children would develop decay in the intermediate time, but it is possible and could have resulted in some misclassification, but this misclassification would be unlikely to be socially patterned. Conversely, if the NDIP was conducted prior to the GUS survey responses, it is possible that tooth decay could develop in the intervening time and could explain the slight drop in PPV. In both these scenarios it is unlikely that visible decay would develop in a short period of time within a single school year, but the possibility should be considered. The use of ‘basic’ NDIP inspection could be seen as a limitation, however the findings derived from the 'basic' inspections, closely mirror the data obtained from more comprehensive ‘detailed inspection’ assessments (Macpherson *et al.*, 2020). The latter involves a 20% subsample of the population and employs the more thorough British Association of Community Dentistry (BASCD) criteria, particularly the decayed, missing, and filled teeth (d3mft) index (Pine, Pitts and Nugent, 1997). Another possible limitation of using NDIP data is that some private/public school children are not included (approximately 5%), this could lead to an overestimation of caries experience overall but would have limited

impact on the current study. Lastly, the use of SIMD, an area-based socio-economic measure, as a proxy for individual level socioeconomic circumstances comes with both strengths and limitations. It is extensive, robust, very well documented and its 37 indicators covering a plethora of socioeconomic factors, however, due it being given as a combined score of an amalgamation of lots of domains across an area it isn't possible to tease out specific information or information about an individual and can lead to the risk of ecological fallacy (Scottish Government, 2009).

4.8 Conclusion

Parent/carer proxy-reporting of caries experience in 5-year-old children had very low sensitivity and was lowest in children from the least deprived areas. In contrast, however parents/carers who reported their child had caries experience did so reasonably accurately.

This study concludes that proxy reported surveys may not be sufficiently sensitive to replace trained/standardised clinician examination measures in assessing dental caries experience in child populations.

4.9 Acknowledgments

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Chapter 5

5 Early Life Behaviours Associations with Childhood Caries Experience Before and After Childsmile Implementation

This chapter answers research questions 2 and 3.

5.1 Preface

Existing overarching evaluations of the Childsmile programme rely primarily on routine administrative data and therefore lack detailed measures of early life behaviours such as diet and toothbrushing. Consequently, it has not been possible to directly assess whether Childsmile influences the behavioural mechanisms through which improvements in child oral health are theorised to occur. Programme theory underpinning Childsmile suggests that its interventions operate by promoting positive behaviour change, which in turn leads to improved oral health outcomes. Understanding these behavioural associations is therefore an important step in evaluating the programme.

This chapter examines the associations between early life behaviours and caries experience at age five using two nationally representative birth cohorts from the Growing Up in Scotland (GUS) study, linked to clinical dental outcomes from the National Dental Inspection Programme. The primary exposures of interest are child oral health behaviours (cariogenic diet, toothbrushing, and regular dental attendance).

Family and community-level characteristics are included as covariates to account for potential confounding, as these factors are likely to be associated with both early life behaviours and child oral health outcomes. Socioeconomic circumstances are considered as a distinct domain, reflecting their well-established and independent influence on child oral health and their central role in shaping both family environments and health-related behaviours. Their inclusion allows assessment of the extent to which observed associations between behaviours and caries are attenuated after adjustment for broader social and environmental conditions.

A staged multivariable modelling approach is employed, beginning with univariable analyses of behaviours, then progressively adding family and socioeconomic factors to assess their influence on behavioural associations with caries. Latent constructs for cariogenic diet (section 3.10.3) and socioeconomic circumstances (section 3.10.4) improve measurement precision and reduce multicollinearity, allowing more robust estimates of behavioural effects.

By stratifying analyses by pre- and early post-Childsmile (Birth Cohort 1 and Birth Cohort 2), this chapter explores whether associations between early life behaviours and caries experience differ following the early national roll-out of Childsmile in Scotland. While this chapter focuses on adjusted associations, more complex relationships between behaviours, family context, and oral health outcomes are explored in subsequent analyses using structural equation modelling.

5.2 Research Questions

2. What is the association between early life behaviours (diet, toothbrushing, dental attendance) and child caries experience; have these associations changed before and after early national roll-out of the Childsmile programme?

3. To what extent do family and community-level factors influence the association between early life behaviours and child caries experience; have these changed before and after early national roll-out of the Childsmile programme?

5.3 Abstract

Objective: To assess how early-life oral health behaviours—diet, toothbrushing, and dental attendance—are associated with childhood caries experience at age five, and whether these associations differ between pre- and post- early Childsmile roll-out in Scotland, after accounting for family and socioeconomic context.

Methods: Data from two nationally representative birth cohorts (BC1: born 2004/05; BC2: born 2010/11) from the Growing Up in Scotland (GUS) study were

linked to caries experience from the National Dental Inspection Programme (NDIP)(P1) and dental attendance records from Management Information. Early-life behaviours were the exposures, while family factors (household size, home chaos, formal service use) and socioeconomic circumstances (income poverty, parental education and employment, area deprivation) were included as confounders. Latent constructs for cariogenic diet and socioeconomic circumstances were derived using confirmatory factor analysis. Associations with caries experience were examined using staged multivariable adapted modified Poisson regression, stratified by cohort.

Results: In multivariable models, higher cariogenic diet scores were similarly associated with increased caries experience risk in both cohorts (BC1: aRR 1.19, 95% CI 1.13–1.26; BC2: aRR 1.17, 95% CI 1.10–1.26). More frequent toothbrushing was protective in both cohorts (BC1: aRR 0.89, 95% CI 0.81–0.97; BC2: aRR 0.81, 95% CI 0.71–0.92). Regular dental attendance was associated with reduced caries experience in unadjusted models, but the effect attenuated after adjustment for socioeconomic circumstances and family factors, particularly in BC2 (aRR 0.90, 95% CI 0.79–1.04). Family factors produced modest attenuation of associations, whereas adjustment for socioeconomic circumstances substantially reduced effect sizes and improved model discrimination (BC1: AUC 0.65–0.70; BC2: AUC 0.64–0.69). Direct comparisons between cohorts showed no meaningful differences in behavioural associations, with ratios of risk ratios close to 1.

Conclusions: Early-life oral health behaviours are important determinants of caries experience, although their associations operate within the context of family and socioeconomic circumstances. Following the introduction of the Childsmile programme, the association between regular dental attendance and caries experience appears to be attenuated after adjustment for these factors, whereas diet and toothbrushing remain consistently associated with caries outcomes. These findings suggest that, while promoting dental attendance remains important, greater emphasis may be needed on supporting healthy dietary behaviours and effective toothbrushing behaviours. At the same time, policies should recognise and address the broader family and socioeconomic conditions that influence these behaviours in early childhood.

5.4 Introduction

Oral health behaviours—such as diet, toothbrushing, and early primary care dental services attendance—are associated with oral health outcomes including caries (Issrani *et al.*, 2025). Health behaviours are established early in life and are strongly shaped by family and community conditions (Lawlor and Mishra, 2009). These in turn reflect broader social determinants and inequalities related to living circumstances, including income, educational attainment, and employment (Marmot *et al.*, 2010; Watt, 2023). To capture these multiple layers of influence, this study draws on the Fisher-Owens framework, which emphasises child, family, and community determinants of oral health (Fisher-Owens *et al.*, 2007), situated within Dahlgren and Whitehead (1991) model of health inequality.

Fisher-Owens *et al.* (2007) framework informed the development of Childsmile, Scotland's national child oral health improvement programme, introduced in the mid-2000s. Childsmile combines universal and targeted interventions, including supervised nursery toothbrushing, fluoride varnish applications, family support, and primary dental care behaviour change interventions, with the aim of reducing caries prevalence and narrowing inequalities (Macpherson *et al.*, 2010). Since its introduction, population-wide improvements have been observed (Ross *et al.*, 2023), though marked inequalities in caries experience remain. What remains unclear is whether Childsmile has interacted with social and behavioural pathways through which disadvantage translates into disease risk in early childhood.

This study addresses gaps in understanding the determinants of early childhood caries by employing a natural experimental approach using two birth cohorts from the Growing Up in Scotland study, linked to routine dental inspection records. By comparing a pre-Childsmile cohort (children born 2004/05) with an early post-rollout cohort (children born 2010/11), it examines how early-life oral health behaviours—diet, toothbrushing, and dental attendance—are associated with caries experience at age 5, and whether these associations have changed over time. It also investigates how family environment and socioeconomic circumstances influence these associations, and whether their effects differ between cohorts.

5.5 Methods

This study utilised early life factors data from two nationally representative birth cohorts from the Growing Up in Scotland (GUS) study, linked to caries experience from the National Dental Inspection Programme (NDIP). The first cohort (BC1; children born 2004/05) represents a pre-Childsmile population, while the second cohort (BC2; born 2010/11) reflects the early post-Childsmile roll out era. Therefore, children were included who participated in either GUS Sweep 1 and gave permission for data linkage, who were in both 6-8 week Child Health Surveillance Programme and were subsequently followed up in P1 when their primary school class underwent a NDIP exam, and got a valid primary outcome measures of "caries experience (y/n)" recorded (Section 3.12.2).

Early life dental attendance was linked from the Management Information and Dental Accounting System (MIDAS) dataset which is the system in which dentists are paid to deliver primary dental care (Public Health Scotland, 2019).

Data linkage of the three datasets mentioned was performed by the Electronic Data Research and Innovation Service (eDRIS) at Public Health Scotland (PHS) with strict disclosure protocols. Individual-level data were linked via Scotland's Community Health Index (CHI) numbers through probabilistic matching based on date of birth, sex, and postcode (Section 3.6.2). The linkage agent pseudonymised study-specific identifiers, allowing for the integration of datasets stored within the National Safe Haven (NSH). All NDIP, GUS and MIDAS datasets underwent rigorous data cleaning and quality assurance following standard operating procedures.

5.5.1 Variable Selection Process

A broad set of candidate variables from the GUS surveys encompassing child oral health behaviours as exposure and family context, socioeconomic circumstances, and community factors as confounders.

Variable selection proceeded in steps:

1. Preliminary review of data completeness: Variables with poor response rates, or those non-discriminating were excluded.

2. Conceptual and practical considerations:

    a. Consistency across cohorts: Variables measured in both cohorts were prioritised to ensure comparability.

    b. Early-life prioritisation: For variables collected at multiple time points, the earliest available measure was selected where possible (e.g., cariogenic diet, toothbrushing). Each measurement occasion was counted separately when reporting total numbers; only some variables had more than one time point.

3. Statistical review: Preliminary counts, cross tabulations and univariable associations with caries were examined. Variables that illustrated inconsistent or non-significant risk ratios were deprioritised to reduce redundancy. Area under the curve was also used to analyse the predictive value of each variable individually (Zou, 2004).

After initial variable selection, multicollinearity among dietary, family and socioeconomic variables was observed. To address this, latent constructs representing cariogenic diet, family context, and socioeconomic circumstances were derived using confirmatory factor analysis (CFA) with the lavaan package in R (Rosseel, 2012). Variables with factor loadings below 0.4 were excluded, unless required for model identification (Kline, 2023). The distributions for each of the latent variables are detailed in overarching methods or supplementary materials; Cariogenic Diet (Section 3.10.3), Family Factors (Supplementary Figures for Chapter 5 – SF5.1) and Socioeconomic Circumstances (Section 3.10.4).

5.5.2 Categorisation and Variable Counts

Variables were conceptualised within six categories (3 child level oral health behaviours, 3 family/socioeconomic/community). The number of variables examined within each category is shown, with each measurement time point contributing to the total count; only some variables were assessed at more than one time point, all these variables are available through QR code shown in Supplementary Tables for Chapter 5 (ST 5.1):

- Cariogenic Diet - BC1: n = 29, BC2: n = 18
- Toothbrushing - BC1: n = 6, BC2: n = 4
- Regular Dental Attendance - BC1: n = 8, BC2: n = 7
- Family Factors - BC1: n = 44, BC2: n = 38
- Socioeconomic circumstances - BC1: n = 57, BC2: n = 38
- Community Factors - BC1 n = 16, BC2: n = 10

5.5.3 Key Variables Retained for Multivariable Modelling

The following variables were retained for the multivariable modelling, where latent variables are created for any category with more than one variable. For any latent variable that uses observed variables across multiple sweeps, children had to be present in all sweeps used. Variable are detailed further in Supplementary Material for Chapter 5. The predictive value for each variable of caries experience was also calculated.

5.5.3.1 Outcome variable

Caries experience at age 5 (yes/no): Defined as the presence of obvious decay which was determined clinically by the presence of decay (caries into dentine), missing (extracted due to decay) or filled deciduous teeth following recognised criteria. This variable was obtained from the NDIP.

5.5.3.2 Exposures

Cariogenic Diet (n = 3): Sweet consumption, sugar sweetened beverage (SSB) consumption and crisp consumption were used. The frequency of intake is assessed on a 7-level scale from “never” to “more than once a day”. These variables were obtained from GUS.

Toothbrushing (n = 1): For both cohorts, caregivers were asked how often a toothbrush was used to clean the child’s teeth, with the following response options: Less than once a day; Once a day; and More than once a day. For BC2,

the observed variable is based on just the frequency of toothbrushing with fluoride toothpaste. This variable was obtained from GUS.

Regular Dental Attendance (n = 1): Defined as attending the primary care dental service at least once a year for four out of five years from birth up to the child's 5th birthday from the Management Information & Dental Account System (MIDAS). Defined as a binary yes/no.

5.5.3.3 Confounders

Family Factors (n = 3): Household size, home chaos scale, and formal services used scale (Coldwell, Pike and Dunn, 2006; Mabelis and Marryat, 2011). These variables were obtained from GUS, where 'high' family factors score relates to bigger household, more chaotic household and less formal services used. These variables are detailed further in Supplementary Material for Chapter 5 and Supplementary Figures for Chapter 5 (SF5.1).

Socioeconomic Circumstances (SEC) (n = 4): Household income poverty, highest parental education in household, and highest parental employment status in household; SIMD was conceptually included in SEC instead of community moving forward (European Commission, 2004; Scottish Government, 2006; Galobardes, Lynch and Smith, 2007; Scottish Government, 2012). These variables were obtained from GUS.

Community Factors: Other than SIMD, which was subsumed by Socioeconomic Circumstances, not included in analysis due to concerns for data quality and inconsistent or weak associations with caries experience across cohorts.

Covariates: Age at NDIP Exam from NDIP databases and sex from GUS were also added as covariates.

5.5.4 Statistical Analysis

All analyses were exploratory. Initial descriptive analyses involved cross-tabulations between each exposure and caries experience.

Given the binary outcome and its prevalence, adapted modified Poisson regression with robust standard errors was used to estimate risk ratios (RRs) and 95% confidence intervals (CIs) 3.11.3).

A staged modelling approach was used to examine the stability of associations across domains:

Model 1 (univariable): Cariogenic diet, toothbrushing and regular dental attendance entered separately with caries experience to identify individual associations.

Model 2 (oral health behaviours): Cariogenic diet, toothbrushing frequency, and regular dental attendance entered simultaneously.

Model 3 (oral health behaviours + family factors): Added family factors to model 2 to assess whether family environment explains some of the associations between oral health behaviours and caries experience.

Model 4 (oral health behaviours + socioeconomic circumstances): Added socioeconomic circumstances alongside oral health behaviours to examine whether socioeconomic circumstances attenuated the associations between early-life oral health behaviours and caries experience.

Model 5 (fully adjusted): All factors entered simultaneously to provide comprehensive estimates accounting for behavioural, family, and socioeconomic factors. Testing whether family factors and socioeconomic circumstances impact on the associations between early life oral health behaviours and caries experience.

The five-model approach was used to examine how associations between early-life oral health behaviours and caries experience changed with sequential adjustment for behavioural, family and socioeconomic factors. This allowed the contribution of each domain to be assessed separately and in combination, rather than relying solely on a fully adjusted model. The staged approach was informed by the conceptual framework underpinning the study (Fisher-Owens et

al., 2007), which recognises that oral health behaviours occur within wider family and socioeconomic contexts.

Model 1 examined each oral health behaviour separately to establish their unadjusted association with caries experience. Model 2 included all three oral health behaviours simultaneously to assess their independent associations, accounting for the potential interrelationships between behaviours. Model 3 additionally adjusted for family factors to examine whether these associations were attenuated after accounting for the family factors. Model 4 instead added socioeconomic circumstances to Model 2 to assess the extent to which socioeconomic differences accounted for the observed behavioural associations. Finally, Model 5 included behavioural, family and socioeconomic factors simultaneously to estimate the associations between oral health behaviours and caries experience conditional on the other measured factors. Comparing estimates across models helped identify patterns of attenuation and assess the extent to which associations were robust to adjustment for different domains.

The confounders were also run as exposures for supplementary analysis.

Analyses were stratified by cohort to explore whether associations differed between the pre-Childsmile (BC1), and post roll out of Childsmile (BC2). To formally assess whether the effect of each early oral health behaviour varied between cohorts, an additional version of Model 5 was fitted to the combined dataset, including an interaction term between cohort and the exposure variable. This allowed estimation of ratios of risk ratios (RRRs), which quantify differences in the strength of association between cohorts. Confidence intervals were calculated using robust standard errors.

The area under the Receiver Operating Characteristic curve (AUC) was calculated for each model to assess predictive performance. The most relevant variables within each domain (based on a priori reasoning, AUC scores, and consistent RRs) were carried forward into the modelling framework.

All analyses were conducted as complete case analyses. Survey weights were applied throughout to account for non-response and sampling design, as detailed in the GUS Sweep 5 User Guide (Bradshaw *et al.*, 2011).

The study received ethical approval (College of MVLS, University of Glasgow) and approval from the Public Benefit and Privacy Panel - Health and Social Care (PBPP- Public Health Scotland) and the Statistics- PBPP (Scottish Government) (reference number: 200170146).

5.6 Results

The derivation of the analytic samples from the two longitudinal cohorts used in this study: GUS Birth Cohort 1 (BC1) and Birth Cohort 2 (BC2) is all detailed in Figure 3.8. For BC1, 5,217 initial respondents were reduced to 3,210 participants included in the final model after applying exclusions for data linkage consent, availability of NDIP records, and missing data across relevant variables. Following similar procedure, BC2's 6,127 participants were reduced to 4,770.

Table 5.1 summarises cohort characteristics for children in each cohort. This shows very similar ages for NDIP examination across cohorts (approximately 5.5 years old), with just less than 51% of both cohorts being Male and a drop in caries experience in cohort 2 from cohort 1 from 30.1% (contemporaneous national age 5 prevalence = 35.3%) to 27.9% (contemporaneous national age 5 prevalence = 31.0%). The lower prevalence observed in the study cohorts compared with national estimates may reflect differences in sample composition, including potential volunteer (self-selection) bias, whereby participants may be more health-conscious or engaged with dental services. Additionally, behavioural modification due to study participation (i.e., the Hawthorne effect) could have contributed to improved oral health outcomes. However, these explanations remain speculative and were not tested in this study (Junghans and Jones, 2007; McCambridge, Witton and Elbourne, 2014).

Table 5.1 - Birth cohorts characteristics

Variable		Birth cohort 1	Birth cohort 2
Age (years) at National Dental Inspection Programme Exam	Min	4.11	4.57
	Q1	5.31	5.25
	Median	5.54	5.49
	Q3	5.80	5.76
	Max	6.80	6.99
Sex	Male	1608 (50.7)	2427 (50.9)
	Female	1564 (49.3)	2342 (49.1)
Caries Experience at Age 5	Yes	954 (30.1)	1330 (27.9)
	No	2217 (69.9)	3439 (72.1)

5.6.1 Early-Life Oral Health Behaviours

The frequency, cross tables and univariable regression models are shown for all variables in Supplementary Tables for Chapter 5 (ST5.1). The frequency for each of the Oral Health Behaviours is illustrated in Table 5.2.

All numbers for Table 5.1, Table 5.2 and Table 5.3 are calculated using GUS survey response weights. These numbers differ (approximately for most common sweep - BC1: n = 3113 (for sweep 2) and BC2: n = 4032 (for sweep 3)) from model 5 counts shown in Table 5.4 due to complete case analysis; numbers will also differ from univariable analysis shown in supplementary materials and Model 1 – 4 due to sweep and question response rates.

Table 5.2 - Frequency table for all included oral health behaviours

Age (years)	Variable		Birth cohort 1	Birth cohort 2
			n1/n2 (%)	n1/n2 (%)
2 (BC1)/ 3 (BC2)	How often child eats sweets?	> 1 (day)	358/3117 (11.5)	461/4036 (11.4)
		1 (day)	982/3117 (31.5)	1705/4036 (42.2)
		5 – 6 (week)	157/3117 (5.0)	291/4036 (7.2)
		2 – 4 (week)	973/3117 (31.2)	1098/4036 (27.2)
		1 (week)	352/3117 (11.3)	318/4036 (7.9)
		1-3 (month)	130/3117 (4.2)	85/4036 (2.1)
		Less or never	165/3117 (5.3)	78/4036 (1.9)
		Missing	1	0
2/5	How often child eats crisps?	> 1 (day)	361/3116 (11.6)	66/3651 (1.8)
		1 (day)	1052/3116 (33.8)	696/3651 (19.1)
		5 – 6 (week)	250/3116 (8.0)	261/3651 (7.1)
		2 – 4 (week)	879/3116 (28.2)	1337/3651 (36.6)
		1 (week)	306/3116 (9.8)	642/3651 (17.6)
		1-3 (month)	106/3116 (3.4)	254/3651 (7.0)
		Less or never	162/3116 (5.2)	395/3651 (10.8)
		Missing	1	1
2/3	How often child drinks sugar sweetened beverage?	> 1 (day)	241/3114 (7.7)	36/4034 (0.9)
		1 (day)	128/3114 (4.1)	72/4034 (1.8)
		2 – 6 (week)	82/3114 (2.6)	114/4034 (2.8)
		1 (week)	94/3114 (3.0)	208/4034 (5.2)
		1-3 (month)	94/3114 (3.0)	211/4034 (5.2)
		Less or never	2475/3114 (79.5)	3393/4034 (84.1)
		Missing	1	0
2/3	Frequency of toothbrushing (BC2: using fluoride toothpaste)	> 1 a day	2266/3115 (72.7)	3328/4033 (82.5)
		1 a day	735/3115 (23.6)	647/4033 (16.0)
		< 1 a day	114/3115 (3.7)	58/4033 (1.4)
		Missing	0	0
1-5	Regular Dental Attendance (4 out of the first 5 years)	Yes	1250/3112 (40.2)	1859/4032 (46.1)
		No	1862/3112 (59.8)	2173/4032 (53.9)
		Missing	0	0

BC1 – Birth Cohort 1; BC2 – Birth Cohort 2

In Birth Cohort 1 (BC1) at age 2 years and Birth Cohort 2 (BC2) at age 3 years, daily consumption of sweets was common in both cohorts, with slightly higher reported frequency in BC2. Crisp consumption was measured at age 2 in BC1 and age 5 in BC2, and therefore the distributions are not directly comparable across cohorts, although less frequent consumption appeared more common in BC2. Sugar-sweetened beverage intake, measured at ages 2 (BC1) and 3 (BC2), was

generally low in both cohorts, with most children reported to consume these drinks rarely or never. Toothbrushing behaviour at ages 2 (BC1) and 3 (BC2) suggested more frequent brushing in BC2; however, this difference may partly reflect the slightly older age of children in BC2. Regular dental attendance during the first five years of life was reported more often in BC2 than in BC1.

Family and socioeconomic factors distributions were illustrated in Supplementary Tables for Chapter 5 (ST5.2) broadly similar across Birth Cohort 1 (BC1) and Birth Cohort 2 (BC2). Most children lived in households of three or four members, and levels of household income poverty and area-level deprivation (SIMD) were comparable between cohorts. Higher levels of home chaos were reported more frequently in BC2. The use of formal services showed similar distributions across cohorts. In both cohorts, higher managerial occupations were the most common parental employment category, although BC2 included a slightly higher proportion of semi-routine or routine occupations. Degree-level education was the most frequently reported highest parental education level in both cohorts.

5.6.2 Early-Life Oral Health Behaviours and Caries Experience

Table 5.3 presents caries experience stratified by key factors at the sweep the questions were asked.

Table 5.3 - Caries experience prevalence according to early life behaviours across birth cohorts (presenting only those variables that emerged from univariable analysis)

Age (BC1/BC2)	Variable		Birth cohort 1	Birth cohort 2
			Caries Experience, n/N (%)	Caries Experience, n/N (%)
2/3	How often child eats sweets?	> 1 (day)	161/358 (44.8)	176/461 (38.2)
		1 (day)	362/982 (36.9)	532/1705 (31.2)
		5 – 6 (week)	46/157 (29.6)	77/291 (26.6)
		2 – 4 (week)	260/973 (26.7)	232/1098 (21.1)
		1 (week)	81/352 (23.1)	64/318 (20.1)
		1-3 (month)	20/130 (15.1)	10/85 (11.6)
		Less or never	39/165 (23.4)	10/78 (12.9)
		Missing	1	0
2/5	How often child eats crisps?	> 1 (day)	162/361 (45)	33/66 (50)
		1 (day)	371/1052 (35.3)	231/696 (33.3)
		5 – 6 (week)	68/250 (27.2)	76/261 (29.1)
		2 – 4 (week)	241/879 (27.4)	338/1337 (25.3)
		1 (week)	73/306 (23.7)	137/642 (21.3)
		1-3 (month)	19/106 (18.2)	43/254 (16.9)
		Less or never	34/162 (21.3)	113/395 (28.6)
		Missing	1	1
2/3	How often child drinks sugar sweetened beverage?	> 1 (day)	108/241 (44.8)	23/36 (62.6)
		1 (day)	57/128 (44.4)	29/72 (40.4)
		2 – 6 (week)	36/82 (44.2)	49/114 (42.8)
		1 (week)	42/94 (45.1)	90/208 (43.3)
		1-3 (month)	44/94 (46.7)	78/211 (37)
		Less or never	681/2475 (27.5)	831/3393 (24.5)
		Missing	1	0
2/3	Frequency of toothbrushing (BC2: using fluoride toothpaste)	> 1 a day	643/2266 (28.4)	855/3328 (25.7)
		1 a day	271/735 (36.9)	210/647 (32.5)
		< 1 a day	53/114 (46.4)	35/58 (59.7)
		Missing	0	0
1-5	Regular Dental Attendance (4 out of the first 5 years)	Yes	299/1250 (23.9)	416/1859 (22.4)
		No	668/1862 (35.9)	685/2173 (31.5)
		Missing	0	0

BC1 – Birth Cohort 1; BC2 – Birth Cohort 2

There are clear associations with early life behaviours and caries experience across both cohorts, despite an overall reduction in prevalence of caries experience from BC1 to BC2. Higher levels of caries experience were observed among children with less healthy diets (frequent consumption of sweets, crisps, or soft drinks), less frequent toothbrushing and irregular dental attendance (Table 5.3).

Supplementary Tables for Chapter 5 (ST5.3) shows that caries experience varied across early-life family factors in both Birth Cohort 1 (BC1) and Birth Cohort 2 (BC2). Larger household sizes, particularly households with six or more members, were associated with a higher prevalence of caries experience in both cohorts. Higher levels of home chaos and lower use of formal services were also generally associated with greater caries experience.

Clear socioeconomic gradients in caries experience were also observed. Children living in households experiencing income poverty and those residing in more deprived areas had a higher prevalence of caries experience compared with children from more advantaged households and areas. Similarly, higher caries prevalence was observed among children whose parents were in semi-routine or routine occupations, or who were never employed or long-term unemployed, compared with those in higher managerial occupations, showing a stepwise gradient. A similar gradient was observed for parental education, with higher caries prevalence among children whose parents had lower educational attainment compared with those with degree-level education. These patterns were broadly consistent across both cohorts.

The area-under the curve (AUC) for the predictive value of caries experience in a univariable adapted modified Poisson regression model for each retained variable is shown in Supplementary Tables for Chapter 5 (ST5.4).

Overall, the magnitude of behavioural associations was similar across cohorts as illustrated in Table 5.4.

Table 5.4 - Association between early life behaviours and caries experience at age 5 using multivariable adapted modified Poisson regression models

Model		Model 1 (univariable)	Model 2	Model 3	Model 4	Model 5 (fully adjusted)
Birth cohort 1						
Cariogenic diet (age 2) (latent)	Risk Ratio (95% CI)[1]	1.33 (1.27, 1.40)	1.30 (1.24, 1.37)	1.28 (1.21, 1.35)	1.19 (1.13, 1.25)	1.19 (1.13, 1.26)
	P-value	<0.001	<0.001	<0.001	<0.001	<0.001
	AUC [95% CI]	0.61 [0.59, 0.63]	0.65 [0.63, 0.67]	0.66 [0.64, 0.69]	0.70 [0.68, 0.72]	0.70 [0.68, 0.73]
Frequency of toothbrushing (age 2) (>1 a day vs 1 or never)	Risk Ratio (95% CI)[1]	0.80 (0.74, 0.86)	0.83 (0.76, 0.91)	0.85 (0.78, 0.93)	0.88 (0.81, 0.96)	0.89 (0.81, 0.97)
	P-value	<0.001	<0.001	<0.001	0.004	0.011
	AUC [95% CI]	0.55 [0.53, 0.57]				
Regular dental attendance (Yes vs No)	Risk Ratio (95% CI)	0.67 (0.59, 0.75)	0.71 (0.63, 0.80)	0.73 (0.64, 0.82)	0.85 (0.81, 0.96)	0.84 (0.74, 0.96)
	P-value	<0.001	<0.001	<0.001	0.008	0.008
	AUC [95% CI]	0.56 [0.55, 0.58]				
Birth cohort 2						
Cariogenic diet (latent) (age 3/5)	Risk Ratio (95% CI)	1.34 (1.26, 1.42)	1.30 (1.22, 1.38)	1.24 (1.17, 1.32)	1.20 (1.12, 1.28)	1.17 (1.10, 1.26)
	P-value	<0.001	<0.001	<0.001	<0.001	<0.001
	AUC [95% CI]	0.62 [0.60, 0.64]				
Frequency of toothbrushing (age 3)	Risk Ratio (95% CI)	0.70 (0.62, 0.79)	0.77 (0.69, 0.87)	0.80 (0.71, 0.90)	0.81 (0.71, 0.91)	0.81 (0.71, 0.92)
	P-value	<0.001	<0.001	<0.001	<0.001	0.001
	AUC [95% CI]	0.54 [0.53, 0.56]				
Regular dental attendance (yes vs no)	Risk Ratio (95% CI)	0.72 (0.64, 0.81)	0.74 (0.65, 0.84)	0.81 (0.72, 0.92)	0.89 (0.78, 1.02)	0.90 (0.79, 1.04)
	P-value	<0.001	<0.001	<0.001	0.091	0.14
	AUC [95% CI]	0.55 [0.54, 0.57]				

Model 1 – Univariable; Model 2 – All Oral Health Behaviours; Model 3 – All Oral Health Behaviours + Family; Model 4 – All Oral Health Behaviours + Socioeconomic Circumstances; Model 5 – All Cariogenic Diet – Sweets, Crisps and Sugar Sweetened Beverage Frequency; Family Factors – Home Chaos, Household Size, Formal Services Used; Socioeconomic circumstances – Income, Area-based, Education, Employment; AUC – Area-under the curve; [1] – Risk Ratios – are adjusted risk ratios for model 2-5

From Table 5.4, across both birth cohorts, early-life oral health behaviours were consistently associated with caries experience in the expected directions. Higher cariogenic diet scores—indicating more frequent consumption of sugary snacks and drinks—were associated with increased risk of caries, while more frequent toothbrushing and regular dental attendance were negatively associated. These associations were observed in both the pre-Childsmile (BC1) and early Childsmile (BC2) cohorts in univariable analyses and remained after mutual adjustment of behaviours. Although toothbrushing appeared slightly more protective in BC2 in univariable analyses, confidence intervals overlapped after mutual adjustment, indicating minimal temporal change.

5.6.3 Attenuation of behavioural associations with caries experience by family and socioeconomic factors

Sequential modelling demonstrates the relative contributions of behaviours, family, and socioeconomic circumstances to caries experience. Adjustment for family factors led to only modest attenuation of behavioural associations, and the overall pattern of effects remained largely unchanged across cohorts. In contrast, inclusion of socioeconomic circumstances produced substantial attenuation of all behavioural associations and marked improvements in model discrimination, as reflected by increases in the AUC (from 0.65 to 0.70 in BC1 and 0.64 to 0.69 in BC2). Cariogenic diet and toothbrushing retained independent associations with caries experience in fully adjusted models, whereas the protective effect of regular dental attendance was weaker in BC2. These patterns were consistent across both cohorts, indicating that socioeconomic factors are the primary drivers of variation in caries experience, while family factors play a smaller role (see Table 5.4: Sequential models showing attenuation of behavioural associations and AUC scores).

From the early behavioural model (Table 5.4– Model 1) to the fully adjusted model (Table 5.4 – Model 5), adjusted risk ratios for all behaviours decreased, demonstrating that socioeconomic circumstances explain a proportion of the observed behavioural gradients. The relative importance of socioeconomic circumstances is therefore reflected in both the behavioural attenuation and the corresponding gains in model discrimination.

5.6.4 Comparison of cohort effects

Direct comparisons of effect estimates between cohorts using ratios of risk ratios (RRRs) are presented in Table 5.. An RRR of 1 indicates no difference in the strength of association between cohorts, while values above 1 indicate a stronger association in BC2 relative to BC1, and values below 1 indicate a weaker association in BC2.

Table 5.5 - Ratio of risk ratios across cohorts for association between early life behaviours and caries experience at age 5 using adapted modified Poisson regression

Model	Ratio of Risk Ratios BC2 v BC1 (95% Confidence Interval)	p-value
Cariogenic Diet	0.98 (0.90, 1.07)	0.7
Frequency of toothbrushing	0.91 (0.78, 1.06)	0.2
Regular Dental Attendance	1.07 (0.89, 1.28)	0.5
Family Factors	1.05 (0.96, 1.14)	0.3
Socioeconomic circumstances	0.98 (0.90, 1.07)	0.7

Cariogenic Diet – Sweets, Crisps and Sugar Sweetened Beverage Frequency; Regular Dental Attendance (Yes vs No) – attending in 4 out of the first 5 years; Family Factors – Home Chaos, Household Size, Formal Services Used; Socioeconomic circumstances – Income, Area-based, Education, Employment; BC1, BC2 – Birth Cohort 1, Birth Cohort 2

Across all behaviours examined, relative risk ratios (RRRs) were close to 1, suggesting minimal differences in the associations between early-life behaviours and caries experience at age 5 between cohorts. Although the RRRs for frequency of toothbrushing suggested a potentially weaker association in BC2, this may reflect reduced relative influence of home toothbrushing following the introduction of nursery and school-based toothbrushing programmes. However, the corresponding confidence intervals all included 1 and p-values were not statistically significant; these findings should therefore be interpreted with caution, as the analysis was not powered to detect differences between cohorts.

Overall, these findings support the conclusion that the relationships between early-life behaviours and caries experience remained broadly stable from the pre- to early Childsmile implementation period.

5.6.5 Confounders (Family and Socioeconomic Factors) and Caries Experience

Additional associations between family and socioeconomic circumstances and caries experience are presented in Supplementary Tables for Chapter 5 (ST5.5).

Higher family factors scores on the latent measure—reflecting larger household size, higher household chaos, and less use of formal support—were associated with increased risk of caries in both cohorts (BC1 RR = 1.28, 95% CI 1.21–1.35; BC2 RR = 1.30, 95% CI 1.22–1.37). This association was attenuated following full adjustment (Model 5: BC1 RR = 1.10, 95% CI 1.04–1.17; BC2 RR = 1.15, 95% CI 1.07–1.23) but remained evident in both cohorts.

Socioeconomic circumstances were also associated with caries experience. Higher socioeconomic position (as indicated by income, area-based deprivation, education, and employment) was associated with lower risk of caries (BC1 RR = 0.65, 95% CI 0.62–0.68; BC2 RR = 0.65, 95% CI 0.61–0.69), with some attenuation after full adjustment (Model 5: BC1 RR = 0.72, 95% CI 0.68–0.77; BC2 RR = 0.72, 95% CI 0.67–0.77).

Discrimination was higher for socioeconomic circumstances (AUC: BC1 = 0.68; BC2 = 0.66; increasing to 0.71 and 0.70 in fully adjusted models) than for family factors and behavioural variables (AUC ≈ 0.60).

5.7 Discussion

This study suggests that early-life oral health behaviours play an important role in shaping the prevalence of childhood caries. However, these behaviours do not occur in isolation; family factors and socioeconomic environment influence children's habits. While supportive family environments appeared to help reinforce protective behaviours, socioeconomic circumstances (SEC) were consistently the strongest correlate of caries experience prevalence, though they did not fully account for behavioural associations (Link and Phelan, 1995; Watt, 2012; Peres *et al.*, 2019b). The patterns of behaviours and associations with caries experience were similar across both cohorts, suggesting that early preventive efforts, including the initial introduction of Childsmile, may not have substantially altered behavioural or social gradients in the early years of programme implementation.

Dietary behaviours emerged as the strongest behavioural correlate in both cohorts. More frequent consumption of sugar-sweetened beverages, sweet snacks, and savoury snacks was associated with roughly 20–30% higher prevalence

of caries, with earlier dietary exposures showing stronger associations than later exposures. These findings align with previous evidence on the role of free sugars in caries development (Moynihan and Kelly, 2014; Sheiham and James, 2015) and highlight early childhood as a critical period for establishing dietary patterns (Arora *et al.*, 2024). The stability of dietary associations across cohorts suggests that behaviours were largely unchanged during the early Childsmile period.

Toothbrushing behaviours were associated with lower caries prevalence. Children who brushed regularly with fluoride toothpaste had approximately 10–20% lower prevalence of caries compared with those brushing less frequently. Although univariable analyses suggested slightly stronger associations in the later cohort, these differences did not persist after accounting for family and socioeconomic circumstances (Marinho *et al.*, 2003; NHS England, 2021). These results complement previous work indicating that establishing oral hygiene routines early may support longer-term adherence and reduce bacterial colonisation during tooth eruption (NHS England, 2021).

Regular dental attendance was negatively associated with caries experience. In both cohorts, children with regular attendance (four out of five early years) had roughly 10% lower prevalence of caries compared with those attending irregularly. However, this association was largely attenuated after adjustment for other oral health behaviours, family factors, and socioeconomic circumstances, with no statistically significant difference remaining in BC2. This indicates that while regular attendance was associated with modestly lower caries prevalence, the effect was weaker after accounting for confounding factors, consistent with previous research (Macpherson *et al.*, 2013; Anopa *et al.*, 2015; Ross *et al.*, 2023; Scottish Government, 2024b). There was little evidence of meaningful differences between cohorts, suggesting regular dental attendance importance as a predictor of caries hasn’t changed over time.

