THE EFFECT OF INFANT FEEDING METHODS AND NON-NUTRITIVE SUCKING BEHAVIOURS ON SPEECH DEVELOPMENT AT AGE FIVE YEARS

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List of Abbreviations

ALSPAC	Avon Longitudinal Study of Parents and Children
ALSPAC-G2	Avon Longitudinal Study of Parents and Children-Generation 2
C	Consonant
CC	Consonant cluster
CiF	Child in Focus (Subset of ALSPAC study)
CI	Confidence interval
Coef.	Coefficient
CsPCC	Connected speech percentage consonants correct
CV	Consonant-vowel syllable
DAG	Directed acyclic graph
DEAP	Diagnostic Evaluation of Articulation and Phonology
GP	General practitioner
HRA	Health Research Authority
IRR	Interval rate ratio
NHS	National Health Service
NNS	Non-nutritive sucking
OME	Otitis media with effusion
OR	Odds ratio
PCC	Percentage Consonants Correct
PIS	Patient Information Sheet
PPIE	Patient and Public Involvement and Engagement
PVC	Postvocalic Consonant Sounds
RCPCH	Royal College of Paediatrics and Child Health
REC	Research Ethics Committee
RDLS	Reynell Developmental Language Scales
SLT	Speech and Language Therapy/Therapist
SMCP	Submucous cleft palate
SOP	Standard Operating Procedure
SSD	Speech sound disorder
SwPCC	Single word percentage consonants correct
TPT	Toddler Phonology Test
UK	United Kingdom
USB	Universal Serial Bus

Abstract

Children with speech sound disorders (SSD) constitute the largest population of referrals to speech and language therapy (SLT) services (Broomfield & Dodd, 2004). This study aims to identify potential early risk factors for SSD at the critical ages of two-five years by investigating the relationship between different infant feeding regimes (exclusive breastfeeding, bottle and mixed feeding), non-nutritive sucking (NNS) and motor development of speech in early childhood. If a relationship is identified, this will support parents to make informed care choices from birth onwards, as well as reinforcing national public health messages and maximising positive long-term health and social outcomes for children. This study contains three independent but related strands. Strand One used data from the Avon Longitudinal Study of Parents and Children (ALSPAC) to investigate the relationship between feeding, NNS and speech development at ages two and five in a longitudinal cohort study. Strand Two collected data as part of the ALSPAC Generation Two study (ALSPAC-G2) to look at feeding, NNS and speech development in two- to four-year-olds. Strand Three used NHS SLT clinical caseload data to investigate the feeding histories of children aged two-five years diagnosed with SSD and determine whether a greater proportion were exposed to one particular type of feeding regime and/or NNS than would occur in the general population. Children participating in Strands Two and Three completed detailed standardised speech sound assessments. Data on potential confounding variables for speech was collected and included in the analysis. Speech articulation skills and phonetic inventory were described in detail and statistical analysis undertaken to identify differences between groups of children fed by different methods and with different NNS behaviours. Relationships between variables, and specifically the role that feeding and NNS plays in the speech development of children with and without SSD, were explored. The study found that different patterns of feeding and NNS were associated with different speech sound outcomes between ages two-five years. Longer duration of exclusive breastfeeding was indicated to be associated with reduced parental concern about speech at age 18 months. Associations between feeding and specific consonant sound errors were observed. Exclusive breastfeeding was found to be associated with markedly reduced likelihood of alveolar sound errors at age 5 years compared with exclusive bottle feeding. NNS was not shown to have an impact on speech sound development

at age 5 years. The findings of this study were explored in the context of relevant theoretical mechanisms for sucking and speech sound development. Implications for clinical practice and public health messaging are described, and recommendations for future research are outlined.

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Mum. There are no words.

Chapter One: Introduction

1. Overview of the chapter

This chapter sets out the nature and scope of this PhD study, including the background, rationale and positioning within the field of speech and language therapy (SLT) research. Research aims are stated, together with an outline of potential benefits of this research for clinical practice and health economics.

2. Structure of the thesis

Chapter Two of this thesis presents a published systematic review of the current state of the literature with regard to the association between infant feeding methods, non-nutritive sucking (NSS) behaviours and speech sound development in early childhood (Burr *et al*, 2020). Clearly defined research questions for this PhD study are presented. Chapter Three describes the three strands of this study and the methods applied in each. Chapter Four presents the results from each of the three study strands. Summary sections are presented at the end of each strand to support the readers' understanding. Chapter Five explores the study findings in the context of theoretical mechanisms and current evidence, together with an examination of the strengths and limitations of the present study. Chapter Six sets out the clinical implications of the findings and describes future directions for research. The contribution to knowledge made by this is outlined.

3. Background and rationale for this study

Speech sound disorders (SSDs) are one of the most prevalent conditions seen by SLTs (Broomfield and Dodd, 2004; McKinnon, McLeod and Reilly, 2007; Eadie *et al*, 2015; Wren *et al*, 2016). This is the single largest population on SLT caseloads, with an estimated direct annual cost to the NHS of £24 million (Enderby *et al*, 2009). SSDs occur when there is a difficulty or delay in producing sounds for speech (Bowen, 2015). Children with SSD are at significant risk of poor long-term outcomes with regard to their mental health (Muir, *et al*, 2011; *McAllister*, Collier and Shepstone, 2013), familial and social integration (Hitchcock, Harel and Byun, 2015), educational attainment (Hesketh, 2004; Nathan *et al*, 2004; Roulstone *et al*, 2011; Wren *et al*, 2021), involvement with the criminal justice system (Bryan, Freer and Furlong, 2007) and employment prospects (Felsenfeld, Broen and McGue, 1994;

Elliott, 2011). Identification of early risk factors for SSD is fundamental to the challenge of reducing the impact that the condition has for young children's long term conditions (Churcher, 2016). Previous research in this field has contributed to the development of a profile of risk for SSD (Fox, Dodd and Howard, 2002; Campbell *et al*, 2003; Harrison and McCleod, 2010; Wren *et al*, 2016). This study explored whether information about early feeding and NNS behaviours should be included as part of this risk profile.

4. The relationship between speech and language

While positive outcomes for language have been associated with breastfeeding compared with bottle feeding (Oddy, Robinson and Whitehouse, 2012; Jedrychowski *et al*, 2012; Belfort *et al*, 2013; Lee *et al*, 2016; Huang, Vaughn and Kramer, 2016), the relationship between feeding and speech sound development is not clear (Fox, Dodd and Howard, 2002; Burr *et al*, 2020). Much of the evidence advocating for the benefits of breastfeeding relates to the importance of breast milk, rather than the significance of the feeding mechanism itself. Within this study it is the latter that is of interest.

Previous research has suggested a relationship between feeding and general oral motor development (Evans-Morris, 1998; Dee *et al* l, 2007; Pollock, 2013), and general oral motor skills have been positively associated with speech sound development (Ruark and Moore 1997; Alcock, 2006). However, direct links between feeding and speech sound development have not been found. If language skill is related to speech sound development (Lewis, Freebairn and Taylor, 2000a, 2000b; Lewis, Freebairn and Taylor, 2002; Sices *et al*, 2007; Hayiou-Thomas, 2008), the earlier developing articulatory aspects of speech, such as babbling and early sound development, require precise investigation.

From this articulatory standpoint, investigation of the physical mechanism of speech sound development with regard to feeding is vital because the two processes use similar muscle groups and movements, the learning and mastery of which involve sensory motor feedback (e.g., Parrell and Houde, 2019). Although evidence for a relationship between speech and non-speech mechanisms is mixed (Ruark and Moore, 1997; Watson and Lof, 2008; Bunton, 2008; Clark, 2008; Wilson *et* al, 2008;

Wilson and Nip, 2010; Wren *et al*, 2016), it seems improbable that the intense motor and somatosensory learning experience from early sucking behaviours in infancy could have no impact on subsequent speech sound development (Burr *et al*, 2020). Building on the presented evidence, and identified gaps in the literature, this study examined the direct relationship between feeding, NNS and speech sound development in early childhood.

5. Theoretical mechanisms

Pertinent theories that underpin the rationale for this study are outlined in the following sections. Evidence from studies that have explored sucking mechanisms for feeding, the early somatosensory experience of infants and the variability of child speech sound development is presented.

5.1. Sucking mechanisms for breast feeding, bottle feeding and non-nutritive sucking (NNS)

Several factors related to infant feeding, such as socioeconomic status and maternal education, are already known to impact speech sound development (Kramer and Kakuma, 2004; Reilly *et al*, 2010), but the potential association between speech sound development, infant feeding and sucking patterns remains underexplored. A number of studies cite the advantages of breastfeeding over bottle feeding, with positive cognitive outcomes cited for language and learning in later childhood (Oddy, Robinson and Whitehouse, 2012; Jedrychowski *et al*, 2012; Belfort *et al*, 2013; Lee *et al*, 2016; Huang, Vaughn and Kramer, 2016). While the alleged detrimental impact of NNS (dummy/finger sucking) on speech development has been widely debated (Fox, Dodd and Howard, 2002; Shotts, McDaniel and Neeley, 2008; Barbosa *et al*, 2009; Vieira, de Araújo and Jamelli, 2016; Pereira, Oliveira and Cardoso, 2017; Baker *et al*, 2018; Strutt, Khattab and Willoughby, 2011), the impact of different feeding and sucking behaviours on motor development for speech has not received such thorough investigation. From a mechanical perspective, different feeding and sucking behaviours present subtly different oro-motor experiences for the child. The act of dummy or digit sucking involves maintaining a synthetic teat in the mouth for a sustained period of time, which physically restricts the movements of some of the articulators for speech while in situ (Strutt, Khattab and Willoughby, 2021). Some children may use a dummy for much of the day while others may only use it at night. These different patterns of behaviour restrict movements for speech to different extents, but it is not currently clear whether there is an associated impact on early speech sound development (Burr *et al*, 2020). The mechanisms for successful bottle and breastfeeding are described and compared in the literature, with differences in sucking frequency, pressure and muscle activity highlighted (Woolridge, 1986; Eishima, 1991; Palmer, 1998; Neiva *et al*, 2003; Weiss, 2003; Geddes *et al*, 2008; Moral *et al*, 2010; Harding, 2014; Geddes and Sakalidis, 2015). Although previous research has described the impacts of different feeding methods and NNS behaviours on dentition and general oral development (Palmer, 1998), the direct relationship between feeding, sucking and speech sound development has not been thoroughly measured and explored.