Family factors, including household size, higher household chaos, and lower use of formal support, were associated with higher caries experience, but the effect sizes were smaller (roughly 10–20%) and less consistent (e.g., non-linear effects of household size) than those observed for socioeconomic circumstances. Adjustment for family factors modestly reduced the associations between oral health behaviours and caries, indicating that while family-level influences

contribute to risk, they explain only a small part of the behavioural differences observed. These findings could illustrate family stress and disorganisation with reduced adherence to routines as well as reliance on convenience foods. Parental stress did but did not show strong associations in initial analysis however, parental stress scales accuracy and reliability is mixed (Jabbarifar *et al.*, 2009; Chouchene *et al.*, 2021; Mahapatra *et al.*, 2022).

Socioeconomic circumstances has the strongest association with caries experience. Children from higher SEC households had around 35% lower prevalence of caries in unadjusted models across the latent measures of SEC (with certain individual variables of SEC showing as high as 50% lower). Adjustment for SEC substantially attenuated the associations between oral health behaviours and caries, though it did not fully eliminate them, and additional adjustment for family factors had minimal further impact. This indicates that socioeconomic circumstances account for a significant portion of the observed behavioural effects, but oral health behaviours retain independent associations with caries. Overall, these findings highlight that structural factors shape behavioural risk, but behaviours still matter, and both levels of influence contribute to variation in caries across cohorts. The consistency across all metrics align with national and international research demonstrating persistent social gradients in oral health persist despite public health programmes (Watt, 2012; Peres and Heilmann, 2015; Peres *et al.*, 2019b).

The lack of consistent associations with wider community-level variables other than those picked up by SIMD – such as urban/rural classification, perceived neighbourhood cohesion, local crime, and access to community services - aligns with evidence that proximal family dynamics and household routines are more influential determinants of oral health behaviours and outcomes (Lamarca *et al.*, 2014; Levin *et al.*, 2015). Although could be explained by a lack of quality community variables consistently available in the data.

Taken together, this study demonstrates that early-life behaviours are important determinants of childhood caries especially sugar consumption, but their effects are embedded within—and constrained by—family and, most prominently, socioeconomic circumstances. While the broader preventive environment during early Childsmile implementation coincided with modest reductions in caries

prevalence, there is little evidence that it fundamentally altered behavioural or social gradients in caries risk during this period. These findings suggest that sustained improvements in child oral health will require approaches that combine early behavioural support with policies that address the underlying socioeconomic conditions shaping children's exposure to risk.

5.7.1 Strengths and Limitations

This study has several notable strengths. First, it draws on two large, nationally representative birth cohorts with harmonised variables and early-life exposure data, enhancing both generalisability and the ability to compare associations across time. Second, the use of confirmatory factor analysis (CFA) to construct latent measures for cariogenic diet, family factors, and socioeconomic circumstances improved measurement precision, reliability, and construct validity.

Third, sequential modelling allowed the relative contributions of behaviours, family, and socioeconomic circumstances to be explored. Behavioural associations remained evident after adjustment, but attenuation patterns highlighted the dominant influence of structural socioeconomic factors. Fourth, presenting behavioural associations across two cohorts provided insight into patterns during the early Childsmile programme implementation, showing broadly consistent associations across time. Finally, the combination of univariable, multivariable, and ratio-of-risk-ratios analyses provided a comprehensive assessment of behavioural, family, and structural correlates of childhood caries.

Despite these strengths, several limitations should be considered. First, all behavioural measures were parent-reported, introducing the potential for recall error or social desirability bias, particularly for diet and toothbrushing frequency. Second, although family and socioeconomic factors were included, residual and unmeasured confounding remains possible from misreported measurements and unmeasured influences, such as parental oral health, genetic susceptibility, or reliable community-level access exposures not captured within the cohorts.

Third, the family factors latent construct assumes linear contributions of household size, household chaos, and use of formal support. This may oversimplify non-linear relationships, particularly for household size, where the lowest caries prevalence was observed at a household size of three, and higher prevalence at both smaller and larger households. Consequently, the model may not fully capture nuanced patterns within family dynamics. More broadly, the modelling framework assumes largely linear and additive relationships between exposures and caries prevalence, which may not fully capture more complex or non-linear patterns.

Fourth, the cross-cohort comparison allows examination of associations across early Childsmile implementation but cannot be interpreted as evidence of programme effectiveness. Differences observed between cohorts may reflect secular trends, population differences, or measurement variation rather than the impact of the programme itself. The early stage of Childsmile and relatively modest sample sizes mean that measurable behavioural or prevalence changes may not yet have emerged.

Fifth, all analyses are observational, and the findings should be interpreted as associative rather than causal; it is not possible to conclude that behaviours or socioeconomic conditions directly reduce or increase caries prevalence (Lewer *et al.*, 2025). More robust causal inference or quasi-experimental approaches would be required to evaluate the impact of population-level interventions such as Childsmile.

Finally, minor differences in measurement between cohorts, such as question wording for fluoride toothpaste use, could introduce variability that limits comparability.

5.8 Conclusions

The findings of this chapter affirm that socioeconomic circumstances contribute substantially to early childhood caries experience. They also show that while early-life oral health behaviours are important in preventing dental caries, their impact is constrained by broader structural determinants. Adjustment analyses suggest that behaviours partially mediate the relationship between

socioeconomic circumstances and caries, but causal interpretation is limited by the observational nature of the data. These results indicate that interventions should not only aim to promote individual health behaviours but also address the underlying upstream socioeconomic inequalities that predispose children to caries. As preventive programmes such as Childsmile continue to evolve, these findings can help guide the development and implementation of interventions while acknowledging the methodological constraints on inferring causality; and picking apart the specific Childsmile interventions individual effects.

Chapter 6

6 Assessing the Impact of Childsmile's Behaviour Change Interventions on Early Childhood Oral Health Behaviours and their Associations with Socioeconomic Circumstances

This chapter answers research question 4.

6.1 Preface

In the previous chapter an extensive analysis was conducted of early-life behaviours—diet, toothbrushing, and regular dental attendance—in relation to caries experience. These analyses demonstrated that while wider determinants such as family and socioeconomic circumstances partially influenced these relationships, the behaviours themselves remained important contributors to caries outcomes specifically cariogenic diet and frequency of toothbrushing. Comparing these relationships across birth cohorts, pre- and post-Childsmile, suggested little difference in how behaviours were associated with caries experience, indicating a limited detectable impact of Childsmile interventions at the population level during these early years of implementation.

In this chapter a more focused approach is taken, examining whether behaviour change interventions delivered in NHS primary care dental services, and by Dental health support workers (DHSWs) in the home, may have influenced the specific behaviours they target. These effects may have been obscured in the previous ecological analysis of the programme as a whole.

Childsmile interventions provide universal diet and toothbrushing behaviour change interventions primary care dental services, while DHSWs deliver targeted support to improve diet and toothbrushing to families in the home. These interventions are designed on behaviour change theory using a combination of advice, education, motivational interviewing techniques and practical demonstrations—particularly for toothbrushing—to promote changes in behaviours (intermediate outcomes in the Logic Models). Examining diet, toothbrushing, and regular dental service attendance as intermediate outcomes

allows us to better understand the mechanisms through which Childsmile aims to improve caries experience. This chapter therefore focuses on the proximal behavioural impacts of these interventions, setting the stage for understanding their role in oral health outcomes. Analyses are stratified by area-based socioeconomic circumstances (SIMD fifths), allowing exploration of whether intervention effects vary across the area-based socioeconomic deprivation gradient.

6.2 Research Questions

4. What is the impact of diet and toothbrushing behaviour change interventions delivered by Dental Health Support Workers and in primary care dental settings on children's diet and toothbrushing frequency; are these associations affected by socioeconomic deprivation level?

6.3 Abstract

Objective: To investigate whether Childsmile's targeted Dental Health Support Worker (DHSW) behaviour change interventions and universal behaviour change interventions delivered in NHS primary care dental services are associated with improved early-life oral health-related behaviours, and whether these associations differ by area-based deprivation.

Methods: Data from Birth Cohort 2 (Ages 3 and 5 years) of the Growing Up in Scotland (GUS) study were linked to administrative records of Childsmile contacts. Two outcomes were examined: a latent "cariogenic diet" score at age 5 and parent-reported toothbrushing frequency at age 3. Linear regression estimated associations with frequency of dietary support provided through Childsmile and questionnaire and cariogenic diet scores, and adapted modified Poisson regression. Analyses were stratified by Scottish Index of Multiple Deprivation (SIMD) fifths to assess differential effects across area-based socioeconomic groups.

Results: Neither DHSW nor primary care dietary interventions were associated with improved cariogenic diet score at age 5. DHSW toothbrushing intervention showed no association with toothbrushing more than once daily at age 3 (aRR ≈

1.00–1.05 across exposure levels). In contrast, toothbrushing interventions delivered in primary dental care settings showed a modest dose–response association, with a higher likelihood of toothbrushing more than once daily among children receiving repeated interventions (aRR 1.05, 95% CI 1.02–1.08 for one contact; 1.06, 95% CI 1.02–1.11 for two contacts; 1.10, 95% CI 1.05–1.16 for ≥3 contacts). Socioeconomic gradients in diet score and toothbrushing frequency were observed across all exposure levels. However, there was no evidence that socioeconomic deprivation modified these associations based on interaction tests and stratified analyses.

Conclusions: Childsmile DHSW and primary dental care interventions had limited impact on children's diet and only modest effects on toothbrushing, suggesting that behaviour change interventions alone are insufficient to produce substantial changes in early-life oral health. The lack of stronger effects especially in deprived areas indicates that improving the reach, intensity, and targeting of interventions—particularly for higher-need populations—alongside addressing broader social and structural determinants, will be essential to achieve meaningful and equitable improvements in children's oral health. However, these are early days of Childsmile and there is heterogeneity in intervention delivery, intensity and consistency to consider

6.4 Introduction

Early-life behaviours—particularly limiting the frequency of free sugar consumption and twice-daily toothbrushing with fluoride toothpaste—are central to the prevention of dental caries and the promotion of lifelong oral health (Marinho *et al.*, 2003; World Health Organization, 2025). Socioeconomically patterned differences in these behaviours emerge in the preschool years and contribute to persistent oral health inequalities (Watt and Sheiham, 1999; Watt, 2012; Schwendicke *et al.*, 2015).

Improving oral health across the whole child population while simultaneously reducing socioeconomic inequalities remains a central challenge in public health. Scotland's Childsmile programme was designed to address these twin aims (Macpherson *et al.*, 2015). Although national monitoring demonstrates substantial reductions in caries prevalence among five-year-olds, socioeconomic

inequalities have largely persisted (Conway *et al.*, 2022; Ross *et al.*, 2023). This raises concerns that population-wide improvements may reflect "levelling up" overall outcomes without narrowing social gradients.

Childsmile aims to address this challenge through a proportionate universalism approach, combining universal interventions—such as supervised toothbrushing in nurseries and preventive behaviour change interventions in primary care dental service (mostly General Dental Service practices) — with targeted support delivered by Dental Health Support Workers (DHSWs) to families in the most deprived communities (Macpherson *et al.*, 2010; Turner *et al.*, 2010). These interventions are guided by programme logic models and behaviour change theory, framing early-life oral health behaviours as intermediate outcomes on the pathway to improved dental health (Childsmile, 2010). Importantly, intervention effectiveness depends not only on content but also on reach, intensity, and targeting of contacts delivered in both dental practices and the home.

Oral health education alone has been shown to have limited effectiveness in improving oral health outcomes (Kay and Locker, 1996; Habbu and Krishnappa, 2015). In response, the Childsmile programme incorporates behaviour change interventions that extend beyond simple information provision and are increasingly grounded in behaviour change theory (Ross *et al.*, 2023). Within NHS primary care dental settings, preventive messages are delivered during routine patient contacts, including dietary guidance and toothbrushing instruction, with an emphasis on practical skills such as correct brushing techniques, appropriate fluoride toothpaste use, and parental supervision (Macpherson, Rodgers and Conway, 2019a; Public Health Scotland, 2024a).

In addition, Dental Health Support Workers (DHSWs) provide personalised, home-based support that reinforces these preventive messages within the context of families' daily routines, sometimes using supportive visual tools to aid understanding (Macpherson, Rodgers and Conway, 2019b; Fletcher, 2024). These interactions draw on principles from behavioural and implementation science, including techniques such as goal setting, reinforcement, and elements consistent with motivational interviewing. This reflects a shift away from standardised information delivery towards more responsive, person-centred

communication that recognises the importance of engaging with families' beliefs, capabilities, and everyday circumstances when supporting preventive behaviours (Ross *et al.*, 2023).

Childsmile influences on these oral health behavioural pathways, remains relatively underexamined. The Growing Up in Scotland (GUS) study follows nationally representative samples of children and collects rich data on health behaviours, family circumstances and social environments (Bradshaw, Knudsen and Palmer, 2018). Linking GUS data to administrative records of Childsmile contacts provides a unique opportunity to examine how exposure to specific interventions—both universal and targeted—relates to early-life oral health behaviours, and whether these associations vary by area-based deprivation using the Scottish Index of Multiple Deprivation (Scottish Government, 2016).

The present analysis exploits this linkage to investigate associations between early Childsmile contacts and two key outcomes: a latent "cariogenic diet" score at age five and parent-reported toothbrushing frequency at age three. By explicitly considering programme reach, targeting, and intermediate behavioural outcomes, this study aims to generate robust evidence on the pathways through which national oral health programmes may influence early-life behaviours and, ultimately, child oral health inequalities.

6.5 Methods

Birth Cohort 2 (BC2) of the Growing Up in Scotland (GUS) study (Section 3.5.3), a nationally representative longitudinal survey of children born in 2010/11, was linked to Childsmile administrative records from Public Health Scotland. Primary dental care interventions were obtained from the Management Information and Dental Accounting System (MIDAS) (Section 3.5.2.1), and DHSW interventions from Health Informatics Centre Data (HIC) (Section 3.5.2.2). Linkage used deterministic and probabilistic methods via Scotland's Community Health Index (CHI) and was conducted under pseudonymised identifiers within the PHS National Safe Haven.

6.5.1 Study Population

Children were eligible if they:

- Participated in GUS BC2 with parental consent for data linkage because only BC2 experienced Childsmile interventions.

- Provided parent-reported data on toothbrushing frequency at age 3 and/or all diet indicators at age 5.

6.5.2 Outcomes

Cariogenic Diet (age 5) – Latent "cariogenic diet" score derived from confirmatory factor analysis of sweet, crisps, and sugar-sweetened beverage consumption. Scores were standardised (mean ≈ 0, SD ≈ 1), higher values indicating higher consumption of sweets, crisps and SSB. The methods and distribution of this variable are presented in Section 3.10.3

Toothbrushing frequency (age 3) – Parent-reported frequency, dichotomised as more than once daily vs. once or less, as more than once is the recommended amount of brushing daily (Scottish Dental Clinical Effectiveness Programme, 2026).

6.5.3 Exposures: Childsmile Interventions

Interventions were categorised by type (dietary interventions or toothbrushing interventions) and delivery source (DHSW or NHS primary care dental services which is undertaken by General/Public Dental Services). Intervention counts were truncated at the child's age at the GUS interview to ensure temporal alignment:

- DHSW diet intervention by age 5: 0, 1, 2+ contacts, with "Not Targeted" category,

- DHSW toothbrushing intervention by age 3: 0, 1, 2+ contacts, with "Not Targeted"

- Primary dental care diet intervention by age 5 (0–5+ contacts)

- Primary dental care toothbrushing intervention by age 3 (0,1,2,3+)

Primary dental care exposure variables were derived from routine attendance records. Children who had never attended a dental practice during the study period were included in the "0" intervention category, alongside those who attended but did not receive any recorded intervention.

DHSW contacts were targeted primarily at children living in the most socioeconomically deprived areas, consistent with the Childsmile programme's design. Children's deprivation level was based on their postcode-linked Scottish Index of Multiple Deprivation (SIMD).

6.5.4 Covariates

Analyses adjusted for potential covariates identified a priori: child sex and area-based socioeconomic status measured using the Scottish Index of Multiple Deprivation (SIMD) (2012) (Scottish Government, 2012) at birth then stratified by the same area-based measure.

6.5.5 Statistical Analysis

Initial descriptive statistics summarised exposure frequencies and outcome distributions.

Linear regression estimated associations with cariogenic diet scores (outcome) and receipt of dietary interventions (exposure). Adapted modified Poisson regression (Section 3.11.3) estimated risk ratios (RR) for toothbrushing frequency (outcome) for receipt of toothbrushing interventions (exposure).

For all regression analyses in DHSW settings, the reference group was defined as children who had been referred into the programme but had not received any intervention by the relevant age cut-off (age 5 for cariogenic diet and toothbrushing outcomes). For primary dental care setting children who had received zero interventions by age cut-off were reference category including children who have never attended dentist.

Stratified analyses by SIMD fifths were conducted to explore potential effect modification by area-based deprivation. Formal interaction terms between SIMD (fifth) and each intervention exposure (diet and toothbrushing interventions in primary dental care and DHSW settings) were included in the regression models for each caries related behavioural outcome. Survey weights accounted for sampling design and non-response. Analyses were performed in R Studio.

6.5.6 Ethics and Governance

The Growing Up in Scotland study received ethical approval from the Scotland A Research Ethics Committee. This secondary analysis was approved by the Public Benefit and Privacy Panel for Health and Social Care (PBPP) and was conducted in the PHS National Safe Haven under strict disclosure protocols. All data were pseudonymised and analysed in accordance with the General Data Protection Regulation.

6.6 Results

The analytic sample for this study is 4,135 for Dietary Intervention questions and 4,659 for Toothbrushing Interventions, both down from 6,127 original responses in GUS Birth Cohort 2, due to data linkage, sample attrition and response to questions, this is detailed in

Figure 3.9.

The analytic sample was broadly representative of the original GUS cohort with respect to sex, maternal age, and area-based deprivation. The characteristics for key variables are shown in supplementary tables for Chapter 6 (ST6.1) for both model samples.

6.6.1 Reach of Childsmile Diet and Toothbrushing Behaviour Change Interventions

This section examines the reach of Childsmile interventions across two delivery settings: Dental Health Support Worker (DHSW) contacts and NHS primary care dental attendance, across area-based socioeconomic deprivation level.

6.6.1.1 Reach of Behaviour Change Interventions Delivered by Dental Health Support Workers

This section examines the reach of Childsmile interventions delivered via Dental Health Support Workers (DHSWs). All estimates are weighted using survey response weights to account for differential non-response and improve population representativeness. The counts are detailed in Table 6.1.

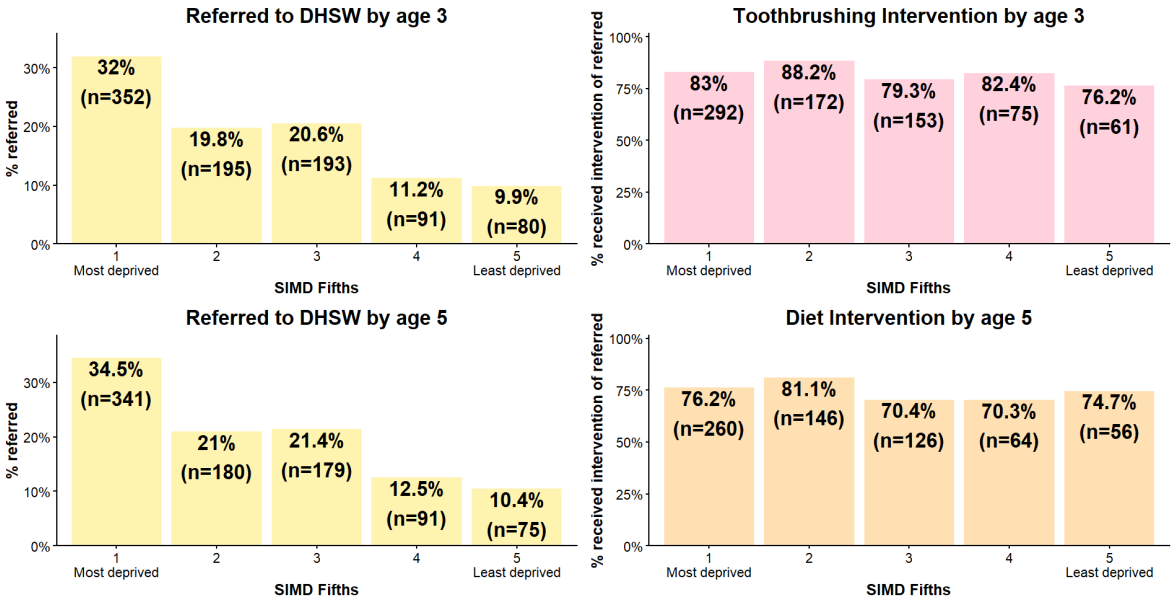
By approximately age 3, 19.5% (906/4639) of children had been referred at least once to a DHSW, increasing slightly to 21.1% (862/4119) by age 5 due to the targeted nature of the intervention. Among those referred, nearly all were successfully contacted (98.6% by age 3; 98.7% by age 5). Due to the very small number not contacted, these children were included in the "no intervention received" group.

Among children referred to a DHSW:

- 83.1% (753/906) received toothbrushing intervention by age 3, equivalent to 16.2% of the total cohort (753/4639)

- 75.4% (650/862) received diet intervention by age 5, equivalent to 15.8% of the total cohort (650/4119)

The reach was also stratified by Scottish Index of Multiple Deprivation fifths (Figure 6.1).



DHSW – Dental Health Support Worker; SIMD – Scottish Index of Multiple Deprivations; Totals in graph don't match exactly with totals listed above due to rounding up of each SIMD fifth after survey weights

Figure 6.1 - Dental Health Support Worker referrals and diet and toothbrushing intervention reach by area-based deprivation

When stratified by SIMD fifths, DHSW referrals were strongly patterned by deprivation, consistent with the programme's targeted design. By age 3, 31.9% (352/1103) of children in the most deprived SIMD fifth had been referred, compared with 9.9% (80/808) in the least deprived fifth. A similar pattern was observed at age 5 (34.5% vs 10.4%).

Among those referred, there was no consistent socioeconomic gradient in the receipt of the behaviour change interventions. The proportion receiving toothbrushing and dietary intervention varied across SIMD groups but without a clear or systematic pattern (see Chapter 6 - ST6.2).

6.6.1.2 Reach of Behaviour Change Interventions Delivered by NHS Primary Care Dental Services

This section examines the reach of Childsmile interventions delivered through primary care dental services. Estimates are weighted using survey response weights to account for differential non-response and improve population representativeness. The counts of intervention are detailed further in Table 6.2.

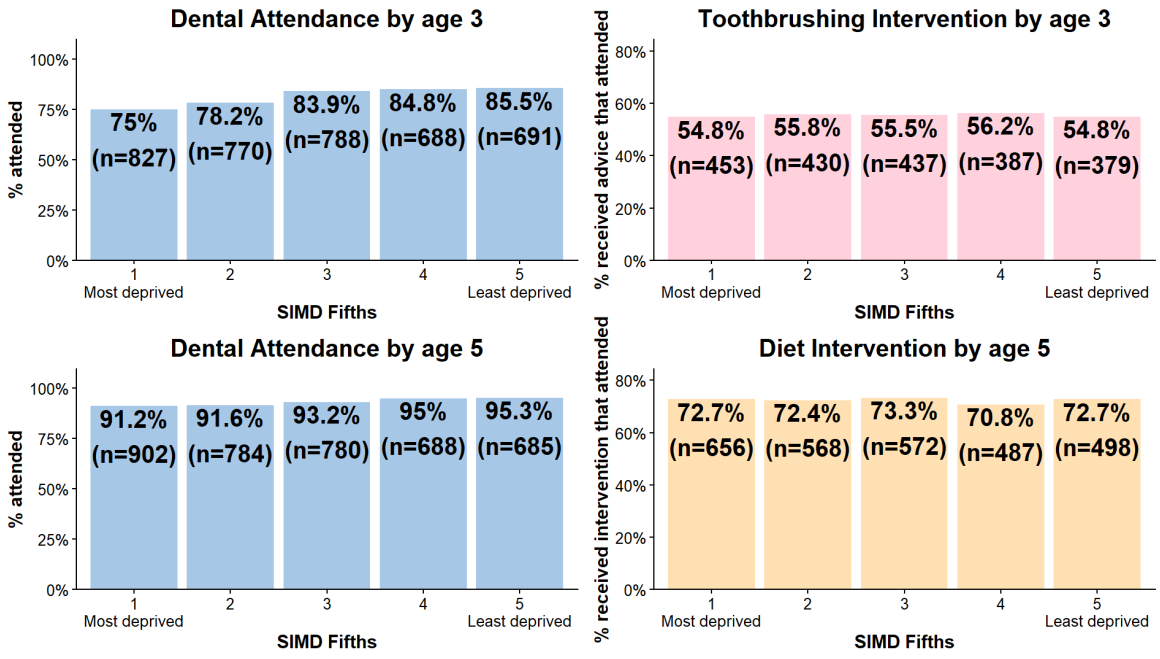
Percentages for ever having attended primary care (both General and Public) dental services were substantially higher than DHSW contact. By age 3, 81.1% (3766/4645) of children had attended a dental practice at least once, increasing to 93.1% (3839/4125) by age 5.

Among children ever having attended primary care dental services:

- 56.1% (2112/3766) received a toothbrushing intervention by age 3, equivalent to 45.5% of the total cohort (2112/4645)

- 72.2% (2772/3839) received a diet intervention by age 5, equivalent to 67.2% of the total cohort (2772/4125)

The dental attendance and reach of intervention were also stratified by Scottish Index of Multiple Deprivation fifths (Figure 6.2).



SIMD – Scottish Index of Multiple Deprivations; Totals in graph don't match exactly with totals listed above due to rounding up of each SIMD fifth after survey weights

Figure 6.2 - Primary care dental attendance and diet and toothbrushing interventions in primary dental care reach by area-based deprivation

When stratified by deprivation, dental attendance showed a very slight inverse care pattern in early childhood. By age 3, ever having attended primary care dental services ranged from 75.0% (827/1103) in the most deprived SIMD fifth to 85.5% (691/808) in the least deprived fifth, indicating a slight social gradient.

Although this disparity narrowed by age 5 (91.2% vs 95.3%), differences persisted.

The proportion of children receiving behaviour change interventions among those having ever attended dental practices showed little variation across deprivation groups (approximately 55% for toothbrushing intervention and 72% for dietary). However, because children in more deprived areas were less likely to attend, they were less likely overall to receive primary dental care interventions (see - ST6.2).

6.6.2 Cariogenic Diet and Toothbrushing Behaviours

At age five, the mean (SD) cariogenic diet score was 0.04 (1.02) (standardised scale; higher scores indicate more cariogenic diets, i.e. more frequent consumption of sugary drinks and snacks); with the minimum = -2.64 and maximum = 3.21. At age 3, 82.3% (3824/4646) of children were reported to brush their teeth more than once daily.

6.6.3 Associations Between Childsmile Behaviour Change Interventions and Oral Health Behaviours

Table 6.1 and Table 6.2 show examination of two key early-life behaviours targeted by Childsmile — cariogenic diet score at age 5 and toothbrushing frequency at age 3.

6.6.3.1 Delivery of Diet Interventions and Cariogenic Diet Score (Age 5)

All cariogenic dietary analysis is illustrated in Table 6.1.

Table 6.1 - Beta scores and adjusted beta scores and 95% confidence intervals for cariogenic diet at age 5 according to Childsmile behaviour change diet interventions based on linear regression

		Counts	Mean (sd)	Beta (95% CI)	P-value	Adj Beta (95% CI)[1]	P-value	r^2
Number of DHSW diet interventions delivered by 5 years old	0	212	0.16 (0.98)	0 (ref)		0 (ref)		<0.01
	1	608	0.14 (1.03)	-0.01 (-0.20, 0.18)	>0.9	-0.03 (-0.21, 0.15)	0.8	
	2+	42	0.21 (1.04)	0.06 (-0.32, 0.43)	0.8	0.04 (-0.34, 0.43)	0.8	
	Not Targeted	3257	0.02 (1.02)	-0.13 (-0.30, 0.03)	0.11	-0.06 (-0.21, 0.11)	0.6	
Number of primary dental care diet interventions delivered by 5 years old	0	1351	0.04 (1.09)	0 (ref)		0 (ref)		<0.01
	1	913	0.08 (0.98)	0.04 (-0.05, 0.14)	0.5	0.04 (-0.06, 0.13)	0.5	
	2	684	0.08 (0.98)	0.04 (-0.06, 0.15)	0.4	0.04 (-0.06, 0.14)	0.4	
	3	501	0.03 (0.97)	-0.00 (-0.13, 0.10)	>0.9	-0.00 (-0.11, 0.12)	>0.9	
	4	336	0.11 (1.02)	0.06 (-0.07, 0.19)	0.2	0.09 (-0.04, 0.22)	0.2	
	5 +	340	-0.12 (0.98)	-0.16 (-0.29, -0.03)	0.05	-0.13 (-0.26, -0.00)	0.05	

[1]Models adjusted for sex and Scottish Index of Multiple Deprivation fifth; CI – Confidence Interval; DHSW- Dental Health Support Worker

For DHSW diet intervention, there was no clear evidence of an association with cariogenic diet score across exposure categories. Effect estimates were small and imprecise, with adjusted beta coefficients close to zero. For example, children in the “not targeted” group had slightly lower cariogenic diet scores than the reference group (adjusted β = -0.06, 95% CI -0.21 to 0.11), corresponding to an average difference of approximately 0.06 standard deviations lower cariogenic diet score compared with those receiving no DHSW intervention, although this was not statistically significant. Children receiving one DHSW intervention showed very similar cariogenic diet scores to the reference group (adjusted β = -0.03, 95% CI -0.21 to 0.15), while those receiving two or more interventions had slightly higher cariogenic diet scores (adjusted β = 0.04, 95% CI -0.34 to 0.43), although estimates were imprecise due to small numbers. All findings were largely unchanged after adjustment for sex and SIMD fifth.

For primary dental care diet intervention, effect estimates were generally null or weakly positive at lower levels of contact. However, at higher exposure levels there was some suggestion of a small negative association with cariogenic diet score. For example, children receiving five or more interventions had slightly lower cariogenic diet scores compared with those receiving none (adjusted β = -0.13, 95% CI -0.26 to -0.00), corresponding to an average difference of approximately 0.13 standard deviations lower cariogenic diet score. The reference category (0 interventions) included both children who had never attended a primary care dental service during the study period and those who attended but did not receive any recorded intervention. While this estimate borders on statistical significance, it should be interpreted cautiously given potential residual confounding and selection effects. Lower levels of contact (1–4 interventions) showed beta estimates close to zero, indicating minimal differences in cariogenic diet score compared with the reference group.

6.6.3.2 Delivery of Toothbrushing Interventions and Toothbrushing Frequency at Age 3

Toothbrushing intervention analysis is illustrated in Table 6.2.

Table 6.2 – Risk ratios and adjusted risk ratios and 95% confidence intervals for toothbrushing frequency at age 3 according to Childsmile behaviour change toothbrushing interventions based on adapted modified Poisson regression

		1 or less	More than 1	RR (95% CI)	P-value	aRR (95% CI)[1]	P-value	AUC
Number of DHSW toothbrushing interventions by 3 years old	0	31 (20.3)	122 (79.7)	1 (ref)		1 (ref)		0.54
	1	115 (16.1)	600 (83.9)	1.05 (0.96, 1.15)	0.3	1.05 (0.96, 1.15)	0.3	
	2+	8 (21.1)	30 (78.9)	1.01 (0.82, 1.23)	>0.9	1.01 (0.83, 1.23)	>0.9	
	Not Targeted	667 (17.9)	3066 (82.1)	1.03 (0.94, 1.12)	0.6	1.02 (0.94, 1.11)	0.6	
Number of primary dental care toothbrushing interventions delivered by 3 years old	0	509 (19.9)	2025 (80.1)	1 (ref)		1 (ref)		0.57
	1	200 (16)	1058 (83.8)	1.05 (1.02, 1.08)	<0.01	1.05 (1.02, 1.08)	<0.01	
	2	82 (14.9)	483 (85.6)	1.06 (1.02, 1.11)	<0.01	1.06 (1.02, 1.11)	<0.01	
	3	31 (11.4)	258 (87.8)	1.11 (1.05, 1.16)	<0.01	1.10 (1.05, 1.16)	<0.01	

[1]Models adjusted for age and Scottish Index of Multiple Deprivation fifths; aRR – Adjusted Risk Ratio; CI – Confidence Interval; DHSW- Dental Health Support Worker

For DHSW toothbrushing intervention, there was no clear evidence of an association with more frequent toothbrushing at age 3. Risk ratios and adjusted risk ratios were close to unity across all exposure categories, indicating minimal differences in the likelihood of brushing more than once per day compared with the reference group. For example, children receiving one DHSW intervention had a similar likelihood of brushing more than once per day compared with those receiving no intervention (aRR = 1.05, 95% CI 0.96 to 1.15), corresponding to approximately a 5% higher relative likelihood. Estimates for children receiving two or more DHSW interventions (aRR = 1.01, 95% CI 0.83 to 1.23) and those not targeted (aRR = 1.02, 95% CI 0.94 to 1.11) were also close to one, suggesting little difference in toothbrushing frequency across exposure groups.

In contrast, primary dental care toothbrushing interventions showed small positive associations with more frequent toothbrushing at age 3. Children receiving one intervention had a slightly higher likelihood of brushing more than once per day compared with those receiving none (aRR = 1.05, 95% CI 1.02 to 1.08), corresponding to an approximate 5% relative increase. The reference category (0 interventions) included both children who had never attended a primary care dental service during the study period and those who attended but did not receive any recorded intervention. This association increased slightly with greater exposure, with adjusted risk ratios of 1.06 (95% CI 1.02 to 1.11) for two interventions and 1.10 (95% CI 1.05 to 1.16) for three interventions, suggesting a small dose–response pattern. Although effect sizes were modest, estimates consistently indicated higher reported toothbrushing frequency with increasing intervention exposure.

Overall, DHSW-delivered interventions showed little variation in toothbrushing frequency across exposure groups, whereas primary dental care interventions showed small incremental increases in reported toothbrushing frequency with greater exposure.

6.6.4 Social Gradient of Cariogenic Diet Score and Toothbrushing Frequency

Clear socioeconomic gradients were observed in outcomes, even among children receiving comparable levels of intervention. The mean cariogenic diet score was

higher in the children living in the 20% most deprived areas (0.29; SD = 1.05) than in the children living in the 20% least deprived areas (−0.22; SD = 0.92). Toothbrushing frequency also varied modestly by deprivation: brushing more than once daily was most frequent in least deprived SIMD fifth (84.7%) and lowest in 2nd most deprived 20% (80.7%), with the most deprived 20% similar at 81.0%. Due to very small numbers 2+ Dental Health Support Worker Interventions in some SIMD fifths are changed to 0,1+ for stratified analysis (see supplementary tables for Chapter 6 - ST6.1).

There was little evidence that the association between intervention exposure and caries-related behaviours differed meaningfully by deprivation level (see supplementary tables for Chapter 6 - ST6.2 (Diet) and ST6.3 (Toothbrushing)). Across SIMD fifths, effect estimates were generally small and similar in magnitude, with diet intervention beta coefficients typically ranging from approximately −0.3 to +0.3 and toothbrushing intervention adjusted risk ratios remaining close to 1. While some variation in estimates was observed between individual deprivation strata, no consistent gradient or pattern was evident to suggest differential effects of intervention delivery according to deprivation level (ST6.4). Interpretation of the stratified analyses should remain cautious, however, as several subgroup categories contained relatively small numbers, particularly for higher intervention frequencies, limiting the ability to detect modest interaction effects reliably.

6.7 Discussion

The recent Childsmile strategy places an explicit emphasis on reducing inequalities in child oral health while continuing to improve child caries experience at the population level (Ross *et al.*, 2023). Oral health behaviours, such as dietary behaviours and toothbrushing, are key proximal determinants of these outcomes (Sheiham and Watt, 2000; Peres *et al.*, 2019b). This study examined whether Childsmile's early-life interventions—delivered through both dental practice teams and Dental Health Support Workers (DHSWs)—influenced key behaviours, and whether these effects differed across area-based socioeconomic groups. The findings suggest that exposure to Childsmile's early-life diet and toothbrushing interventions was associated with only modest improvements in toothbrushing frequency and no consistent changes in dietary

behaviours. There was also no evidence of consistent intervention effects within any of the area-based deprivation groups.

Although DHSW support was intended to be targeted towards families living in more deprived circumstances, the observed patterns of programme engagement suggest that more intensive targeting could have been implemented. Furthermore, the greater intensity of support did not appear to produce differential behavioural changes. DHSWs provide tailored, home-based interventions including practical toothbrushing support, dietary guidance, and facilitation of dental attendance, often alongside links to wider social and community resources (Macpherson, Rodgers and Conway, 2019b). However, there was little evidence that this broader, holistic support influenced dietary behaviours or toothbrushing frequency, likely reflecting the complexity of these behaviours and the material and social constraints faced by families. Dietary behaviours, for example, are shaped by food affordability, household stress, and the local food environment, which can limit the capacity to act on even well-tailored advice (Darmon and Drewnowski, 2015; Schwendicke *et al.*, 2015).

The absence of consistent dietary intervention effects appears to reflect constrained agency rather than lack of engagement, a pattern widely observed in behaviour-change interventions delivered in contexts of socioeconomic disadvantage (Watt, 2012). This is consistent with a systematic review including 33 studies of most high or medium quality showing that family-focused interventions in children under five can reduce sugar-sweetened beverage consumption, but effects are generally modest and difficult to sustain (Foster *et al.*, 2018). In short, the social context can strongly inhibit behaviour change, even when interventions are well designed (Knott, Muers and Aldridge, 2008); with the interplay of values, beliefs, and social context key in shaping health behaviours (Stern, Dietz and Guagnano, 1995). At the same time, the reliance on self-reported behavioural measures may have limited sensitivity to detect small but meaningful changes, suggesting that some intervention effects may be underestimated (Sharman *et al.*, 2016; Martin *et al.*, 2019).

Within primary dental care, all contacts with the dental team represent opportunities to reinforce key preventive oral health messages, including dietary toothbrushing behaviour change interventions (Macpherson, Rodgers and

Conway, 2019a). In this study, such interactions were associated with very modest improvements in toothbrushing frequency, suggesting that repeated reinforcement in a clinical setting may support small behaviour changes. However, these effects were small and showed no clear socioeconomic gradient, indicating that improvements were similar across deprivation groups. This is consistent with evidence that preventive interventions delivered through routine dental attendance often reinforces existing behaviours rather than transforming them, particularly where attendance itself is socially patterned (Donaldson *et al.*, 2008). In this context, the inverse care law remains relevant (Tudor Hart, 1971), whereby parents motivated to attend dentist are most likely to receive dental practice interventions but also the most likely to already be motivated to brush their child's teeth and provide a lower cariogenic diet.