An important consideration with regard to this relationship is the physical structure of the teat on a bottle and dummy, compared to a human nipple. The materials required for bottle feeding and NNS are largely stable and consistent. The bottle and synthetic teat both have physically stable forms and the rate of milk flow from the bottle is regularised by the size of the teat hole and the sucking action applied by the child (Eishima, 1991). Dummy sucking also involves a synthetic teat with a relatively stable form, for which the sucking mechanism more closely resembles bottle feeding than breastfeeding (Eishima, 1991).

In contrast to the synthetic teat used in bottle feeding and NNS, the human breast is considerably more malleable. During lactation, hormonal fluctuations influence human breast tissue on an hourly and daily basis, causing changes in breast volume and firmness, as well as the shape and elasticity of the nipple and areola complex (Elad *et al*, 2014; Alex, Bhandary and McGuire, 2020). To successfully feed from the breast, infants have to be responsive and adaptable to these changes (Elad *et al*, 2014). The human nipple is more elastic than a synthetic teat and is drawn further into the baby's mouth during feeding (Elad *et al*, 2014). Sustained oral pressure is required to maintain the 'latch', extending the nipple, and holding it in the mouth during feeding (Woolridge, 1986; Palmer, 1998; Elad *et al*, 2014). Motor movements of the jaw and tongue must be coordinated with the action of the mother's milk ejection reflex (Woolridge, 1986). In this way, breastfeeding may be seen as a more motorically dynamic and variable oral experience compared with bottle feeding. It is these differences in the sucking mechanisms, which are hypothesised in this study to influence early speech sound development.

5.2. Early somatosensory and motor experience

The relationship between the early development of sensory and motor processes by which children develop their speech sounds and how this relates to breast and bottle feeding mechanisms is currently not clear. Evidence for early motor activity driving somatosensory development and providing foundations for general oral motor programs has previously been highlighted in the literature, but without specific regard to feeding and motor development for speech (Khazipov *et al*, 2004).

Drawing on the evidence from studies of breast and bottle feeding (Eishima, 1991; Mizuno and Ueda, 2006; Elad *et al*, 2014; Harding, 2014), which describe subtly different motor mechanisms for breast and bottle feeding and NNS, this study has considered whether these diverse early somatosensory and motor experiences inform learning at a representational level, which then influences early speech sound development. We know that babies learn about objects in their environment by mouthing them (e.g., Ruff, 1984; Ruff and Dubiner, 1987; Groot, Lekkerkerk and Steenbekkers, 1998; Juberg *et al*, 2001), and it is understood that "*oral sensations provide an important interface experience, of both the objects in the mouth, and of the states and movements of the mouth itself*" (Haggard and de Boer, 2014, p.470). This "*somatosensory information from the oral tissues is important in motor control* […] *for speech.*" (Haggard and de Boer, 2014, p.482). The theoretical model of somatosensory processing presented by Haggard and de Boer (2014) describes three levels of perceptual somatosensory awareness, which underpin a child's early oro-motor experience (Figure 1).

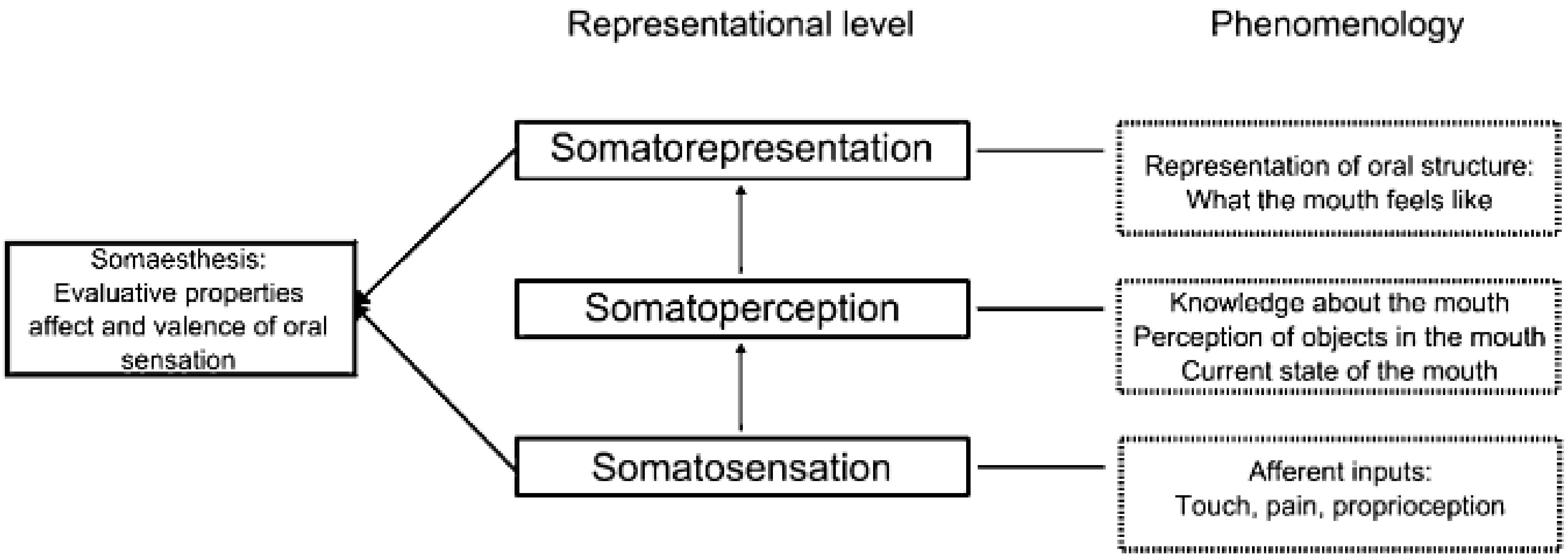

Figure 1. Three levels of somatosensory representation. Adapted from Haggard and de Boer, (2014)

When children suck a synthetic teat, human nipple, plastic dummy or their own finger, mechanoreceptors convey this rich and complex information to the brain (Poore and Barlow, 2009; Haggard and de Boer, 2014). This information is understood to be stored at the level of representation, from which feedforward and feedback processes inform speech motor planning, programming, and execution, as depicted in the model of the Speech Disorders Classification System (SDCS) (The Phonology Project, 2022) (Figure 2). The SDCS is a classification system for paediatric SSDs of unknown origin with a focus on classification by aetiology (Shriberg *et al*, 2010). The model highlights the role of motor and somatosensory input and processing in speech sound production (Figure 2). It is these influences from different patterns of early feeding and sucking behaviours that are hypothesised in this study to influence different patterns of speech sound development in childhood.

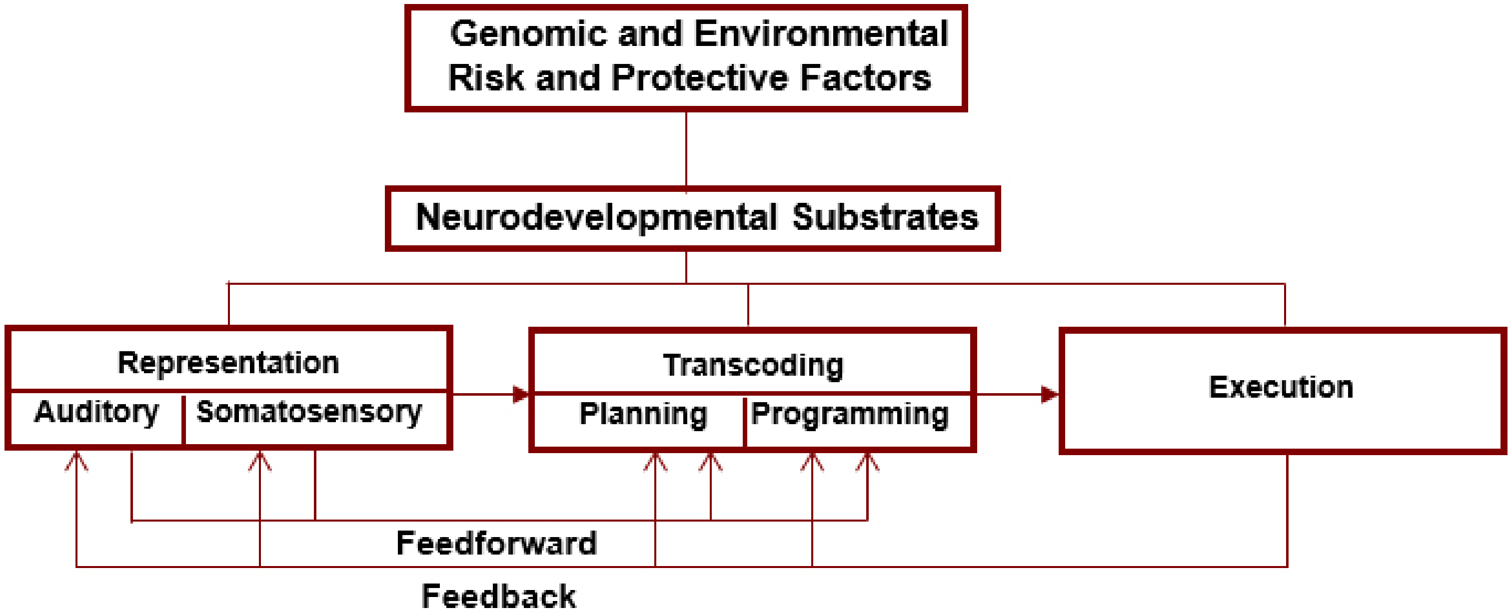

Figure 2. Adapted from the "Speech Disorders Classification System" (The Phonology Project website, 2022)

5.2.1. The relationship with speech processing

There are different theoretical models of speech processing which bring together the motor skills involved in speech with cognitive processes. One such model is the Stackhouse and Wells (1997) Psycholinguistic Framework, which presents the underlying speech processing skills, including phonological representations and motor programming and planning (Figure 3). This model can be used to identify the level of breakdown for children with SSD, and to guide clinical assessment and intervention.

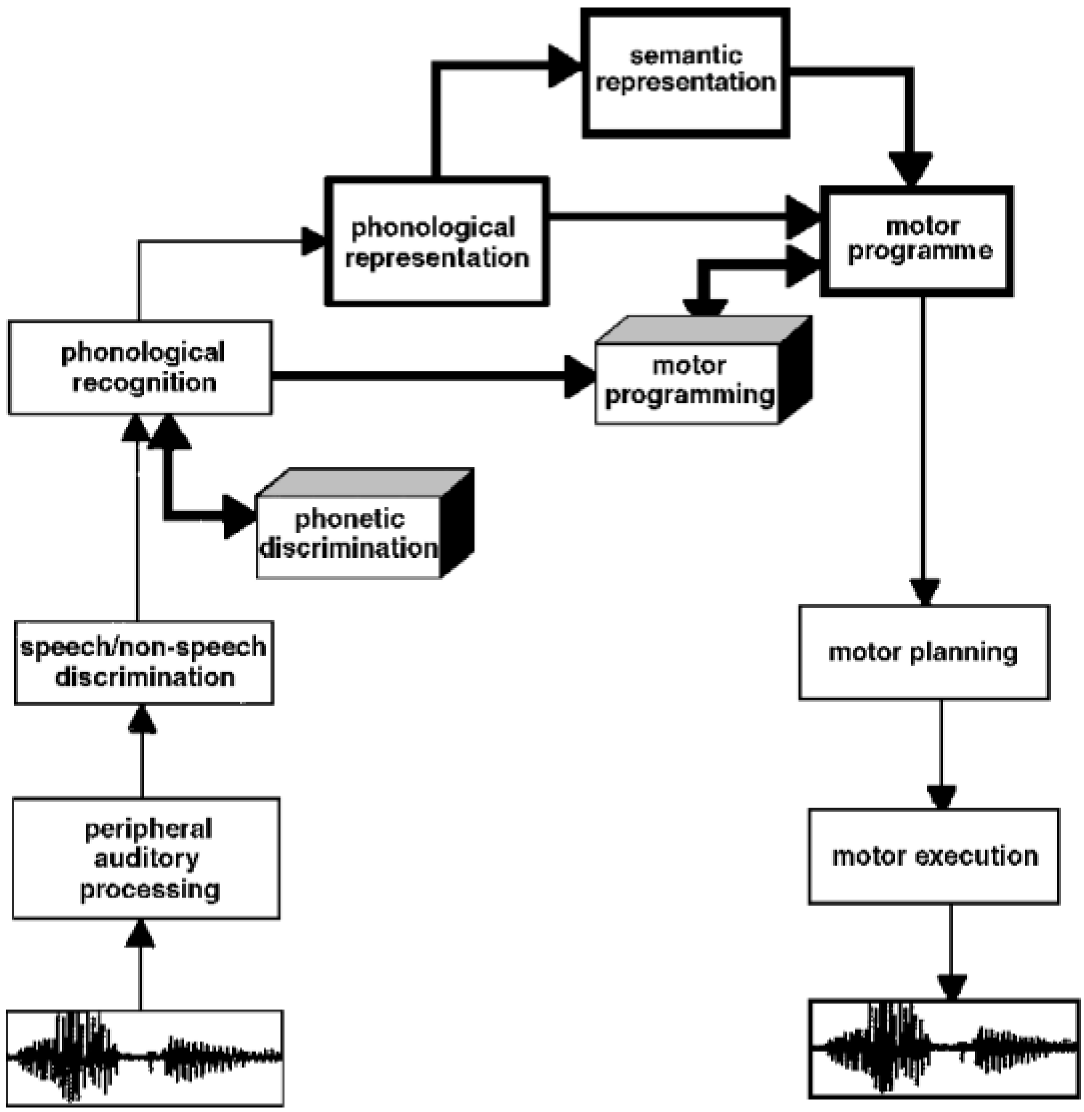

Figure 3. The Psycholinguistic Framework (Stackhouse and Wells, 1997)

We know from the evidence that information stored within the level of representation informs the motor planning and production of speech sounds (Stackhouse and Wells, 1997; Dodd and McIntosh, 2010; The Phonology Project, 2022). If this is the level at which learning from somatosensory and motor experience is stored, then it is conceivable that different sucking experiences may influence how children develop their speech sounds.

It is not suggested that different patterns of sucking in infancy have a causal effect on speech sound development, but rather that there may be some level of influence as part of a wider, highly complex picture of development that evolves over time. From a dynamic systems perspective, "*at a very global level, the constraints imposed by our biological heritage and […] similarities in human environments […] result in similar developmental outcomes*" (Thelen and Smith, 2007, p.302). This assertion helps to illustrate how, while we may observe differences and variability in early speech development, for the most part these reduce over time, and 'typical' developmental stages and outcomes are observed. For those children who continue to exhibit clinically significant developmental differences, the influences exerted by factors, such as early oro-motor experiences, may offer valuable insights into these patterns.

5.3. Variability in early speech sound development

Individual differences may arise from the influence of real-time events with the child's experience and environment, and at the microlevel, development is likely to appear very messy (Thelen and Smith, 2007). Because systems, such as early child speech sound development, are always in flux, the key dimension of interest is the relative stability of behaviour in context over time, from which we can gauge a developmental trajectory (van Geert, 2000).

At age two years, the child's speech sound system is in a state of flux with high variability, but at the same time, emerging signs of self-organisation and regulation, such as decreasing error rates for sounds known to develop earlier in childhood (Stoel-Gammon and Dunn, 1985; Grunwell, 1987; Vihman, 1996; Dodd *et al*, 2003, Broomfield and Dodd, 2004). Examination of the influence of sucking behaviours on speech sound development at this age could provide insights for comparison with development later in childhood to support early identification of SSD.

As the system self-organises and stabilises around age five years, less 'noise' is observed in the data as other influential factors (adult speech models, self-regularisation) come in to play (Vihman, 1996; Roulstone *et al*, 2009). At age five years, we may see the stronger influences of early sucking patterns on speech sound development as the variability observed in early development diminishes. This theory is not supported by Smith and Gerber (1993), who state that, if feeding had an influential role in speech sound development, then it would be unlikely to be seen at age five years without the effect also being observed in earlier development. However, it may be that the developmental 'noise' observed at age two years could mask some of the more enduring influences observed later in childhood.

Evidence from the theoretical mechanisms presented in this chapter support the rationale for examining whether early sucking behaviours (nutritive and non-nutritive) influence the development of speech sounds in young children. If a relationship between feeding, NNS and speech development in early childhood is identified, this will be vital to enable parents to make informed care choices from birth onwards, as well as informing national evidenced-based public health messages and maximising positive long-term health and social outcomes for children.

6. Justification for the systematic review

The described theoretical mechanisms have given rise to a number of questions with regard to the relationship between feeding, NNS and early speech sound development in childhood. To fully explore what is available in the current evidence in relation to these issues a systematic review of the available literature was conducted (Burr *et al*, 2020) (chapter two).

7. Potential benefits of this research

Identification of evidence indicating a relationship between feeding regime, NNS and speech sound development could add support to local and national public health strategies and campaigns. If different patterns of speech sound development are found to be associated with different feeding methods, an investigation could explore whether different SLT assessment and intervention methods are warranted for breast versus bottle fed children. A more targeted approach to assessment and/or intervention could increase efficiency and quality of SLT care, while greater awareness of early risk factors for SSD with regard to feeding and NNS could reinforce universal and targeted care packages delivered by Health Visitors and Midwives.

8. Health economics

Increasing financial pressures on NHS SLT services necessitate identification of opportunities for maximising therapeutic effectiveness and efficient use of limited resources. If the findings of this study support a focus on more targeted assessment and intervention for children with SSD, this will lead to more efficient use of SLT time and resources.

Highlighting these potential early risk factors for SSD with regard to feeding and NNS through public health messaging and awareness campaigns could achieve a certain preventative effect and reduce numbers referred for this client group. This could potentially reduce the current estimated annual £24 million burden on NHS SLT services, as well as wider financial implications for the national economy with regard to employment and social care.