These findings should be considered within the broader Childsmile model of proportionate universalism, in which universal preventive interventions—such as supervised nursery toothbrushing, fluoride varnish application, and the provision of fluoride toothpaste—are delivered at scale, with additional tailored support provided to families at higher risk (Macpherson *et al.*, 2010). The programme is not intended to rely solely on the delivery of preventive messages and instructions but integrates these with practical support and wider structural measures. The limited behavioural effects observed here underscore the importance of these upstream components, which are more likely to influence population-level outcomes. Indeed, evaluations of Childsmile have demonstrated improvements in child oral health at the population level, although socioeconomic inequalities in caries experience persist (Ross *et al.*, 2023). Future research would benefit from examining later dietary and toothbrushing outcomes to assess their effects in the context of the full range of Childsmile interventions, as has been done previously for caries experience (Kidd *et al.*, 2020).

The early phase of programme implementation captured in this study, when DHSW outreach models and preventive activity within primary care dental services were still developing, may have limited the observable behavioural effects. Behaviour change, particularly for socially patterned behaviours, often requires sustained exposure and reinforcement over time (Singh *et al.*, 2024). These findings highlight that behaviour change interventions, even when well

targeted and rooted in behaviour change theory, are unlikely on their own to substantially alter behaviours or reduce inequalities in these behaviours.

Overall, this study indicates that Childsmile's early-life interventions were delivered partially in line with principles of equitable targeting and tailored support but had limited impact on early oral health behaviours. There was no evidence that intervention limited effects differed across socioeconomic group. Therefore, it is unlikely they have contributed to any inequalities in oral health behaviours being reduced since the introduction of the interventions, with it also known inequalities in outcome have persisted (Conway *et al.*, 2024). Achieving the programme's equity ambitions will likely require sustained investment in more effective targeting alongside universal preventive measures and structural policies that address the social and material conditions shaping families' capacity to adopt and maintain healthy behaviours.

6.7.1 Strengths and Limitations

This study draws on the Growing Up in Scotland (GUS) cohort, a large, population-based longitudinal dataset linked to administrative Childsmile records. This linkage enables examination of early-life pathways between socioeconomic circumstances (SEC), preventive interventions, and oral health behaviours, with temporal alignment between exposures and outcomes. The longitudinal design supports assessment of how early-life exposure to interventions relates to subsequent behaviours, allowing more robust inference than cross-sectional analyses.

A further strength is the availability of detailed information on both universal (practice-based) and targeted (DHSW) interventions, alongside rich, multidimensional measures of family SEC and key confounders. This facilitates exploration of potential differential effects across socioeconomic groups. The use of survey weights enhances the representativeness of the analytic sample.

However, several limitations should be considered. Behavioural outcomes were based on parent-reported measures, which may be subject to recall and social desirability bias, potentially limiting sensitivity to detect small but meaningful changes. The timing of outcome measurement may also influence interpretation;

for example, toothbrushing behaviours were assessed at age three, prior to most children entering pre-school, when exposure to further components of Childsmile may still be limited.

In addition, the intensity, fidelity, and quality of DHSW and practice-based interventions were not directly measured, and administrative data may under-capture the extent of preventive input delivered. The study reflects an early phase of Childsmile implementation, limiting the ability to assess longer-term impacts of sustained exposure. While temporal ordering of exposures and outcomes strengthens inference, residual confounding cannot be excluded, and causal relationships cannot be definitively established from observational data.

It is therefore important to interpret the findings cautiously. Associations between intervention exposure and behaviours may partly reflect underlying parental motivation, with families who are more engaged with dental services also more likely to adopt recommended behaviours. Without a randomised or internal control group, it is not possible to disentangle intervention effects from such pre-existing differences. Furthermore, although socioeconomic gradients in behaviours were observed, the study was not designed to assess changes in inequalities over time; therefore, conclusions regarding the impact of Childsmile on reducing behavioural inequalities should be made with caution. Finally any behaviour change interventions delivered by Public Dental Services are not captured due to the salaried nature of the job meaning thee activity is not processed as it is not related to payments.

6.8 Conclusion

In this cohort, exposure to primary dental care–based toothbrushing intervention was associated with modest improvements in toothbrushing behaviour, while DHSW-delivered support showed limited observable effects, and dietary interventions from both settings were not consistently associated with changes in behaviour. There was no evidence that these effects differed across area-based socioeconomic groups.

These findings suggest that, while early-life preventive interventions may support small improvements in oral health behaviours, they are unlikely on their

own to produce substantial behavioural change or differential effects across socioeconomic groups, particularly in the context of wider social and material constraints. This reinforces the importance of Childsmile's model of proportionate universalism, in which individual-level support is delivered alongside universal and structural interventions. Achieving sustained improvements in oral health and progress towards equity is therefore likely to depend on continued investment in upstream approaches, as well as alignment with wider policies addressing child poverty, diet, and the social determinants of health.

Chapter 7

7 Pathways Linking Socioeconomic Circumstances to Childhood Dental Caries: The Mediating Role of Parenting and Oral Health Behaviours Before and After Childsmile Implementation

The contents of this chapter were published to the journal Community Dentistry and Oral Epidemiology on the 9th of March 2026. This chapter answers research question 5.

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Keywords: epidemiology, socioeconomic factors, dental caries, longitudinal, child health, medical record linkage

7.1 Preface

Findings from Chapter 5 confirmed the central role of socioeconomic circumstances (SECs) as a key determinant of childhood caries. Yet, while these associations were strong, they did not fully explain how disadvantage translates into oral health inequalities. This chapter advances the analysis by introducing more robust methods to examine the underlying pathways, moving beyond traditional multivariable regression to structural equation modelling (SEM).

Parenting styles are socially patterned and have demonstrated associations with both children's oral health behaviours and caries experience; therefore, this study investigates the extent to which parenting styles (responsiveness and demandingness) and early oral health behaviours (toothbrushing, diet, and dental attendance) mediate the relationship between SECs and caries experience at age five. Drawing on linked data from Growing Up in Scotland (GUS), the National Dental Inspection Programme (NDIP), and the Management

Information and Dental Accounting System (MIDAS), SEM allows for simultaneous estimation of direct and indirect effects within a theoretically informed framework.

By stratifying models across pre- and post-Childsmile cohorts, the chapter also assesses whether the introduction of the programme has altered these mediating pathways, potentially weakening the link between disadvantage and poor oral health. In doing so, this analysis both strengthens methodological rigour and provides a deeper understanding of how modifiable behaviours and parenting practices interact with structural inequalities, informing the design of socially responsive interventions.

7.1.1 Author Contributions to this Manuscript

I led the development and conduct of this study, including conceptualisation of the research questions, methodology and study design, formal analysis, interpretation of the findings, and preparation and writing of the manuscript. Andrea Sherriff provided supervision and guidance throughout the study and reviewed the manuscript, providing feedback. Mariél de Aquino Goulart contributed to the iterative development of the statistical models and analysis and reviewed the manuscript, providing feedback. David Conway and Paul Bradshaw reviewed the manuscript and provided feedback.

7.2 Research Questions

5. To what extent do parenting styles or oral health behaviours—explain socioeconomic circumstances association with child caries experience; and how have these changed before and after early national roll-out of the Childsmile programme

7.3 Abstract

Objectives: To determine the extent that parenting styles and oral health behaviours mediate the relationship between socioeconomic circumstances (SEC) and childhood dental caries experience: pre-/post-national roll-out in 2011 of Childsmile the child oral health improvement programme for Scotland.

Methods: A longitudinal design linked 2798 participants from Birth Cohort-1 (following from age 10 months in 2005/06 to age 5 years in 2009/10) and 3015 from Birth Cohort-2 (following from age 10 months in 2011/12 to age 5 years in 2015/16) of the Growing Up in Scotland study with caries experience at age five from the National Dental Inspection Programme. Two Structural Equation Models (Birth Cohort-1 and 2) tested an a priori framework to explain the social gradient (SEC: Income Poverty, Area-based Deprivation, Household Parental Education, Household Parental Employment) in caries experience, considering proximal behaviours (toothbrushing, cariogenic diet, regular dental attendance); before introducing validated parenting styles (Parental Responsiveness and Demandingness).

Results: Models for both the pre-/post-Childsmile cohorts illustrated similar pathways. Dental attendance and parenting had no direct effect on caries experience. Responsiveness partially mediated the SEC-toothbrushing relationship, while demandingness partially mediated the SEC-diet relationship. Cariogenic diet directly increased caries experience prevalence (β = 0.33/0.24), while increased toothbrushing persistently decreased caries (β = -0.18/-0.13). Total mediated effect of SEC decreased from 58.8% to 39.1%, with the largest relative decrease being directly via toothbrushing (9.5%/4.0%). The effect mediated through parenting pathways remained minimal (4.8%/3.5%).

Conclusions: Pathways between SEC and childhood caries were unchanged after Childsmile roll-out, with minimal effects from parenting styles. The diminishing SEC effects via toothbrushing may be positively attributed to Childsmile interventions. The persistent unexplained effect of SEC on caries experience highlights the need for equity-focused structural approaches that address broader socioeconomic inequalities.

7.4 Introduction

Childsmile, the national child oral health improvement programme in Scotland, was introduced to improve overall oral health and reduce inequalities by addressing wider determinants beyond individual behaviours. Recognising the limitations of traditional oral health education, Childsmile was designed as a preventive, population-level intervention, integrating oral health promotion within broader public health strategies, combining targeted and universal components across education, community and dental practice settings (Macpherson *et al.*, 2015; Ross *et al.*, 2023). Piloted in 2006 and rolled out nationally by 2011, Childsmile is subject to constant monitoring and evaluation of processes and outcomes.

The association between socioeconomic circumstances (SEC) and childhood dental caries is well-established (Schwendicke *et al.*, 2015), but the mechanisms underlying this social gradient remain complex and multifactorial. SEC influence health through a combination of material, psychosocial, and behavioural pathways, as outlined in the social determinants of health framework (World Health Organization, 2010). Material pathways involve access to tangible resources such as nutritious food, oral hygiene products, and preventive dental care. Psychosocial pathways could involve stress, parenting practices, and the emotional environment shaped by SEC. Behavioural pathways encompass individual health-related actions, such as toothbrushing and dietary habits. These mechanisms are interrelated; for example, material deprivation may constrain behavioural choices or exacerbate psychosocial stressors (Watt and Sheiham, 2012).

SEC is a multidimensional construct encompassing income, housing conditions, education and employment status, each reflecting different aspects of socioeconomic position and having both individual and area-based dimensions (Galobardes, Lynch and Smith, 2007). For instance, household income affects access to nutritious food, while parental education shapes health literacy and caregiving practices (Galobardes, Lynch and Smith, 2007); notably education is systemically intertwined with income and employment (Marmot *et al.*, 2010). In Scotland, research often relies on an area-based measure, the Scottish Index of Multiple Deprivation (SIMD) (Scottish Government, 2020b), which, while useful

and cost-effective, may not fully capture individual socioeconomic experiences (McCartney *et al.*, 2023).

Parenting styles, defined as the emotional and behavioural environment in which children are raised, represent a plausible but underexplored mediator between SEC and oral health. Grounded in Baumrind's framework, parenting styles — authoritative (high responsiveness, high demandingness), authoritarian (low responsiveness, high demandingness), and permissive (high responsiveness, low demandingness) — may influence children's oral health behaviours such as diet and oral hygiene, though evidence remains mixed (Pristina, Arief and Armini, 2023; Moya-López *et al.*, 2024). Two recent systematic reviews illustrate this ambiguity: one found consistent associations between parenting styles and children's oral health in 10 studies, whereas another only found significant relationships in five of nine studies, mostly linking authoritative parenting to lower caries risk and permissive parenting to higher risk. The dimensions of responsiveness and demandingness are considered relatively stable traits during early childhood.

This study draws on two birth cohorts from the Growing Up in Scotland (GUS) study — one born before Childsmile implementation (2004/05) and one during early roll-out (2010/11) — to examine pathways linking SEC to childhood caries experience. It assesses the mediating roles of parenting styles and oral health behaviours, and whether these mechanisms differ before and after programme introduction. This work contributes evidence on how early Childsmile may have impacted on the processes underpinning oral health inequalities from early life.

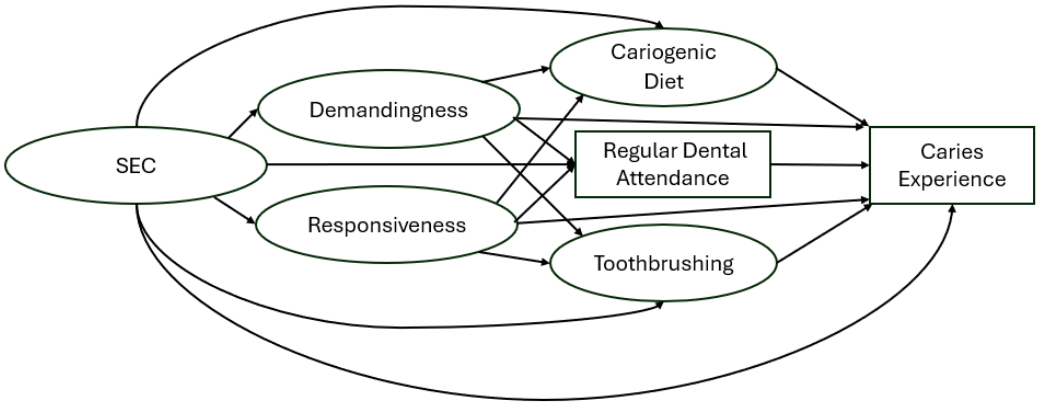
The conceptual model underpinning this analysis is theoretically grounded in Bronfenbrenner's ecological systems theory (Bronfenbrenner, 1977), alongside a broader social determinant of health framework (World Health Organization, 2010). It aligns with the theory of multilevel influences put forward in conceptual models of child oral health (Fisher-Owens *et al.*, 2007). The theoretical model is posited from previous findings that SEC are associated with parenting (Hoff, Laursen and Tardif, 2002), and parenting styles (responsiveness, demandingness) are associated with oral health behaviours (cariogenic diet, toothbrushing, regular dental attendance) and caries experience prevalence (Pristina, Arief and Armini, 2023; Moya-López *et al.*, 2024).

7.5 Methods

This study leverages a natural experiment by analysing two cohorts of the GUS study. Structural equation modelling (SEM) was used to evaluate direct and indirect effects within a theoretically grounded life course framework, incorporating latent variables to reduce measurement error.

7.5.1 Theoretical Framework

The pathways mentioned in the introduction and the theoretical model are shown in a Directed Acyclic Graph (Figure 7.1). The step-by-step algorithm for testing this model is detailed in Supplementary Material for Chapter 7 (S7.1).



SEC – Socioeconomic Circumstances; Freq – Frequency; Circular nodes: Latent variables; Rectangular nodes: Observed variable; Note: Toothbrushing is observed not latent variable for BC2

Figure 7.1 - Theoretical model from socioeconomic circumstances to caries experience at age 5; through parenting styles and oral health behaviours

7.5.2 Data Sources and Cohorts

This study used a longitudinal data linkage design combining two nationally representative GUS birth cohorts with dental inspection data from the National Dental Inspection Programme (NDIP), and National Health Service (NHS Scotland) dental attendance records from the Management Information & Dental Accounting System (MIDAS).

- Birth Cohort 1 (BC1): 5,217 children born in 2004/05, with data from sweep 2 (age 2) to sweep 5 (age 5) – pre-Childsmile cohort.

- Birth Cohort 2 (BC2): 6,127 children born in 2010/11, with data from sweep 1 (age 10 months) to sweep 3 (age 5) – immediately after early Childsmile roll-out.

NDIP includes an annual census of caries experience on all Primary 1 school-year (approximately 5 years old) children attending local authority schools.

GUS questionnaires were administered to participants by trained interviewers face-to-face using a computer-assisted format (Bradshaw, Palmer and Knudsen, 2018).

Analytic samples were derived through progressive inclusion, carrying participants forward only if they: (i) provided consent for data linkage and were successfully linked; (ii) had data from all GUS sweeps used in the model; (iii) had a valid NDIP examination at age five; finally those without complete-case requirements were excluded (see Supplementary Figures for Chapter 7 (SF 7.1)).

Individual participant-level data linkage was performed securely by Public Health Scotland's eDRIS service, using probabilistic matching via the Community Health Index (CHI) number, where all analysis is conducted in the secure National Safe Haven. Ethical approval was obtained from the University of Glasgow MVLS College and Public Benefit and Privacy Panels (ref: 200170146).

7.5.3 Variables and Measures

All variables except dental attendance and caries experience were collected from the GUS cohort surveys.

7.5.3.1 Outcome

Caries experience (yes/no) at age 5 was derived from NDIP records. The dental inspection involves a simple assessment of the mouth and teeth of each child undertaken by trained and standardised dental teams within primary schools, recording obvious dental caries experience (decay into dentine).

7.5.3.2 Exposure

SEC latent variable was constructed from four indicators (age 2/3): household income poverty defined as equivalised household income below 60% of national median income (annual median income at BC1 = £19,604 and at BC2 = £22,800), area-level socioeconomic deprivation (SIMD), highest household education, and parental occupational class (NS-SEC) (Hagenaars, de Vos and Zaidi, 1994; Pevalin and Rose, 2002; Raffe, 2003; Scottish Government, 2012). Further description of these variables in Supplementary Material for Chapter 7 (S7.2).

7.5.3.3 Mediators

Parenting Styles: two latent constructs were created — Responsiveness and Demandingness — using items from the Pianta Child–Parent Relationship Scale, the Parenting Practices Questionnaire (PPQ), and GUS-specific data on rules, routines, chaos, and discipline (Pianta, 1992; Robinson *et al.*, 1995; Coldwell, Pike and Dunn, 2006). Responsiveness generally reflects parental warmth and attentiveness, while Demandingness reflects the extent to which parents provide structure and set expectations. A full description of variables, coding and time points is included in S7.2.

Oral Health Behaviours (Three variables – Cariogenic Diet, Toothbrushing and Regular Dental Attendance):

Cariogenic Diet (BC1: Age 2 and BC2: Age 3/5, Latent): There were 29 possible diet variables in BC1 and 18 in BC2 (Supplementary Tables for Chapter 7 (ST7.3)); many were mutually correlated and would not sit independently in a model therefore a process of data reduction was carried out ending with a latent class variable for diet. Variables with a non-significant effect on the final latent variable or a factor loading < 0.4 were removed. Sweet consumption, sugar sweetened beverage (SSB) consumption and crisp consumption were used. The frequency of intake of each is assessed on an eight-point scale from “never” to “more than once a day”.

Toothbrushing (BC1: Age 2 and BC2: Age 3, Latent in BC1): For both cohorts, caregivers were asked how often a toothbrush was used to clean the child’s teeth, with the following response options: Less than once a day; Once a day;

More than once a day. For BC1, the latent variable is based on a combination of two questions:

- The frequency of toothbrushing (as described above).
- Whether toothpaste was used during toothbrushing, with a simple yes/no response.

For BC2, the observed variable is based on just the frequency of toothbrushing. However, for BC2 this question was changed to include 'with fluoride toothpaste'.

Regular Dental Attendance (Yes/no): Defined as attending the dentist at least once a year for four out of five years from birth up to the child's 5th birthday from the MIDAS.

7.5.3.4 Covariates

Age at NDIP Exam from NDIP databases and sex from GUS.

7.5.4 Statistical Analysis

7.5.4.1 Preliminary analysis

Univariable associations between all early life factors within GUS and caries experience were assessed using adapted modified Poisson regression adjusted for age and sex. Predictive performance was evaluated via Receiver Operating Characteristic (ROC) curves (Supplementary Tables for Chapter 7 ST7.1 and ST7.2). This was to help guide variable inclusion in final latent variables within model.

Survey weights are used throughout this analysis. The weights are developed using a model-based weighting technique where response behaviour is modelled using data from previous sweeps detailed further in GUS User Guides (Bradshaw, Palmer and Knudsen, 2018).

7.5.4.2 Structural Equation Modelling

SEM was conducted using the Lavaan package (version 0.6-19; (Rosseel, 2012)) in R Studio (version 2025.05.0). Given the categorical and ordinal nature of much of the data, models were estimated using the WLSMV estimator (Weighted Least Squares Mean and Variance adjusted), which provides robust standard errors and adjusted chi-square statistics, ensuring valid inference under conditions of non-normality and non-continuous data. P-values for individual pathways were derived from Wald z-statistics, computed using asymptotically robust standard errors. Model specification followed an iterative process: non-significant paths ($p > 0.05$) were removed sequentially, except where theoretical or empirical evidence indicated the variable's importance in the broader model structure.

Model fit was assessed using the chi-squared statistic (x^2), Comparative Fit Index (CFI > 0.95), Root Mean Square Error of Approximation (RMSEA < 0.06), and Standardised Root Mean Square Residual (SRMR < 0.08). Where needed, modification indices guided the inclusion of theoretically justifiable residual covariances to improve fit and model stability.

Latent variables were used to capture shared variance among correlated observed indicators, reducing measurement error and providing more precise estimates of theoretical constructs. Confirmatory factor analysis supported the latent structure, with most factor loadings greater than or equal to 0.4 and p-values less than 0.01 (Kline, 2023), except for "Toothpaste used (BC1)" which had $p = 0.08$.

7.6 Results

Analytic samples were derived sequentially from the GUS birth cohorts (Supplementary Figure 1). For BC1, 5,217 respondents were recorded; of these, 3,665 provided consent and were successfully linked. Among the linked cases, 3,275 had data for all sweeps, and 2,893 had a valid NDIP exam. The BC1 analytical sample included 2,798 participants (96.7% of those with NDIP). For BC2, 6,127 respondents were recorded; 5,599 consented and were successfully linked. Of these, 3,975 had data for all sweeps, and 3,442 had a valid NDIP

exam. The BC2 analytical sample had 3,015 participants (87.6% of those with NDIP).

Missingness was <5% for most variables except Poverty Status in BC2 (12.2% missing), but there was no evidence of social patterning. Variables collected in later sweeps are affected by the dropout rate of children between GUS survey sweeps (Bradshaw, Palmer and Knudsen, 2018).

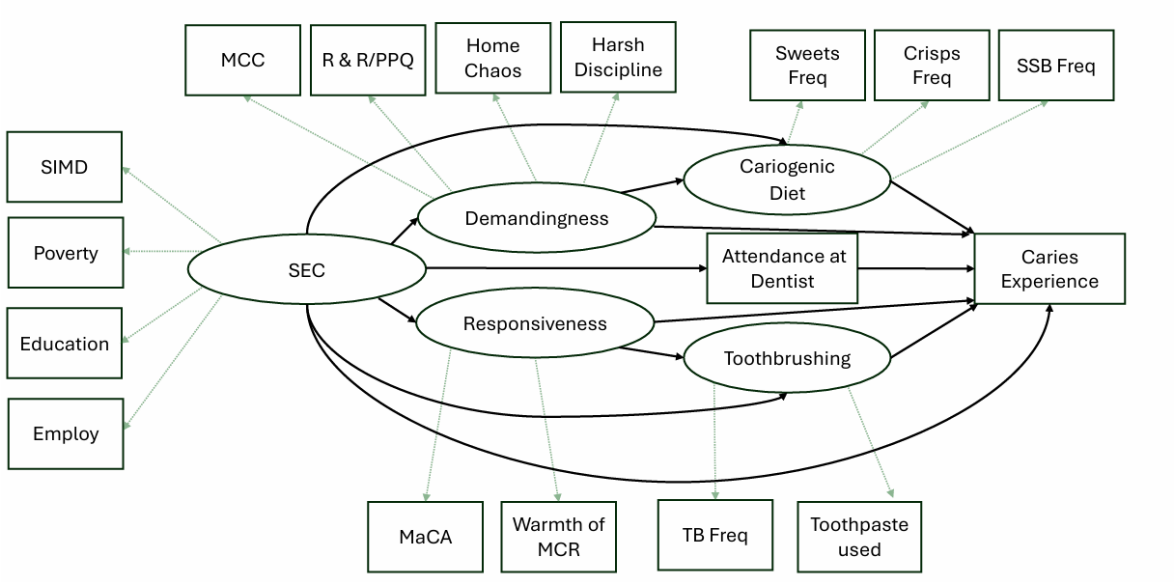
Table 7.1 summarises cohort characteristics of participants at the first sweep of GUS BC1 or BC2. ST7.1 (Supplementary Tables for Chapter 7) presents caries prevalence stratified by key predictors at the sweep when those variables were collected. All numbers are calculated using GUS survey response weights (Approx BC1: n = 3113 and BC2: n = 4004). These numbers differ from final SEM models counts shown in Figure 2 due to complete case analysis.

Table 7.1 - Birth cohorts characteristics

Variable		Birth cohort 1	Birth cohort 2
Age (years) at National Dental Inspection Programme Exam	n	3171	4769
	Min	4.11	4.57
	Q1	5.31	5.25
	Median	5.54	5.49
	Q3	5.80	5.76
	Max	6.80	6.99
Sex	Male	1608 (50.7)	2427 (50.9)
	Female	1564 (49.3)	2342 (49.1)
Caries Experience at Age 5	Yes	954 (30.1)	1330 (27.9)
	No	2217 (69.9)	3439 (72.1)

7.6.1.1 Preliminary Analysis Results

After running the univariable adapted modified Poisson regression models, the theoretical constructs were further specified by incorporating the observed variables, as illustrated in Figure 7.2. This specification represented the original SEM, which was subsequently refined through an iterative process of testing and modification (Supplementary Material for Chapter 7 – S7.1).



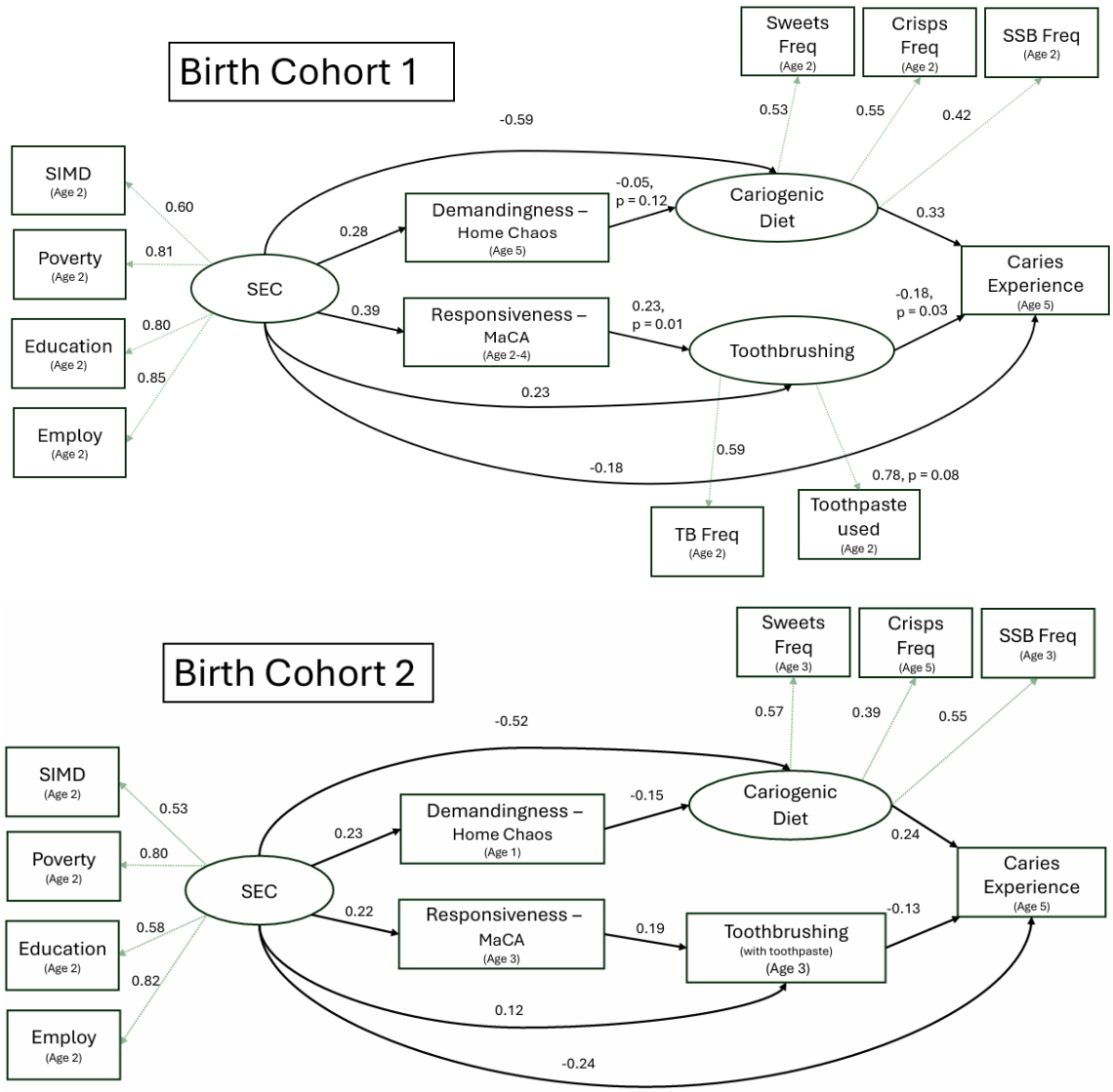
SEC – Socioeconomic Circumstances; MCC – Mother Child Conflict (Pianta Scale); R & R/PPQ – Rules and Routines (BC1)/Parenting Practices Questionnaire Authoritarian Score (BC2); MaCA – Mother and Child Activities ; MCR – Mother Child Relationship (Pianta Scale); SIMD – Scottish Index of Multiple Deprivation; TB – Toothbrushing; SSB – Sugar Sweetened Beverages; Employ – Managerial Employment; Freq – Frequency; Circular nodes: Latent variables; Rectangular nodes: Observed variable; Note: Toothbrushing is observed not latent variable for BC2

Figure 7.2 - Original structural equation model with observed variables

7.6.1.2 Structural Equation Modelling Results

Measurement models for parenting styles indicated that only one indicator per construct met the loading threshold (≥0.4): mother–child activities for parental responsiveness, and home chaos for parental demandingness. As no other indicators loaded strongly onto these constructs, parenting styles were treated as observed variables in the final model to avoid overparameterization.

The final pathway models diagram examining to what extent parenting styles and oral health behaviours mediate the relationship between SEC and childhood caries experience is presented in Figure 7.3. All significant pathways were consistent across cohorts. All $p < 0.01$ unless stated.



SEC – Socioeconomic Circumstances; MaCA – Mother and Child Activities; SIMD – Scottish Index of Multiple Deprivation; TB – Toothbrushing; SSB – Sugar Sweetened Beverages; Employ – Managerial Employment; Freq – Frequency; Circular nodes: Latent variables; Rectangular nodes: Observed variables

Figure 7.3 - Final models with standardised path coefficients (p<0.01 unless stated)

SEC exhibited direct effects on caries experience (BC1: ß = -0.18; BC2: ß = -0.24) as well as indirect effects through parenting and health behaviours. SEC was directly associated with parental responsiveness (BC1: ß = 0.39; BC2: ß = 0.22), which in turn was positively associated with toothbrushing (BC1: ß = 0.23; BC2: ß = 0.19), though SEC retained an additional direct effect on toothbrushing (BC1: β = 0.23, BC2: ß = 0.12), suggesting partial mediation.

Similarly, SEC was directly associated with higher demandingness (BC1: ß = 0.28, BC2: ß = 0.23), which was linked to a lower cariogenic diet (BC1: ß = -0.05, BC2: ß = -0.15). Again, SEC had an additional direct effect on the cariogenic diet (BC1: ß = -0.59, BC2: ß = -0.52). While parenting styles had no direct effects on caries experience, they exerted small indirect influences through oral health

behaviours; responsiveness on toothbrushing and demandingness on diet. Diet showed stronger associations with caries (BC1: β = 0.33, BC2: β = 0.24) than toothbrushing (BC1: β = -0.18, BC2: β = -0.13), with effects generally larger in birth cohort 1 (pre-Childsmile).

Table 7.2 - Mediation percentages of Socioeconomic Circumstances-caries experience pathways in final models

Pathway	**Mediation percentage**	
	Birth Cohort 1	Birth Cohort 2
Demandingness – Cariogenic Diet	1.06	2.10
Responsiveness - Toothbrushing	3.70	1.38
Cariogenic Diet	44.6	31.67
Toothbrushing	9.48	3.96
Total	58.80	39.11

Notably, total mediated effects declined from BC1 (58.8%) to BC2 (39.1%), primarily due to reduced direct oral health behaviours mediation (Toothbrushing: 9.5% to 4.0% and Diet: 44.6% to 31.7%), while parenting pathways mediated ≤5% of effects in both cohorts (Table 7.2). Sensitivity analyses confirmed these patterns were robust across alternative model specifications, including analyses using continuous parenting variables and models with dental attendance included.

SEM demonstrated excellent fit using standard thresholds for both cohorts (CFI/TLI >0.95, RMSEA <0.06, SRMR <0.08):

- **BC1:** CFI = 0.988, TFI = 0.983, RMSEA = 0.028 (90% CI: 0–0.049), SRMR = 0.032.

- **BC2:** CFI = 0.979, TLI = 0.968, RMSEA = 0.033 (90% CI: 0.022–0.043), SRMR = 0.026.

7.6.1.3 Sensitivity Analysis

Sensitivity analyses supported the stability of the primary model findings. Several sensitivity checks were conducted to assess the robustness of the models. Reversing the order of parenting styles and oral health behaviours led to poorer model fit and reduced interpretability, supporting the original theorised

sequence. Including parental stress as an additional mediator did not improve model fit and was therefore excluded. Using variables measured at different time points across cohorts produced minimal changes in estimates, and consistency in measurement timing was prioritised.

7.7 Discussion

This study examined how SEC affect childhood caries experience in Scotland, showing the salient repercussions of these inequalities. SEC exhibit sustained detrimental associations with oral health behaviours and childhood caries experience, as well as enduring relationships with parenting styles. Even after accounting for behavioural and parenting pathways, a substantial proportion of the SEC and caries experience association remained unexplained, with minimal parenting styles mediation.

Despite Childsmile's national implementation in 2011 and the population child oral health improvement observed since, SEC-caries pathways remained unchanged across cohorts. This persistence may reflect the entrenched nature of SEC effects, which are resistant to short-term interventions. Broader factors including austerity measures following the 2008 financial crisis, rising childhood poverty, and food insecurity, likely further constrained Childsmile's ability to reduce inequalities, which have remained stubbornly persistent (Scottish Government, 2011; Conway *et al.*, 2022). Six years may also have been too short a period for longstanding patterns in inequalities to shift or for national policies to become fully embedded and generate measurable impact.

Turning to specific behaviours, regular home toothbrushing emerged as a protective factor and showed a consistent positive association with SEC, in conjunction with previous findings (Levin *et al.*, 2015). However, its mediating role in caries inequalities declined in the later cohort, possibly due to Childsmile's supervised toothbrushing in nurseries and schools and distribution of free toothbrushing packs, both previously shown to be delivering population-level caries prevention regardless of socioeconomic background (Macpherson *et al.*, 2015; Ross *et al.*, 2023).

Cariogenic diet's associations remained relatively stable across cohorts and were less influenced by Childsmile's dietary interventions — including advice from dental practices and health support workers, which have shown thus far to have limited impact (Ross *et al.*, 2023). Children from lower socioeconomic groups consistently face barriers to healthy diets, including food availability and affordability, issues rooted in environmental and resource constraints rather than individual behaviour (Briazu *et al.*, 2024). These reflect systemic challenges that behaviour-change programmes alone cannot address. Initiatives like the UK-wide Healthy Start scheme (2006) (Scantlebury *et al.*, 2018) and Scotland's Best Start Foods (2019) (Scottish Government, 2019) have aimed to reduce these material barriers through food vouchers and prepaid cards, showing some improvement in access for disadvantaged families.

Parenting styles had small indirect effects on caries through oral health behaviours. Responsive parenting was associated with more frequent toothbrushing, while demandingness was modestly associated with a less cariogenic diet. Toothbrushing may be supported through cooperative parent–child interactions and gentle coaxing, creating a feedback loop in which positive interactions encourage consistency, whereas dietary choices may more commonly require structure, rules, limit-setting and firm guidance. Although, diet has also shown to benefit from higher levels of responsiveness in other studies (Hughes *et al.*, 2005; Lopez *et al.*, 2018). Despite this, parenting styles overall mediating influence was minimal. Their small magnitude may partly reflect measurement limitations, as parenting constructs were represented with single indicators rather than latent variables due to weak factor loadings—an approach known to attenuate path coefficients and potentially underestimate mediation effects (Cole and Preacher, 2014). More fundamentally, the overall influence of parenting was overshadowed by the direct and indirect effects of SEC. This finding aligns with the Family Stress Model (Conger and Conger, 2002), wherein material constraints increase parental stress and limit resources, constraining the capacity of even positive parenting to offset structural disadvantage. Consequently, while parenting interventions may support specific healthy behaviours, they are unlikely to meaningfully reduce oral health inequalities without concurrent strategies to address underlying economic hardship.

Evidence consistently shows that oral health behaviours alone do not fully account for inequalities. This has been confirmed through structural equation modelling analysis (Polk, Weyant and Manz, 2010), including with similarly aged children (Qiu *et al.*, 2014). Education can influence oral health behaviours (Sabbah *et al.*, 2009), while employment status and income can shape habits like toothbrushing, but behavioural improvements alone rarely eliminate inequalities, underscoring the need for structural solutions.

Despite incorporating parenting factors, a persistent preponderance of SEC remains unexplained by the models, highlighting a potential limitation of behaviour change interventions. This is a matter of paramount importance to Scotland's Childsmile programme. It suggests that broader structural inequalities continue to shape oral health outcomes through mechanisms not fully captured by current approaches. Socioeconomic gradients in childhood caries have been shown to persist even after controlling for known risk factors (Schwendicke *et al.*, 2015), indicating deeply entrenched effects resistant to behaviour- or parenting-focused interventions alone. Evidence suggests that universal welfare programmes will be more effective than targeted approaches in reducing inequalities and sustaining public support for redistribution. Future research should investigate alternative pathways, further exploring parental stress (Menon *et al.*, 2013), epigenetic changes (Silva *et al.*, 2022), wider family/social factors (Hooley *et al.*, 2012) and more detailed neighbourhood-level deprivation (van Meijeren-van Lunteren *et al.*, 2021).

From a policy perspective, these findings underscore the need to pair clinical and behavioural intervention with broader, equity-oriented strategies that address the structural determinants of oral health. This could include expanding the community linking role of Childsmile teams with organisations that provide social and economic support. Moreover, while Childsmile combines universal and targeted components, sustained reductions in inequalities will likely require more comprehensive social policies that tackle material deprivation and socioeconomic disadvantage (Ross *et al.*, 2023). This includes expanding access to healthy food through schemes like the "Healthy Start" vouchers, embedding oral health into broader poverty-reduction efforts. Although conducted within the Scottish context, the mechanisms identified are likely relevant to similar high-income settings with comparable welfare and oral health systems.

7.7.1 Strengths and Limitations

This study draws on two large, prospective, population-based cohorts in the GUS longitudinal study with further data linkage of routine administrative datasets, enabling robust examination of early-life pathways linking SEC, parenting, oral health behaviours, and clinically assessed childhood caries. The inclusion of two birth cohorts spanning the implementation of a major public health intervention (Childsmile) allows for comparative analysis of structural and behavioural mechanisms over time.