Chapter Two: Systematic Literature Review

1. Overview of the chapter

This chapter presents the current available evidence for the relationship between infant feeding, NNS and speech sound development in the first five years of life. A published systematic review (Burr *et al*, 2020) is presented as a research output from this study (Appendix A). Relevant updates to the review, which have added to the available evidence since the publication by Burr *et al* (2020), are provided. Finally, the primary and secondary research questions for this study are outlined.

2. Summary of the systematic review

A systematic review of the literature was conducted to synthesise the evidence for the relationship between feeding and NNS on speech sound development in children. Searches were conducted using a range of electronic databases and a mainstream search engine. From 1031 initial results, four primary studies met the eligibility criteria for inclusion in the review (Burr *et al*, 2020).

To ensure all available evidence had been reviewed and appraised prior to completion of this PhD study, searches from Burr *et* al (2020) were repeated to identify relevant publications after February 2020. While a small number of new studies were identified that focussed on NNS and early speech sound development (Barca, 2021; Strutt, Khattab & Willoughby, 2021), none were found that explored the relationship between feeding, NNS and speech sound development.

The review found that the evidence for a relationship between feeding, NNS and speech sound development was limited, inconsistent and inconclusive (Burr *et al*, 2020). There was limited and mixed evidence for a relationship between feeding and speech sound development or SSD (Burr *et al*, 2020). Weak or no evidence for an association between bottle feeding and poorer speech development outcomes were indicated by the retained studies. Longer duration of breastfeeding was indicated in some studies to be beneficial for speech development (Burr *et al*, 2020). With regard to NNS, half of the included studies found some association with poorer outcomes for speech in early childhood, with longer duration of NNS associated with increased occurrence of SSDs (Burr *et al*, 2020).

The findings of the review highlight the gaps in the current evidence for the potential influence that early feeding and sucking behaviours may have on child speech sound development. Exploring this relationship is important because of the overlapping physical mechanisms for feeding, sucking and speech sound development, as described in chapter one of this thesis. Better understanding of the impact that early feeding and sucking behaviours may have on speech sound development in early childhood could inform clinical understanding of early assessment and intervention for SSDs. This could serve to improve outcomes for children with SSDs by optimising specialist clinical care, as well as reinforcing public health messages to support parents to make informed choices about how they care for their children.

3. Research aims, objectives and questions

The aim and objectives of this study build on the findings of the systematic review and the theoretical mechanisms that underpin clinical understanding of the motor and sensory mechanisms for feeding, sucking and speech sound development (chapter one). The hypothesis of this study is that different sucking behaviours (nutritive and non-nutritive) in early childhood influence speech sound development in different ways. This study aimed to establish whether there is a relationship between different infant feeding methods, NNS and speech sound development, to identify risk factors for potential SSD in pre-school children. The objectives of this study were:

- To understand and describe how the mechanisms of breast feeding, bottle feeding and NNS relate to early oral motor development for speech.

- To identify potential indicators of SSD with regard to feeding and sucking, for inclusion and consideration in routine SLT assessment to inform appropriate selection of specific clinical management and intervention approaches.

- To make recommendations for further study based on the findings of this work. This may include intervention studies, longitudinal follow-up or further investigation into determining the mechanism behind the influence that particular feeding regimes and NNS may have on early speech development.

- To make recommendations based on the findings of this study for SLTs and other health professionals, in supporting the early identification of children at risk of developing SSD.

- To identify any public health messaging with regard to infant feeding and NNS.

The research questions were developed from these objectives and the findings of the systematic review. The questions, and rationale for this study, were further informed and endorsed by patient and public involvement and engagement (PPIE) activities with families of children with SSD and health professionals (see chapter three, section three). Specifically, parents and professionals wanted to know whether SSD can be linked to some extent to a particular type of feeding or NNS. The research questions for this study were as follows:

Primary research question

Is there a relationship between infant feeding regime and speech development in the first five years of life?

Secondary research questions

- Is there a relationship between NNS and speech development in the first five years of life?

- Within a population of children diagnosed with SSD, are different patterns of speech disorder observed in children with different histories of infant feeding regime and NNS?

- What are the potential indicators of SSD with regard to feeding and NNS?

Chapter Three: Methodology

1. Overview of chapter

This chapter outlines the structure of this PhD study, and the three different strands, which it comprises. Details of the PPIE activities undertaken within this study are presented. The methodologies for each of the three strands of this study are described and directed acyclic graphs (DAGs) are presented to illustrate the nature of the association(s) of interest in each strand.

2. Strands of the thesis

A study design comprising three separate, but related, strands was devised to enable comprehensive examination of the relationship between feeding, NNS and speech sound development in the first five years of life. The inclusion of normative data from large-scale birth cohort studies (Strands One and Two) and clinical data from NHS caseloads (Strand Three) allowed for comparison of findings across the strands and data samples (Table 1).

Table 1. The three strands of this PhD study

<table>
<tr><td></td><td colspan="5">Age of Child</td></tr>
<tr><td></td><td>18 Months</td><td>25 Months</td><td>36 Months</td><td>48 Months</td><td>61 Months</td></tr>
<tr><td rowspan="2">Strand One
ALSPAC Data</td><td rowspan="2">Part A: Feeding & Parent Concern about Speech
(Questionnaire data)</td><td>Part B:
Feeding & Speech Sound Development
(Clinical speech assessment data of children with/without SSD compared with feeding history)</td><td colspan="2" rowspan="2"></td><td>Part B:
Feeding & Speech Sound Development
(Clinical speech assessment data of children with/without SSD compared with feeding history)</td></tr>
<tr><td>Part C:
NNS & Speech Sound Development
(Clinical speech assessment data of children with/without SSD compared with NNS history)</td><td>Part C:
NNS & Speech Sound Development
(Clinical speech assessment data of children with/without SSD compared with NNS history)</td></tr>
<tr><td rowspan="2">Strand Two
ALSPAC-G2 Data</td><td rowspan="4"></td><td colspan="3">Part A: Feeding & Speech Sound Development
(Clinical speech assessment data of children with/without SSD compared with feeding history)</td><td rowspan="2"></td></tr>
<tr><td colspan="3">Part B: NNS & Speech Sound Development
(Clinical speech assessment data of children with/without SSD compared with NNS history)</td></tr>
<tr><td rowspan="2">Strand Three
NHS Clinical Data</td><td colspan="4">Part A: Feeding & SSD
(Clinical speech assessment data of children with SSD compared with feeding history)</td></tr>
<tr><td colspan="4">Part B: NNS & SSD
(Clinical speech assessment data of children with SSD compared with NNS history)</td></tr>
</table>

3. Strand One: Avon Longitudinal Study of Parents and Children (ALSPAC)

This strand describes the first step in exploring the primary research question of this PhD study about whether there is a relationship between infant feeding regimes and speech sound development in the first five years of life. Using data from a birth cohort population sample, the Avon Longitudinal Study of Parents and Children (ALSPAC), the secondary research questions of whether there is a relationship between NNS and speech development in the first five years of life, and what potential indicators of SSD there may be with regard to feeding and NNS are explored.

This strand is comprised of three parts (Table 1):

A. the relationship between feeding regime (exposure variable) and parental concern about speech development at age 18 months (outcome variable)

B. the relationship between feeding regime (exposure variable) and speech error frequencies at ages 25 and 61 months (outcome variables)

C. the relationship between NNS (exposure variable) and speech error frequencies at ages 25 and 61 months (outcome variables).

3.1. An overview of ALSPAC

The ALSPAC study is a world-leading birth cohort study, which collected biological, environmental and lifestyle data from three generations of Bristol families in the early 1990s (ALSPAC, 2021). The aim of the study is "to understand the ways in which the physical and social environment interact, over time, with the genotype to affect health, behaviour and development" (Golding and the ALPSAC Study Team, 2004). The ALSPAC data used in this study were collected in the 1990s by a team of ALSPAC fieldworkers via face-to-face clinics, questionnaires and through access to patient records (where consent was given) (ALSPAC, 2021).

The ALSPAC study offers a large and rich population dataset, which includes specific variables for feeding, NNS and speech sound development for the age group of interest in this PhD study. For this reason, and with the support of PhD supervisors with experience of accessing and working with the dataset and ALSPAC study team, it was decided that the ALSPAC data should be used.

3.2. Research governance and ethics

This strand used existing data, which were collected prospectively in a community population study (ALSPAC). Ethical approval to collect the data was obtained when the study was set up and conducted in the 1990s. Permission to use the data for the purpose of this study was obtained in May 2016, following submission of a research proposal to the ALSPAC Executive Board for consideration (Appendix G).

3.3. Accessing ALSPAC data

The publicly available ALSPAC data dictionary and variable catalogue were accessed from the ALSPAC study website and were examined to determine which variables from the ALSPAC dataset would be used in the study. Support and guidance was provided from the ALSPAC study team by a Data Buddy, who was allocated to support identification and request of the required variables. A variable request form was completed and submitted to the ALSPAC study team. The Data Buddy prepared the requested data in Microsoft Excel format, which was then electronically sent via the University of Bristol Facility for the Upload of Large Files (fluff) platform to the PhD student. The data were further examined and explored using the software analysis programme STATA 15 (StataCorp, 2017).

3.4. Study Sample

The ALSPAC sample included all pregnant women resident in Avon, UK with expected dates of delivery 1st April 1991 to 31st December 1992 who had been invited to take part in the study. The initial number of pregnancies enrolled was 14,541 (for these at least one questionnaire had been returned or a "Children in Focus" clinic had been attended by 19th July 1999). Of these initial pregnancies, there was a total of 14,676 foetuses, resulting in 14,062 live births and 13,988 children who were alive at one year of age. A 10% sample of the ALSPAC cohort, known as the Children in Focus (CiF) group, attended clinics at the University of

Bristol at various time intervals between four and 61 months of age. The CiF group were chosen at random from the last six months of ALSPAC births (1,432 families attended at least one clinic). Excluded were those mothers who had moved out of the area or were lost to follow-up, and those taking part in other research. Clinical speech sound assessment data were collected at two age points (25 and 61 months), resulting in 779 speech samples for children aged 61 months.

3.4.1. Inclusion criteria

Part A included the whole ALSPAC cohort of 15,445 children. Parts B and C explored the 10% subset, the CiF group. In all cases, the maximum number of participants who have data available for all of the measures of interest (exposure, outcome and potential confounders) were included in the analysis.

3.4.2. Exclusion criteria

Children with the following diagnoses, which could impact early speech development, were excepted from the analysis where it was possible to identify and exclude them. Additional diagnoses, such as Down syndrome, cerebral palsy and global developmental delay were also recognised as having potential impact on speech development. It was not possible to identify children with these conditions within the data, and therefore these did not form part of the exclusion criteria. Children with English as an additional language were also excluded from the analysis as this represented a further significant confounding factor (Hambly *et al*, 2013).

- Sensorineural hearing loss
- Cleft Lip +/- Cleft Palate +/- sub-mucous cleft palate (SMCP)
- Premature birth – due to the impact of enteral feeding.

3.5. Plan for analysis

The software programme STATA 15 was used throughout this PhD study (StataCorp, 2017). Descriptive statistics were undertaken in the form of means, standard deviations and proportions. The first stage of analysis for each of parts A, B and C tested all variables for their association with the outcome variable. In all cases regression coefficients, *p* values and 95% confidence intervals (CIs) are reported. Statistical advice was sought on missing data and repeated measures. Variables with a *p* value of <.10 in univariable analyses were retained for use in the multivariable analyses. This more tolerant level was used in order not to miss any potentially influential variables at the point of univariable analysis (Wren *et al*, 2016). In all multivariable analyses $p<.05$ was used as the threshold for significance. Maternal age was retained in all regression models. This decision was based on evidence from Roulstone *et al* (2009), in a related study using the same data, which indicated a potential association with speech sound development.

3.5.1. Exposure variables

The exposure variables for Parts A and B of Strand One are taken from the ALSPAC parent self-report questionnaire data on feeding regime from the whole cohort at three age points (four weeks (categorical), six months (binary) and 15 months (categorical)). The three feeding groups are categorised as exclusive breastfeeding (from age four weeks to at least age six months), exclusive bottle feeding (started age four weeks or earlier and continued), and mixed feeding (both breast and bottle feeding used at some point between age four weeks and 15 months). Although data are available on feeding methods in the first three weeks of life, these have been disregarded for the purpose of this study because of the variability of feeding method that occurs during these first three weeks of life, as parents and infants settle in to feeding and establish a routine. By age four weeks, the feeding routine is likely to be more established and therefore a more reliable measure of feeding can be obtained at this point (e.g., Buxton *et al*, 1991). The criteria for exclusive breast feeding were selected with PhD supervisors. For the second time point for reporting feeding routine, data from age six months was used because this is an important point in typical speech development as it is when children move from cooing to babbling (Oller, 1980; Stark, 1980; Vihman, 1996). The primary interest of this study concerns the mechanism of feeding (i.e., bottle or breast), rather than milk type. It is acknowledged that, at the 15 month age point, children will have also been eating solids to varying extents, however this is not the focus of the present study. All subsequent references in the analysis to 'exclusive' breast or bottle feeding refer to milk feeding methods only. It is important to note that the data did not enable identification of those who may have responded to the questionnaire as breastfeeding their child, but via expression and bottle, rather than direct from the breast. It is, therefore, not possible to rule out some potential element of bottle fed breast milk within this sample.

Exact feeding group variable matches for the defined exposure criteria (section 3.2) were not available within the dataset for two of the three age points. At age four weeks, variables for the three main exposure groups were available in the dataset. At six months and 15 months, feeding groups were determined using new variables derived from the data set (

Table 2). Specifically, at age six months, new variables were derived from a variable for breast feeding from the original dataset (Question: *Did you breast feed?* Response: *'Yes, still breast feeding; Yes but stopped prior to age six months; Never breast fed')*. Because of the way these data were coded, it was not possible to determine exclusively breast fed children from mixed fed children and so a binary variable was derived for feeding at age six months. For the 15 month age group the exclusively breast fed group were defined as those who were reported at age 15 months not to have started formula milk at all, or to have started having it at, or after, age seven months (i.e. they were exclusively breast fed until at least age six months). The mixed fed group were selected as those who started having formula milk between age four weeks and six months. The exclusively bottle fed group were those who were reported at age 15 months never to have been breast fed (Table 2. Exposure variables: feeding groups by age).

Table 2. Exposure variables: feeding groups by age

	Feeding Group		
Age Point	**Exclusive Breast Fed**	**Mixed Fed**	**Exclusive Bottle Fed**
4 Weeks	Single, predetermined variable	Single, predetermined variable	Single, predetermined variable
6 Months	Novel variable created "Breast fed +/- Bottle"		Single, predetermined variable
15 Months	Derived from existing variable	Derived from existing variable	Single, predetermined variable

The exposure variables for Part C of Strand One were taken from the ALSPAC parent questionnaire data on NNS behaviours for the whole cohort at four age points (four weeks (binary variable), 15 months,24 months and 38 months (categorical variables) (Table 3). Data on digit sucking at age 4 weeks was not available within the ALSPAC dataset. NNS data at age 54 months were also available, however the numbers of observations for these groups were very small and so these data were excluded from the study.

Table 3. Exposure variables: NNS groups by age

	NNS Group	
Age Point	**Dummy Sucking**	**Digit Sucking**
4 Weeks	Yes/No	-
15 Months	Never / Sometimes / Mostly	Never / Sometimes / Mostly
24 Months	Never / Sometimes / Mostly	Never / Sometimes / Mostly
38 Months	Never / Sometimes / Mostly	Never / Sometimes / Mostly

3.5.2. Outcome variables

The binary outcome variable for part A was taken from the ALSPAC parent questionnaire variable, '*Are you worried about any aspects of your child's growth and development?*', where '*speech*' was one of five multiple choice responses provided at age 18 months.

In parts B and C, the outcome variable was taken from direct assessment at two time points and is a quantitative measure of speech sound error frequencies (ages

25 and 61 months). The assessment at age 25 months comprised a non-standardised, object naming assessment based upon work by Paden, Novak & Beiter (1987), aimed at identifying broad error patterns rather than specific phonological processes. This speech assessment contained 16 items that were considered to be common to the environment and vocabularies of most young British children (Appendix H). Testers recorded the participants' responses in the absence of audio or video equipment. The testers were psychology graduates who had received phonetic discrimination training and explanations on phonology from speech and language therapists. The responses were recorded and the numbers of errors for five different consonant sounds were counted (velars, consonant clusters, liquids, fricatives and postvocalic sounds) (Table 4). These classifications were selected to reflect the sound classes and syllabic shapes most actively emerging at this age point (Paden, Novak & Beiter, 1987). Two of the consonant classifications are based on place (velar, alveolar), two are based on manner (liquid, fricative) and two are based on phonotactic principles (clusters, postvocalic). Target words were selected accordingly to provide repeated opportunities for production of these target patterns.

The clinical speech assessment at age 61 months comprised an adapted version of the object-naming task administered at the age 25 month point. At this age children's speech would be more adult-like, therefore the words (n=20) selected included a higher proportion of consonant clusters and polysyllabic contexts (Appendix I). The responses for the 25 month and 61 month speech data were recorded, providing specific, quantifiable speech error frequency data. Error frequencies were counted for six classes of consonants based on the manner or place of articulation, specifically: velar, consonant cluster, liquid, fricative, postvocalic and alveolar sounds (Table 4). Although data on metathesis were also available, these were not used in the analysis because this is an error pattern rather than a class of consonant and also because only binary data were available and not continuous, as for the other measures.