The use of an objective clinical measure of caries is a key strength, reducing reliance on self- or parent-reported outcomes. In addition, the study benefits from high-quality, multidimensional data on family SECs and parenting, including multiple validated measures. The data also have repeated measures for SECs and some oral health behaviours. The richness of these variables enhances confidence in the measurement of both exposures and mediators, allowing more nuanced pathway analysis than typically possible in oral health research.

The NDIP examination used for the study outcome is slightly limited in detail but provides high population coverage and data quality. Dental caries experience data from basic inspections (presence vs. absence of obvious caries) produced results comparable to detailed assessments on a 20% subsample by trained examiners using British Association for the Study of Community Dentistry criteria.

The use of latent constructs and SEM strengthens the measurement of complex constructs and supports the investigation of indirect pathways. However, the timing and structure of data collection did not allow for a fully temporally ordered longitudinal SEM. As a result, the analysis relied on associations at key timepoints, which limits the ability to establish causal inference between mediators and outcomes. While the hypothesised ordering was supported by theoretical and developmental rationale, alternative model specifications were tested and found to be less consistent with the data.

Furthermore, the use of the WLSMV estimator in Lavaan, while appropriate for categorical data, did not support bootstrapped confidence intervals for indirect

effects. Consequently, only point estimates were reported, and uncertainty around mediation pathways could not be fully quantified.

A final possible limitation is that the available survey-based parenting measures did not support creation of multivariable latent constructs, requiring responsiveness and demandingness to be represented by single indicators. This may limit our ability to capture the multidimensional nature of parenting and may introduce measurement error that could underestimate the mediation effects.

7.8 Conclusion

Despite the population-level child oral health improvement observed with the national implementation of the Childsmile programme, the underlying pathways linking SEC and childhood caries experience remained largely unchanged across cohorts. Parenting styles exerted minimal influence, while improvements in oral health behaviours—particularly toothbrushing—suggest some positive impact of Childsmile interventions. However, these behavioural shifts were insufficient to eliminate inequalities. The persistent and substantial unexplained effect of SEC highlights the enduring role of structural disadvantage, operating through material, psychosocial, and behavioural pathways. To meaningfully reduce oral health inequalities from early life, behaviour change and clinical interventions must be complemented by upstream, equity-oriented policies that address material deprivation and food insecurity.

7.9 Acknowledgements

The authors acknowledge the support of the electronic Data Research and Innovation Services (eDRIS) in Public Health Scotland (PHS) and the Indexing Team in National Records Scotland along with the data providers in the Dental Team in PHS. This work was supported by funding from The Borrow Foundation. The GUS data used in this article are publicly accessible via the UK Data Service (Scottish Centre for Social Research, 2019). The authors also acknowledge the work of Dr Ryan Stewart and Dr Jamie Kidd for their work creating the standard operating procedure (SOP) used when cleaning the National Dental Inspection Programme data used in this study.

7.10 Supplementary Material

The supplementary materials included in supplementary results for Chapter 7 in Appendix D detailed methodological information and supporting results. S7.1 describes the SEM model-building algorithm and model estimation procedures. S7.2 provides full variable definitions and measurement details for socioeconomic circumstances and parenting across both cohorts. SF7.1 presents the sample derivation flow diagram, and ST7.1 reports descriptive statistics with caries experience prevalence of all variables in initial models, AUC results from univariable models with caries experience for these variables are given in ST7.2, and all additional diet variables assessed but not retained in the final latent variables and their caries prevalence are given in ST7.3.

Chapter 8

8 Early Life Trajectories of Household Poverty and Area-Level Deprivation and Childhood Dental Caries: A Longitudinal Data Linkage Cohort Study

The contents of this chapter were published to the journal Community Dentistry and Oral Epidemiology on the 10th of June 2025. Parental Employment in Household (section 3.9.2.3) and Parental Education in Household (Section 3.9.2.2) of parents were also analysed but not included in publication so key tables are shown in Supplementary Tables for Chapter 8 (ST8.4 - ST8.6) and Supplementary Figures for Chapter 8 (SF8.1 - SF8.3). This chapter answers research question 6.

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Keywords: epidemiology, socioeconomic factors, dental caries, longitudinal, child health, medical record linkage

8.1 Preface

Earlier chapters have shown that socioeconomic circumstances are the strongest and most consistent predictors of childhood caries. This chapter builds on those findings by linking rich longitudinal data from the Growing Up in Scotland (GUS) study with clinical outcomes from the National Dental Inspection Programme (NDIP), providing a unique opportunity to further examine how early-life socioeconomic disadvantage shapes caries risk at age five.

Where much existing evidence relies on cross-sectional or area-based measures, this linkage enables analysis of individual and household-level socioeconomic conditions measured repeatedly from birth to age five. The study examines both cumulative exposure to poverty and deprivation and distinct trajectories of socioeconomic mobility, capturing not only who is disadvantaged but also when and for how long.

By integrating nationally representative survey data with routine dental inspection records, this chapter deepens understanding of how the timing, persistence, and movement into or out of disadvantage contribute to inequalities in child oral health. In doing so, it provides new insight into the early pathways through which socioeconomic influences become embedded in dental outcomes and highlights the importance of early-years policies to mitigate these risks.

It should be noted that the area-based measure used here may partly act as a proxy for individual socioeconomic circumstances, as no individual-level adjustment was included. However, evidence from multilevel model focussed systematic studies suggests that area-level deprivation retains independent contextual effects above and beyond individual-level influences (de Aquino Goulart *et al.*, 2025).

8.1.1 Author Contributions to this Manuscript

I led the development and conduct of this study, including conceptualisation of the research questions, methodology and study design, formal analysis, interpretation of the findings, and preparation and writing of the manuscript. Andrea Sherriff provided supervision and guidance throughout the study and reviewed the manuscript, providing feedback. David Conway and Paul Bradshaw reviewed the manuscript and provided feedback.

8.2 Research Questions

6. What is the longitudinal impact of changes in household income poverty and area-based socioeconomic-deprivation on child caries experience in early childhood

8.3 Abstract

Objective: This study aimed to explore the longitudinal impact of changes in household income poverty and area-based socioeconomic-deprivation on dental caries prevalence in early childhood.

Methods: Data from the Growing Up in Scotland (GUS) longitudinal study (2005/6-2009/10) were linked to dental caries experience data at age 5 from Scotland's National Dental Inspection Programme. Latent Class Analysis identified trajectories of household poverty (income below 60% of the national median) and area-based deprivation across multiple time points between birth and age 5. Cumulative exposure scores were also calculated and adapted modified Poisson regression assessed associations between socioeconomic pathways and caries experience in 2893 children.

Results: Children living in persistent household poverty or in socioeconomically deprived areas had the highest risk of caries experience compared with children who were never exposed to poverty or area deprivation. Elevated caries risk was also observed among children who fell into poverty (aRR 1.4, 95% CI 1.1–1.8) and those who escaped poverty (aRR 1.6, 95% CI 1.3–2.1). Children who moved into more deprived areas also had higher caries risk (aRR 1.6, 95% CI 1.2–2.2), whereas moving out of deprived areas was not associated with increased risk (aRR 1.1, 95% CI 0.8–1.7). Caries risk increased with the cumulative number of years spent in household poverty and living in socioeconomically deprived areas.

Conclusions: Unstable poverty and downward socioeconomic-deprivation mobility were associated with greater caries risk in early childhood, underscoring the importance of considering the duration and persistence of socioeconomic disadvantage in relation to oral health outcomes and should inform early-years focused policies to address these. Longitudinal data linkage combining representative surveys and routine data is a powerful way to uncover these issues.

8.4 Introduction

The detrimental impact of negative socioeconomic circumstances (SEC) on children's oral health outcomes is clear (Schwendicke *et al.*, 2015). Understanding their complex role is crucial for developing and evaluating efficient and effective interventions, with early-year interventions such as Scotland's Childsmile Programme highlighted as critical for addressing health inequalities (Marmot *et al.*, 2010; Burns, 2011; Macpherson, Rodgers and Conway, 2019a). These points are particularly relevant to child dental caries, an early physical marker of general health (Watt *et al.*, 2018) and the most prevalent non-communicable disease in the world (Vos, 2020), with stark socioeconomic inequalities existing both between (World Health Organization, 2022) and within countries (Public Health England, 2020; Conway *et al.*, 2022).

Defining an individual's socioeconomic circumstances can be complex, as the relevance of each possible metric varies depending on the focus of the study (Shavers, 2007). In Scotland, monitoring health inequalities has primarily relied on multifaceted area-based socioeconomic deprivation measure, the Scottish Index of Multiple Deprivation (SIMD) (Scottish Government, 2020b). This assesses levels of deprivation based on multiple indicators across 7 domains (Scottish Government, 2020c). Area-based measures of deprivation are easier to obtain than individual measures, relying mostly on readily available routine data and home address. These measures are cost-effective, maintain privacy and are useful for identifying geographic concentrations of need (McCartney *et al.*, 2023). However, they have limitations, such as overlooking individual socioeconomic experiences. SIMD, for example, has been shown to exhibit low sensitivity in identifying individuals suffering from income poverty (McLoone, 2001). This is vital, as household income poverty has been identified as a recurring key factor in previous studies investigating childhood caries (Schwendicke *et al.*, 2015; Brondani *et al.*, 2024). As of 2022/23, 26% of the children in Scotland were living in relative poverty (Scottish Government, 2024c), where individuals lack the minimum income or resources to maintain the average standard in their country of residence, defined by a household receiving less than 60% of the relevant country's median household income.

In addition to the use of individual-level versus area-based measures, it is crucial to consider different data collection methods and a variety of analysis techniques when considering socio-economic circumstances (SEC). For example, cross-sectional studies versus longitudinal studies and social mobility trajectories versus cumulative effects each present their own strengths and limitations (Kuh *et al.*, 2003; Caruana *et al.*, 2015). For research on oral health inequalities to shift away from documenting to explaining, and association to causation the use of longitudinal data are necessary (Dao *et al.*, 2025). They allow the exploration of prolonged exposure and social mobility (Caruana *et al.*, 2015), improving understanding of complex mechanisms producing inequalities and helping refine effective interventions. Longitudinal data also help address temporality concerns and avoid the bias common during the interpretation of cross-sectional analyses of associations (Tsakos, Watt and Guarnizo-Herreño, 2023).

Social mobility has been shown to have a substantial effect on health outcomes. Upward social mobility potentially mitigates the negative health effects associated with low SEC (Savelieva *et al.*, 2017), while downward socioeconomic mobility has been shown to lead to worse health outcomes (Dahl, 1996; Lynch, Kaplan and Salonen, 1997; Schmeisser *et al.*, 2010). These findings emphasise the importance of understanding the dynamics over time and lay the foundations for using trajectory analyses in SEC studies (Ben-Shlomo and Kuh, 2002; Kuh *et al.*, 2003).

To effectively address dental caries, understanding the role of SEC in shaping health disparities is critical to optimising the impact of public health interventions, such as the Childsmile Programme in Scotland (Macpherson, Rodgers and Conway, 2019a). Analysing these disparities demands a temporal approach that integrates multiple measures and metrics. Therefore, the aim of this study is to investigate the impact of early life longitudinal and cumulative exposures to income poverty and area-based deprivation on caries experience at 5 years.

8.5 Methods

8.5.1 Data

This study utilised a data linkage, longitudinal design, linking data from the Growing Up in Scotland (GUS: 2005/06-2009/10) study with caries experience data at age 5 from the National Dental Inspection Programme (NDIP) in Scotland. GUS is a longitudinal birth cohort study with a nationally representative sample of 5,217 children born in 2004/05 in Scotland. This analysis covers data from sweep 1 (2005/06, age 10 months), sweep 2 (2006/07, age 2), sweep 3 (2007/08, age 3), sweep 4 (2008/09, age 4) and sweep 5 (2009/10, age 5)(Bradshaw *et al.*, 2011). The data were collected from a main carer/parent at each sweep, with face-to-face surveys carried out in participants' homes by trained social survey interviewers using laptop computers.

The National Dental Inspection Programme (NDIP) database (Conway *et al.*, 2022) includes an annual survey of oral health outcomes for all Primary 1 school-year (approximately 5 years old) children attending local authority schools and some public schools. The inspection involves a simple standardised assessment of the mouth and teeth undertaken in the school by trained and standardised community dental teams.

Inclusion was based on consistent participation across survey sweeps, agreeing to data linkage and having a valid NDIP exam from school years 2009/10 and 2010/11 (n = 2893). Numbers will still vary for each socio-economic (SE) variable due to varying item missingness. Complete data for each SE variable and caries experience outcome needed to be included in analyses.

Data linkage was performed by the Electronic Data Research and Innovation Service (eDRIS) at Public Health Scotland (PHS) with strict disclosure protocols. Individual-level data were linked via Scotland's Community Health Index (CHI) numbers through probabilistic matching based on date of birth, sex, and postcode. The linkage agent pseudonymised study-specific identifiers, allowing for the integration of datasets stored within the National Safe Haven (NSH). Both the NDIP and GUS datasets underwent rigorous data cleaning and quality assurance following standard operating procedures.

8.5.2 Key Variables

Household income poverty status at age 2 – 5 years old: Measured as income poverty, defined by the respondent's annual income after tax but before housing costs being less than 60% of median equivalised income in Scotland, using the modified Organisation for Economic Co-operation and Development equivalence scale. This scale assigns weights of 0.67 for the first adult, 0.33 for additional adults aged 15 or over, and 0.2 for children aged 0 – 14 years, providing a comparable poverty threshold across time and populations (Treanor and Troncoso, 2022).

Area-based deprivation was measured using a mix of the Scottish Index of Multiple Deprivation (SIMD) 2004 (Sweep 1), 2006 (Sweeps 2 – 4), and 2009 (Sweep 5) at ages 10 months to 5 years (Scottish Government, 2004; Scottish Government, 2006; Scottish Government, 2009). It is based on 31/37/38 indicators in six/seven individual domains of current income, employment, housing, health, education, skills and training, geographic access to services with crime added as a domain in 2006. SIMD is calculated at data zone level, enabling small pockets of deprivation to be identified. The data zones are ranked from most deprived (1) to least deprived (6,505) on the overall SIMD index. The data are then recorded in fifths (SIMD1-SIMD5), with SIMD1 being the most 20% deprived areas in the population.

The multi-category variable area-based deprivation was dichotomised with children living in the 20% most deprived areas versus children living in the 80% least deprived areas to simplify the modelling process by reducing the complexity of the grouping output. This facilitated identifying and interpreting distinct patterns or trajectories.

All calculations were conducted at four or five distinct time points between the ages of 10 months/2 years and 5 years. At each time point, a binary coding system was applied: a value of 1 indicated that the individual was in a low SEC, while a value of 0 indicated otherwise. The exposure variable was quantified as both the trajectory over time and the cumulative number of years spent in poverty or deprivation, represented as a factor ranging from 0 to 4 or 5, depending on the total number of time points assessed.

Caries experience at age 5 (yes/no) (Outcome): Defined as the presence of obvious decay which was determined clinically by the presence of decay (caries into dentine), missing (extracted due to decay) or filled deciduous teeth following recognised criteria. This variable was obtained from the National Dental Inspection Programme database (Conway *et al.*, 2022).

8.5.3 Statistical Analysis

Latent Class Growth Analysis (LCGA) is a statistical tool for analysing trajectory patterns in data over time. LCGA identifies distinct subgroups within a population that share similar developmental trajectories, revealing patterns that might be missed in cross-sectional studies (Muthén and Muthén, 2000).

In this study LCGA was used to identify longitudinal trajectories of household income poverty from age 2 to age 5 years (four discrete time points) and area-based deprivation from 10 months to age 5 (five discrete time points). This discrepancy was caused due to not having access to income data at 10 months of age. LCGA classifies individuals into mutually exclusive latent classes based on patterns in observed categorical variables (Jung and Wickrama, 2008). Models' parameters were estimated using maximum likelihood with robust standard errors. The best-fitting model was selected based on the lowest Bayesian Information Criterion (BIC) value, interpretability, and theoretical relevance. Models with 3 to 5 classes were estimated using the R package 'poLCA' (Linzer and Lewis, 2011). Model adequacy was assessed through posterior probabilities, with cumulative exposure scores calculated (Jung and Wickrama, 2008).

Due to the binary nature of caries experience an adapted modified Poisson regression model with robust error variances was used to estimate risk ratios and 95% confidence intervals (CI) for caries experience with those consistently never in poverty or deprivation as the reference categories. The regression models were adjusted for the child's sex and age at the time of the NDIP exam.

Longitudinal Survey weights are used throughout this study. The weights are developed using a model-based weighting technique where response behaviour is modelled using data from previous sweeps detailed further in GUS Sweep 5 User Guide (Bradshaw *et al.*, 2011).

The study received ethical approval (College of MVLS, University of Glasgow) and approval from the Public Benefit and Privacy Panel – Health and Social Care (PBPP- Public Health Scotland) and the Statistics- PBPP (Scottish Government) (reference number: 200170146).

8.6 Results

There were 3621 children in the GUS Birth Cohort 1 present in all sweeps, of which 3275 (90.4%) provided consent for their data to be linked and analysed in the NSH. Those missing (n= 346) did not give consent for their survey data to be linked to routine administrative data or were not successfully linked.

There were 51,074 Primary 1 children who had a NDIP record in the same timeframe; of the 3275 children in GUS, 2893 (88.3%) had a valid NDIP exam. This becomes 2875 children after survey weights are applied. For these children, the item response rates for each socioeconomic variable differ. Income Poverty has n = 2516 (87.0%) responses, or n = 2484 (85.9%) after GUS survey weights are applied. The missing data for Income Poverty did not appear to be socially patterned according to SIMD. The sample characteristics along with the number of children in poverty/deprivation at each age are displayed in table 8.1.

Table 8.1 - Characteristics of sample

Variable	n (%)				
Age (years) at NDIP					
Min	4.110				
Q1	5.311				
Median	5.541				
Q3	5.802				
Max	6.795				
Sex					
Male	1462 (50.9)				
Female	1413 (49.1)				
Caries Experience at Age 5 based on basic NDIP examination					
Yes	916 (31.8)				
No	1960 (68.2)				
Sweep Age	**10 months**	**2 years**	**3 years**	**4 years**	**5 years**
SIMD fifths					
1	697 (24.5)	703 (24.7)	697 (24.4)	687 (24.1)	660 (23.1)
2	528 (18.5)	520 (18.2)	505 (17.7)	513 (18.0)	551 (19.3)
3	556 (19.5)	535 (18.8)	542 (19.0)	539 (18.9)	517 (18.1)
4	553 (19.4)	568 (19.9)	558 (19.6)	562 (19.7)	577 (20.2)
5	516 (18.1)	525 (18.4)	549 (19.3)	551 (19.3)	546 (19.1)
Income Poverty[4]					
Yes	N/A	709 (28.6)	667 (26.9)	640 (25.8)	633 (25.5)
No	N/A	1772 (71.4)	1814 (73.1)	1842 (74.2)	1849 (74.5)
Area-based deprivation: In lowest SIMD 20%					
Yes	697 (24.5)	703 (24.7)	697 (24.4)	687 (24.1)	660 (23.1)
No	2152 (75.5)	2146 (75.3)	2153 (75.6)	2163 (75.9)	2190 (76.9)

NDIP – National Dental Inspection Programme; SIMD – Scottish Index of Multiple Deprivation; 1 - Small discrepancy in totals due to rounding of survey weight counts; 2 - Defined by the respondent's annual income after tax but before housing costs being less than 60% of median equivalised income in Scotland, using the modified Organisation for Economic Co-operation and Development equivalence scale

The trajectory groups for both variables are shown below in Figure 8.1. It can be seen from the findings that some groups are regularly not 100% assigned to either of the binary results for that variable; however clear patterns still emerge. The SEC levels are defined as 'Always' in low SES, 'Never' in the low

SEC, ‘Upward’ mobility from the low SEC or ‘Downward’ mobility into the low SEC.

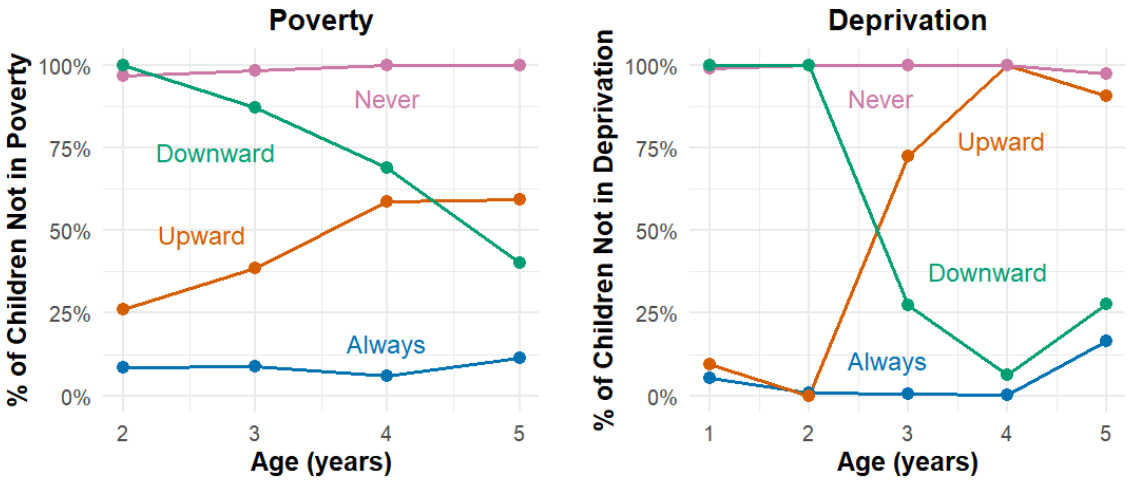


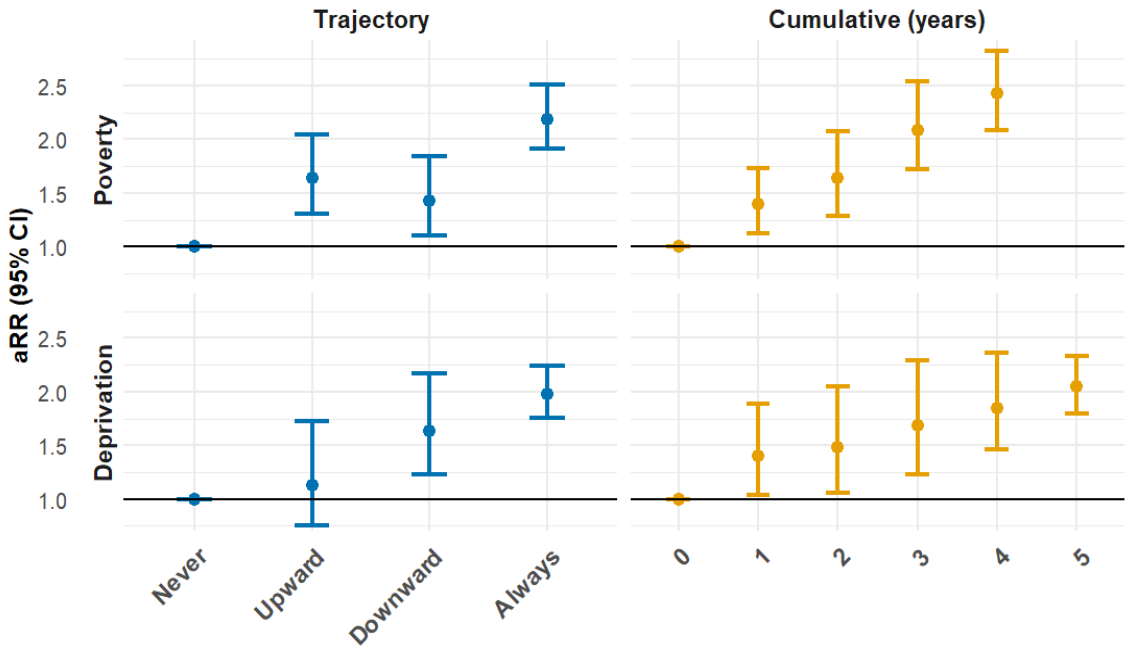
Figure 8.1 - Latent class analysis trajectories of socioeconomic circumstances

Income Poverty has four trajectories: never in income poverty, upward social mobility (escaping Income poverty), downward social mobility (falling into income poverty) and always in income poverty. There are four trajectories present for Area-based Deprivation, which can be similarly labelled. Table 8.2 displays the membership within each trajectory group for each of the variables.

Table 8.2 - Numbers of children in each poverty/deprivation trajectory

Outcomes	Poverty (%)	Deprivation (%)
Never	1629 (65.6)	2069 (72.5)
Upward social mobility	199 (8.0)	74 (2.6)
Downward social mobility	145 (5.8)	95 (3.3)
Always	511 (20.6)	615 (21.5)
Total	2484	2853

Table 8.2 illustrates that the transitional groups only make up a small proportion of the population; poverty 13.8% (n = 344) and deprivation 5.9% (n = 169). The proportion of households in poverty and deprivation in every trajectory group also differs at each age (Supplementary tables for Chapter 8 - ST1). The associations of these groups with caries experience compared to the risk in the ‘Never’ group for each measure adjusted for sex and age are shown in Figure 8.2, the values and predictive value of each model as well as the crosstabulations and risk ratios are given in the supplementary tables for Chapter 8 (adjusted for age at exam and sex) (ST8.2).



aRR – adjusted Risk Ratio (adjusted for Age at NDIP exam and Sex); CI – Confidence Interval

Figure 8.2 - Adjusted risk ratios for caries experience in Primary 1 according to poverty/deprivation trajectories and cumulative effects against caries experience at 5

The findings highlight the important impact of poverty trajectories on the risk of caries experience. Children who fell into poverty during the first 5 years had an increased risk (aRR 1.43, 95% CI 1.11–1.85), while those persistently living in poverty faced the highest risk (aRR 2.19, 95% CI 1.84–2.60) compared with those who were never in poverty. Risk also remained elevated among those who escaped poverty (aRR 1.64, 95% CI 1.33–2.03). A cumulative association was observed, with adjusted risk ratios increasing from 1.40 (95% CI 1.12–1.75) after 1 year of poverty exposure to 2.43 (95% CI 1.98–2.99) after 4 years, indicating a worsening impact of prolonged poverty exposure.

Children who moved into the 20% most deprived areas also had an increased risk of caries experience (aRR 1.63, 95% CI 1.28–2.07), while those consistently living in the 20% most deprived areas faced the highest risk (aRR 1.98, 95% CI 1.64–2.39). In contrast, children who experienced upward residential mobility had a lower risk compared with other deprivation groups (aRR 1.13, 95% CI 0.75–1.72). A cumulative association was again evident, with adjusted risk ratios increasing from 1.40 (95% CI 1.04–1.89) after 1 year to 2.05 (95% CI 1.80–2.33) after 5 years living in the 20% most deprived areas. As an additional check in the study, the Area-based Deprivation trajectory model was adjusted for Income Poverty

trajectories and vice versa. This was to ensure both socioeconomic variables weren't both measuring the same constructs. The key findings were upheld, with income poverty effect once again proving particularly strong. These findings are detailed in supplementary tables for Chapter 8 (ST8.3).

8.7 Discussion

This study highlights the profound impact of sustained socioeconomic disadvantage, particularly income poverty and area-based deprivation, on children's dental health. By examining longitudinal patterns of deprivation, this study provides a more comprehensive understanding of how early-life socioeconomic conditions shape health outcomes, offering insights beyond those of cross-sectional studies.

There is a well-established link between early-life income poverty and poor health outcomes (Treanor and Troncoso, 2022; McCabe *et al.*, 2024; Royal College of Paediatrics and Child Health, 2024), with effects manifesting regardless of other socioeconomic factors (Cooper and Stewart, 2013). Poverty is believed to be a key factor perpetuating the clear inequalities still present in child health outcomes (McCabe *et al.*, 2024). These findings are consolidated by this study; with numerous studies already linking income poverty specifically to increased risk of caries experience (Costa, Daher and Queiroz, 2013; Foley and Akers, 2019; Folayan *et al.*, 2020b; Almajed *et al.*, 2024). This study found that any exposure to poverty—regardless of how many years—elevates caries risk. These findings echo those of Peres *et al.* (2007) who reported that even brief experiences of poverty in early life are associated with poorer dental health.

The risk of caries increased with each additional year of poverty, clearly demonstrating a cumulative effect. This cumulative effect of poverty was also observed in a previous child caries study (Matsuyama *et al.*, 2023) and is consistent across other health studies; such as stress responses (Evans and Kim, 2007) and child development (Roos, Wall-Wieler and Lee, 2019). The unequivocal and cumulative effect of poverty was also demonstrated by the same GUS cohort when analysing emotional and conduct problems and other health outcomes (Barnes, Chanfreau and Tomaszewski, 2010; Treanor and Troncoso, 2022). These findings align with research showing that cumulative

exposure to poverty in childhood can have lasting negative impacts on health, even if socioeconomic circumstances improve later (Evans and Kim, 2007; Evans and Cassells, 2014).

In addition to income poverty, this study found a strong link between area-based deprivation and caries experience risk, corroborating previous research (Duijster *et al.*, 2014; Conway *et al.*, 2022). Those living in the 20% most deprived areas consistently displayed higher caries experience risk, with each additional year spent in deprivation further increasing the risk. This supports earlier findings that area-based deprivation, as a proxy for community-level inequalities, is a powerful predictor of health disparities (Sweeney, Nugent and Pitts, 1999). These findings exemplify that prolonged socioeconomic disadvantage, as measured by both income poverty and area-based deprivation, creates a cumulative risks that exacerbate health inequalities over time, a phenomenon well-documented in previous health research (Marmot and Wilkinson, 2005).

The trajectory analysis revealed a novel aspect; children who moved out of the most deprived areas during the study did not experience a notable increase in caries experience risk. This supports the idea that improving socioeconomic conditions can mitigate some negative impacts (Savelieva *et al.*, 2017). In contrast, other studies suggest that early socioeconomic disadvantage has lasting impacts on oral health (Poulton *et al.*, 2002; Peres *et al.*, 2019b), with early life being a critical period for disease development (Peres *et al.*, 2007; Treanor and Troncoso, 2022). This mitigating effect also diverged from the findings on poverty, which may be explained by the differing thresholds required to move out of each circumstance. Escaping poverty could require a minimal financial increase to cross the poverty threshold, whereas reducing area-based deprivation necessitates substantial changes, such as relocating to a less deprived area or significant improvements in local socioeconomic conditions—changes that are far less common. All this suggests that long-term exposure to deprivation and social mobility, rather than just a snapshot of current area-based deprivation status or deprivation at birth, plays a critical role in determining health outcomes. This adds to previous findings drawn from cross-sectional studies, such as NDIP (Conway *et al.*, 2022), and provides new insights into the long-lasting effects of early deprivation and suggests negative effects can be reversed by consequential later improvements measured by a multi-

domain area-based deprivation. This demonstrates the value of having access to longitudinal data to provide a greater understanding in this area of study.

This study illustrates the importance of understanding the multifaceted effects of living in a less deprived neighbourhood, to evaluate and optimise interventions such as Scotland's Childsmile programme which may target children more appropriately for additional support (Macpherson, Rodgers and Conway, 2019a). However, it also highlights the powerful effect of income poverty alone, suggesting it must be targeted to reduce inequalities in child caries experience; evidence in favour of Scotland's introduction of the child poverty payment in 2022 (Scottish Government, 2022). The study's longitudinal design enriches our understanding of how both individual and area-based socioeconomic conditions impact caries experience risk. It highlights the compounding effects of multiple years spent in poverty or deprivation, while also demonstrating that the increased caries risk associated with area-based deprivation may not persist if children move to less deprived areas. These findings underscore the importance of addressing both the duration and context of socioeconomic disadvantage to effectively reduce health inequalities in children.

8.7.1 Strengths and Limitations

One of the key strengths of this study was the emphasis on capturing the early years of life, recognising that these formative years are crucial in shaping long-term health outcomes. This study offers long-term follow-up, sufficiently large representative sample sizes, and rich baseline covariate data, which collectively help minimise bias and provide a comprehensive view of how early life experiences influence health over time (Peres *et al.*, 2020).

Another key strength of this study was that the linkage between datasets was robust, with a high linkage rate that did not exclude many records. This along with the use of high-quality routine data for the study's outcome and high item response rates for other variables was an efficient use of time and resources, without any compromise on analysis.

Despite these strengths, the study does have a few limitations. Firstly, this study faced constraints due to a reduced number of time points for poverty status, with area-based illustrating the clearer trajectories when including a 5th time point at 10 months. This was due to the lack of availability of the data in the National Safe Haven at the time of this study.

Another limitation to consider is that the findings of this study may not extrapolate to other countries and age groups given the different social contexts and healthcare systems.

Furthermore, LCGA presents methodological challenges, including determining the number of latent trajectory classes, selecting appropriate model fit indices, and overcoming convergence issues (Jung and Wickrama, 2008). Identifying the number of components in a growth mixture model often involves selecting the model with the smallest Bayesian Information Criterion (BIC) value, but convergence problems may arise due to the mathematical complexity of modelling a sample distribution that comprises multiple sub-distributions (Hipp and Bauer, 2006). LCGA is susceptible to local solutions, necessitating careful methodological considerations.

A final limitation of this study is the small number of children within the transitional deprivation groups. This is due to few children in the study cohort experiencing a change in SIMD level within the first five years of life. This led to wider confidence intervals in the models comparing caries experience across deprivation trajectories, which has reduced the precision of the results.

8.8 Conclusion

In the population studied, unstable income poverty trajectories and area-based downward socioeconomic mobility were associated with a higher risk of caries experience. These findings underscore the importance of considering the duration and persistence of socioeconomic disadvantage in relation to oral health outcomes. They also emphasise the importance of preventing the first instance of poverty experience to reduce risk. All these findings should inform policies and interventions to address these issues, particularly in the early years.

Using longitudinal data linkage to combine representative surveys and routine data is a powerful way to uncover these issues.

8.9 Acknowledgements

The authors acknowledge the support of the electronic Data Research and Innovation Services (eDRIS) in Public Health Scotland (PHS) and the Indexing Team in National Records Scotland along with the data providers in the Dental Team in PHS. This work was supported by funding from The Borrow Foundation. The GUS data used in this article are publicly accessible via the UK Data Service (Scottish Centre for Social Research, 2019). The authors also acknowledge the work of Dr Ryan Stewart and Dr Jamie Kidd for their work creating the standard operating procedure (SOP) used when cleaning the National Dental Inspection Programme data used in this study.

Chapter 9

9 Discussion

This thesis draws on a uniquely rich programme of longitudinal data to examine the early-life determinants of childhood dental caries in Scotland. By integrating detailed survey data from the Growing Up in Scotland (GUS) birth cohorts with clinician-assessed outcomes from the National Dental Inspection Programme (NDIP) and administrative records from the Childsmile programme and NHS primary care dental services, the thesis addresses key limitations of previous oral health research, particularly reliance on cross-sectional designs, proxy-reported outcomes, single-source data and area-based measures of socioeconomic circumstances. This integrated approach enables the examination of oral health behaviours, socioeconomic circumstances, and policy interventions within a single, population-based analytical framework.

The GUS cohort surveys provide high-quality, nationally representative longitudinal individual-level data capturing children's early-life environments, family characteristics, and oral health related behaviours. Their breadth and temporal depth allow early-life behaviours and socioeconomic measures to be precisely aligned with later clinical outcomes, supporting analyses that extend beyond simple associations to examine pathways, accumulation of risk, and change over time. Linkage to objective NDIP 'caries experience' data further strengthens this framework by providing standardised, clinician-assessed measures of caries experience, enabling robust assessment of inequalities and limiting biases inherent in parent- or carer-reported outcomes.

The fortuitous positioning of the GUS birth cohorts on either side of the national rollout of the Childsmile programme provides an opportunity to examine the programme within a natural experimental framework, albeit during the early phase of its implementation. This configuration allows Childsmile to be considered as a complex public health intervention, consistent with Medical Research Council (MRC) guidance on the evaluation of complex interventions, which emphasises the importance of assessing effects across multiple levels and within changing policy contexts (Skivington *et al.*, 2021). In this thesis, the cohort structure enables analysis at both a macro level—through examination of

population-level patterns in dental caries and socioeconomic inequalities across cohorts—and a micro level—through investigation of associations between early-life behaviours, socioeconomic circumstances, and oral health outcomes at the individual level. Considering these perspectives in parallel provides an opportunity for analytical triangulation, whereby individual-level risk patterns can be interpreted alongside broader population changes occurring during the early implementation of Childsmile. While this approach does not constitute a direct causal evaluation of the programme, it situates the analyses within the context of its introduction and provides a means of exploring whether established patterns of risk, behaviour, and inequality in dental caries remained stable or showed indications of change following the programme's initial implementation.

Establishing the validity of the oral health outcome was a critical first step in this research. Previous work comparing oral health questions from Growing Up in Scotland demonstrated that parent-reported measures substantially underestimate tooth decay among 5-year-olds. A crude comparison in 2011 reported a caries prevalence of 16.9% in the GUS cohort based on parental report, compared with approximately 34% in the Primary 1 population based on clinical inspection (Macpherson *et al.*, 2011; Skafida and Chambers, 2018). This discrepancy may have been partly influenced by selection bias, as the GUS cohort may not fully represent the population distribution of dental disease. The present thesis improves on this approach by linking GUS survey data with NDIP records, allowing direct comparison of proxy-reported and clinically assessed caries for the same children assessed at the same time. This analysis confirmed substantial underestimation of caries experience in GUS and revealed clear socioeconomic patterning in reporting accuracy, with children from more advantaged backgrounds more likely to have undetected disease when relying solely on parental report. These findings reinforce the importance of clinically assessed outcomes for both surveillance and policy evaluation and provide strong justification for the use of NDIP-measured caries experience as the primary outcome throughout this thesis.

A large portion of the analysis utilised the structure of the Fisher-Owens *et al.* (2007) conceptual model to examine whether associations between early-life oral health behaviours and childhood caries experience persisted after

accounting for family factors and socioeconomic circumstances, and to assess whether these associations had changed following the implementation of Childsmile. Regression analyses were conducted with clinically assessed caries experience from the National Dental Inspection Programme as the outcome, and early-life behaviours—including dietary practices and toothbrushing frequency—as exposures and household- and socioeconomic indicators as confounders/covariates. Across all analyses, socioeconomic circumstances emerged as the dominant and most persistent determinant of caries experience, consistent with evidence that while Childsmile has improved population oral health, socioeconomic inequalities remain (Ross *et al.*, 2023; Conway *et al.*, 2025). Multivariable models showed that although early-life behaviours were associated with caries outcomes, these associations were substantially attenuated after adjustment for socioeconomic factors. This pattern suggests that oral health behaviours are strongly socially structured, reflecting material and contextual constraints rather than individual choice. These analyses were on the birth cohorts pre-Childsmile and post early implementation, with all associations appearing comparable. Evaluation of Childsmile's behaviour change interventions further supported this interpretation, demonstrating limited capacity to modify dietary or toothbrushing practices, this was true across all socioeconomic area-based deprivation levels.