Table 4. Description of speech sound errors and available data at ages 25 and 61 months

Speech Sound Error Type	Description	Examples	Available Data	
			25 Months	61 Months
Velar	Voiced (g) and voiceless (k) velar plosive	*Spa**g**hetti* *heli**c**opter*	✓	✓
Consonant Cluster	A group of consonants with no intervening vowel	*Butter**fl**y* ***gl**asses*	✓	✓
Liquid	A resonant, vowel-like consonant sound	*squi**rr**el* *ye**ll**ow*	✓	✓
Fricative	A consonant sound made with audible friction	*Chip**s*** *star**f**i**sh***	✓	✓
Postvocalic	A consonant that occurs after a vowel	*Glasse**s*** *stri**ng***	✓	✓
Alveolar	A sound made against or close to the alveolar ridge in the mouth	*Pho**t**ograph* *hippopo**t**amus*	✕	✓

3.5.3. Potential confounding variables

Several measures associated with SSD were explored and included as potential confounders in this study where these data were available within the existing dataset (Table 5). Maternal education was included in the analysis as a categorical variable (below O Level; O Level; above O Level) in line with similar approaches adopted in other studies in this field using similar data (Wren *et al.*, 2016). Home ownership was included as a binary variable (owned/privately rented; council rented/other) derived from a categorical variable available in the dataset. Due to small group sizes in the original variable, categories were collapsed to facilitate statistical analysis. Data on hearing impairment (diagnosis of otitis media with effusion (OME)) from pure tone audiometry assessment were grouped by severity (type AA: normal; type B: fluid in middle ear (unilateral); type BB: fluid in middle ear (bilateral); other: some Eustachian tube dysfunction). The language score (continuous) variable provides an overall score based on the parent questionnaire responses provided at age 38 months about the child's use and understanding of a range of vocabulary, plurals, past tenses, and their ability to combine words. Data for the Reynell Developmental Language Scales (RDLS) (Reynell, 1969) comprehension scores were transformed from a standardisation based on a mean of zero, to a standardisation based on a mean of 100 using the formula below. This was to reflect more closely the scoring used in clinical practice.

$$y = (15z) + 100$$

Table 5. Summary of potential confounding variables included in the analysis of Strand One

Grouped Variable	Variable	Data Source	Timing of data collection	Inclusion in Analysis (Part)
Demographic	Biological sex (categorical: male/female)	Birth records from midwife	Birth	A B C
	Maternal age at birth of child (continuous)	Midwife records	Recruitment to study	A B C
	Level of maternal education (categorical:): <O Level/O Level/>O Level)	Questionnaire to mother	32 weeks gestation	A B C
	Home ownership (categorical: owned/privately rented or council rented/other)	Questionnaire to mother	8 weeks gestation	A B C
Early speech and language performance	Word combination (categorical: babble/single words/2 words/3-4 word phrases)	Questionnaire to mother	Child age 24 months	B C
	Language score (continuous)	Questionnaire to mother	Child age 38 months	B C
	RDLS comprehension score (continuous)	Reynell Developmental Language Scales (Reynell, 1969)	Focus at 25 and 61 months	B C
Other early developmental variables	Weak sucking at age 4 weeks (categorical: yes/no)	Questionnaire to mother	Child age 4 weeks	A B C
	Hearing impairment (OME) (categorical: AA/B/BB/other)	Pure tone audiometry	Focus at 25 and 61 months	B C

DAGs set out the exposure, outcome and potential confounders and covariates included in the analyses for each of the three parts of Strand One of this PhD study (Figure 4, Figure 5 and Figure 6).

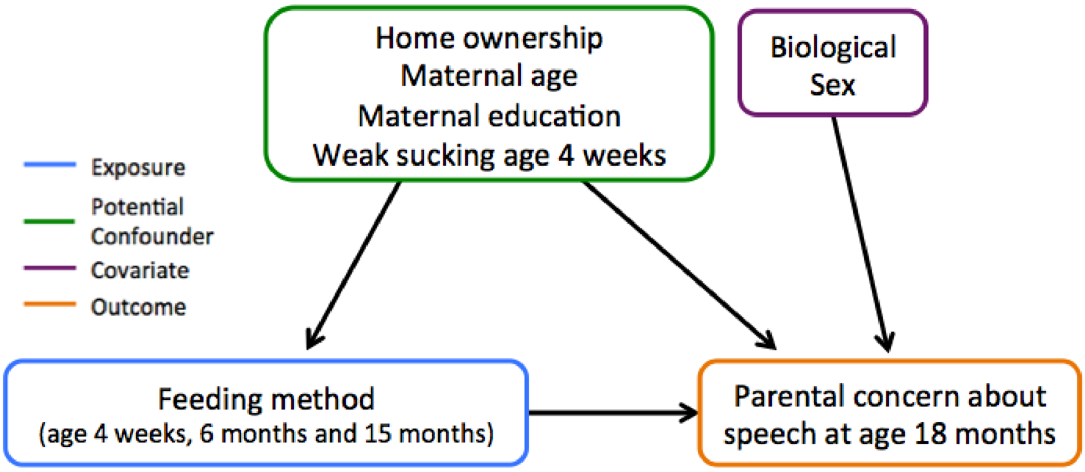

Figure 4. Directed acyclic graph (DAG) for Part A: the potential effect of feeding method on parental concern about speech at age 18 months

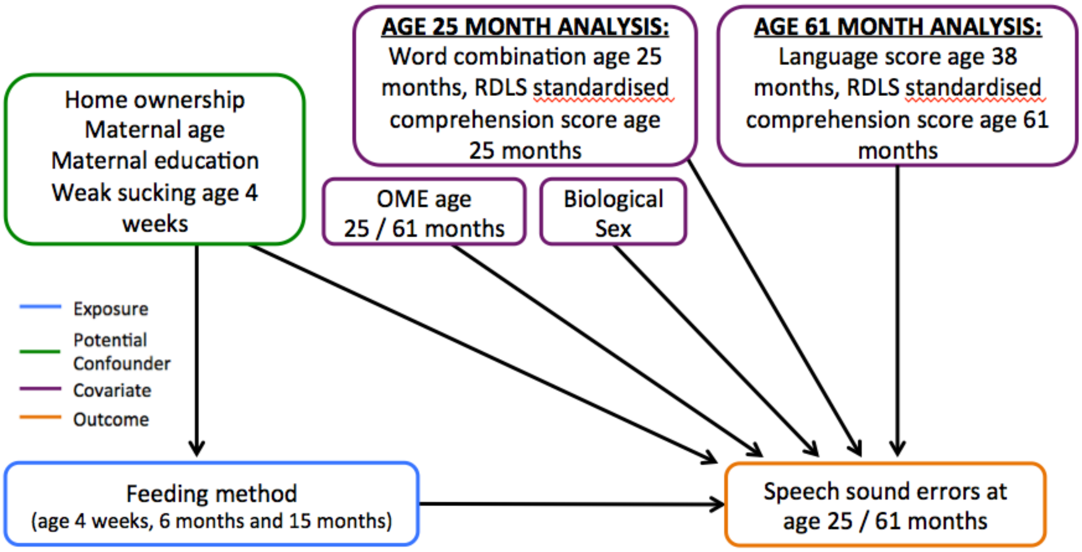

Figure 5. Directed acyclic graph (DAG) for Part B: the potential effect of feeding method on speech sound error frequency at ages 25 and 61 months

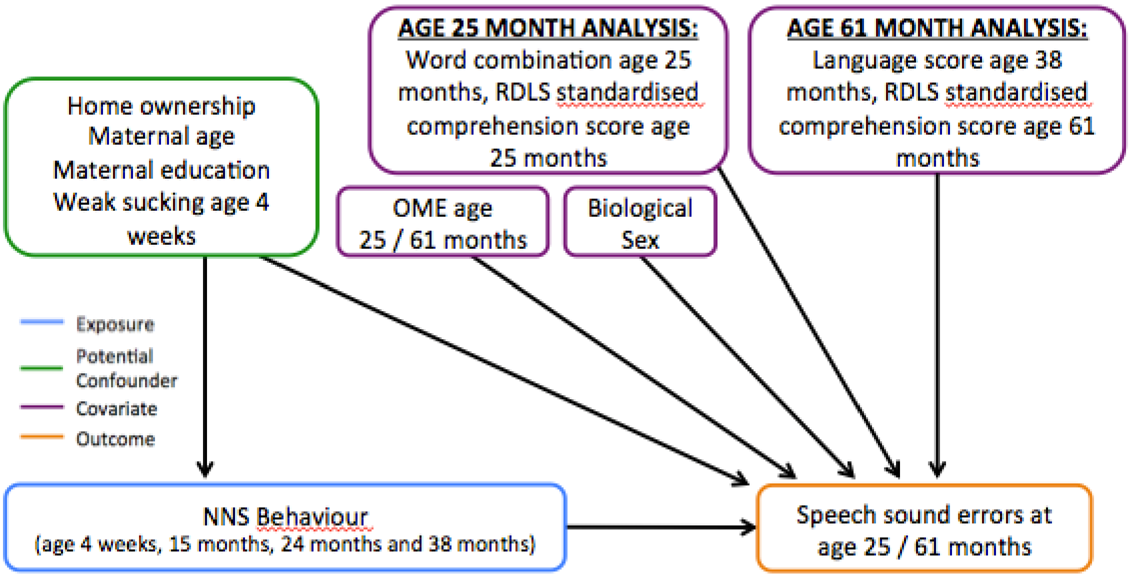

Figure 6. Directed acyclic graph (DAG) for Part C: the potential effect of NNS behaviour on speech sound error frequency at ages 25 and 61 months

3.5.4. Part A: infant feeding and parental speech concern at age 18 months

In part A, multivariable logistic regression analysis considered the relationship between each of these feeding regimes (at ages four weeks, six months and 15 months) and reported parent concern regarding speech development at age 18 months. Unadjusted and adjusted regression models are presented.

3.5.5. Part B (feeding) & Part C (NNS): 25 month speech sound error frequencies

The 25 month speech sound error frequency outcome variables are all continuous with velar, fricative and postvocalic errors showing skewed distribution (Appendix J). Linear regression models were initially trialled and likelihood ratio tests performed to explore the distribution of the residuals and determine whether linear regression model would be a good fit for the data. The skewed distribution of the residuals confirmed that negative binomial regression would provide a better and more accurate fit for the exposure variables. An unadjusted model was created first with just the exposure and outcome variables to explore the association. An adjusted model was then created including all of the potential confounders and covariates. For each of the five consonant types, unadjusted and adjusted regression models are presented in the results.

3.5.6. Part B (feeding) & Part C (NNS): 61 month speech sound error frequencies

The 61 month speech sound error frequency outcome variables in the original dataset are continuous but, unlike the 25 month outcome data, distribution of the 61 month error frequencies showed strong ceiling effects (Appendix K). To provide more accurate statistical modelling, binary variables were derived from the original variables. Logistic regression models were used in the analysis of the exposure (feeding methods or NNS) and outcome (speech error at 61 months) variables of interest. For each of the six consonant types, unadjusted (exposure and outcome) and adjusted (exposure, outcome, confounders and covariates) logistic regression models are presented.

4. Strand Two: ALSPAC Generation Two (ALSPAC-G2)

This strand explored the primary research question of this PhD study about whether there is a relationship between infant feeding regimes and speech sound development in the first five years of life. The secondary research questions of whether there is a relationship between NNS and speech development in the first five years of life, and what potential indicators of SSD may exist with regard to feeding and NNS were also investigated.

This strand is comprised of two parts (Table 1):

A. the relationship between feeding regime (exposure variable) and PCC scores at ages 24, 36 and 48 months (outcome variables)

B. the relationship between NNS (exposure variable) and PCC scores at ages 24, 36 and 48 months (outcome variables).

4.1. An overview of ALSPAC-G2

This strand used data from the second phase of the ALSPAC birth cohort study, known as ALSPAC Generation Two (ALSPAC-G2). The ALSPAC-G2 study currently collects a broad range of biological, environmental and lifestyle data on the offspring of the children who were born to mothers of the original ALSPAC study in the 1990s, providing a unique multi-generational cohort study (Lawlor *et al*, 2019).

As well as offering researchers access to the existing data being routinely collected by the ALSPAC-G2 study, researchers can work with the ALSPAC-G2 team to collect new data from the cohort through a variety of activities including face-to-face clinics and questionnaires. Prior to this PhD study, the ALSPAC-G2 data collection plan did not include specific clinical speech sound assessment data or specific, detailed parent questionnaire data on infant feeding and early NNS behaviours. Through support and discussions with an experienced ALSPAC-G2 study manager, a plan and proposal were developed to incorporate the collection of clinical speech samples into the routine face-to-face clinic appointments being carried out by the study (section 4.3.4.).

4.2. Research governance and ethics

This strand involved the collection of new data in the ALSPAC-G2 study. A research proposal was submitted to the ALSPAC Executive Committee and ethical approval was obtained from ALSPAC for the collection and use of the data. As this phase of the study required novel data collection, the required standard operating procedure (SOP) document was completed to provide the ALSPAC-G2 fieldworker team with clear instruction for questionnaire and clinical assessment administration (Appendix L). The ALSPAC-G2 fieldworker team obtained written consent from the parents of participants in line with the ALSPAC-G2 consent process.

4.3. Study Sample

Mothers who had participated in the original ALSPAC study as child participants (section 1.2) were invited to bring their children to routine study research clinics at the University of Bristol at ages 24, 36 and 48 months. Questionnaire data about feeding, NNS and developmental aspects was obtained from the mothers. Clinical speech sound assessment data were collected from the children at each session.

4.3.1. Inclusion criteria

In all cases, the maximum number of participants who had data available for all of the measures of interest (exposure, outcome and potential confounders and covariates) were included in the analysis.

4.3.2. Exclusion criteria

The exclusion criteria for this strand of the study include those described in section 1.2.2 and the following additional exclusions. These conditions were chosen because there were data available on these, but not others, such as cerebral palsy.

- Developmental Verbal Dyspraxia
- Genetic syndrome
- Learning disability
- English as a second or additional language

Children who had received regular speech and language therapy intervention targeting speech sounds were also excluded from the study, because of the direct potential influence intervention would have on their speech production in the clinical assessment. It was not possible to identify these children from Strand One because the data were not available to identify them.

4.3.3. Participant identification and recruitment

Potentially eligible participants for the study were identified by ALSPAC-G2 fieldworkers by application of the inclusion and exclusion criteria (sectons 4.4.1. and 4.4.2.) .

4.3.4. Data collection

Prior to each speech assessment, infant feeding and NNS data were collected by the fieldworkers as part of a larger parent questionnaire administered by the ALSPAC-G2 study. Face-to-face training was delivered to the fieldworker team on correct procedure for administering the clinical speech sound assessment , including how to set up and manage the resources (flipbook of picture stimuli, record form and audio recording equipment). To maximise the quality of modelling accuracy, specific training was provided on the correct modelling of individual speech sounds (C) and syllables (CV/VC). Training was also provided on how to cue children in to saying words in a picture-naming task if they were unable to spontaneously name the target object (Appendix L). Training was reinforced by customised written and video materials created for the fieldworker team to support ongoing supervision and training review. A further follow-up training session was delivered virtually later in the data collection period. Regular training review using the materials provided was recommended to the fieldworker team in order to maintain high quality stimulus modelling and assessment administration throughout the data collection period. The SOP, assessment forms and recording equipment were demonstrated and discussed with the fieldworker team during the face-to-face training session. The speech assessments were audio recorded in a quiet clinical room using a snowball iCE USB microphone. The microphone was connected directly to an ALSPAC-G2 laptop using free, open-source audio software Audacity. Speech assessments were administered during routine ALSPAC-G2 study clinic appointments for children aged 24, 36 and 48 months.

The audio recordings and assessment forms were securely sent to the PhD student by the ALSPAC-G2 study team as described in section 3.3. The PhD student, a qualified SLT, scored the assessments by listening back to the audio recordings and using the DEAP and TPT manuals. Consistency of scoring was achieved by the use of a guideline document for clinical decision-making developed and agreed between the PhD student and Academic Supervisor (both qualified SLTs) (Appendix M). Microsoft Access software was used to create a dataset, which was then sent securely to the ALSPAC-G2 study team for inclusion in the wider ALSPAC-G2 dataset. Additional variables, which represented potential confounding variables relevant to the study (see section 4.4.3. below), were identified and requested via the process detailed in section 3.3. The final dataset, including potential confounding variables and parent questionnaire data on feeding and NNS, was collated and prepared by the ALSPAC-G2 data buddy and transferred to the PhD student as described in section 3.3. Support for navigation of and familiarisation with the dataset, variable labels and formatting was available from the Data Buddy.

4.4. Plan for analysis

Data exploration and analysis were undertaken solely by the PhD student with advice from the ALSPAC Data Buddy and statisticians where appropriate. Appropriate descriptive statistics were performed and presented for all group sizes where $n>=10$ (means, standard deviations and proportions). This cut-off was agreed with a statistician to be appropriate to preserve data anonymity (Ritchie, 2019). The first stage of analysis for each of parts A and B tested all variables for their association with the outcome variable (univariable analysis). In all cases, regression coefficients, *z* scores, *p* values and 95% confidence intervals (CIs) are reported. Statistical advice was sought on missing data. Threshold *p* values were applied as described in section 1.3. Maternal age was retained in all regression models (see section 1.3). Consultation with a statistician determined that ordinary least squares regression was the most appropriate approach for analysing the PCC score data.

4.4.1. Exposure variables

The feeding exposure variables for this part of the study were derived from specific multiple choice questions and included in the parent questionnaire for the ALSPAC-G2 assessment clinic at ages 24, 36 and 48 months (Appendix N). Parents were specifically asked whether their child was exclusively breast fed, exclusively bottle fed or mixed fed at each of the ages four weeks, two-three months, four-six months and seven-nine months. Following discussion with PhD supervisors, it was decided that recall bias could best be mitigated by posing a question about a small age range (e.g. two-three months), rather than a specific age point (e.g. 12 weeks). An additional variable for feeding at age 12 months was available from the questionnaire data set by the ALSPAC-G2 team ("*has the child ever been breast fed?*"). From these data, a binary variable was derived for exclusively bottle fed children at age 12 months (yes/no). Five feeding exposure variables were then available from the dataset: feeding at age four weeks, two-three months, four-six months, seven-nine months and 12 months. For ease of reading, and to support comparison with other strands of this PhD study, these were renamed in the analysis as ages four weeks, 12 weeks, six months and nine months (Table 6).

Table 6. Exposure variables: feeding groups by age

	Exposure: Feeding Group		
Age Point	**Exclusive Breast Fed**	**Mixed Fed**	**Exclusive Bottle Fed**
4 Weeks	Single, predetermined variable	Single, predetermined variable	Single, predetermined variable
12 weeks	Single, predetermined variable	Single, predetermined variable	Single, predetermined variable
6 Months	Single, predetermined variable	Single, predetermined variable	Single, predetermined variable
9 Months	Single, predetermined variable	Single, predetermined variable	Single, predetermined variable
12 Months	Derived from pre-existing variable		Single, predetermined variable

The NNS exposure variables for this part of the study were also derived from specific binary response and multiple-choice questions as part of the parent questionnaire for the ALSPAC-G2 assessment clinic at ages 24, 36 and 48 months (Appendix N). Binary (yes/no) data on presence of NNS was obtained from parents with the question '*has your child ever sucked a dummy* OR *finger/thumb?'*. If NNS was present, parents were asked further multiple-choice questions to provide NNS frequency data for specific age points (ages six, 12, 24, 36 and 48 months) (e.g. *At age six months did your child suck their thumb most of the time/sometimes, or never?')* (Appendix N) (Table 7).