To explore the mechanisms underlying socioeconomic inequalities in childhood caries in greater depth, structural equation modelling (SEM) was employed. Childsmile's behaviour change interventions aim to improve early-life oral health behaviours and may also influence parenting oral health practices. However, the analysis focused on parenting styles—the broader emotional and behavioural environment in which children are raised—because these have more established links with child behaviours and have been shown to be socioeconomic patterned (Pristina, Arief and Armini, 2023; Moya-López *et al.*, 2024). There are also limited parent oral health practices collected in Growing Up in Scotland surveys. Building on this framework, SEM allowed simultaneous assessment of both direct effects of socioeconomic disadvantage and indirect effects mediated through parenting styles and early-life oral health behaviours. These analyses confirmed that parenting styles and behaviours partially mediated socioeconomic inequalities but parenting styles accounted for consistently less than 10% of the

overall effect. A substantial direct effect of disadvantage remained (approximately 41% pre-Childsmile and 61% post-Childsmile implementation), highlighting the enduring influence of structural conditions.

A further utilisation of the longitudinal data was to examine the cumulative and dynamic effects of socioeconomic circumstances on childhood caries experience. Socioeconomic disadvantage is a well-established determinant of oral health (Schwendicke *et al.*, 2015), with early-life interventions such as Scotland's Childsmile Programme highlighted as critical for reducing inequalities (Macpherson, Rodgers and Conway, 2019a). Area-based measures, and individual level measures were compared. Considering both longitudinal exposure and social mobility was essential, as prolonged disadvantage increases health outcome inequalities, whereas improvements in circumstances can potentially mitigate it (Caruana *et al.*, 2015; Savelieva *et al.*, 2017). This approach allows exploration of complex mechanisms linking socioeconomic circumstances, parenting, and early-life behaviours to caries outcomes, supporting more effective evaluation of public health interventions and clarifying pathways of inequality.

Taken together, the linked GUS, NDIP, and Childsmile evaluation data enable a comprehensive and policy-relevant examination of childhood dental caries, demonstrating that inequalities are rooted in cumulative socioeconomic conditions, with behaviours and preventive programmes operating within these constraints. This discussion situates the findings of the thesis within the wider literature, critically considers the strengths and limitations of the studies within the thesis, places the analysis within the wider context of birth cohort analyses in UK and globally, and presents conclusions and recommendations for future policy, practice, and research.

9.1 Findings

The key findings of the thesis are structured around the aims outlined in Section 2.1 and follow the overall analytical progression of the thesis: first, exploratory analyses of early-life oral health behaviours and socioeconomic context (Research Questions 2 and 3 – Chapter 5); second, evaluation of Childsmile intervention effects on these behaviours (Research Question 4 – Chapter 6); and

finally, more complex analyses examining the association between early-life socioeconomic circumstances and childhood dental caries (Research Question 5 and 6 – Chapter 7 and 8).

9.1.1 Early-Life Behaviours and Socioeconomic Context Findings (Research Questions 2 and 3 - Chapter 5)

The analyses conducted in this thesis demonstrated clear associations between early-life oral health behaviours across the first five years and dental caries experience at age five. Dietary behaviours were the most strongly associated with caries experience, with more frequent consumption of sugary snacks and beverages linked to higher prevalence. Toothbrushing frequency also demonstrated a clear, though slightly more moderate, association, with more frequent brushing associated with reduced caries risk. Associations with regular dental attendance were weaker and less consistent. This likely reflects the relatively high levels of dental attendance across the population, particularly in the context of Scotland's preventive oral health programmes, meaning there was limited variability to detect an association with caries outcomes.

Diet and toothbrushing associations largely remained evident after adjustment for family and socioeconomic level factors although effect sizes were attenuated with cariogenic diet showing an increased risk of approximately 33% (Birth Cohort 1 - BC1) and 34% (Birth Cohort 2 - BC2) in univariable models compared with around 19% (BC1) and 17% (BC2) in fully adjusted models and frequent toothbrushing showing a protective association of around 20% (BC1) and 30% (BC2) lower risk in univariable models compared with approximately 11% (Bc1) and 19% (BC2) lower risk in fully adjusted models. The greatest attenuation occurred after adjustment for socioeconomic circumstances which highlights their dominant role in shaping both early life behaviours and childhood caries outcomes consistent with evidence that behaviours alone cannot fully explain oral health inequalities (Watt, 2007; Schwendicke *et al.*, 2015). This pattern is most clearly seen when comparing sequential adjustment models. After accounting for family-level factors, associations attenuated modestly; however, the largest reduction occurred once socioeconomic circumstances were included, with cariogenic diet decreasing to around BC1: 20% and BC2: 20% in socioeconomic-adjusted models, similar to fully adjusted models. A similar

pattern was observed for frequent toothbrushing, where estimates changed after socioeconomic adjustment (BC1: 12% and BC2: 19%), with minimal change thereafter in the fully adjusted models.

This is also reflected in the supplementary analyses where socioeconomic circumstances showed strong associations with caries experience with children in more favourable socioeconomic circumstances showing approximately 35% lower risk (BC1/BC2) in unadjusted models reducing to around 28% after full adjustment while family level factors remained independently associated with caries outcomes but with smaller effects approximately 28% (BC1) and 30% (BC2) higher risk in unadjusted models reducing to around 10% (BC1) and 15% (BC2) higher risk after full adjustment. These findings reinforced the central role of structural factors in shaping both exposure to cariogenic risk and children/parent/carer's ability to adhere to recommended oral health practices, suggesting that interventions focusing solely on behaviour modification are likely to have limited impact unless upstream determinants of disadvantage are addressed.

Comparisons across pre- and early-post Childsmile cohorts indicated that these behavioural associations remained largely stable over time, with similar associations between early-life behaviours and caries experience in both cohorts despite overall reductions in prevalence. This suggests that, although Childsmile has contributed to improvements in population oral health, behaviour change components appear to have had a limited effect on modifying early-life behaviours. Importantly, all behaviours were strongly socioeconomically patterned: children from more disadvantaged backgrounds were more likely to have higher intake of cariogenic foods and beverages, lower toothbrushing frequency, and lower counts of regular dental attendance. This pattern underscores that early-life behaviours should be interpreted as socially structured risk factors, reflecting the broader material and contextual constraints imposed by socioeconomic disadvantage rather than individual lifestyle choices.

9.1.2 Childsmile Behaviour Change Interventions Impacts and Pathways Findings (Research Question 4 – Chapter 6)

The evaluation of the Childsmile programme provided insight into both the limitations and potential of early-life behaviour change interventions. The universal dental practice components produced only modest improvements in toothbrushing behaviours and minimal effects on dietary practices. The targeted Dental Health Support Worker (DHSW) intervention showed no measurable effect on either toothbrushing or diet.

Dental attendance is socially patterned with children in more deprived areas are less likely to attend primary care dental services. The DHSW intervention is targeted by area-based deprivation, and as expected, there was a difference in reach by deprivation, reflecting this targeting. However, once children had been seen or had attended dental practice, there was no pattern in intervention given by deprivation. There was also no impact difference across deprivation levels.

These findings highlight the role of constrained agency: families' ability to implement largely behaviour change interventions is limited by structural socioeconomic barriers, such as costs/affordability, food access, and broader social stressors (Watt, 2012). While Childsmile has been shown to contribute to population-level improvements in child oral health (Conway *et al.*, 2024), it cannot fully offset the influence of entrenched socioeconomic disadvantage which has grown in Scotland over recent decades due to austerity (Ross *et al.*, 2023; Scottish Government, 2025a).

Pathway analyses confirmed that behavioural interventions mediated some risk, but a substantial residual effect of socioeconomic conditions remained, reinforcing the importance of upstream structural determinants. It should also be noted that these findings reflect early implementation stages; there is limited evidence on fidelity to Programme Theory, suggesting that interventions may require further embedding to achieve their full potential.

9.1.3 Early Life Socioeconomic Circumstances and Caries Experience (Research Questions 5 and 6 - Chapter 7 and 8)

Socioeconomic circumstances were confirmed as the dominant determinant of children's caries experience, consistent with extensive prior evidence linking disadvantage to poor oral health outcomes (Schwendicke *et al.*, 2015; Peres *et al.*, 2019b). Across multiple measures—including household income, parental education and employment, and area-based deprivation—children exposed to disadvantage consistently exhibited higher caries risk. Longitudinal analyses further highlighted the cumulative nature of these effects: each additional year of exposure to income poverty or high area deprivation incrementally increased caries risk. Notably, even a single year of income poverty during the first five years of life substantially elevated caries risk, reinforcing the sensitivity of early childhood to socioeconomic disadvantage. Conversely, improvements in area-level deprivation or upward socioeconomic mobility were associated with reduced caries risk, demonstrating that positive changes in social circumstances can meaningfully alter oral health trajectories.

In Scotland, childhood socioeconomic disadvantage remains both widespread and persistent. Up to 2024, approximately 23 % of children lived in relative poverty (20% absolute poverty) after housing costs, equivalent to around 240,000 children annually, a rate lower than the UK average of 31%. This relative advantage is largely attributable to lower housing costs and the impact of Scottish social policies (Birt *et al.*, 2025). Although child poverty declined substantially from the 1990s to around 2010, it has remained broadly stable over the past decade. The introduction of the Scottish Child Payment has yielded only modest reductions, consistent with antecedent trends observed in the Growing Up in Scotland cohort studies.

Childhood disadvantage in Scotland is multidimensional, extending beyond low income alone. Approximately 10 % of children experience both low income and material deprivation, while 22 % reside in households with marginal to very low food security (Scottish Government, 2024c). Certain groups are at elevated risk, comprising nearly half of all disadvantaged children. These include larger families, households with a disabled member, younger children, minority ethnic households, and children of younger mothers, indicating that disadvantage is

concentrated among specific populations and perpetuates inequalities across generations (Scottish Government, 2024c).

Disadvantage is further amplified by area-level deprivation, reflecting substantial geographic clustering. Around 22 % of primary school children live in areas classified within the most deprived 20 % according to the Scottish Index of Multiple Deprivation (SIMD), with rates exceeding 25 % in Glasgow and North Lanarkshire (Scottish Government, 2024a; Scottish Government, 2024c). These figures highlight the intersection of economic, social, and geographic factors in shaping childhood disadvantage, demonstrating that despite policy interventions, socioeconomic inequalities remain entrenched, persisting well above Scottish Government targets.

Behavioural and parenting factors partially mediated these associations, but substantial inequalities persisted even after accounting for these pathways. This pattern is consistent with life course and fundamental causes perspectives (Kuh *et al.*, 2003; Marmot and Wilkinson, 2005), which emphasise that material and social resources exert enduring influence on health outcomes through multiple, interacting mechanisms. Parenting styles offered modest protection, yet the broader socioeconomic context remained the primary driver of observed inequalities—a finding that may also reflect limitations in the parenting measures captured in this analysis.

9.2 Comparison with Previous Literature

This section situates the findings of the thesis within the broader international literature. This shows oral health is particularly well suited to a life course approach, as most oral diseases are chronic, cumulative, and develop over extended periods in response to sustained behavioural, social, and environmental exposures (Crall and Forrest, 2018). Key determinants of childhood dental caries—including socioeconomic circumstances, diet and nutrition, access to fluoride, and engagement with dental care—are established early in life and often track throughout childhood (Peres *et al.*, 2009; Peres *et al.*, 2019a; Peres *et al.*, 2019b).

Birth cohort studies provide a critical framework for understanding how early-life conditions shape oral health trajectories and inequalities, allowing investigation of cumulative exposure, mediation pathways, and interactions between general and oral health across development. Notably, longitudinal cohorts such as the Dunedin Multidisciplinary Health and Development Study offer population-representative data with repeated clinical dental assessments, demonstrating how early-life determinants influence oral health from childhood into adulthood (Hong *et al.*, 2020).

Mirroring the structure of the findings chapter, this review first examines evidence on early-life behaviours, then evaluates intervention effectiveness, and finally explores the role of socioeconomic circumstances in shaping childhood oral health. Policy-relevant implications from previous research are integrated throughout.

9.2.1 Early-Life Behaviours and Social Context Literature (Research Questions 2 and 3 - Chapter 5)

The associations between early-life behaviours and childhood dental caries observed in this thesis align closely with robust international evidence (Selwitz, Ismail and Pitts, 2007; Moynihan and Kelly, 2014; Kirthiga *et al.*, 2019). Dietary sugar intake consistently emerges as the strongest behavioural predictor of caries, with multiple systematic reviews and WHO guidance emphasising the importance of limiting free sugars in early childhood (Moynihan and Kelly, 2014; Sheiham and James, 2015; World Health Organization, 2017; Echeverria *et al.*, 2025). There is also copious systematic evidence illustrating fluoride exposure through regular toothbrushing is effective in preventing caries (Santos, Oliveira and Nadanovsky, 2013; Wright *et al.*, 2014; Al-Sharani *et al.*, 2025) and mitigates the effect of sugar consumption (Burt and Pai, 2001). In contrast, evidence for dental attendance is more limited, with smaller and less consistent associations compared with dietary and fluoride-related behaviours (Mohd Khairuddin *et al.*, 2024).

Across high-income settings, these behaviours are consistently socially patterned, with children from more disadvantaged backgrounds experiencing higher sugar intake, lower toothbrushing frequency, and reduced dental

attendance (Peres *et al.*, 2007; Thomson, 2012; Watt, 2012; Senavirathna *et al.*, 2025). This supports the interpretation of early-life behaviours as socially structured exposures rather than individual-level choices, consistent with theoretical frameworks emphasising the role of material and social conditions in shaping health risks (Link and Phelan, 1995; Ben-Shlomo and Kuh, 2002).

Longitudinal cohort evidence strengthens these associations by demonstrating how early-life exposures accumulate over time. The Australian SMILE cohort recruited over 2,100 mother–infant dyads from birth from Adelaide's three major public hospitals between July 2013 and August 2014. They followed the child from infancy through age 2 showing that socioeconomic disadvantage was associated with earlier exposure to free sugars and less frequent toothbrushing by age 2, alongside higher likelihood of exceeding recommended free sugar intake thresholds by 6 months (Do *et al.*, 2020). Its strengths include its large sample, intergenerational design, and detailed behavioural and dietary measurement, although attrition was higher in lower socioeconomic groups and early oral microbial data were not available. In contrast to SMILE, which primarily described early-life behavioural patterning, this thesis extends the evidence by quantifying the relative contribution of socioeconomic versus family-level factors to behavioural associations, demonstrating that socioeconomic circumstances account for most of the observed attenuation and situating these patterns within a policy context through comparison of pre- and post-Childsmile cohorts.

Evidence from the Pelotas 1993 birth cohort in Brazil followed 359 children from birth to age 12, with dental examinations and interviews at ages 6 and 12 assessing caries experience (DMFT), oral health behaviours, nutritional status, and socioeconomic factors. This similarly demonstrated that early-life indicators of disadvantage, including growth deficits and early caries experience, are associated with later childhood caries (Peres *et al.*, 2009). Although longitudinal, its smaller sample size and observational design limit causal inference. The Dunedin Multidisciplinary Health and Development Study further extends this evidence base by following a population-representative birth cohort of 1,037 New Zealand based children born in 1972-1973 over the life course with over 70 peer-reviewed articles, showing that early socioeconomic disadvantage is associated with persistent and socially patterned oral health outcomes into

adulthood (Hong *et al.*, 2020). Together, these cohorts demonstrate continuity of risk at the start of the life course but are less able to disentangle specific behavioural pathways or quantify the relative contribution of structural versus behavioural determinants in detail. However, both these studies may not fully reflect current conditions due to their age.

In contrast, this thesis provides a more detailed decomposition of early-life behavioural and structural influences on caries risk. By separating dietary, toothbrushing, and dental attendance behaviours and quantifying their attenuation across sequential adjustment models, it demonstrates that socioeconomic circumstances are the primary drivers of observed associations, with comparatively smaller contributions from family-level factors. In addition, the comparison of pre- and post-Childsmile cohorts provides evidence on the persistence of behavioural inequalities within a preventive policy context.

Collectively, these findings and the wider longitudinal literature indicate that early-life behaviours are socially patterned, accumulate over time, and reflect underlying structural disadvantage. However, important gaps remain in quantifying cumulative exposure pathways and formally distinguishing behavioural mediation from structural effects. The Growing Up in Scotland (GUS) study addresses several of these limitations by combining repeated behavioural and socioeconomic measures which in this study have been linked to clinically verified dental outcomes in a large, nationally representative cohort, enabling more robust assessment of how early-life behaviours contribute to oral health inequalities and how these are shaped by broader social conditions.

9.2.2 Childsmile Behaviour Change Interventions Impacts and Pathways Literature (Research Question 4 - Chapter 6)

The wider evaluation literature on early-life oral health interventions broadly aligns with findings from this thesis, showing that behaviour change interventions typically produce modest improvements in oral health behaviours and small reductions in caries. However, such interventions often disproportionately benefit families with greater socioeconomic resources (Watt, 2012) and may unintentionally widen inequalities (Schou and Wight, 1994). A systematic review of studies up to December 2020 found that whole-population

approaches were more consistently effective in reducing socioeconomic inequalities in childhood caries, whereas targeted or individual-level interventions showed smaller or inconsistent effects, although heterogeneity in study design and intervention intensity limited comparability (Shen, Bernabé and Sabbah, 2021).

Similar conclusions were reached in an earlier Cochrane systematic review of 38 community-based oral health promotion studies involving almost 120,000 children (de Silva *et al.*, 2016). The review found little evidence that oral health education alone produced meaningful reductions in caries, whereas interventions combining education with supervised toothbrushing using fluoridated toothpaste or professional preventive oral care demonstrated modest but more consistent improvements in caries outcomes. The authors concluded that multi-component, community-based interventions were more effective than educational approaches delivered in isolation, although the overall certainty of evidence ranged from moderate to very low and few studies reported impacts on equity, sustainability, or cost-effectiveness (de Silva *et al.*, 2016). These findings reinforce the view that interventions operating beyond individual behaviour change are more likely to achieve population-level improvements in child oral health.

Within Childsmile and wider, universal and structural components such as supervised nursery and school toothbrushing and the widespread provision of fluoride toothpaste demonstrate greater population reach and more equitable effects than behaviour change components alone (Macpherson, Rodgers and Conway, 2019a; Peres *et al.*, 2019b). Collectively, these findings support the conclusion that reducing inequalities requires interventions that address structural determinants rather than relying solely on individual behaviour change.

This is consistent with the principle of proportionate universalism, whereby universal interventions are delivered with intensity scaled to need (Marmot *et al.*, 2010; World Health Organization, 2010). While Childsmile reflects this approach in its design, persistent inequalities suggest that implementation is constrained, particularly in relation to the reach and effectiveness of behaviour change components. It remains difficult to disentangle whether these limited

impacts reflect shortcomings in intervention efficacy, differential uptake across socioeconomic groups, or the persistence of upstream determinants such as poverty, food insecurity, and wider material disadvantage.

The Dunedin Study demonstrates that socioeconomic inequalities in oral health persist into adulthood even within a context of universal, state-funded dental care in New Zealand (Hong *et al.*, 2020). However, as a longitudinal observational cohort, its findings remain associational and cannot isolate the extent to which inequalities are driven by service-level factors versus earlier life social and behavioural trajectories. Key risk factors, including high sugar consumption, suboptimal oral hygiene practices, and early caries experience, were already established prior to sustained engagement with dental services, suggesting that observed inequalities likely reflect cumulative life-course exposure rather than limitations of clinical care per se. Despite numerous high-quality studies being completed on the cohort, given that the cohort was established in the early 1970s, findings may not fully reflect contemporary preventive dentistry systems or current patterns of service delivery, limiting direct transferability to present-day policy contexts.

By linking early-life behavioural data with Dental Health Support Worker (DHSW) involvement and primary dental care contacts, this study enables partial empirical examination of the pathways through which targeted preventive support operates within Childsmile. This allows assessment of whether early interventions modify associations between early-life behaviours and later oral health outcomes, while also separating intervention reach from any detectable behavioural impact.

DHSW interventions showed strongly patterned reach, with 19.5% of children referred by age 3 and 21.1% by age 5 and marked socioeconomic gradients in exposure (31.9% in the most deprived SIMD fifth compared with 9.9% in the least deprived). Once children were referred, nearly all were successfully contacted and received broadly similar levels of dietary and toothbrushing behaviour change interventions across deprivation groups, indicating equity in delivery conditional on access. However, there was no consistent evidence that DHSW-delivered interventions were associated with improved dietary or toothbrushing behaviours, with small and imprecise estimates likely reflecting confounding by

indication, limited statistical power in higher exposure categories, and targeting of higher-risk families rather than causal intervention effects.

A different pattern was observed for primary dental care interventions, where reach was substantially higher due to very high attendance rates (81.1% by age 3 and 93.1% by age 5). Despite this, a slight inverse care gradient persisted in attendance (75.0% versus 85.5% at age 3), meaning children in more deprived areas remained less likely to be exposed to preventive behaviour change interventions overall. Among those attending, approximately 56% received toothbrushing intervention and 72% received dietary intervention, with little variation by deprivation, suggesting delivery within services was relatively uniform but conditional on prior access. As with DHSW delivery, associations between intervention exposure and behaviours were weak and inconsistent, with only limited evidence of behavioural improvement at higher levels of exposure.

Overall, these findings indicate that Childsmile's effectiveness could be driven more by differential reach than by measurable behavioural change within intervention components. The lack of clear exposure–response gradients suggests that structural inequalities in access and uptake outweigh variation in intervention delivery, and that behavioural trajectories may already be largely established before contact with preventive services. This limits the extent to which these components alone can modify inequalities.

More broadly, the GUS cohorts function as a quasi-natural experiment by linking repeated behavioural and socioeconomic measures with intervention exposure across multiple delivery settings. This allows a more nuanced assessment of how inequalities are generated and maintained, distinguishing between differential access to preventive care and differential responsiveness once reached. In doing so, it provides a level of granularity not previously achieved in Childsmile evaluation studies, particularly in separating reach, uptake, and behavioural impact within a single longitudinal framework.

9.2.3 Early Life Socioeconomic Circumstances and Caries Experience Literature (Research Questions 5 and 6 - Chapter 7 and 8)

A substantial body of research demonstrates strong and persistent associations between socioeconomic circumstances (SEC) and oral health outcomes across the life course (Locker, 2000; Watt, 2007; Schwendicke *et al.*, 2015; de Aquino Goulart *et al.*, 2025). Socioeconomic disadvantage is consistently associated with higher prevalence and severity of childhood dental caries, contributing to pronounced inequalities in both oral health behaviours and disease outcomes (Moynihan and Kelly, 2014; Peres *et al.*, 2019a; Jevdjevic and Listl, 2025). These inequalities have been documented across multiple indicators of socioeconomic position (Galobardes, Lynch and Smith, 2007; Foley and Akers, 2019). For example, population-based studies have reported higher caries prevalence among children living in lower-income households (McCabe *et al.*, 2024), while lower parental education and parental occupation have been linked to poorer oral health behaviours and increased disease risk (Kato *et al.*, 2017; Lam *et al.*, 2022; Yousaf *et al.*, 2022). However, much of this evidence derives from cross-sectional analyses, which limit the ability to examine how socioeconomic circumstances evolve over time and influence oral health trajectories.

Parenting behaviours, including supervision of toothbrushing, dietary control, and parental oral health knowledge, have been identified as key proximal determinants of children's oral health. Hooley *et al.* (2012) conducted a systematic review of 55 studies, reporting that 85% found consistent associations between parenting and childhood caries risk, although only 10 of the total studies examined parental attitudes. The review also highlighted considerable heterogeneity in study designs and measures of parenting, most of which were cross-sectional, limiting causal inference. More recent systematic reviews entrenched in Baumrind's (1966) parenting styles continue to show mixed results. The first study found consistent associations across ten studies (Pristina, Arief and Armini, 2023), whereas the later study reported significant associations in only five of nine studies (Moya-López *et al.*, 2024), primarily linking authoritative parenting to lower caries risk and permissive parenting to higher risk. These inconsistencies likely reflect differences in sample characteristics, operational measures of parenting, and analytical approaches, emphasising the

need for careful interpretation of findings. Despite this variability, evidence suggests that dimensions of Baumrind's parenting styles—relatively stable traits during early childhood—can shape adherence to oral hygiene and dietary routines, making parenting a critical proximal influence on oral health behaviours. Even with mixed findings, this substantial body of work highlights a clear rationale for exploring these relationships further using improved longitudinal designs and more robust measures, offering the potential for a deeper understanding of how parenting mediates socioeconomic influences on children's oral health.

Parenting also represents a pathway through which socioeconomic disadvantage may affect children's oral health. Disadvantaged parents often face constraints in time, knowledge, and resources, which may hinder the establishment of consistent routines and limit the reinforcement of healthy behaviours (Fisher-Owens *et al.*, 2007). Interventions targeting parenting, such as some of those delivered through the Childsmile programme, provide practical evidence of behaviour change strategies that aim to improve oral hygiene supervision, dietary practices, and adherence to recommended routines; targeting modifying proximal behaviours to reduce oral health risk (Ross *et al.*, 2023). Nevertheless, the extent to which parenting mediates socioeconomic effects appears limited. Structural equation modelling conducted in this thesis suggests that parenting behaviours explain only a small proportion of the relationship between SECs and childhood caries, highlighting that broader structural and contextual factors play a dominant role in shaping observed inequalities.

Empirical studies support the notion that socioeconomic inequalities in oral health arise through multiple mechanisms beyond individual behaviours, including material resources, psychosocial stress, and environmental exposures (Link and Phelan, 1995; Watt, 2007). Registry-based repeated cross-sectional studies in 2010 and 2019 in Sweden, consistently found that behavioural and family-level factors could not fully explain socioeconomic gradients in caries across 7,697 (94% of the population) 6-year-old children (Blomma *et al.*, 2024).

Estimates of behavioural mediation vary across studies, largely due to differences in design and analytical approach. The Australian National Child Oral Health Survey (n = 24,664) is one of the most robust cross-sectional

decomposition studies, using multilevel regression and Blinder–Oaxaca/Neumark decomposition (Peres *et al.*, 2019a). It reported that modifiable factors explained substantial proportions of area-level inequalities in dental caries, including dental visiting (30.3% primary; 12.7% permanent), sugar consumption (20.7%; 22.1%), water fluoridation (15.9%; 33.6%), parental education (14.2%), and household income (20.0% in primary dentition). However, despite its methodological strength in decomposition, the cross-sectional design limits interpretation to compositional differences at a single time point and cannot capture cumulative exposure, reverse causation, or behavioural change over time.

Similarly, Zhou *et al.* (2026), analysing 9,866 children from the UK Children's Dental Health Survey, reported partial mediation of socioeconomic circumstances (SEC) association with oral health outcomes through behaviours, with dental attendance explaining 16% of the SEC and decayed, missing, fillings teeth association at age 12, sugary drink intake 8%, and toothbrushing 5%, increasing to 34% for toothbrushing and self-reported oral health at age 15. However, these estimates are based on cross-sectional mediation assumptions and self-reported behaviours, likely underestimating cumulative effects while inflating short-term associations.

In contrast, the present study uses longitudinal cohort data and structural equation modelling to explicitly model temporal ordering and decompose direct and indirect pathways over time. Total mediation of socioeconomic circumstances decreased from 58.8% in BC1 to 39.1% in BC2, with cariogenic diet contributing 44.6% and 31.7%, toothbrushing 9.5% and 4.0%, parenting pathways 4.8% and 3.5%; and found dental attendance not to be a mediator consistently. These findings demonstrate that even with longitudinal modelling of behaviours and parenting, a substantial proportion of socioeconomic inequality remains unexplained, suggesting that cross-sectional decomposition approaches such as Peres *et al.* (2019a) may overestimate the extent to which modifiable behaviours account for inequalities by relying on contemporaneous exposure–outcome structures rather than longitudinal processes.

Longitudinal evidence demonstrates the persistent influence of SECs on oral health outcomes over the life course (Ben-Shlomo and Kuh, 2002). Sustained

exposure to disadvantage is associated with higher caries risk, and early-life socioeconomic disadvantage predicts oral health outcomes decades later (Poulton *et al.*, 2002; Peres *et al.*, 2019b). The trajectory analyses (Chapter 7) conducted in this thesis provide further insight by showing that children who moved out of highly deprived areas experienced reduced caries risk, whereas upward movement out of household poverty did not confer the same benefit. This difference may reflect the broader environmental and infrastructural changes required to improve neighbourhood deprivation compared with relatively small increases in household income, highlighting the importance of contextual influences beyond the household. These findings underscore the value of analysing multiple longitudinal socioeconomic trajectories rather than relying on single time-point measures, as patterns of sustained deprivation and upward mobility appear to be important determinants of caries risk.

One possible explanation for these differences relates to the thresholds required to move out of each form of disadvantage. Escaping poverty may require only a relatively small increase in income to cross the poverty threshold, whereas movement out of highly deprived areas generally requires more substantial changes, such as relocation or broader improvements in neighbourhood socioeconomic conditions. Consequently, changes in area-level deprivation may represent more meaningful shifts in environmental conditions, including access to services, community resources and neighbourhood infrastructure that influence oral health. This may also be true of change in occupation or education level. Although, this should be interpreted cautiously when unadjusted for individual measures, as area-based measures can work as a proxy for individual circumstances when unadjusted for individual measures.

Comparable patterns have been observed in wider health outcomes; for example, a longitudinal Finnish cohort study of 697 participants followed from age 11 to 43 found that a latent measure of education, occupation, and income predicted cardiovascular outcomes, indicating that early-life disadvantage has persistent effects into adulthood (Savelieva *et al.*, 2017). Similarly, analyses of the Growing Up in Scotland (GUS) Birth Cohort 1 have examined poverty trajectories from age 4 to 12 in relation to mental health, reporting a comparable lack of protective effect among children who were upwardly mobile out of poverty (Treanor and Troncoso, 2022), suggesting that this absence of

benefit stems from the lingering negative impacts of early-life financial instability. Together, these findings suggest that while improvements in neighbourhood conditions and broader socioeconomic circumstances may mitigate some health risks, upward mobility out of poverty alone is often insufficient to fully offset the effects of early disadvantage across childhood, adolescence, and adulthood.

Taken together, the literature demonstrates that SECs are strongly associated with childhood oral health outcomes, that parenting behaviours contribute but mediate only a small proportion of this relationship, and that broader structural and contextual factors remain critical drivers of inequalities. While previous research has highlighted these associations, limitations—including cross-sectional designs, heterogeneous measures of parenting, and limited modelling of mediated pathways—have constrained causal interpretation and mechanistic understanding. By integrating longitudinal data, robust parenting measures, and structural equation modelling, this thesis extends the literature by quantifying the mediated and direct pathways through which SECs influence childhood caries, providing a nuanced understanding of both individual and structural determinants of oral health inequalities.

9.2.4 Global Oral Health Related Birth Cohort Studies

Birth cohort studies offer a valuable framework for investigating early-life determinants of children's oral health by following participants from birth through early childhood and, in some cases, into adolescence and adulthood. Established across a variety of countries, these cohorts reflect growing recognition of the long-term influence of early exposures on oral health trajectories (Peres *et al.*, 2020; Berat *et al.*, 2025). Through repeated assessments using clinical dental examinations, standardised indices, self-reported questionnaires, and sometimes biological samples, these studies have examined a range of outcomes, including early childhood caries, enamel defects, tooth eruption patterns, malocclusion, and dental trauma. Some cohorts have even incorporated interventions, such as breastfeeding promotion or caries-prevention programs, while maintaining longitudinal follow-up (Peres *et al.*, 2022).

Despite the breadth of these efforts, significant variability exists in study design, population characteristics, and outcome measurement, limiting comparability and synthesis across cohorts. Many studies focus primarily on early childhood, and few systematically explore the broader psychosocial, behavioural, or environmental factors that may promote oral health or buffer against disease (Berat *et al.*, 2025). Moreover, parental influences appear underexamined despite their known role in shaping children's oral health trajectories. These gaps highlight the need for harmonised methodology, more comprehensive data collection, and consistent follow-up periods to fully understand the developmental origins of oral health disparities and to identify actionable targets for early intervention (Peres *et al.*, 2022; Berat *et al.*, 2025).

Overall, the body of oral health birth cohorts has yielded critical insights into the epidemiology of early-life oral health outcomes, but it also underscores the need for more integrated, multidisciplinary approaches that consider both biological and psychosocial determinants. Strengthening these studies—through improved methodology, attention to underrepresented populations, and a focus on promotive as well as risk factors—will be essential for guiding policy and practice aimed at fostering oral health from the earliest stages of life (Peres *et al.*, 2020).

9.2.5 Positioning Thesis Findings within the United Kingdom Cohort Landscape and Implications for Future Research

The United Kingdom has its own longstanding tradition of longitudinal birth cohort studies that track individuals from early life into later development, providing a foundation for understanding health trajectories and social inequalities. Early examples include the 1946 National Survey of Health and Development and the 1958 National Child Development Study, with more recent cohorts focus specifically on contemporary child health and development (Wadsworth *et al.*, 2006). Specifically in Scotland there is Growing Up in Scotland (GUS), which began in 2005, recorded repeated behavioural measures and is utilised in this thesis with near-complete linkage to the National Dental Inspection Programme (NDIP), which has enabled analysis of early-life oral health outcomes in relation to both socioeconomic circumstances and oral health behaviours.

Other UK birth cohorts offer complementary opportunities for exploring early-life determinants of oral health. For example, Born in Bradford (BiB) follows over 12,400 families in a multi-ethnic, urban population, with extensive socio-demographic, household, and environmental data. Diet information in the main BiB cohort is collected firstly at 6 years old, meaning early-life dietary behaviours for most participants are captured relatively late. Routine oral health behaviour measures are not systematically collected across the full cohort, so most dental data come from linked routine records (e.g., dental attendance) or smaller subsample studies. The nested BiB1000 sub-study recruited a subset of families and collected repeated early-life measures of feeding practices, dietary patterns, socioeconomic status, and other behavioural exposures at 6, 12, 18, 24, and 36 months. This enables more detailed analyses of modifiable determinants of health. Studies using the BiB1000 data linked to the Oral Health Survey of 5-Year-Olds (OHS5) — a national, biennial survey conducted in England under the National Dental Epidemiology Programme (NDEP) using a standardised inspection protocol — demonstrated associations between early-life risk factors and clinical caries experience; through the lens of school readiness (Giles *et al.*, 2024) as well as common risk factors with obesity (Uerlich *et al.*, 2021). However, OHS5 data cover only a small subset (approximately 10% school going 5-year-olds in England), which when analysed with BiB 1000 subsample led to notably smaller sample sizes that lack generalisability.

The newer BiBBS cohort (Born in Bradford's Better Start study) which includes 4600 families with children born 2016-2024 is a more interventional and detailed cohort, currently in early stages, which will collect formal oral health questionnaires and dental examinations in early life. This promises to fill gaps in behavioural and clinical dental measures not captured in the main cohort. Meanwhile, the final BiB data set BiB4All functions as a "light-touch" linkage cohort across the wider BiB population, focusing on routine administrative and health data without detailed early-life behavioural or interventional measures.

Across all these BiB datasets, the study population benefits from highly granular area- and neighbourhood-level measures, including deprivation indices and environmental exposures such as air quality, green space, and food environment, providing rich opportunities to explore contextual determinants of oral health that are not fully captured in cohorts like GUS.

Other UK cohorts contribute additional but distinct strengths. ALSPAC (Avon Longitudinal Study of Parents and Children), recruiting children born April 1991–December 1992, provides extensive repeated measures of diet (including a 10% subsample with detailed food diaries – 'Children in Focus (CIF)'), family routines, and psychosocial factors, supporting detailed life course analyses. Oral health assessments in the CIF focus sample were conducted at 31, 43, and 61 months of age, with dentists performing visual examinations to detect cavitated carious lesions and existing restorations at 31 and 43 months, and trained health examiners conducting the assessments at 61 months. This would allow ALSPAC to be used for analysis similar to that carried out in this thesis but only in a subsample of children. Parent/carer proxy reporting accuracy of caries has been also been analysed finding low to moderate correlation with clinical outcome (Akinkugbe *et al.*, 2020); however it should be noted these cohorts are now dated.

MCS (Millennium Cohort Study), following children born in 2000–2001 and extended across the UK, similarly offers repeated data on family environment, diet, health behaviours, and socioeconomic circumstances. Both cohorts excel in behavioural and psychosocial data quality but lack comprehensive, systematic dental inspection measures due to the later introduction of OHS5, limiting direct investigation of clinically validated oral health outcomes.

Emerging cohorts present further opportunities. C-GULL in Liverpool, a multi-generational longitudinal study with repeated psychosocial and health measures, may serve as a replication cohort or allow subgroup analyses not possible in national designs. Generation New Era, announced in September 2025 and recruiting ≈ 30,000 children born from 2026, will provide the first UK-wide birth cohort in over 25 years, with planned early-life assessments at 9–11 months and 3–4 years and potential longer-term follow-up. Together, these studies offer scope to further enrich UK public health research on early-life exposures.

Taken together, these cohorts illustrate both the opportunities and constraints of UK birth cohort research for understanding oral health inequalities. GUS uniquely integrates repeated behavioural measures, socioeconomic circumstances, with opportunity to link to nationally representative caries outcomes, providing a novel framework for investigating cumulative exposures.

BiB and BiB1000 offer detailed early-life behavioural and environmental measures in an ethnically diverse population, though with limited clinical dental coverage in the main cohort; BiBBS promises to fill these gaps in the near future, while BiB4All extends routine data coverage without new behavioural measures. ALSPAC and MCS contribute extensive psychosocial and lifestyle data but are less suited to population-level oral health outcomes. This underscores the potential to extend similar analyses to this thesis in other cohorts, exploring contextual and structural determinants of oral health inequalities and providing a platform for future comparative and longitudinal research.

To this research's knowledge, analyses integrating repeated oral health behaviours, cumulative exposure to socioeconomic disadvantage, and nationally representative clinical outcomes in this way have not been undertaken elsewhere, highlighting the novel contribution of the work presented in this thesis.

9.3 Thesis Limitations

While this thesis provides novel insights into early-life determinants of childhood dental caries and the impact of the Childsmile programme on caries prevalence and early oral health behaviours, several limitations should be considered when interpreting the findings.

9.3.1 Data and Measurement Limitations

A key strength of this thesis is the linkage of cohort and administrative datasets, which provides a rich source of information from a birth cohort study. However, these datasets also introduce certain constraints. Parent- or carer-reported measures of child oral health behaviours, child factors, family factors and health outcomes are subject to recall and social desirability biases (Cullinan and Cawley, 2017; Folayan *et al.*, 2020a). As demonstrated in the comparison of parental proxy reports and clinically assessed caries outcomes (Section 4.6), parental reports tend to underestimate caries prevalence, particularly among children from less deprived backgrounds, highlighting the potential for misclassification of other self-reported variables.

Limitations in data availability also constrained the measurement of some complex constructs. For example, parenting styles were operationalised using simplified single-variable for composite measures derived from the available GUS items (Section 7.6). While these measures captured key dimensions relevant to oral health behaviours, they may not fully reflect the multidimensional and dynamic nature of parenting. The availability of more comprehensive or theoretically aligned parenting measures could have improved the precision of pathway analyses and strengthened the assessment of mediation effects. As a result, the contribution of parenting and related family processes to socioeconomic inequalities in caries experience may be misestimated in the present analyses.

Dietary behaviours were also difficult to capture comprehensively within the available dataset. Measures of sugar consumption and snacking behaviours relied on relatively limited parent-reported indicators, which are susceptible to both recall and social desirability bias. Parents and carers may have had difficulty accurately recalling the frequency and timing of children's food and drink consumption, particularly for snacks consumed outside the home or in informal settings. In addition, socially undesirable behaviours, such as frequent consumption of sugary snacks or drinks, may have been under-reported. The available measures also did not capture broader dietary patterns, portion sizes, frequency and timing of free sugar intake, food insecurity, or changes in diet over time. Given the central role of diet in caries development, these limitations may have resulted in residual confounding or underestimation of behavioural pathways linking socioeconomic disadvantage and oral health outcomes.

The lack of high-quality community-level variables within the GUS dataset also limited analysis of this domain of the Fisher-Owens model. Important contextual factors such as neighbourhood food environments, access to affordable healthy food, density of fast-food outlets, availability of fluoridated products, access to NHS dental services, neighbourhood social cohesion, and local area deprivation trajectories were not available in sufficient detail for inclusion in multivariable analyses. Where possible, community-level factors were explored in univariable analyses (Section 5.6.2), but the absence of detailed data constrained inclusion in more nuanced modelling.

As with all longitudinal cohort studies, the GUS survey experiences sample attrition across successive sweeps. Attrition was socially patterned, with higher levels of area deprivation, younger maternal age, employment instability, and non-homeownership associated with non-response (Bradshaw *et al.*, 2011). This pattern is consistent with evidence from other longitudinal studies showing that individuals from more socio-economically disadvantaged backgrounds are significantly more likely to drop out of panel surveys over time (Watson and Wooden, 2009; Schmidt and Woll, 2017). Such attrition may have attenuated observed socio-economic inequalities in caries prevalence and behaviours, as the most disadvantaged children were under-represented in later sweeps. Although survey weights were applied to mitigate bias, residual non-response remains possible. Retention strategies can reduce but not fully eliminate differential attrition (Mostafa and Wiggins, 2015).

A further limitation relates to the historical context of the Growing Up in Scotland (GUS) cohort. The children included in this thesis were born in the mid-2000s, and much of the data collection pre-dated the decade of austerity policies introduced following the 2008 financial crisis (Scottish Government, 2011). Since then, wider social, economic and policy environments relevant to child oral health in Scotland have changed substantially, including increases in child poverty and food insecurity, changes to welfare provision, cost-of-living pressures, and evolving public health and dental service contexts. In particular, the post-2010 austerity period has been associated with widening child health inequalities and increased material hardship among families across the UK. Consequently, the magnitude and patterning of socioeconomic inequalities observed in this thesis may differ for more recent child populations. Nevertheless, the cohort remains highly valuable for examining developmental, behavioural and family pathways underlying oral health inequalities, many of which are likely to persist despite changing social conditions.

9.3.2 Analytical Approach Limitations

The observational, longitudinal design precludes definitive causal inference. Although exposures were measured before outcome assessment and temporal ordering was maintained, residual confounding from unmeasured family, community, or structural factors, such as parental health literacy and

neighbourhood characteristics, cannot be entirely excluded. Furthermore, the primary outcome measure, dental caries experience at age 5 years, was derived from NDIP data. As dental caries is a cumulative disease process that develops throughout early childhood, the outcome reflects the accumulated effects of exposures over several years rather than disease occurring at a specific point in time. Consequently, while the temporal sequence of the analyses is consistent with the hypothesised causal pathways underpinning Childsmile, it is not possible to determine precisely when caries developed or to attribute observed effects to exposures within a specific temporal window. Therefore, the findings should be interpreted as evidence of associations that are consistent with, but do not establish, causal relationships.

Structural equation and mediation models assume correctly specified pathways and no unmeasured confounding; violations of these assumptions may introduce spurious associations or collider bias, particularly when conditioning on mediators such as child oral health behaviours (Cole *et al.*, 2009). Careful specification of measurement windows aimed to minimise immortal time bias, particularly for longitudinal exposures such as parenting behaviours and programme participation, though residual risk is likely minimal (Lévesque *et al.*, 2010).

Sample attrition, although partially addressed through the application of survey weights (detailed in Section 3.11.2), may further influence representativeness, particularly for disadvantaged families, potentially underestimating inequalities in indirect pathways. In the Growing Up in Scotland (GUS) study, weights are constructed to account for both the original sampling design and longitudinal non-response across successive sweeps. This involves adjusting for differential probabilities of selection at baseline and then incorporating models of attrition over time using observed socio-demographic predictors of continued participation (e.g. area deprivation, maternal age, household composition, and socio-economic status). The resulting longitudinal weights are applied so that analyses better reflect the characteristics of the original target population at each wave. However, because these weights are based on observed variables, they cannot fully adjust for unmeasured differences between respondents and non-respondents, and some residual attrition bias is likely to remain (Mostafa and Wiggins, 2015).

Analytical constraints within the Safe Haven environment, including restrictions on available software and R packages, limited the exploration of alternative model specifications and more advanced longitudinal modelling approaches. In particular, methods such as group-based trajectory modelling implemented in Stata (e.g., the Traj plugin), latent class mixed models (e.g., lcmm in R), or structural equation modelling approaches in Mplus were not readily accessible within the secure environment used for this analysis. These approaches offer different strengths and assumptions compared with the methods employed in this thesis, including greater flexibility in modelling within-class variability, alternative estimation frameworks, and more extensive diagnostic and model comparison options. However, each also introduces additional complexity and, in some cases, greater sensitivity to model specification and convergence issues. As a result, the present analyses were undertaken using the most feasible and robust methods available within the constraints of the Safe Haven setting, with an emphasis on interpretability, computational stability, and reproducibility.

9.3.3 Intervention Measurement Limitations

The evaluation of the Childsmile programme is limited by the granularity of exposure data in the administrative data recording systems. These programme records capture intervention components and intensity, but variation in implementation fidelity across primary care dental practices or dental health support workers was not fully measured, which may have led to underestimation of the programme's true impact on behaviour change and caries outcomes (Conway *et al.*, 2025). Time constraints within routine dental appointments may further limit opportunities for comprehensively delivering prevention interventions, including behaviour-change support and follow-up. In addition, prevention may compete with the immediate demands of clinical treatment, potentially reducing the emphasis placed on the former

Similarly, although Dental Health Support Workers (DHSWs) receive structured training to support families and promote preventive behaviours, differences in experience, communication skills, and workload may influence how consistently interventions are delivered. In addition, implementation and utilisation approaches vary across local authorities. In some instances, service delivery has shifted from face-to-face contacts to telephone-based support since the COVID-

19 pandemic, which may reduce opportunities for direct demonstration of oral health practices or for building rapport with families. Engagement may also differ among families experiencing socioeconomic disadvantage or other barriers that make sustained participation more challenging. Furthermore, as DHSWs do not provide clinical care, the success of their interventions often depends on effective referral pathways and subsequent community linking.

9.3.4 External Validity and Generalisability

Findings are primarily generalisable to the Scottish population and mostly to similar high-income settings with structured oral health programmes; however, Scotland does have a unique national and world leading child oral health improvement programme context. While broader patterns of socio-economic disadvantage and behaviour-mediated oral health inequalities are consistent across countries, the magnitude of these associations varies according to social, economic and healthcare contexts (Schwendicke *et al.*, 2015). The paucity of birth cohorts in low- and middle-income countries further limits extrapolation (Lawlor, Andersen and Batty, 2009).

9.3.5 Summary

Overall, these limitations highlight the importance of cautious interpretation of effect sizes and the recognition that structural, contextual, and measurement factors influence observed associations. Despite these constraints, the robust longitudinal design, linkage of high-quality clinical and survey data, and multi-dimensional assessment of socioeconomic circumstances provide confidence that the findings reflect meaningful patterns relevant to policy, practice, and future research. These strengths will be explained further in the next section.

9.4 Thesis Strengths

This thesis possesses several key strengths that support the validity, relevance, and policy significance of its findings.

9.4.1 Clinically Validated Outcome

A key strength of this thesis is the use of clinician-assessed dental caries outcomes from the National Dental Inspection Programme (NDIP). The NDIP provides standardised, population-level assessments conducted by trained dental professionals, ensuring consistent and objective measurement of caries prevalence and severity across children. Its systematic, national coverage reduces bias associated with epidemiological outcome measurement.

9.4.2 Robust Longitudinal Data Linkage

A principal strength of this thesis lies in the linkage of multiple high-quality, longitudinal datasets, which overcomes common limitations in oral health research. By combining survey data from the Growing Up in Scotland (GUS) birth cohort, which follows children from early life into childhood, with clinician-assessed caries outcomes from the National Dental Inspection Programme (NDIP), Childsmile programme exposure records and NHS primary care records this study enables robust investigation of temporal relationships between early-life exposures, mediators, and outcomes. Longitudinal cohort designs like GUS are particularly valuable because they allow tracking of developmental trajectories and socio-economic influences over time alongside detailed individual level socioeconomic, and behavioural data, supporting analyses of causal plausibility and life course pathways.

There has long been a need for more longitudinal evidence in early childhood oral health research (Harris *et al.*, 2004; Issrani *et al.*, 2025). The GUS cohort's repeated measures across multiple sweeps, combined with population-level coverage, enable analysis of both pre- and early post-Childsmile cohorts, capturing changes in behaviours and outcomes across time. The cohort's representative sampling and rich socio-demographic data reduce selection bias and strengthen the generalisability of findings within Scotland and similar high-income contexts.

9.4.3 Multi-Dimensional Assessment of Socioeconomic Circumstances

The thesis incorporates a comprehensive set of socioeconomic indicators, including household income, parental education and employment, and area-level deprivation. This multi-dimensional combination of multiple measures enables a more nuanced characterisation of socioeconomic circumstances than reliance on a single indicator alone (Galobardes, Lynch and Smith, 2007). By capturing both household-level resources and the wider social and environmental contexts in which families reside, this approach acknowledges the complex and layered nature of socioeconomic position, which is particularly relevant for oral health research where behaviours and outcomes are shaped by influences operating across both individual and area-based levels (Bradford *et al.*, 2023). Overall, the inclusion of multiple socioeconomic measures strengthens the analytical framework and enhances the robustness and interpretability of the findings.

9.4.4 Advanced Analytical Approaches

The use of advanced statistical methods, including structural equation modelling, confirmatory factor analysis, and mediation analysis, enables the testing of complex causal pathways (Kline, 2023). These approaches allow examination of how early-life behaviours and parenting practices mediate the relationship between socioeconomic circumstances and caries outcomes. By formally quantifying mediation, the thesis moves beyond descriptive associations to explore mechanisms underpinning observed inequalities. In addition, latent constructs derived through these methods permit complex, multidimensional processes to be represented as single variables, reducing measurement error and facilitating parsimonious modelling of otherwise unobservable phenomena.

The application of latent class growth analysis enables the identification of distinct developmental trajectories in caries experience over time (Jung and Wickrama, 2008). This person-centred approach moves beyond average population trends to uncover unobserved subgroups that follow heterogeneous patterns of disease progression. By classifying children into trajectory classes, the analysis allows examination of how early-life behaviours, parenting practices, and socioeconomic circumstances predict membership in high-risk or

low-risk pathways. In doing so, the thesis elucidates how inequalities in oral health emerge and persist across childhood, providing insight into dynamic processes underlying divergent caries trajectories rather than static outcomes.

9.4.5 Real-World Policy Relevance

Another key strength is the integration of programme evaluation with population-based data. Linking cohort survey information with Childsmile exposure records enables assessment of the reach, effectiveness, and equity impact of both universal and targeted interventions in real-world settings. This combination of observational and intervention data enhances the translational value of the findings, providing actionable evidence for policy and practice.

9.4.6 Comprehensive Life Course Perspective

Oral health is a highly relevant area to apply the life course approach as most oral diseases and conditions are chronic; hence, they need time to develop and are relatively prevalent (Crall and Forrest, 2018). The use of longitudinal birth cohorts is pivotal for most effective life course analyses in health (Cooper *et al.*, 2012).

This thesis captures both the accumulation of disadvantage and the timing of socioeconomic exposures during early childhood (Ben-Shlomo and Kuh, 2002; Kuh *et al.*, 2003). This long-term developmental approach enables a more comprehensive understanding of how socioeconomic circumstances influence oral health outcomes over time, as well as the potential for mitigation through changes in social conditions at different stages of development (Kuh *et al.*, 2003). By situating oral health within broader child development and public health frameworks, the analysis aligns with contemporary approaches that conceptualise oral health as an integral component of overall health across the life course (Peres *et al.*, 2019b).

The use of multidimensional and longitudinal measures allows nuanced examination of both cross-sectional and temporal processes, including the timing, duration, and persistence of socioeconomic disadvantage (Ben-Shlomo and Kuh, 2002). Consideration of cumulative exposure and socioeconomic mobility trajectories provides novel insights into the mechanisms through which

early-life disadvantage shapes caries risk across the life course (Peres *et al.*, 2011).

9.4.7 Summary

Collectively, these strengths—the use of linked longitudinal birth cohort data, multi-dimensional socioeconomic measures, advanced analytical techniques, real-world intervention evaluation, and a life course perspective—enhance the robustness, relevance, and generalisability of the findings. They provide confidence that the patterns identified are meaningful and can inform both national policy and international oral health research.

Another key strength of this thesis is the integration of programme evaluation with population-based data. Linking cohort survey information from GUS with clinician-assessed outcomes and Childsmile exposure records enables assessment of the reach, effectiveness, and equity impact of both universal and targeted interventions in real-world settings. The Medical Research Council (MRC) and related policy frameworks emphasise the importance of using and sharing linked data to maximise research value and societal benefit, especially in population and patient cohorts (Skivington *et al.*, 2021). MRC-supported strategies also encourage cohort studies to capitalise on the availability of health and administrative records to enhance longitudinal analyses (Craig *et al.*, 2012). Combining observational and intervention data aligns with methodological best practice in data linkage research and enhances the translational value of findings by enabling larger, more representative analyses that inform policy and practice.

9.5 Conclusions and Recommendations

This section summarises and synthesises key findings from previous literature combined with findings from this thesis before laying out suggestions and next steps for policy, practice and research.

9.5.1 Summary of Key Findings

This thesis demonstrates that socioeconomic circumstances are the fundamental determinant of childhood dental caries in Scotland. Household income, parental

education and employment, and area-level deprivation were consistently associated with oral health outcomes across analyses. Longitudinal findings showed clear cumulative effects of socioeconomic disadvantage, whereby prolonged exposure to poverty and deprived environments increased caries risk, while improvements in socioeconomic circumstances reduced it. Although behavioural and parenting factors partially mediated these associations, substantial socioeconomic gradients remained after adjustment, indicating that structural disadvantage exerts an independent and persistent influence on child oral health (Link and Phelan, 1995; Sanders, Spencer and Slade, 2006; Schwendicke *et al.*, 2015; Peres *et al.*, 2019a).

Within this broader socioeconomic context, early-life oral health behaviours also contributed to caries risk. Dietary behaviours emerged as the strongest behavioural predictor, with frequent consumption of sugary foods and drinks significantly increasing the likelihood of caries. Toothbrushing frequency and regular primary care dental attendance during the first five years of life were likewise associated with oral health outcomes, although their effects were smaller. Importantly, these behaviours were themselves strongly socially patterned, reflecting the influence of socioeconomic circumstances rather than wholly individual choice or agency (Peres *et al.*, 2019a).

The evaluation of the Childsmile programme demonstrated modest improvements in toothbrushing frequency and limited effects on cariogenic dietary behaviours. Critically, there was no clear evidence that these interventions substantially differed across socioeconomic strata. These findings suggest that interventions focused primarily on behaviour change are insufficient to overcome the influence of entrenched social and economic disadvantage, whether because of limitations in reach, differential uptake, or constrained intervention effectiveness. The limited impact observed is consistent with systematic review evidence indicating that educational and individual-level interventions generally produce modest effects and are less effective at reducing inequalities than broader population-level approaches (de Silva *et al.*, 2016; Shen, Bernabé and Sabbah, 2021).

Parenting interventions can play a role in shaping children's oral health by encouraging supportive behaviours and fostering healthy hygiene habits (Moya-

López *et al.*, 2024). However, their impact on socioeconomic inequalities in dental caries is limited, as families' capacity to engage with such interventions is strongly influenced by broader social, economic, and community contexts (Marmot *et al.*, 2010; World Health Organization, 2010). Evidence suggests that even with stronger targeting of high-risk families, standardised and rigorous implementation, or integration with other preventive strategies, parenting-focused programmes alone are unlikely to produce meaningful reductions in inequalities (Watt, 2007; Watt, 2023). Their effectiveness depends on concurrent structural interventions, such as policies reducing material deprivation, improving access to dental care, and strengthening community infrastructure. Consequently, while parenting programmes are a valuable component of oral health promotion, they should be framed as one element within a comprehensive, multi-level strategy, rather than as a standalone solution to inequalities.

9.5.2 Implications for Practice

The findings indicate that socioeconomic circumstances (SECs) remain the strongest and most consistent determinant of inequalities in child oral health, exceeding the independent contribution of reported oral health behaviours. Although behaviours were associated with caries experience, these behaviours were themselves socially patterned and therefore insufficient to explain the magnitude and persistence of inequalities. This suggests that behaviour-change approaches delivered in isolation are unlikely to substantially reduce socioeconomic gradients in oral health, even where they achieve improvements in individual practices. This interpretation is consistent with Fundamental Cause Theory, which proposes that socioeconomic position influences access to flexible resources that shape health outcomes across multiple risk pathways (Link and Phelan, 1995). It also aligns with wider evidence demonstrating that health inequalities arise through unequal social and economic conditions rather than individual behaviours alone (Marmot *et al.*, 2010). Within oral health specifically, social determinants frameworks have emphasised that downstream behavioural interventions are unlikely to eliminate inequalities without addressing the upstream conditions that generate differential exposure to risk (Watt, 2007; Watt and Sheiham, 2012).

A key implication is the need to reconsider how preventive activity is operationalised within early years systems, particularly within Dental Health Support Worker (DHSW) roles. Given the strong and persistent association between area-based deprivation and caries experience observed throughout this thesis, DHSWs are likely to have the greatest equity impact when functioning not only as providers of oral health advice but also as connectors across health visiting, early years education, and wider community support services. In areas of greater deprivation, oral health support may therefore be most effective when embedded within existing family-facing services rather than delivered as a discrete intervention. This interpretation is supported by evidence that interventions relying heavily on individual agency are generally less effective at reducing inequalities because the capacity to act on health advice is unequally distributed across socioeconomic groups (Adams *et al.*, 2016). Material and social constraints—including financial insecurity, competing priorities, time scarcity, chronic stress, and food insecurity—can limit families' ability to translate health knowledge into sustained behavioural change (Michie, van Stralen and West, 2011; Briazu *et al.*, 2024).

The findings also support the continued importance of universal, settings-based prevention in early childhood oral health. National Dental Inspection Programme (NDIP) surveillance demonstrates substantial reductions in childhood caries over time (Conway *et al.*, 2025). However, persistent socioeconomic gradients in caries experience indicate that improvements have not been distributed equitably across SECs. This reinforces a key public health principle: population-level improvements do not necessarily translate into reductions in health inequalities (Marmot *et al.*, 2010).

The findings further suggest that while routine primary care dental attendance may contribute to modest improvements in toothbrushing behaviours, preventive behaviour change interventions in primary care are unlikely alone to substantially influence dietary behaviours that are shaped by wider structural and socioeconomic conditions. This has implications for how prevention is conceptualised within NHS dental practice and policy, particularly as newer contractual and payment reforms seek to support a more prevention-focused model of care (Scottish Government, 2018). Although these reforms may facilitate greater emphasis on prevention, evolving administrative and reporting

systems will provide less detailed information regarding the specific content being reduced from over 700 items to 45 including specificity of delivery of preventive interventions being removed (Scottish Government, 2023). This could reduce the ability to evaluate which aspects of preventive primary dental care are most effective.

These findings should also be interpreted within the context of developments in both programme delivery and the wider socioeconomic environment since the period captured by the early Childsmile implementation data analysed in this thesis. Childsmile has evolved substantially since its initial implementation, becoming embedded within Scotland's wider oral health improvement infrastructure through sustained delivery across nursery, school, primary care and community settings (Macpherson, Rodgers and Conway, 2019a). Subsequent evaluations have highlighted continued programme development, workforce expansion, and adaptation of delivery approaches to support engagement with families experiencing disadvantage (Ross *et al.*, 2023). More recent policy and operational documentation further demonstrate ongoing investment in workforce capability and preventive delivery systems, including the introduction of structured behaviour-change support tools such as the STAR tool (Fletcher, 2024).

These developments underline the importance of ongoing process and outcome evaluation. Complex interventions delivered across multiple settings require continuous monitoring not only to assess effectiveness and implementation fidelity, but also to determine whether intended equity impacts are being achieved (Craig *et al.*, 2018). Importantly, improvements in overall outcomes and reductions in inequalities should not be assumed to occur simultaneously. Monitoring must therefore distinguish between changes in average oral health outcomes and changes in their distribution across socioeconomic groups. Without sustained evaluation of both implementation and equity outcomes, there is a risk that population-level improvements could obscure persistent or widening inequalities. Furthermore, any benefits arising from programme developments are likely to be subject to implementation lag, with delays between changes in delivery practice and observable effects within population-level surveillance data.

9.5.3 Policy Implications

As with practice, the pivotal finding of this thesis for policy was that socioeconomic circumstances emerged as a key determinant of childhood oral health, operating through multiple interrelated pathways. The findings of this thesis emphasise the central role of upstream social determinants in shaping childhood dental caries and the persistent inequalities observed in Scotland. While early-life behaviours and family characteristics influence oral health outcomes, these behaviours are embedded within broader structural conditions. As such, policies focused primarily on individual behaviour change are unlikely to substantially reduce inequalities (Sanders, Spencer and Slade, 2006).

The analysis of different dimensions of disadvantage demonstrates that neighbourhood, household, and parental measures each capture distinct mechanisms of exposure and opportunity. Upward mobility in area-based deprivation was associated with mitigated caries risk, whereas changes in household or parental socioeconomic position showed weaker and less consistent effects. This highlights the importance of policy approaches that address the multidimensional nature of disadvantage rather than relying on single indicators of deprivation.

Evidence indicates that area-based deprivation captures contextual effects beyond individual socioeconomic circumstances (de Aquino Goulart *et al.*, 2025). Neighbourhood and community contexts shape access to services, opportunities for social participation, and the environments in which families live. Improvements at the area level can enhance access to preventive services and strengthen community infrastructure, supporting families in adopting positive health behaviours (Kawachi and Berkman, 2003). Such mechanisms operate most effectively when delivered through contextually embedded community approaches that reflect local socioeconomic conditions and service landscapes, and when integrated with broader upstream strategies addressing poverty, education, employment, and living conditions (Watt and Sheiham, 1999; World Health Organization, 2010; Watt, 2012).

In this way, local, context-sensitive approaches may help translate structural improvements into improved health outcomes but cannot replace broader

structural action. Household-level poverty remained consistently associated with higher caries risk, highlighting the detrimental effect of low income on early childhood oral health. This underscores the importance of adequate family income as a structural determinant of health and supports income-based policy interventions aimed at reducing material deprivation. However, persistent stagnation in child poverty rates suggests that current policy measures remain insufficient relative to the scale of inequality (Birt *et al.*, 2025). The weaker associations observed in mobility analyses may reflect limitations in standard poverty thresholds in capturing income changes sufficient to influence health outcomes (Chapter 8).

Early-life oral health behaviours contribute to caries risk but operate within structural constraints. Behavioural interventions are therefore most effective when implemented alongside policies that reduce material hardship and improve access to services, reinforcing the need for coordinated multi-level public health action (Watt, 2007; World Health Organization, 2010).

Despite a strong evidence base supporting upstream action, policy translation into oral health has remained limited. A recent scoping review highlights a persistent lack of upstream interventions specifically designed to reduce oral health inequalities, with policy activity continuing to be dominated by downstream, individual-level and behavioural approaches (Stennett *et al.*, 2026). This reinforces longstanding concerns that oral health policy has not fully reflected the broader social determinants evidence base (Watt, 2007). The resulting gap between evidence and implementation suggests that inequalities are unlikely to narrow without a deliberate shift towards structural and population-level policy interventions.

This implementation gap may also reflect broader political determinants of oral health inequalities. Serban *et al.* (2025) argue that policymaking processes are shaped not only by scientific evidence but also by political ideologies, commercial interests, governance structures, and power dynamics. Their analysis identified barriers to upstream policy implementation including industry lobbying, ideological resistance to state intervention, misinformation strategies, and conflicts of interest, all of which may limit adoption of structural public health measures. Conversely, facilitators included cross-sector collaboration,

strong evidence translation, political support across parties, and ongoing policy evaluation. These findings suggest that persistent oral health inequalities are not solely the consequence of adverse social conditions, but also of political and institutional processes that determine which public health interventions become feasible, prioritised, and sustainable. Recognising these political determinants strengthens the argument that reducing oral health inequalities requires sustained cross-government commitment and political engagement, rather than reliance on behavioural interventions alone.

A key implication of these findings is the need to align oral health policy more explicitly with wider population health and child poverty reduction strategies, as articulated in Scotland's Population Health Framework (Scottish Government, 2025b). This framework places child poverty at the centre of prevention policy and reinforces the importance of addressing structural drivers of health inequalities rather than relying solely on downstream interventions. Addressing oral health inequalities requires systemic reform that moves beyond treatment-oriented models towards prevention-focused approaches integrated within wider public health policy (Watt *et al.*, 2019).

In addition to place-based approaches, there is also scope to strengthen upstream action through more comprehensive population-level sugar control policies. Existing fiscal interventions, such as the UK Soft Drinks Industry Levy, demonstrate the potential of taxation to reduce sugar consumption at population level have shown health benefits (Briggs *et al.*, 2017; Scarborough *et al.*, 2020). However, evidence suggests that further policy expansion could enhance impact. This may include extending fiscal approaches to other categories of high-sugar or ultra-processed foods, including potential "junk food" taxation mechanisms, as implemented in countries such as Colombia, where broader food taxation has formed part of a structural approach to diet-related disease prevention (Daniels, 2025).

Taken together, these policy directions reinforce the argument that meaningful reductions in child oral health inequalities are unlikely to be achieved through downstream behavioural interventions alone. Instead, progress requires coordinated upstream action across fiscal policy, food environment regulation,

child poverty reduction, and place-based investment, alongside targeted improvements in service integration.

The broader socioeconomic context has also changed considerably since the period examined in this study. Rising living costs, increasing food insecurity, and growing reliance on emergency food provision have altered the material conditions within which families make decisions about diet, routines, and engagement with preventive guidance (Scottish Government, 2024c; The Trussell Trust, 2026). Concurrently, recent child poverty reduction measures, including the Scottish Child Payment and the removal of the two-child limit, form part of a wider policy agenda intended to strengthen household financial security (Scottish Government, 2022; UK Government, 2026). Although the direct effects of such measures on oral health behaviours were beyond the scope of this thesis, they highlight the broader structural context within which preventive interventions operate and the extent to which behavioural responsiveness is shaped by changing socioeconomic conditions.

Finally, robust population-level surveillance remains essential for informing and evaluating policy. Clinical dental surveillance, when integrated with longitudinal and administrative datasets, enables monitoring of trends, assessment of intervention impact, and identification of emerging inequalities. Continued investment in surveillance infrastructure is therefore critical to ensuring that improvements in childhood oral health are both sustained and equitably distributed (Conway *et al.*, 2025).

9.5.4 Recommendations for Future Research

The findings of this thesis highlight several priorities for future research. Firstly, they exhibit the necessity to continue ongoing data linkage evaluation of Childsmile. There is a continued need to introduce further longitudinal data, birth cohort studies, quasi-experimental designs and use of synthetic data with more detailed information and extended follow-up to evaluate the long-term effects of early-life disadvantage and intervention exposure on dental caries, enabling stronger causal inference (Pearl, 2009; Hernán and Robins, 2010; Dao *et al.*, 2025). Future research should prioritise data sources that provide temporal information, allowing better disentangling of pathways linking

socioeconomic circumstances, parenting styles, behaviours, and oral health outcomes. Future work should continue to investigate constrained agency; particularly how structural barriers interact with parenting and community supports to mediate the effects of socioeconomic circumstances.

Analyses would ideally combine area-level measures, such as the Scottish Index of Multiple Deprivation (SIMD), which provide a practical, population-level proxy for disadvantage, with individual and household-level socioeconomic indicators to capture the full nuance of exposure (Bradford *et al.*, 2023; McCartney *et al.*, 2023). Where only area-level data are available, SIMD alone remains a robust metric for examining population-level patterns and targeting interventions efficiently (Bradford *et al.*, 2023). Comparative research across both other high-income contexts and low- and middle-income countries (LMICs) would help clarify how local policy frameworks, programme implementation, and broader social and economic conditions shape equity in childhood dental outcomes. Such studies could identify context-specific mechanisms, highlight strategies transferable across settings, and further inform interventions sensitive to structural, cultural, and economic determinants of oral health inequalities. Further research is also needed to examine the role of child poverty and other social determinants, including through policy testing, to understand how upstream measures may enhance the effectiveness of parenting and community programmes.

Later oral health behaviours will be key to further evaluating Childsmile interventions, as oral health behaviour questions in Growing Up in Scotland were asked at ages three and five, prior to the full implementation of toothbrushing and fluoride varnish programmes. Linking later birth cohorts will also be important, since this thesis has only examined the very early stages of Childsmile implementation, and the effects of complex, evolving interventions may take time to emerge especially as they are still evolving.

Further research is also needed to examine the role of child poverty and other social determinants, including through policy testing, to understand how upstream measures may enhance the effectiveness of parenting and community programmes. Ongoing development of the Childsmile evaluation data, including linkage of additional cohorts and administrative datasets, would strengthen the

capacity to analyse multi-level trajectories of disadvantage and oral health outcomes, providing a more comprehensive evidence base for designing interventions and targeting resources effectively.

Moreover, there is limited understanding of how parenting interventions interact synergistically with community and health system initiatives, highlighting a need for research that explicitly examines multi-level mechanisms and equity outcomes.

9.5.5 Final Remarks

This thesis demonstrates that childhood dental caries is shaped by complex interactions between early-life behaviours, family factors, and most notably by socioeconomic circumstances. While programmes such as Childsmile contribute to improvements in population oral health, their equity potential is maximised only when combined with broader structural strategies that address the root social and material determinants of health. Importantly, oral health inequalities also represent an underused but highly valuable marker of early-life physical health and wider social inequality. Dental caries is measurable, routinely collected at population scale, and reflects cumulative exposure to material, behavioural, and environmental disadvantage, making it a possible robust indicator of inequality in early childhood health. A holistic perspective, integrating mixed-method health, social, and economic policy, is essential to achieving sustained reductions in oral health (and wider health) inequalities and ensuring that all children have the opportunity to achieve optimal oral health outcomes.

10 References

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11 Appendix

11.1 A – Literature Searches

A comprehensive literature search was undertaken to identify relevant studies on childhood caries and its associated determinants. The search was designed around a common base strategy focused on children, dental caries, and epidemiological contexts, which was subsequently adapted to address the specific themes explored in each chapter—namely, dietary factors, socioeconomic conditions (SECs), and the structural equation modelling (SEM).

The initial and core search strategy was developed in Ovid Embase due to its extensive biomedical and international coverage, detailed indexing through Emtree terms, and flexibility in constructing complex search queries. This database served as the foundation for all subsequent searches, ensuring methodological consistency and facilitating efficient adaptation to other platforms. The Embase syntax was then translated and refined for other major databases, including Ovid MEDLINE, PubMed, Scopus, Web of Science, and the Cochrane Library, to maximise retrieval across disciplines and reduce publication bias.

Both controlled vocabulary (e.g., MeSH in MEDLINE/PubMed; Emtree in Embase) and free-text keywords were employed to capture the full scope of relevant literature. Core terms described the population (e.g., children, infants, preschoolers), disease or condition (e.g., dental caries, early childhood caries, oral health), and study type (e.g., epidemiology, prevalence, determinants). These were then combined using Boolean operators (AND/OR) and tailored with topic-specific terms in each sub-search to address the unique focus of each chapter—for instance:

Diet-related searches incorporated terms such as sugar intake, cariogenic diet, feeding practices, and dietary patterns.

Socioeconomic condition (SEC) searches included terms such as socioeconomic status, income, education, inequality, and health inequalities.

Structural equation model (SEM) searches focused on mediation analysis and causal pathway analysis, looking at modifiable factors such as parenting and health behaviours.

To ensure comprehensive coverage, the electronic database searches were supplemented by manual techniques, including reference list screening, forward citation tracking in Scopus and Web of Science, and grey literature searches using Google Scholar, OpenGrey, ProQuest Dissertations, WHO IRIS, CDC Stacks, and government or public health websites. These sources were used to identify relevant policy documents, reports, and unpublished or non-indexed studies.

No restrictions were applied regarding publication date or language, to minimise the risk of selection bias and to capture the full historical and global scope of evidence. The detailed search syntax and iterative adaptations for each thematic area are presented in Appendix A. The strategy was continuously refined throughout the thesis to align with the specific research questions addressed in each chapter while maintaining consistency in methodological principles.

11.1.1 Child - Tooth Demineralisation / Caries / Lesions

- exp Tooth demineralization/
- (teeth adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (tooth adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (dental adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (enamel adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (dentin adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- ('DMF Inde*' or 'dental plaque inde*').mp.
  [mp = title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word]
- Dental plaque/
- ((dental or tooth or teeth) adj4 plaque).mp.
- “early childhood caries”.mp.
- or/1-10
- exp child$/

- child$/
- infant/
- exp infant/
- Child, Preschool
- or/12-16
- 11 and 17
- diet, cariogenic/
- exp Drinking Behavio?r/
- exp Dietary Carbohydrates/
- exp Feeding Behavio?r/
- exp Avitaminosis/
- (diet$ or nutrition or (food adj habit$) or (feeding adj habit$)).mp.
- ((sugar adj intake) or (diet$ adj sugar) or (sugar$ adj food$) or (sugar adj beverage$) or (sugar adj drink$) or (carbonated adj beverage$) or (carbonated adj drink$) or (fizzy adj drink$) or (fizzy adj beverage$) or alcohol).mp.
- ((baby adj food$) or (babies adj food$) or (baby adj drink$) or (babies adj drink$)).mp.
- ((dinky adj feeder$) or ((baby or babies or infant$) and (comforter$ or soother$))).mp.
- Cariogenic Agents/
- exp Sucrose/
- (wean$ or sucrose).mp.
- ((supper adj drink$) or (supper adj bottle$) or (supper adj snack$) or (night$ adj drink$) or (night$ adj bottle$) or (night$ adj snack$) or (evening$ adj drink$) or (evening$ adj bottle$) or (evening$ adj snack$) or (bed$ adj drink$) or (bed$ adj bottle$) or (bed$ adj snack$) or (sleep$ adj drink$) or (sleep$ adj bottle$) or (sleep$ adj snack$)).mp.
- (avitaminosis or (vitamin adj deficien$) or (mineral adj deficien$)).mp.
- (diet$ or food$ or (fruit adj juice$) or sweet$ or confectionery or xylitol or sorbitol or (sugar adj4 free)).mp.
- or/19-33
- 11 and 17 and 34

11.1.2 Socioeconomic Circumstances

- exp Tooth demineralization/
- (teeth adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (tooth adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (dental adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (enamel adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (dentin adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- ('DMF Inde*' or 'dental plaque inde*').mp.
  [mp = title, book title, abstract, subject heading word, keyword heading word, supplementary concept fields]
- Dental plaque/
- ((dental or tooth or teeth) adj4 plaque).mp.

- “early childhood caries”.mp.
- or/1-10
- exp child$/
- child$/
- infant/
- exp infant/
- Child, Preschool/
- or/12-16
    - and 17
- exp Socioeconomic Factors/
- (socioeconomic adj3 (status or factor$ or determinan$ or indicator$)).mp.
- (income adj3 (level$ or bracket$ or inequalit$ or disparit$ or low or high)).mp.
- (education adj3 (level$ or attainment or achievement)).mp.
- (employment adj3 (status or occupation or work or job$ or unemployed or underemployed)).mp.
- (poverty or deprived or deprivation or neighborhood or inequality or social class).mp.
- (access adj3 (care or dental or healthcare or service$)).mp.
- or/19-25
- 11 and 17 and 26

11.1.3 Structural Equation Modelling, Parenting styles and Oral Health Behaviours

- (“causal pathway models” or “causal pathway analysis” or “causal modeling” or “causal modelling” or CPM).mp.
- (“structural equation modelling” or “structural equation modelling” or “SEM” or "mediation analysis" or “path analysis”).mp.
- (“causal pathway models” or “causal pathway analysis” or “causal modelling” or “causal modelling” or CPM).ti.
- (“structural equation modelling” or “structural equation modelling” or “SEM” or “mediation analysis” or “path analysis”).tw.
- exp Tooth demineralization/
- (teeth adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (tooth adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (dental adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (enamel adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- (dentin adj5 (cavit$ or caries or carious or decay$ or lesion$ or demineral$ or remineral$)).mp.
- ('DMF Inde*' or 'dental plaque inde*').mp.
- Dental plaque/
- ((dental or tooth or teeth) adj4 plaque).mp.
- (“early childhood caries” or ECC).mp.
- or/5-14

- exp child$/
- child$/
- infant/
- exp infant/
- Child, Preschool/
- or/16-20
- 15 and 21
- exp Socioeconomic Factors/
- (socioeconomic adj3 (status or factor$ or determinan$ or indicator$)).mp.
- (income adj3 (level$ or bracket$ or inequalit$ or disparit$ or low or high)).mp.
- (education adj3 (level$ or attainment or achievement)).mp.
- (employment adj3 (status or occupation or work or job$ or unemployed or underemployed)).mp.
- (poverty or deprived or deprivation or neighborhood or inequality or social class).mp.
- (access adj3 (care or dental or healthcare or service$)).mp.
- or/23-29
- exp Parenting/
- (parenting adj3 (style$ or practi$ or approach$ or strategy$)).mp.
- (caregiver adj3 (style$ or behaviour$ or practice$)).mp.
- (maternal adj3 (attitude$ or involvement or behaviour$)).mp.
- (paternal adj3 (attitude$ or involvement or behaviour$)).mp.
- (authoritative or authoritarian or permissive or neglectful).mp.
- or/31-36
- exp Oral Health Behavior/
- (toothbrushing or flossing or oral hygiene or dental care).mp.
- (diet$ or sugar intake or bottle feeding or snacking or juice or sugary beverage$).mp.
- (dental visit$ or preventive care or fluoride use).mp.
- or/38-41
- 22 and 30 and 42

11.2 B – Approval Letters, Ethics and Amendments

11.2.1 Public Benefit and Privacy Panel for Health and Social Care Approval Letter

Public Benefit and Privacy Panel for Health and Social Care
nss.PBPP@nhs.net
www.informationgovernance.scot.nhs.uk

NHS SCOTLAND

Mr Ahmed Mahmoud,
University of Glasgow Dental School,
378 Sauchiehall Street,
Glasgow,
G2 3JZ

Date: 16th November 2018
Your Ref:
Our Ref: 1516-0368 Mahmoud

Dear Mr Mahmoud,

Re Application: Application 1516-0368 Mahmoud - Evaluation of Childsmile Outcomes
Version: 4

Further to your approval issued by the Public Benefit and Privacy Panel for Health and Social Care on 2nd November 2015, I am writing to confirm that we accept the amendment(s) to the proposal notified on 15/11/2018.

The accepted amendments are:

1. Add a new PhD student to the application for access to the data.

2. Add additional variables in order to achieve our aims and objectives from the linkage project:

- episode start date,
- episode end date,
- placement type,
- episode end date,
- foster placement type,
- legal reason for each episode,
- placement type for each episode and care plan for each episode.

Please note that any conditions attached to your original approval remain in place and you should continue to comply with those conditions outlined in the approval letter. In addition, please provide the amended Information Sharing Agreement with Scottish Government/ Education Analytical Services Division.

This approval is given to process data as specified in the approved application form, and is limited to this.

Requests for access to NHS Scotland data as part of this approved application should be supported by evidencing a copy of your approval letter and application form to the relevant local board contacts/data providers.

I would take this opportunity to remind you of the declaration you have made in your application form committing you to undertakings in respect of information governance, confidentiality and data protection.

Yours sincerely,

Phil Dalgleish
Panel Manager
NHS Scotland Public Benefit and Privacy Panel for Health and Social Care
Email: nss.PBPP@nhs.net

11.2.1.1 Amendment Email

PH

Pauline Hunter<Pauline.Hunter2@phs.scot>

To: Andrea Sherriff

Cc: phs pbpp <phs.pbpp@phs.scot>

Dear Andrea,

Thank you for your amendment request. Please consider this email as acceptance of your minor change to:

- Add Researcher Kyle Cousins to Study.

The updated application form (v10.3) has also been sent on to the PBPP team to update their records. No further action is required.

Kind regards

Senior Information Development Manager / Research Coordinator /**Public Health Scotland**
eDRIS Electronic Data Research & Innovation Service
Nine Bioquarter
Little France Road
Edinburgh EH16 4UX

Email - pauline.hunter2@phs.scot
Email – phs.edris@phs.scot
Tel – 0131 275 6407
Mobile – (up and coming annual leave -)

Public Health Scotland
publichealthscotland.scot
@P_H_S_Official
@publichealthscotland

11.2.2 Statistics Public Benefit and Privacy Panel Update Approval Letter

National Records of Scotland | The Scottish Government

Dr Andrea Sherriff
University of Glasgow
378 Sauchiehall Street
G2 3JZ

Date: 3 February 2023
Your ref:
Our ref: 1516-0368

Dear Andrea,

Re: 1516-0368 : Amendment - Evaluation of Childsmile Outcomes

Thank you for your amendment application to the Statistics Public Benefit and Privacy Panel, for the following changes to your project:

- Addition of two new researches, Kyle Cousins, Mariel De Aquino Goulart
- Extend end date of project to November 2026

Your application has undergone proportionate governance review and has been given full approval.

This approval is given to process data as specified in the submitted application form and is limited to this.

Yours Sincerely,

Jaimie Taylor,
Panel Manager
Statistics Public Benefit and Privacy Panel

11.2.3 Ethics Approval Amendment Confirmation

From: Andrea Sherriff
Sent: 22 March 2021 09:59
To: Alastair Ross; David Conway
Subject: FW: Query re: amendment

From: MVLS Ethics Admin <mvls-ethics-admin@glasgow.ac.uk>
Sent: 19 March 2021 20:38
To: Andrea Sherriff <Andrea.Sherriff@glasgow.ac.uk>; MVLS Ethics Admin <mvls-ethics-admin@glasgow.ac.uk>
Subject: RE: Query re: amendment

Hi Andrea

Sorry for the delay with this. This amendment is fine to approve. I've sored a copy in our files for reference.

Regards
Neil

Neil Allan
MVLS Ethics Committee Administrator

Direct line: 0141 330 5206
email is the only reliable form of contact at this time

Institute of Infection, Immunity & Inflammation
College of Medical, Veterinary & Life Sciences
Glasgow Biomedical Research Centre
Room 314, Sir Graeme Davies Building
University of Glasgow
120 University Place
Glasgow G12 8TA
The University of Glasgow, charity number SC004401

11.3 C – National Safe Haven Documentation

11.3.1 National Safe Haven Disclosure Document

National Safe Haven: Requesting Outputs

This request form and checklist will help you develop your requests for outputs and prepare for disclosure control. Following this advice will help you anticipate some of the queries that might come back to you, meaning that your outputs could be released faster.

Processing Time: All outputs are checked by two members of eDRIS staff before being released. Please allow sufficient time to review and assess your output. We aim to turnaround a request within 3 full working days. However, this could vary dependent on the quantity, staff availability and complexity of tables, charts or other files in your request.
N.B. If your project includes data where the data controller has not delegated authority to eDRIS to carry out checks, for example NRS Census data, then statistical disclosure control checks and authorisation will also be carried out by the data controller so please factor this into your lead time.

Consider the following prior to requesting a file to be released from the National Safe Haven (see also the more detailed checklists on p. 3-4):

- Make sure your titles and descriptions are clear and self-explanatory
- Make sure your outputs do not contain embedded data which could be made available after release
- Check for small, potentially disclosive numbers
- Differencing from previously released outputs: Have you produced similar analysis before that combined with this output could be used to identify someone?
- Do you need it released? Do you want a draft output to be released so that you can discuss with your project team? You could consider reviewing it within the National Safe Haven alongside any members of your project team that are named in your governance documentation and have completed relevant Information Governance training.
- If you do need output released on a restricted basis for internal use, please be aware this will be for sharing within the research team only (named on your approvals and with relevant IG training) and is subject to any conditions notified to you by the eDRIS research co-ordinator.

On completion save in the Results folder and email your eDRIS researcher coordinator to request release of your files. Your output files that have been cleared for release will be sent to you by your eDRIS research coordinator either through email or secure file transfer.

Acknowledgements in publications:

The eDRIS team ask that you acknowledge the use of our service and the National Safe Haven in any publications/presentations where appropriate. An example of this is shown below:

"The authors would like to acknowledge the support of the eDRIS Team (Public Health Scotland) for their involvement in obtaining approvals, provisioning and linking data and the use of the secure analytical platform within the National Safe Haven."

National Safe Haven Output Request Form

eDRIS office use only

Date of eDRIS sign out	
Date and name of other data controller sign out where applicable	

Please complete all sections below

Study Number:	
Name:	
Date of request	

I have read the 'A guide for users requesting outputs from the National Safe Haven'	☒
I have completed the Disclosure Control Checklist (below)	☒
I confirm that the requested outputs fall within the scope of the project's aims and objectives	☒

Brief description of study cohort including dates and geographical coverage of data

Please complete the table below for each file to be released. *(Hover over titles for examples. Insert additional rows as required)*

File Name	**File Type**	**Which datasets is this output derived from?**	**Description of file contents**	**Is this an update to a previously released file? If so, please provide details of changes**	**Level of release** Unrestricted/restricted ***Restricted may only be shared with IG trained staff named on your approvals. Usually those in section 1 of PBPP form. Check with RC if unsure.***
					Unrestricted - can be published

Disclosure Control Checklist for National Safe Haven Outputs Requests

Complete the following checks: *(Please answer all questions)*

- **Any white** boxes ticked, your output will fail SDC. If you think your output should still pass, please discuss this with your research coordinator.
- **Any light grey** boxes ticked, your output may fail SDC. If your output fails, your research coordinator can also provide advice about how to re-design your outputs so they will pass.
- **All dark grey** boxes ticked, your output is likely to pass SDC, but it still needs to be checked.

Frequency tables/charts

	Yes	No
Are there any cells in the table with a value >0 and ≤5?	☐	☐
If there is any sensitive information or low-level geography, are there any cells in the table with a value >0 and ≤10?	☐	☐
Can any suppressed numbers be calculated based on remaining contents, either within or between tables?	☐	☐
Can this table be combined with any table in this or any previous, outputs to compute small counts?	☐	☐
Are there any columns or rows dominated by zeros or 100% of observations?	☐	☐
Are there any cells with suppressed values/hidden columns or rows?	☐	☐
Has the table used a different population base from previous similar tables?	☐	☐
Has the table used a different variable breakdown from a previous similar table?	☐	☐
Has the table used a different definition or source for a variable previously tabulated?	☐	☐
Are there any minima/maxima present?	☐	☐

Models

	Yes	No
Does the model have fewer than 10 residual degrees of freedom?	☐	☐
Does the model description quote or plot any individual values, such as minimum or maximum values or outliers?	☐	☐
Does the model description include a residual plot or residual values?	☐	☐
Has the model used a different population base from a previously described model?	☐	☐
Is the regression undertaken on a single unit?	☐	☐
Does the regression solely consist of categorical variables?	☐	☐

Coding files (syntax)

	Yes	No
Is the code clearly annotated with comments to assist the reviewer?	☐	☐
Are there any references or figures in the comments or code that could lead to potential identification of individuals?	☐	☐
Are there any pseudo anonymised ID numbers included in the code or the comments?	☐	☐
Has the volume of code needed been minimised?	☐	☐
Are there any counts from the data present in the comments or code?	☐	☐
File paths are not permitted to be released in code output. Have all file paths been redacted?	☐	☐

The research coordinator will compare your outputs to all outputs previously released from the same dataset to make sure it is not possible to identify any individuals or small cells by comparing outputs.

Because of this, it is a good idea to think carefully about the population base and variable breakdowns you will need to use later on, before you release your first outputs.

Example scenarios:

Changing variable breakdowns

- You release a table showing a variable against age and sex, in wide age bands (i.e. 16-39, 40-64, 65+). Later you decide to release some tables with different age bands (16-39, 40-59, 60+), to coincide with routine screening for a particular disease starting at age 60. The new tables can be compared against the old tables to produce a table of information about people in your sample aged 60-64. Your new tables will only pass SDC if they would pass for the 60-64 age group in their own right.

Excluding data points

- You release some tables of results based on your whole sample of linked records. You later discover that a particular medical condition interacts with the effect you are investigating, so you decide to exclude all individuals with this medical condition from your analysis. Your new tables could now be compared against the original tables you released, to reveal information about the people you excluded from your analysis. Your new tables will now only pass SDC if the equivalent table for the excluded group also passes in its own right. If the group you want to exclude is small, this will limit your chances of any tables passing SDC.

Adding data points

- You release some data on all individuals registered as blind or partially sighted, and later decide to widen the scope to all individuals with any visual impairment in order to have a larger sample size for your model. Your new outputs could be used to produce results about all people with visual impairments who are not registered as blind or partially sighted. These outputs will also need to pass an SDC check.

Changing definitions

- You release some results on all individuals in your sample who said they were retired at a certain date. You later change your definitions to include only people who both said they were retired and were over the state pension age at that date. Any new outputs will reveal some information about people who retired under the state pension age, and this will also need to pass an SDC check.

- You release some data on all individuals in your sample who said they were retired at a certain date. You later change your definitions to use HMRC records showing whether or not an individual received a state pension. This would not necessarily create a problem for SDC, as it is possible to be either retired with no state pension or receiving a state pension while not retired.

11.4 D – Supplementary material for results chapters

11.4.1 Chapter 5

11.4.1.1 Supplementary Material for Chapter 5

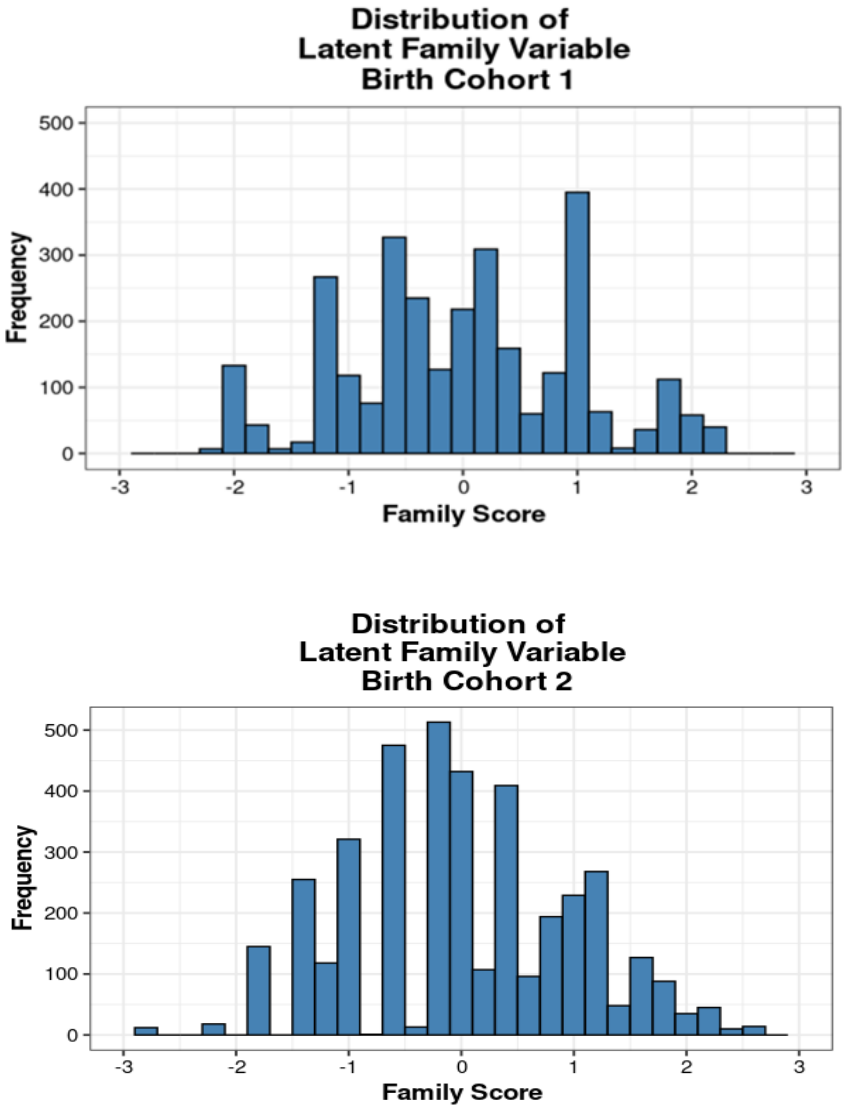
S5.1 – Family Factors Variable Description

Family Factors:

1. ***Household Size – Timing Age 10 months*** – A simple count of number of individuals living in the household of the child at the time of the GUS interview.

2. ***Home Chaos - Timing: Age 5 (BC1) and Age 1 (BC2):*** Uses an abbreviated version of the Confusion, Hubbub, and Order scale (Coldwell, Pike and Dunn, 2006). This scale assesses household disorganisation (Matheny *et al.*, 1995). Scores were grouped into thirds of the population as low, medium, or high.
3. ***Formal Services Used Scale – Timing: Age 10 months*** – Nine yes/no questions about different services available to parent/carers in the first ten months of a child's life; each yes is 1 and each no is 0. The scale defined in GUS literature uses the cine variables listed (Mabelis and Marryat, 2011): Any information/advice received from health professionals during pregnancy; Info sought from family doctor; Info sought from health visitor, Attended antenatal class; Advice on breastfeeding; Regularly attended parent and baby group; Ever attended parenting class; Had at least one accident requiring medical attention; and Used formal childcare.

11.4.1.2 Supplementary Figures for Chapter 5



Supplementary Figure 5.1 (SF5.1) – Distribution of latent family variables

11.4.1.3 Supplementary Tables for Chapter 5

Supplementary table 5.1 (ST5.1) - Larger tables are available in the online repository with QR code access



Note: The numbers presented in these tables may be slightly larger than those reported in the main chapter and some of the variables names may slightly differ. This is because these analyses were conducted as part of earlier exploratory work using a version of the cohort dataset that had undergone fewer data cleaning steps than the final analytical dataset used in the chapter. However, when cross-checked, the overall distributions and patterns were consistent with those reported in the main analyses.

Supplementary Table 5.2 (ST5.2) - Frequency table for all observed family and socioeconomic factors

Age (Birth Cohort 1/2)	Variable		Birth cohort 1 (%)	Birth cohort 2 (%)
	Family Factors			
1	Size of household	2	172/2893 (5.9)	360/4493 (8.0)
		3	1326/2893 (45.8)	1870/4493 (41.6)
		4	1050/2893 (36.3)	1627/4493 (36.2)
		5	456/2893 (15.8)	636/4493 (14.2)
		6+	169/2893 (5.8)	278/4493 (6.2)
		Missing	0	0
5/1	Home chaos	High	1007/2914 (34.6)	2076/4031 (51.5)
		Medium	1143/2914 (39.2)	1172/4031 (29.1)
		Low	764/2914 (26.2)	783/4031 (19.4)
		Missing	183	1
1	Formal services used	0	301/3127 (9.6)	472/4589 (10.3)
		1	664/3127 (21.2)	1026/4589 (22.4)
		2	788/3127 (25.2)	1258/4589 (27.4)
		3	745/3127 (23.8)	1013/4589 (22.1)
		4	448/3127 (14.3)	604/4589 (13.2)
		5+	181/3127 (5.8)	216/4589 (4.7)
		Missing	42	97
2/3	Household income poverty	Yes	823/2963 (27.8)	984/3511 (28.0)
		No	2140/2963 (72.2)	2527/3511 (72.0)
		Missing	149	
2/3	SIMD fifths	1 (Most deprived)	728/3087 (23.6)	948/4036 (23.5)
		2	565/3087 (18.3)	873/4036 (21.6)
		3	586/3087 (19.0)	818/4036 (20.3)
		4	630/3087 (20.4)	691/4036 (17.1)
		5 (Least deprived)	578/3087 (18.7)	706/4036 (17.5)
		Missing	30	0
2/3	Highest parental employment in household	Higher managerial	1613/3115 (51.8)	1914/4035 (47.4)
		Intermediate occupation	465/3115 (14.9)	568/4035 (14.1)
		Small employees / own account	183/3115 (5.9)	262/4035 (6.5)
		Lower supervisory / technical	268/3115 (8.6)	327/4035 (8.1)
		Semi-routine / routine	519/3115 (16.7)	848/4035 (21.0)
		Never worked / long-term unemployed	67/3115 (2.2)	116/4035 (2.9)
		Missing	0	4

Age (Birth Cohort 1/2)	Variable		Birth cohort 1 (%)	Birth cohort 2 (%)
2/3	Highest parental education in household	Degree / NVQ5	1115/3109 (35.9)	1577/4017 (39.3)
		HNC / HND / NVQ4	444/3109 (14.3)	550/4017 (13.7)
		A levels / Highers / NVQ3	633/3109 (20.4)	843/4017 (21.0)
		GCSE / NVQ2 or below	736/3109 (23.7)	852/4017 (21.2)
		No qualification / Other	181/3109 (5.8)	195/4017 (4.9)
		Missing	6	17

SIMD – Scottish Index of Multiple Deprivation

Supplementary table 5.3 (ST5.3) – Caries experience prevalence according to early life family and socioeconomic variables across birth cohorts (presenting only those variables that emerged from univariable analysis)

Age (Birth Cohort 1/2)	Variable		Birth cohort 1	Birth cohort 2
			Caries Experience, n/N (%)	Caries Experience, n/N (%)
	Family Factors			
1	Size of household	2	83/172 (48.3)	134/360 (37.2)
		3	313/1326 (23.6)	423/1870 (22.6)
		4	309/1050 (29.4)	430/1627 (26.4)
		5	167/456 (36.5)	204/636 (32)
		6+	84/169 (49.7)	142/278 (50.9)
		Missing	0	0
5/1	Home Chaos	High (10 – 20/9 – 15)	383/1007 (38.1)	502/2076 (24.2)
		Medium (8 – 9/7 – 8)	305/1143 (26.7)	301/1172 (25.7)
		Low (4 – 7/3 – 6)	200/764 (26.2)	297/783 (37.9)
		Missing	183	1
1	Formal Services Used (e.g. Childcare)	0	117/301 (38.9)	178/472 (37.6)
		1	264/664 (39.8)	341/1026 (33.2)
		2	249/788 (31.6)	386/1258 (30.7)
		3	174/745 (23.4)	243/1013 (24)
		4	106/448 (23.7)	109/604 (18)
		5 +	32/181 (17.8)	27/216 (12.5)
		Missing	42	97
	Socioeconomic Factors			
2/3	Household Income Poverty	Yes	385/823 (46.8)	399/984 (40.5)
		No	531/2140 (24.8)	526/2527 (20.8)
		Missing	149	493
2/3	SIMD fifths	1 (Most Deprived)	358/728 (49.2)	384/948 (40.5)
		2	195/565 (34.5)	262/873 (30)
		3	165/586 (28.1)	199/818 (24.3)
		4	142/630 (22.6)	145/691 (21)
		5 (Least Deprived)	102/578 (17.7)	112/706 (15.9)
		Missing	30	0
2/3	Highest Parental Employment in Household	Higher managerial	363/1613 (22.5)	335/1914 (17.5)
		Intermediate Occupation	127/465 (27.4)	149/568 (26.2)
		Small employees and own account workers	68/183 (36.9)	72/262 (27.5)
		Lower supervisory and technical occupations	108/268 (40.3)	115/327 (35.2)
		Semi routine and routine occupations	255/519 (49.1)	370/848 (43.6)

Age (Birth Cohort 1/2)	Variable		Birth cohort 1	Birth cohort 2
		Never worked/long-term unemployed	49/67 (73.3)	62/116 (53.4)
		Missing	0	4
2/3	Highest Parental Education in Household	Degree/ NVQ level 5 or equivalent	193/1115 (17.3)	251/1577 (15.9)
		HNC, HND, NVQ level 4 or equivalent	121/444 (27.2)	137/550 (24.9)
		A levels/Highers/NVQ level 3 or equivalent	225/633 (35.6)	251/843 (29.8)
		GCSE's/Standard Grades/NVQ level 2 or below	316/736 (42.9)	339/852 (39.8)
		No Qualification or Other	112/181 (61.9)	115/195 (59)
		Missing	6	17

SIMD – Scottish Index of Multiple Deprivation

Supplementary Table 5.4 (ST5.4) - Area under the curve scores with 95 confidence intervals of univariable adapted modified Poisson models against caries experience at age 5 adjusted for age at National Dental Inspection Programme exam and sex

	AUC [95 CI%]	
Variable	Cohort 1	Cohort 2
Oral Health Behaviours		
Diet		
How often child eats sweets?	0.611 [0.589, 0.632]	0.601 [0.582, 0.621]
How often child eats crisps?	0.599 [0.578, 0.621]	0.590 [0.569, 0.612]
How often child drinks sugar sweetened beverages?	0.581 [0.559, 0.603]	0.585 [0.564, 0.606]
Toothbrushing		
Frequency of toothbrushing (BC2: with fluoride toothpaste)	0.560 [0.538, 0.583]	0.551 [0.53, 0.572]
Dental Attendance		
Regular Dental Attendance (4 out of the first 5 years)	0.575 [0.553, 0.596]	0.575 [0.556, 0.593]
Family Factors		
Home Chaos	0.572 [0.549, 0.595]	0.558 [0.54, 0.577]
Household Size	0.601 [0.579, 0.623]	0.595 [0.576, 0.613]
Formal Services Used	0.606 [0.585, 0.628]	0.604 [0.586, 0.622]
Socioeconomic Circumstances		
Household Income Poverty	0.609 [0.586, 0.631]	0.605 [0.583, 0.628]
SIMD fifths	0.648 [0.627, 0.669]	0.623 [0.602, 0.643]
Highest Parental Employment in Household Status	0.629 [0.606, 0.651]	0.645 [0.625, 0.666]
Highest Parental Education in Household Level	0.664 [0.643, 0.685]	0.652 [0.632, 0.672]

SIMD – Scottish Index of Multiple Deprivation

Supplementary Table 5.5 (ST5.5) – Family and socioeconomic circumstances associations with caries experience at age 5, across birth cohort 1 and birth cohort 2, using adapted modified Poisson regression models

Model		Model 1 (univariable)	Model 2	Model 3	Model 4	Model 5 (fully adjusted)
Birth cohort 1						
Family factors (latent)	Risk Ratio (95% CI)	1.28 (1.21, 1.35)	N/A	1.18 (1.11, 1.25)	N/A	1.10 (1.04, 1.17)
	P-value	<0.001		<0.001		0.001
	AUC [95% CI]	0.60 [0.58, 0.63]		0.66 [0.64, 0.69]		0.70 [0.68, 0.73]
Socioeconomic circumstances (latent)	Risk Ratio (95% CI)	0.65 (0.62, 0.68)	N/A	N/A	0.71 (0.67, 0.75)	0.72 (0.68, 0.77)
	P-value	<0.001			<0.001	<0.001
	AUC [95% CI]	0.68 [0.65, 0.70]			0.70 [0.68, 0.72]	0.70 [0.68, 0.73]
Birth cohort 2						
Family factors (latent)	Risk Ratio (95% CI)	1.30 (1.22, 1.37)	N/A	1.21 (1.13, 1.29)	N/A	1.15 (1.07, 1.23)
	P-value	<0.001		<0.001		<0.001
	AUC [95% CI]	0.60 [0.58, 0.62]		0.66 [0.64, 0.68]		0.69 [0.67, 0.72]
Socioeconomic circumstances (latent)	Risk Ratio (95% CI)	0.65 (0.61, 0.69)	N/A	N/A	0.70 (0.65, 0.75)	0.72 (0.67, 0.77)
	P-value	<0.001		<0.001	<0.001	<0.001
	AUC [95% CI]	0.66 [0.64, 0.68]		0.66 [0.64, 0.68]	0.69 [0.67, 0.71]	0.694 [0.67, 0.72]

Model 1 – Univariable; Model 2 – All Oral Health Variables; Model 3 – All Oral Health Variables + Family; Model 4 – All Oral Health Variables + SEC; Model 5 – All; Diet – Sweets, Crisps and SSB; Regular dental attendance (Yes vs No) – attending in 4 out of the first 5 years; Family Factors – Home Chaos, Household Size, Formal Services Used; Socioeconomic circumstances – Income, Area-based, Education, Employment

11.4.2 Chapter 6

Supplementary Table 6.1 (ST6.1) - Characteristics of the Growing Up in Scotland birth cohort 2 (BC2) analytic sample

Characteristic		Age 5 (n/N) - Cariogenic Diet	Age 3 (n/N) - Toothbrushing
Sex	Male	2124/4123 (51.5)	2405/4646 (51.2)
	Female	1999/4123 (48.5)	2241/4646 (48.8)
SIMD	SIMD 1	988/4125 (24)	1101/4648 (23.7)
	SIMD 2	857/4125 (20.8)	987/4648 (21.2)
	SIMD 3	836/4125 (20.3)	939/4648 (20.2)
	SIMD 4	726/4125 (17.6)	812/4648 (17.5)
	SIMD 5	718/4125 (17.4)	809/4648 (17.4)
Referred to DHSW in first 5/3 years	Overall	866/4125 (21)	911/4648 (19.6)
	SIMD 1	341/988 (34.5)	352/1101 (31.9)
	SIMD 2	180/857 (21)	195/987 (19.8)
	SIMD 3	179/836 (21.4)	193/939 (20.6)
	SIMD 4	91/726 (12.5)	91/812 (11.2)
	SIMD 5	75/718 (10.4)	80/809 (9.9)
Children that got intervention from those referred to DHSW	Overall	652/866 (75.3)	753/911 (82.7)
	SIMD 1	260/341 (76.2)	292/352 (83)
	SIMD 2	146/180 (81.1)	172/195 (88.2)
	SIMD 3	126/179 (70.4)	153/193 (79.3)
	SIMD 4	64/91 (65.9)	75/91 (82.4)
	SIMD 5	56/75 (74.7)	61/80 (76.3)
Ever attended primary dental care in first 5/3 years	Overall	3839/4125 (93.1)	3764/4646 (81.0)
	SIMD 1	902/989 (91.2)	827/1103 (75)
	SIMD 2	784/856 (91.6)	770/985 (78.2)
	SIMD 3	780/837 (93.2)	788/939 (83.9)
	SIMD 4	688/724 (95)	688/811 (84.8)
	SIMD 5	685/719 (95.3)	691/808 (85.5)
Children that received intervention from those attended primary dental care setting	Overall	2781/3839 (72.4)	2086/3764 (55.4)
	SIMD 1	656/902 (72.7)	453/827 (54.8)
	SIMD 2	568/784 (72.4)	430/770 (55.8)
	SIMD 3	572/780 (73.3)	437/788 (55.5)
	SIMD 4	487/688 (70.8)	387/688 (56.3)
	SIMD 5	498/685 (72.7)	379/691 (54.8)
Mean Diet Score (SD)	Overall	0.04 (1.02)	
	SIMD 1	0.29 (1.05)	
	SIMD 2	0.13 (1.01)	
	SIMD 3	0.00 (1.07)	
	SIMD 4	-0.05 (0.94)	
	SIMD 5	-0.22 (0.92)	

Characteristic		Age 5 (n/N) - Cariogenic Diet	Age 3 (n/N) - Toothbrushing
Children brush their teeth more than once a day	Overall		3817/4637 (82.3)
	SIMD 1		891/1100 (81)
	SIMD 2		793/983 (80.7)
	SIMD 3		777/935 (83.1)
	SIMD 4		675/811 (83.2)
	SIMD 5		683/806 (84.7)

Numbers don't match exactly to sample because of survey weights; this the same reason SIMD breakdown doesn't exactly match total, as well as missing toothbrushing and diet variables.; SIMD – Scottish Index of Multiple Deprivation; DHSW – Dental Health Support Worker

Supplementary Table 6.2 (ST6.2) – Beta scores and adjusted beta scores for cariogenic diet scores at age 5 according to Childsmile behaviour change diet interventions using linear regression models; stratified by area-based deprivation

		Counts	Mean (sd)	Beta	P-value	r^2
Number of DHSW diet interventions in first 5 years						
SIMD 1	0	81	0.43 (1.00)	0 (ref)		81
	1+	260	0.40 (1.00)	-0.03 (-0.36, 0.31)	0.9	260
	Not Targeted	647	0.24 (1.08)	-0.19 (-0.50, 0.12)	0.2	647
SIMD 2	0	34	0.30 (0.98)	0 (ref)		<0.01
	1+	146	-0.03 (0.99)	-0.32 (-0.72, 0.08)	0.12	
	Not Targeted	677	0.16 (1.01)	-0.13 (-0.50, 0.23)	0.5	
SIMD 3	0	53	-0.15 (0.95)	0 (ref)		<0.01
	1+	126	0.07 (1.12)	0.22 (-0.12, 0.57)	0.2	
	Not Targeted	657	-0.00 (1.07)	0.15 (-0.12, 0.43)	0.3	
SIMD 4	0	27	-0.16 (0.81)	0 (ref)	27	<0.01
	1+	64	0.06 (0.92)	0.22 (-0.16, 0.60)	64	

		Counts	Mean (sd)	Beta	P-value	r^2
	Not Targeted	635	-0.06 (0.95)	0.11 (-0.21, 0.42)	635	
SIMD 5	0	19	0.03 (0.86)	0 (ref)		<0.01
	1+	56	-0.26 (0.92)	-0.29 (-0.75, 0.17)	0.2	
	Not Targeted	643	-0.23 (0.92)	-0.27 (-0.65, 0.12)	0.2	
Number of primary dental care diet interventions in first 5 years						
SIMD 1	0	333	0.30 (1.13)	0 (ref)		<0.01
	1	252	0.34 (0.97)	0.04 (-0.17, 0.25)	0.7	
	2	172	0.34 (0.97)	0.04 (-0.19, 0.28)	0.7	
	3	109	0.30 (1.01)	0.00 (-0.28, 0.29)	>0.9	
	4	64	0.32 (1.19)	0.02 (-0.35, 0.39)	>0.9	
	5 +	59	-0.08 (1.08)	-0.37 (-0.74, -0.01)	0.04	
SIMD 2	0	291	0.11 (1.07)	0 (ref)		<0.01

		Counts	Mean (sd)	Beta	P-value	r^2
	1	192	0.20 (0.98)	0.09 (-0.12, 0.30)	0.4	
	2	147	0.19 (1.00)	0.09 (-0.13, 0.32)	0.4	
	3	94	0.00 (0.87)	-0.11 (-0.35, 0.14)	0.4	
	4	73	0.36 (1.14)	0.25 (-0.05, 0.55)	0.1	
	5 +	62	-0.15 (0.74)	-0.27 (-0.51, -0.03)	0.03	
SIMD 3	0	265	-0.10 (1.19)	0 (ref)		<0.01
	1	169	0.06 (1.07)	0.16 (-0.07, 0.39)	0.2	
	2	132	0.03 (1.00)	0.13 (-0.10, 0.37)	0.3	
	3	120	0.00 (0.92)	0.11 (-0.12, 0.34)	0.3	
	4	65	0.17 (1.03)	0.28 (0.00, 0.56)	0.05	
	5 +	86	0.00 (1.05)	0.11 (-0.18, 0.39)	0.5	
SIMD 4	0	240	0.00 (1.05)	0 (ref)		<0.01
	1	143	-0.11 (0.84)	-0.11 (-0.31, 0.09)	0.3	

		Counts	Mean (sd)	Beta	P-value	r^2
	2	120	-0.11 (0.92)	-0.11 (-0.32, 0.1)	0.3	
	3	97	-0.12 (0.96)	-0.12 (-0.36, 0.11)	0.3	
	4	62	-0.07 (0.79)	-0.07 (-0.30, 0.14)	0.5	
	5 +	65	0.05 (0.92)	0.05 (-0.22, 0.31)	0.7	
SIMD 5	0	221	-0.21 (0.93)	0 (ref)		<0.01
	1	157	-0.26 (0.87)	-0.05 (-0.23, 0.12)	0.5	
	2	115	-0.18 (0.93)	0.03 (-0.17, 0.22)	0.8	
	3	83	-0.08 (1.02)	0.13 (-0.13, 0.39)	0.3	
	4	74	-0.24 (0.80)	-0.03 (-0.23, 0.17)	0.8	
	5 +	69	-0.44 (1.00)	-0.23 (-0.49, 0.02)	0.07	

DHSW – Dental Health Support Worker; SIMD – Scottish Index of Multiple Deprivation; All analyses were then run stratified by SIMD fifths. It should be noted that for this analysis DHSW interventions were reduced to 0,1+, Not Targeted due to small counts of 2+ in multiple SIMD fifths.

Supplementary Table 6.3 (ST6.3)- Risk ratios and adjusted risk ratios for toothbrushing frequency at age 3 according to Childsmile behaviour change toothbrushing interventions using adapted modified Poisson regression models; stratified by area-based deprivation

		1 or less	More than 1	aRR (95% CI)	P-value	AUC
Number of DHSW toothbrushing interventions in first 3 years						
SIMD 1	0	13 (21.7)	47 (78.3)	1 (ref)		0.50
	1+	59 (20.2)	233 (79.8)	1.01 (0.85, 1.19)	>0.9	
	Not Targeted	138 (18.4)	611 (81.6)	1.03 (0.88, 1.21)	0.7	
SIMD 2	0	4 (17.4)	19 (82.6)	1 (ref)		0.51
	1+	27 (15.7)	145 (84.3)	1.00 (0.83, 1.21)	>0.9	
	Not Targeted	161 (20.3)	631 (79.7)	0.95 (0.79, 1.14)	0.6	
SIMD 3	0	10 (25)	30 (75)	1 (ref)		0.52
	1+	22 (14.4)	131 (85.6)	1.13 (0.94, 1.36)	0.2	
	Not Targeted	129 (17.3)	617 (82.7)	1.09 (0.91, 1.30)	0.4	
SIMD 4	0	4 (25)	12 (75)	1 (ref)		0.50

		1 or less	More than 1	aRR (95% CI)	P-value	AUC
	1+	11 (14.7)	64 (85.3)	1.12 (0.82, 1.52)	0.5	
	Not Targeted	121 (16.8)	600 (83.2)	1.09 (0.81, 1.47)	0.6	
SIMD 5	0	2 (11.1)	16 (88.9)	1 (ref)		0.53
	1+	3 (4.8)	59 (95.2)	1.06 (0.90, 1.26)	0.5	
	Not Targeted	120 (16.5)	609 (83.5)	0.94 (0.80, 1.11)	0.5	
Number of primary dental care toothbrushing interventions in first 3 years						
SIMD 1	0	136 (20.9)	515 (79.1)	1 (ref)		0.53
	1	54 (19.6)	221 (80.4)	1.02 (0.94, 1.10)	0.7	
	2	13 (11.5)	100 (88.5)	1.12 (1.03, 1.23)	0.01	
	3+	8 (12.3)	57 (87.7)	1.12 (1.01, 1.24)	0.03	
SIMD 2	0	117 (21)	441 (79)	1 (ref)		0.54

		1 or less	More than 1	aRR (95% CI)	P-value	AUC
	1	41 (16.3)	210 (83.7)	1.06 (0.98, 1.14)	0.15	
	2	23 (19.5)	95 (80.5)	1.02 (0.92, 1.13)	0.7	
	3+	12 (19.7)	49 (80.3)	1.02 (0.88, 1.18)	0.8	
SIMD 3	0	100 (20)	401 (80)	1 (ref)		0.57
	1	33 (13.4)	213 (86.6)	1.08 (1.01, 1.16)	0.02	
	2	21 (15.8)	112 (84.2)	1.05 (0.96, 1.15)	0.3	
	3+	7 (12.1)	51 (87.9)	1.10 (0.99, 1.22)	0.08	
SIMD 4	0	81 (19)	345 (81)	1 (ref)		0.56
	1	41 (16)	215 (84)	1.04 (0.97, 1.11)	0.3	
	2	12 (14.1)	73 (85.9)	1.06 (0.97, 1.17)	0.2	
	3+	<5 (6.5)	43 (93.5)	1.16 (1.06, 1.27)	<0.01	
SIMD 5	0	77 (17.8)	355 (82.2)	1 (ref)		0.57

		1 or less	More than 1	aRR (95% CI)	P-value	AUC
	1	33 (14.4)	196 (85.6)	1.05 (0.98, 1.12)	0.2	
	2	14 (13.2)	92 (86.8)	1.06 (0.97, 1.15)	0.2	
	3+	<5 (6.8)	41 (93.2)	1.15 (1.07, 1.23)	<0.01	

DHSW – Dental Health Support Worker; SIMD – Scottish Index of Multiple Deprivation

Supplementary table 6.4 (ST6.4) – Interaction tests for diet/toothbrushing between birth Scottish Index of Multiple Deprivation and Childsmile diet/toothbrushing interventions; using adapted modified Poisson regression/linear regression models.

		SIMD Birth	
	Level	**Estimate**	**Interaction p-value**
Number of DHSW Diet Interventions in first 5 years	0	Ref	N/A
	1	0.01	0.88
	2	0.37	0.05
	Not Targeted	0.04	0.06
	Overall	N/A	0.17
Number of dental practice diet interventions in first 5 years	0	Ref	N/A
	1	-0.04	0.25
	2	-0.02	0.55
	3	0.02	0.64
	4	-0.04	0.36
	5	0.06	0.25
	Overall		0.38
Number of DHSW Toothbrushing Interventions in first 3 years	0	Ref	N/A
	1	-0.14	0.31
	2	-0.29	0.49
	Not Targeted	0.01	0.94
	Overall		0.24
Number of dental practice toothbrushing interventions in first 3 years	0	Ref	N/A

		SIMD Birth	
	Level	**Estimate**	**Interaction p-value**
	1	-0.00	0.74
	2	0.01	0.56
	3	-0.02	0.33
	Overall		0.65

DHSW – Dental Health Support Worker; All analyses were then run stratified by SIMD fifths. It should be noted that for this analysis DHSW interventions were reduced to 0,1+, Not Targeted due to small counts of 2+ in multiple SIMD fifths.

11.4.3 Chapter 7

11.4.3.1 Supplementary Material for Chapter 7

S7.1 – Variable Description

Socioeconomic Circumstances (latent variable)

Timing: Age 2 (BC1), Age 3 (BC2)

- **Household Income Poverty**: Defined by the respondent's household annual income after tax but before housing costs being less than 60% of median equivalised income in Scotland, using the modified Organisation for Economic Co-operation and Development equivalence scale (Hagenaars, de Vos and Zaidi, 1994; European Commission, 2004).
- **Area-based deprivation**: Measured using a mix of the Scottish Index of Multiple Deprivation (SIMD) 2006/2012. It is based on 37/38 indicators in seven domains of current income, employment, housing, health, education, skills and training, geographic access to services and crime. SIMD is calculated at data zone level, enabling small pockets of deprivation to be identified. The data zones are ranked from most deprived (1) to least deprived (6,505) on the overall SIMD index. The data are then recorded in fifths (SIMD1-SIMD5), with SIMD1 being the most 20% deprived areas in the population (Scottish Government, 2006; Scottish Government, 2012).
- **Highest Parental Employment in Household**: classified using the National Statistics Socio-economic Classification (NS-SEC). For this study, categories were condensed into five groups, with a sixth category, 'never worked' (Pevalin and Rose, 2002).
- **Highest Parental Education in household**: the maximum education of respondent or partner categorised according to the National Vocational Qualifications (NVQ) and Qualifications and Credit Framework (QCF) levels (Raffe, 2003). The levels are: No Qualification or Other; GCSEs/Standard Grades/NVQ Level 2 or Below; A Levels/Highers/NVQ Level 3 or Equivalent; HNC, HND, NVQ Level 4 or Equivalent; and Degree/NVQ Level 5 or Equivalent.

Parenting styles:

Theoretical Framework: Baumrind's Framework (Baumrind, 1966).

Constructs: Responsiveness and Demandingness

Note: Different sweep timings and instruments across BC1 and BC2

Responsiveness (latent variable)

- ***Warmth (Pianta-scale) - Timing: Age 5 (BC1), Age 3 (BC2):*** Seven items from the Pianta scale (Pianta, 1992), with acceptable reliability (Cronbach's alpha = 0.67). Each item was rated on a scale from 1 ("definitely does not apply") to 5 ("definitely applies"), with "can't say" responses treated as missing. Scores were summed for parents who completed all responsiveness items. The approximately lowest third of parents (low warmth) are compared with those who scored higher (High Warmth).
- ***Mother Child Activities - Timing: Age 2-4 (BC1), Age 3 (BC2):*** A count was made of how many of six activities the mother had engaged in with the child in the past week. These activities included reading books or stories, playing outdoors, painting or drawing, singing nursery rhymes or songs, practicing letters or shape recognition, and using a computer or games console. A mean score was computed for each sweep, and these scores were divided into three categories: low (0 to 3 activities), medium (4 activities), and high (5 or 6 activities). For BC2, the data were collected at age 3, and the question regarding computer use was excluded.

Demandingness (latent variable)

- ***Rules and Routines (BC1) - Timing: Age 2 & 5:*** At age 2, caregivers were asked about the regularity of meals, with a response of "always." At age 5, caregivers were asked about regular bedtime and whether the child had to tidy up toys, brush teeth, stay in their room, and turn off the TV or music, using a 4-point scale (always, usually, sometimes, never or almost never). The total number of "always" responses was counted excluding the brush teeth due to collinearity, and the number of rules was categorised into low, medium, or high (Parkes and Wight, 2011).

- ***Home Chaos - Timing: Age 5 (BC1) and Age 1 (BC2):*** Uses an abbreviated version of the Confusion, Hubbub, and Order scale. (Coldwell, Pike and Dunn, 2006). This scale assesses household disorganisation (Matheny *et al.*, 1995). Scores were grouped into thirds of the population as low, medium, or high.
- ***Harsh discipline - Timing: Age 2 (BC1) and Age 3 (BC2):*** Binary variable asking whether the parents had ever smacked their child.
- ***Mother-Child Conflict (Pianta-scale) - Timing: Age 5 (BC1) and Age 3 (BC2):*** Using eight/seven items from the Pianta scale (Pianta, 1992) with items scored on a 4-point scale as for the Pianta warmth items (see above). Cronbach's alpha indicated good reliability (0.80). Scores were grouped into thirds as low, medium and high conflict.
- ***Authoritarian Questions (Parenting Practices Questionnaire) (BC2) - Timing: Age 5:*** Parenting Practices Questionnaire (PPQ) (Robinson *et al.*, 1995) was used to assess parenting styles. Authoritarian section was used to represent high demandingness.

Further observed variables were trialled as part of latent variables and proved to be non-significant Parental Supervision (Age 4 (BC1) – Demandingness) (Morrongiello and Corbett, 2006) and Early mother infant attachment (Age 10 months (BC1/2 – Responsiveness) (Condon and Corkindale, 1998). Neither were included in final theoretical model.

S7.2 – SEM Model-Building Algorithm

Step 1: Preliminary Analysis

Conduct univariable modified Poisson regressions of each candidate variable on caries experience, adjusting for NDIP exam age and sex.

Evaluate statistical significance ($p < 0.05$) and predictive performance (AUC).

Retain variables based on significance and theoretical relevance.

Step 2: Weighting

Apply survey weights developed via model-based techniques to adjust for non-response and sampling design throughout the analysis.

Step 3: Measurement Model Specification

Define latent variables for:

- Socioeconomic Circumstances (SEC) using household income poverty, area-based deprivation, parental employment, and education level.
- Parenting Dimensions (Responsiveness and Demandingness) from Pianta scales, parenting practices questionnaire, rules and routines, home chaos, and harsh discipline indicators.
- Cariogenic Diet (latent class variable) from sweet, sugar-sweetened beverage, and crisp consumption variables.
- Toothbrushing (latent for BC1; observed for BC2) based on toothbrushing frequency and toothpaste use.

Conduct confirmatory factor analysis, retaining indicators with standardised loadings ≥ 0.4 (with justified exceptions).

Add covariances between residuals of observed variables only if theoretically justified.

Step 4: Structural Model Specification

Specify the theoretical model where:

- SEC predicts Parenting Dimensions (Responsiveness and Demandingness).
- Parenting Dimensions predict oral health behaviours: Toothbrushing, Regular Dental Attendance, Diet.
- Oral health behaviours predict caries experience at age 5.

Include direct paths from SEC to oral health behaviours and caries experience to allow for partial mediation.

Step 5: Model Estimation

Estimate the model using WLSMV estimator in the lavaan package in R, appropriate for categorical and ordinal data.

Use robust standard errors and Wald z-statistics for p-values to adjust for non-normality.

Step 6: Iterative Model Refinement

Examine path coefficients and p-values.

Sequentially remove non-significant paths ($p > 0.05$), retaining borderline paths ($0.05 \leq p \leq 0.15$) if theoretically justified.

Review modification indices and add covariances between residuals of observed variables only when theoretically defensible.

Re-estimate the model after each change until final model fit criteria are met.

Step 7: Model Fit Evaluation

Confirm final model fit using:

- Chi-square statistic (x^2).

- Comparative Fit Index (CFI) > 0.95.
- Root Mean Square Error of Approximation (RMSEA) < 0.06.
- Standardised Root Mean Square Residual (SRMR) < 0.08.

Step 8: Mediation Analysis

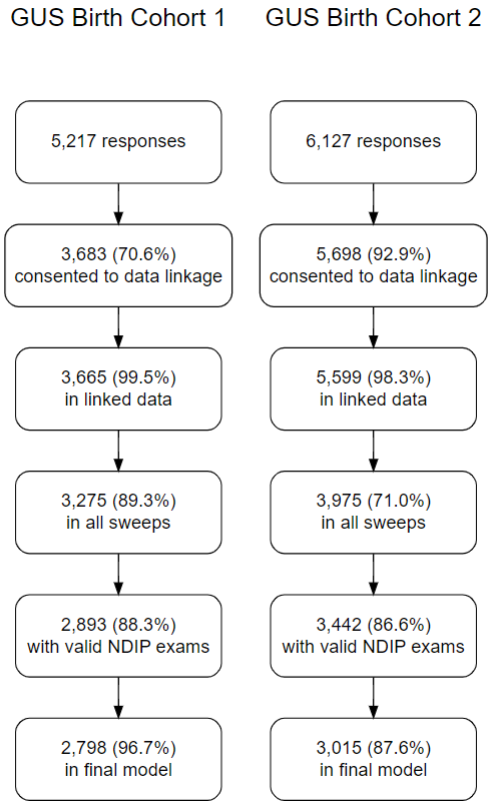
Calculate indirect effects as the product of path coefficients from the independent variable (SEC) to mediators (parenting and behaviours) and from mediators to caries experience.

Compute total effects as the sum of direct and indirect effects.

Calculate proportion mediated as the ratio of indirect to total effects.

Note: Bootstrapped confidence intervals for indirect effects are unavailable under WLSMV; hence only point estimates are reported.

11.4.3.2 Supplementary Figures for Chapter 7



Supplementary Figure 7.1 (SF7.1): Sample derivation flow diagram for the Growing Up in Scotland birth cohorts 1 and 2

Supplementary Tables for Chapter 7

Supplementary Table 7.1 (ST7.1): Caries experience prevalence across each variable

Age	Variable		Birth Cohort 1	Birth Cohort 2
			n (%)	n (%)
	Socioeconomic Circumstances			
2/3	Household Income Poverty	Yes	385/823 (46.8)	399/984 (40.5)
		No	531/2140 (24.8)	526/2527 (20.8)
		Missing	149	493
2/3	SIMD fifths	1	358/728 (49.2)	384/948 (40.5)
		2	195/565 (34.5)	262/873 (30)
		3	165/586 (28.1)	199/818 (24.3)
		4	142/630 (22.6)	145/691 (21)
		5	102/578 (17.7)	112/706 (15.9)
		Missing	30	0
2/3	Highest Parental Employment in Household	Higher managerial	363/1613 (22.5)	335/1914 (17.5)
		Intermediate Occupation	127/465 (27.4)	149/568 (26.2)
		Small employees and own account workers	68/183 (36.9)	72/262 (27.5)
		Lower supervisory and technical occupations	108/268 (40.3)	115/327 (35.2)
		Semi routine and routine occupations	255/519 (49.1)	370/848 (43.6)
		Never worked/long-term unemployed	49/67 (73.3)	62/116 (53.4)
		Missing	0	4
2/3	Household Parental Education in Household	Degree/ NVQ level 5 or equivalent	193/1115 (17.3)	251/1577 (15.9)
		HNC, HND, NVQ level 4 or equivalent	121/444 (27.2)	137/550 (24.9)
		A levels/Highers/NVQ level 3 or equivalent	225/633 (35.6)	251/843 (29.8)
		GCSE's/Standard Grades/NVQ level 2 or below	316/736 (42.9)	339/852 (39.8)
		No Qualification or Other	112/181 (61.9)	115/195 (59)
		Missing	6	17
	Parenting Styles			
5/3	Warmth of Mother Child Relationship	High Warmth (34 – 35)	521/1870 (27.9)	554/2251 (24.6)

Age	Variable		Birth Cohort 1	Birth Cohort 2
			n (%)	n (%)
	(Pianta Scale)	Low Warmth (7 – 33)	333/970 (34.3)	459/1560 (29.4)
		Missing	73	212
2-4/3	Mother Child Activities	High (5 – 6)	855/2870 (29.8)	656/2735 (24)
		Medium (4)	97/218 (44.5)	257/782 (32.9)
		Low (0 – 3)	16/26 (61.8)	180/489 (36.8)
		Missing	6	13
5	Rules and Routines	High (5)	162/564 (28.8)	
		Medium (4)	595/2089 (28.5)	
		Low (0 – 3)	127/259 (49.1)	
		Missing	3	
5/1	Home Chaos	High (10 – 20/9 – 15)	384/1007 (38.1)	502/2076 (24.2)
		Medium (8 – 9/7 – 8)	305/1143 (26.7)	301/1172 (25.7)
		Low (4 – 7/3 – 6)	200/764 (26.2)	297/783 (37.9)
		Missing	183	1
4/3	Harsh Discipline	Yes	167/508 (32.8)	251/842 (29.8)
		No	799/2604 (30.7)	830/3158 (26.3)
		Missing	0	0
5/3	Conflict of Mother Child Relationship	High (19 – 40 /18 – 35)	841 (33.1)	1252 (27.7)
	(Pianta Scale)	Medium (13 – 18 /12 – 17)	1068 (29.3)	1638 (25.7)
		Low (8 – 12 /7 – 11)	946 (28.8)	1044 (27.7)
		Missing	57	89
5	Authoritarian Score	Q1 – Low		187/710 (25.5)
	(Parenting Practices Questionnaire)	Q2		179/763 (23.5)
		Q3		155/687 (22.6)
		Q4		122/526 (23.2)
		Q5 – High		208/699 (29.8)
		Missing		54
	Oral Health Behaviours			
	Diet			
2/3	How often child eats sweets?	> 1 (day)	161/358 (44.8)	176/461 (38.2)

Age	Variable		Birth Cohort 1	Birth Cohort 2
			n (%)	n (%)
		1 (day)	362/982 (36.9)	532/1705 (31.2)
		5 – 6 (week)	46/157 (29.6)	77/291 (26.6)
		2 – 4 (week)	260/973 (26.7)	232/1098 (21.1)
		1 (week)	81/352 (23.1)	64/318 (20.1)
		1-3 (month)	20/130 (15.1)	10/85 (11.6)
		Less or never	39/165 (23.4)	10/78 (12.9)
		Missing	1	0
2/5	How often child eats crisps?	> 1 (day)	162/361 (45)	29/60 (47.8)
		1 (day)	371/1052 (35.3)	203/626 (32.5)
		5 – 6 (week)	68/250 (27.2)	68/247 (27.5)
		2 – 4 (week)	241/879 (27.4)	303/1277 (23.7)
		1 (week)	73/306 (23.7)	122/612 (19.9)
		1-3 (month)	19/106 (18.2)	39/248 (15.8)
		Less or never	34/162 (21.3)	102/369 (27.5)
		Missing	1	1
2/3	How often child drinks sugar sweetened beverage?	> 1 (day)	108/241 (44.8)	23/36 (62.6)
		1 (day)	57/128 (44.4)	29/72 (40.4)
		2 – 6 (week)	36/82 (44.2)	49/114 (42.8)
		1 (week)	42/94 (45.1)	90/208 (43.3)
		1-3 (month)	44/94 (46.7)	78/211 (37)
		Less or never	681/2475 (27.5)	831/3393 (24.5)
		Missing	1	0
	Toothbrushing			
2	Frequency of toothbrushing	> 1 a day	643/2266 (28.4)	
		1 a day	271/735 (36.9)	
		< 1 a day	53/114 (46.4)	
		Missing	0	
2	Toothpaste Used	Yes	946/3072 (30.8)	
		No	17/29 (58.9)	

Age	Variable		Birth Cohort 1	Birth Cohort 2
			n (%)	n (%)
		Missing	0	
3	Frequency of toothbrushing using fluoride toothpaste	> 1 a day		855/3328 (25.7)
		1 a day		210/647 (32.5)
		< 1 a day		35/58 (59.7)
		Missing		0
	Attendance at Dentist			
1-5	Regular Dental Attendance (4 out of the first 5 years)	Yes	299/1250 (23.9)	416/1859 (22.4)
		No	668/1862 (35.9)	685/2173 (31.5)
		Missing	0	0

SIMD – Scottish Index of Multiple Deprivation

Supplementary Table 7.2 (ST7.2): Area under the Curve scores with 95% Confidence Intervals of univariable modified Poisson models against caries experience at age 5 adjusted for age and sex

Variable	Birth Cohort 1	Birth Cohort 2
Household Income Poverty	0.609 [0.586, 0.631]	0.605 [0.583, 0.628]
SIMD fifths	0.648 [0.627, 0.669]	0.623 [0.602, 0.643]
Highest Parental Employment in Household	0.629 [0.606, 0.651]	0.645 [0.625, 0.666]
Highest Parental Education in Household	0.664 [0.643, 0.685]	0.652 [0.632, 0.672]
Parenting Styles		
Warmth of Mother Child Relationship	0.544 [0.521, 0.567]	0.535 [0.514, 0.556]
Mother Child Activities	0.541 [0.519, 0.563]	0.543 [0.522, 0.564]
Rules and Routines	0.576 [0.553, 0.599]	
Home Chaos	0.572 [0.549, 0.595]	0.558 [0.54, 0.577]
Harsh Discipline	0.528 [0.506, 0.55]	0.529 [0.508, 0.55]
Conflict of Mother Child Relationship	0.533 [0.51, 0.556]	0.527 [0.506, 0.548]
Authoritarian Score		0.549 [0.527, 0.572]
Oral Health Behaviours		
How often child eats sweets?	0.611 [0.589, 0.632]	0.601 [0.582, 0.621]
How often child eats crisps?	0.599 [0.578, 0.621]	0.590 [0.569, 0.612]
How often child drinks sugar sweetened beverages?	0.581 [0.559, 0.603]	0.585 [0.564, 0.606]
Frequency of toothbrushing	0.560 [0.538, 0.583]	
Toothpaste Used	0.535 [0.513, 0.557]	
Frequency of toothbrushing using fluoride toothpaste		0.551 [0.53, 0.572]
Regular Dental Attendance (4 out of the first 5 years)	0.575 [0.553, 0.596]	0.575 [0.556, 0.593]

SIMD – Scottish Index of Multiple Deprivation

Supplementary Table 7.3 (ST7.3): Counts of diet variables not used in final diet latent variable with caries experience prevalence in each exposure level

Age	Variable		Birth Cohort 1	Birth Cohort 2
			(% prevalence of caries)	(% prevalence of caries)
10m	Child drinks:			
	Water	No		309/831 (37.2)
		Yes		1020/3938 (25.9)
	Baby Juice	No		749/3241 (23.1)
		Yes		580/1529 (37.9)
	Fruit Juice (Diet)	No		925/3570 (25.9)
		Yes		404/1199 (33.7)
	Fruit Juice (NOT diet)	No		1240/4460 (27.8)
		Yes		90/310 (29)
	Fizzy/Soft Drinks	No		1325/4753 (27.9)
		Yes		6/17 (35.3)
	Herbal Drinks	No		1308/4722 (27.7)
		Yes		21/47 (43.8)
	Tea	No		1240/4538 (27.3)
		Yes		93/231 (40.1)
	Coffee	No		1330/4763 (27.9)
		Yes		2/7 (28.6)
	Something Else	No		1320/4731 27.9)
		Yes		11/38 (28.9)
	Only Milk or Formula	No		1286/4625 (27.8)
		Yes		45/144 (31)
		Missing		0
2/3	How many fruit in a day?	0	40/92 (43.5)	147/403 (36.5)
		1	154/360 (42.8)	165/610 (27)
		2-3	545/1842 (29.6)	617/2268 (27.2)
		4-5	188/686 (27.4)	151/665 (22.7)
		6+	41/135 (30.4)	14/50 (28)
		Missing	1	36
5	How many fruit in a day?	0	156/416 (37.5)	94/359 (26.2)
		1	224/646 (34.7)	221/729 (30.3)
		2-3	495/1597 (31)	540/2086 (25.9)
		4-5	71/311 (22.8)	1043/422 (24.4)
		6+	4/18 (21.1)	7/37 (18.4)
		Missing	12	15
2/3	How many veg in a day?	0	71/184 (38.6)	294/917 (32)
		1	278/737 (37.7)	262/915 (28.6)
		2-3	537/1899 (28.3)	425/1793 (23.7)
		4-5	69/253 (27.3)	103/338 (30.4)
		6+	10/39 (25.6)	5/30 (16.1)
		Missing	2	34
5	How many veg in a day?	0	314/832 (37.7)	281/915 (30.7)
		1	202/644 (31.3)	199/682 (29.1)
		2-3	382/1257 (30.4)	389/1577 (24.7)
		4-5	46/222 (20.6)	78/379 (20.6)
		6+	6/23 (26.1)	7/56 (12.3)
		Missing	20	37
5	How often child eats sweets?	1+ (day)	145/283 (51.4)	105/252 (41.7)

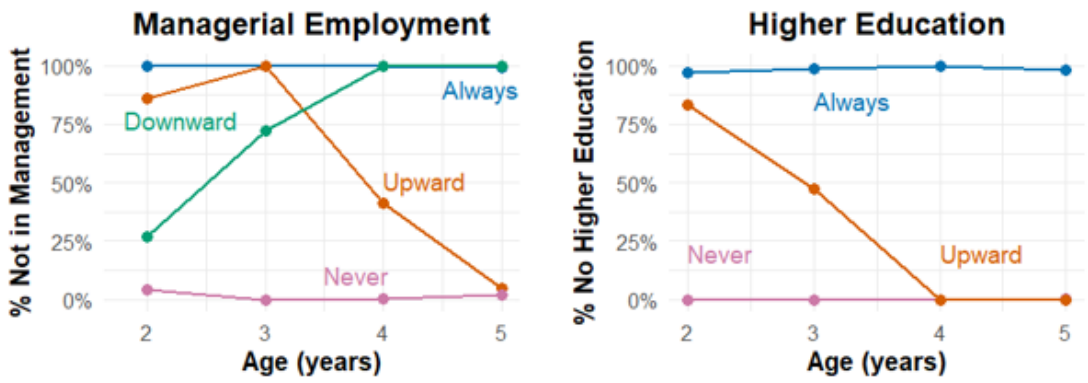
Age	Variable		Birth Cohort 1	Birth Cohort 2
			(% prevalence of caries)	(% prevalence of caries)
		1 (day)	417/1190 (35)	446/1472 (30.3)
		5-6 (week)	69/254 (27.1)	68/320 (21.2)
		2-4 (week)	245/954 (25.7)	263/1132 (23.2)
		1 (week)	50/221 (22.6)	48/293 (16.4)
		1-3 (month)	14/49 (28)	14/64 (21.9)
		Less often or never	19/48 (39.6)	27/115 (23.3)
		Missing	0	1
5	How often child eats crisps?	1+ (day)	67/107 (62.6)	
		1 (day)	249/609 (40.9)	
		5-6 (week)	62/194 (31.8)	
		2-4 (week)	339/1132 (29.9)	
		1 (week)	121/510 (23.7)	
		1-3 (month)	55/243 (22.6)	
		Less often or never	61/204 (29.9)	
		Missing	0	
5	How often child has soft drinks?	1+ (day)	342/867 (39.4)	284/827 (34.3)
		1 (day)	113/386 (29.2)	101/386 (26.1)
		2-6 (week)	92/283 (32.5)	92/347 (26.5)
		1 (week)	43/148 (28.9)	62/224 (27.7)
		1-3 (month)	35/111 (31.5)	38/158 (24.1)
		Less often or never	329/1203 (27.3)	394/1707 (23.1)
		Missing	1	1
3	How often child has fruit juice/smoothie?	1+ (day)		151/547 (27.6)
		1 (day)		275/991 (27.7)
		2-6 (week)		233/858 (27.2)
		1 (week)		103/389 (26.4)
		1-3 (month)		62/237 (26.2)
		Less often or never		278/1013 (27.5)
		Missing		0
3	How often child has diluting juice/sport drink?	1+ (day)		672/2031 (33.1)
		1 (day)		177/700 (25.3)
		2-6 (week)		97/408 (23.7)
		1 (week)		19/147 (12.9)
		1-3 (month)		17/104 (16.2)
		Less often or never		120/643 (18.6)
		Missing		0
5	How often child has diet soft drinks?	1+ (day)	192/553 (34.7)	
		1 (day)	81/225 (36)	
		2-6 (week)	83/224 (36.9)	
		1 (week)	70/194 (35.9)	
		1-3 (month)	35/130 (26.7)	

Age	Variable		Birth Cohort 1	Birth Cohort 2
			(% prevalence of caries)	(% prevalence of caries)
		Less often or never	493/1672 (29.5)	
		Missing	0	
5	How often child has milk?	1+ (day)	319/1131 (28.2)	
		1 (day)	312/931 (33.5)	
		2-6 (week)	137/393 (34.8)	
		1 (week)	41/126 (32.5)	
		1-3 (month)	11/33 (33.3)	
		Less often or never	134/385 (34.7)	
		Missing	0	
5	How often child has water?	1+ (day)	370/1294 (28.6)	
		1 (day)	196/627 (31.3)	
		2-6 (week)	147/432 (34.1)	
		1 (week)	52/155 (33.5)	
		1-3 (month)	16/59 (27.1)	
		Less often or never	173/433 (39.9)	
		Missing	0	
3	Savoury Snack:	No	565/1641 (34.4)	
		Yes	403/1472 (27.4)	
	Crisps	No	534/2008 (26.6)	
		Yes	433/1105 (39.2)	
	Cereal	No	845/2724 (31)	
		Yes	123/389 (31.5)	
	Cakes/Biscuits	No	649/2068 (31.4)	
		Yes	319/1046 (30.5)	
	Fruit	No	295/760 (38.8)	
		Yes	672/2353 (28.6)	
	Bread etc	No	568/1875 (30.3)	
		Yes	400/1239 (32.3)	
	Sweets etc	No	709/2386 (29.7)	
		Yes	260/727 (35.7)	
	Other	No	903/2924 (30.9)	
		Yes	65/190 (34.2)	
	Child not hungry between meals	No	966/3106 (31.1)	
		Yes	2/8 (25)	
5	Snacking on:			
	Savoury Snack:	No	574/1621 (35.4)	
		Yes	378/1375 (27.5)	
	Crisps	No	462/1602 (28.8)	
		Yes	489/1395 (35.1)	
	Cereal	No	794/2555 (31.1)	
		Yes	158/442 (35.7)	
	Cakes/Biscuits	No	565/1755 (32.2)	
		Yes	387/1241 (31.2)	
	Fruit	No	389/962 (40.4)	
		Yes	563/2034 (27.7)	
	Bread etc	No	601/1856 (32.4)	
		Yes	350/1140 (30.7)	

Age	Variable		Birth Cohort 1 (% prevalence of caries)	Birth Cohort 2 (% prevalence of caries)
	Sweets etc	No	635/2028 (31.3)	
		Yes	316/968 (32.6)	
	Rice cakes	No	905/2776 (32.6)	
		Yes	45/220 (20.5)	
	Yoghurt	No	267/982 (27.2)	
		Yes	683/2015 (33.9)	
	Other	No	920/2891 (31.8)	
		Yes	32/105 (30.2)	

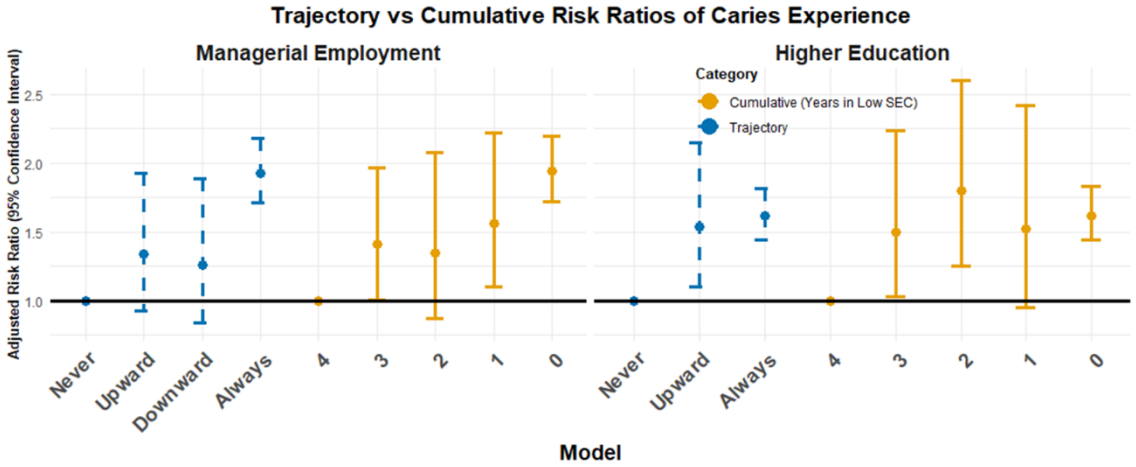
11.4.4 Chapter 8

11.4.4.1 Supplementary Figures for Chapter 8



Managerial Employment – Yes = Managerial or professional level of Highest Employment in Household/ No
Higher Education – Yes = Level 4 or Level 5 of Highest Education in Household/ No

Supplementary Figure 8.1 (SF8.1): Latent class analysis trajectories of employment and education



Managerial Employment – Yes = Managerial or professional level of Highest Employment in Household/No;
Higher Education – Yes = Level 4 or Level 5 of Highest Education in Household/No

Supplementary Figure 8.2 (SF8.2): Adjusted risk ratios for caries experience in Primary 1 by employment and education trajectories and cumulative effects at age 5 years

11.4.4.2 Supplementary Tables for Chapter 8

Supplementary Table 8.1 (ST8.1): Percentage of people in each group in poverty/deprivation at each age

		% Of people in each group in poverty/deprivation				
Variables	Outcomes	Age 10m	Age 2	Age 3	Age 4	Age 5
Income Poverty	Never In Poverty	N/A	3.2	1.5	~0	0
	Upward Social Mobility	N/A	73.9	61.6	41.3	40.6
	Downward Social Mobility	N/A	0	12.9	31.2	59.8
	Always in Poverty	N/A	91.4	91.1	94.2	88.5
Area-based Deprivation: In Lowest SIMD 20%	Never in 20%	1.1	0	0	0	2.5
	Upward Social Mobility	90.6	100	27.6	0	9.2
	Downward Social Mobility	0	0	72.5	93.7	72.3
	Always in 20%	94.7	99.3	99.6	99.7	83.4

This table illustrates the percentage of each group in poverty/deprivation of each group at each age. E.g 3.2% of all individuals in the 'Never in Poverty' Group are in income poverty at Age 2, this decreases to 1.5% by age 3.

Supplementary Table 8.2 (ST8.2): Risk ratios for caries experience in Primary 1 by poverty/deprivation trajectories and cumulative effects at age 5 years, using adapted modified Poisson regression

Variables	Outcomes	No caries Experience n (%)	Caries Experience n (%)	RR (95% CI)	P-value	AUC [95% CI]
Income Poverty	Never In Poverty	1246 (76.5)	383 (23.5)	1 (ref)		0.611 [0.585, 0.637]
	Upward Social Mobility	123 (61.8)	76 (38.2)	1.64 (1.31, 2.05)	<0.001	
	Downward Social Mobility	96 (66.2)	49 (33.8)	1.43 (1.11, 1.84)	0.005	
	Always in Poverty	247 (48.3)	264 (51.7)	2.19 (1.91, 2.51)	<0.001	
Income Poverty: Years in Poverty	0	1156 (77.5)	336 (22.5)	1 (ref)		0.622 [0.596, 0.647]
	1	169 (68.7)	77 (31.3)	1.40 (1.13, 1.73)	0.002	
	2	114 (63)	67 (37)	1.64 (1.29, 2.08)	<0.001	
	3	116 (52.7)	104 (47.3)	2.09 (1.72, 2.54)	<0.001	
	4	157 (45.1)	191 (54.9)	2.43 (2.09, 2.82)	<0.001	
Area-based Deprivation: In Lowest SIMD 20%	Never in Deprivation	1533 (74.1)	536 (25.9)	1 (ref)		0.603 [0.579, 0.627]
	Upward Social Mobility	52 (70.3)	22 (29.7)	1.13 (0.75, 1.72)	0.6	
	Downward Social Mobility	55 (57.9)	40 (42.1)	1.63 (1.23, 2.17)	<0.001	
	Always in Deprivation	300 (48.8)	315 (51.2)	1.98 (1.76, 2.24)	<0.001	
Area based Deprivation: Years in Lowest SIMD 20%	0	1466 (74.6)	498 (25.4)	1 (ref)		0.611 [0.588, 0.635]
	1	75 (64.7)	41 (35.3)	1.40 (1.04, 1.89)	0.027	
	2	52 (62.7)	31 (37.3)	1.48 (1.06, 2.05)	0.020	
	3	44 (57.1)	33 (42.9)	1.68 (1.23, 2.29)	0.001	
	4	65 (52.4)	59 (47.6)	1.85 (1.46, 2.36)	<0.001	
	5	237 (48.5)	252 (51.5)	2.05 (1.80, 2.33)	<0.001	

RR – Risk Ratio (Adjusted for Age at NDIP exam and sex); AUC – Area-under the curve; CI – Confidence Interval

Supplementary Table 8.3 (ST8.3): Adjusted risk ratios for caries experience in Primary 1 by poverty/deprivation trajectories adjusting for other poverty/deprivation trajectory at age 5 years, using adapted modified Poisson regression.

Variables	Outcomes	RR (95% CI)	P-value	AUC [95% CI]
Income Poverty	Never In Poverty	1 (ref)		0.637 [0.612, 0.662]
	Upward Social Mobility	1.54 (1.24, 1.91)	<0.001	
	Downward Social Mobility	1.40 (1.13, 1.74)	0.002	
	Always in Poverty	1.88 (1.61, 2.20)	<0.001	
Area-based Deprivation: In Lowest SIMD 20%	Never in Deprivation	1 (ref)		0.637 [0.612, 0.662]
	Upward Social Mobility	0.92 (0.58, 1.45)	0.7	
	Downward Social Mobility	1.45 (1.04, 2.03)	0.029	
	Always in Deprivation	1.57 (1.36, 1.81)	<0.001	

RR – Risk Ratio (Adjusted for Age at NDIP exam sex and Poverty/Deprivation Trajectory); AUC – Area-under the curve; CI – Confidence Interval

Supplementary Table 8.4 (ST8.4): Number of children in each employment and education trajectory

Outcomes	Employment (%)	Education (%)
Never	1308 (45.5)	1541 (53.7)
Upward Social Mobility	76 (2.6)	79 (2.8)
Downward Social Mobility	74 (2.6)	N/A
Always	1418 (49.3)	1251 (43.5)
Total	2876	2871

Employment – Yes = Managerial or professional level of Highest Employment in Household /No; Education – Yes = Level 4 or Level 5 of Highest Education in Household/No

Supplementary Table 8.5 (ST8.5): Percentage of people in each group in employment/education at each age

		% of People in each group in Low SEC					No in Each Group (%)
Variables	Outcomes	Age 10m	Age 2	Age 3	Age 4	Age 5	
Employment: Parental Managerial Employment in Household	Never Low SEC	N/A	4.3	0	0.4	2.0	1308 (45.5)
	Upward Social Mobility	N/A	85.7	100	41.2	4.8	76 (2.6)
	Downward Social Mobility	N/A	27	72.1	100	100	74 (2.6)
	Always Low SEC	N/A	100	100	100	99.2	1418 (49.3)
							Total = 2876
Education: Parental Higher-Level Education in household	Never Low SEC	N/A	0	0	~0	~0	1541 (53.7)
	Upward Social Mobility	N/A	83.3	47.6	0	0	79 (2.8)
	Always Low SEC	N/A	97.3	98.8	100	98.0	1251 (43.5)
							Total = 2871

SEC – Socioeconomic Circumstances

Supplementary Table 8.6 (ST8.6): Adjusted risk ratios for caries experience in Primary 1 by employment and education trajectories and cumulative effects at age 5 years, using adapted modified Poisson regression.

Variables	Outcomes	No caries Experience n (%)	Caries Experience n (%)	RR (adjusted)	P-value	AUC
Employment: Parental Managerial Employment in Household	Never Low SEC	1025 (78.4)	283 (21.6)	1 (ref)		0.613 [0.590, 0.636]
	Upward Social Mobility	54 (71.1)	22 (28.9)	1.34 (0.93, 1.93)	0.11	
	Downward Social Mobility	54 (73)	20 (27)	1.26 (0.84, 1.89)	0.3	
	Always Low SEC	827 (58.3)	591 (41.7)	1.93 (1.71, 2.18)	<0.001	
Employment: Years with Parental Managerial Employment in Household	4	1025 (78.4)	283 (21.6)	1 (ref)		0.614 [0.591, 0.637]
	3	65 (69.9)	28 (30.1)	1.41 (1.01, 1.97)	0.043	
	2	39 (69.6)	17 (30.4)	1.35 (0.87, 2.08)	0.2	
	1	59 (66.3)	30 (33.7)	1.56 (1.10, 2.22)	0.013	
	0	773 (57.9)	561 (42.1)	1.94 (1.72, 2.20)	<0.001	
Education: Higher-Level Parental Education in household	Never Low SEC	1157 (75.1)	384 (24.9)	1 (ref)		0.602 [0.579, 0.625]
	Upward Social Mobility	49 (62)	30 (38)	1.54 (1.10, 2.15)	0.012	
	Always Low SEC	748 (59.8)	503 (40.2)	1.62 (1.44, 1.82)	<0.001	
Education: Parental Years of Higher-Level Education in Household	4	1150 (75.2)	379 (24.8)	1 (ref)		0.603 [0.58, 0.626]
	3	35 (62.5)	21 (37.5)	1.52 (1.03, 2.24)	0.034	
	2	30 (55.6)	24 (44.4)	1.80 (1.25, 2.60)	0.002	
	1	30 (62.5)	18 (37.5)	1.52 (0.95, 2.42)	0.078	
	0	710 (59.9)	475 (40.1)	1.62 (1.44, 1.83)	<0.001	

SEC – Socioeconomic Circumstances

11.5 References for supplementary material

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