Table 7. Exposure variables: NNS groups by age

	NNS Group	
Age Point	**Dummy Sucking**	**Digit Sucking**
6 Months	Never / Sometimes / Mostly	Never / Sometimes / Mostly
12 Months	Never / Sometimes / Mostly	Never / Sometimes / Mostly
24 Months	Never / Sometimes / Mostly	Never / Sometimes / Mostly
36 Months	Never / Sometimes / Mostly	Never / Sometimes / Mostly
48 Months	Never / Sometimes / Mostly	Never / Sometimes / Mostly

4.4.2. Outcome variables

The clinical assessments selected for use in this study were the Toddler Phonology Test (TPT) (McIntosh and Dodd, 2011) and the Articulation and Oro-motor Assessment subtest of the Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd *et al*, 2002). These assessments were chosen because they are widely recognised by SLTs around the world as reliable clinical tools for speech sound assessment in young children. The Articulation and Oro-motor Assessment subtest was selected for its focus on the motor aspect of speech production, which aligns with the theoretical basis of this PhD study.

The assessments were scored by a qualified SLT. The outcome variables were derived from scores from clinical speech assessments carried out at ALSPAC-G2 clinics. Specifically, the were used at ages 24 months and 36/48 months respectively. Single word PCC (SwPCC) scores were calculated for all children who completed the single word naming subtest of each assessment. Connected speech (CsPCC) PCC scores were calculated for those children aged 36 and 48 months who completed the connected speech picture description task of the DEAP (Table 8). The connected speech picture description task forms part of a larger subtest within the DEAP (Phonology Assessment), which was itself not administered in this study. Calculation of all PCC scores was undertaken as specified in the TPT and DEAP assessment manuals (Dodd *et al*). SwPCC and CsPCC scores are the primary exposure variables of interest for this strand of the study (Table 8).

Table 8. Outcome variables: SwPCC and CsPCC scores

	Outcome: PCC Score	
Assessment Clinic Age	**SwPCC**	**CsPCC**
Age 24 Months	✓	-
Age 36 Months	✓	✓
Age 48 Months	✓	✓

4.4.3. Potential confounding variables and covariates

As in Strand One of this study, several measures associated with SSD were explored and included as potential confounders and covariates, where these data were available within the ALSPAC-G2 dataset (Table 9). Although it was not possible to replicate the variable categorisation used for maternal education and home ownership in Strand One of this study because the data were collected and coded differently, where possible these groups were collapsed or derived to be similar (section 3.2.5.). Limited data were available for early speech and language measures (syllable combination at age 12 months and word combination at age 24 months) (Table 9). Hearing impairment data were only available from parental questionnaires at age 12 months (*"Has the child been to the GP for ear infection in the past six months?"*) and 48 months (*"Has the child been to the GP for ear infection in the past 12 months?"*).

Table 9. Summary of potential confounding variables and covariates included in the analysis of Strand Two

Grouped Variable	Variable	Data Source	Timing of data collection
Demographic	Biological sex (categorical: male/female)	Birth records from midwife	Birth
	Maternal age at birth of child (continuous)	Midwife records	Recruitment to study
	Level of maternal education (categorical:): <O Level/O Level/>O Level)	Questionnaire to mother	32 weeks gestation
	Home ownership (categorical: owned/privately rented or council rented/other)	Questionnaire to mother	8 weeks gestation
Early speech and language performance	Syllable combination (categorical: yes/no)	Questionnaire to mother	Child age 12 months
	Word combination (categorical: yes/no)	Questionnaire to mother	Child age 24 months
Other early developmental variables	Weak sucking (categorical: yes/no)	Questionnaire to mother	Child age 4 weeks
	Ear infection (categorical: yes/no)	Questionnaire to mother	Child age 12 and 48 months

DAGs set out the exposure, outcome and potential confounders and covariates included in the analyses for each of the two parts of Strand Two of this PhD study (Figure 7 and Figure 8).

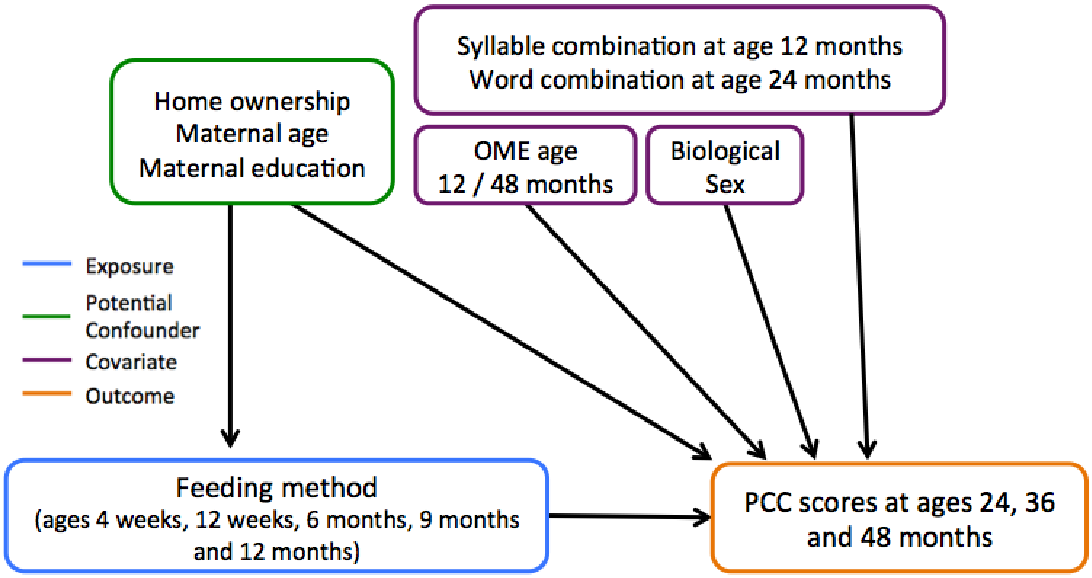

Figure 7. Directed acyclic graph (DAG) for Part A: the potential effect of feeding method on PCC scores at ages 24, 36 and 48 months

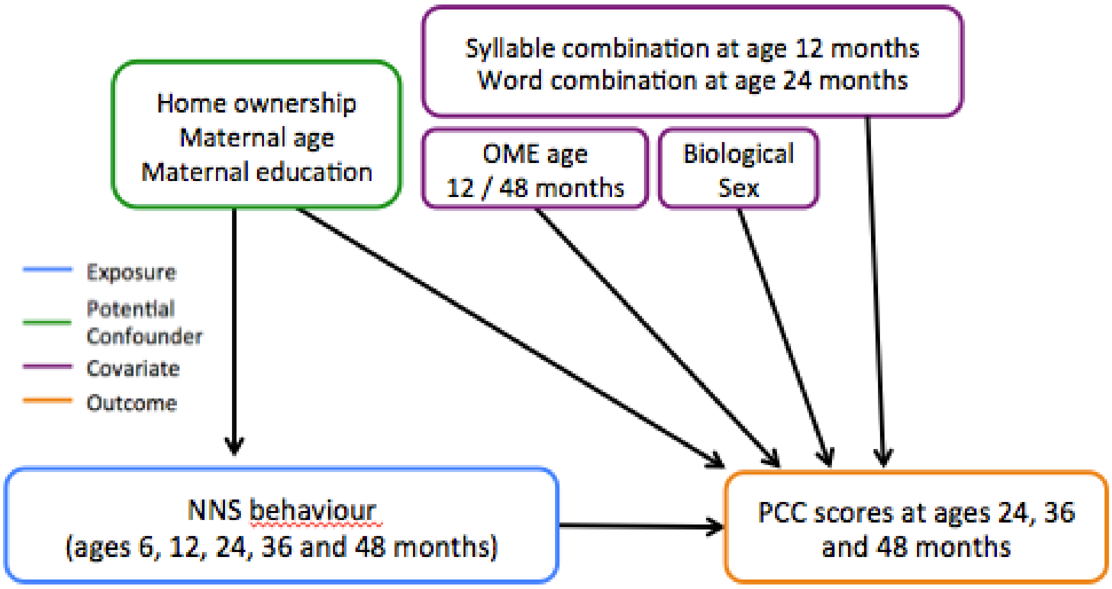

Figure 8. Directed acyclic graph (DAG) for Part B: the potential effect of NNS behaviour on PCC scores at ages 24, 36 and 48 months

4.4.4. Part A: Feeding and PCC score at ages 24, 36 and 48 months

In part A, least squares regression analyses considered the relationship between each of these feeding regimes (at ages four weeks, 12 weeks, six months, 9 months and 12 months) and SwPCC score. In the first phase of the analysis the SwPCC score was analysed with age included as a variable in the analysis. In this way the analysis controlled for age while allowing identification of broader associations. The outcome variable SwPCC scores was split into age groups (ages 24, 36 and 48 months) to facilitate exploration of age-specific conclusions. This two-phase analysis approach was repeated for the secondary outcome variable, CsPCC score. Unadjusted and adjusted regression models are presented.

4.4.5. Part B: NNS and PCC score at ages 24, 36 and 48 months

In part B, least squares regression analyses considered the relationship between dummy or digit use (at ages 24, 36 and 48 months) and SwPCC (24, 36 and 48 months) and CsPCC scores (at ages 36 and 48 months). The same approach to analysis was taken as described for part A (section 1.1.1). Unadjusted and adjusted regression models are presented.

5. Strand Three: NHS Clinical Caseload Data

This strand describes the final step in exploring the primary research question of this PhD study about whether there is a relationship between infant feeding regimes and speech sound development in the first five years of life. Using data from NHS clinical caseloads, the secondary research questions are explored regarding whether there is a relationship between NNS and speech development in the first five years of life; whether, within a population of children diagnosed with SSD, there is an association between severity of SSD and pattern/type of infant feeding regime and NNS.

This strand is comprised of two parts (Table 1):

A. the relationship between feeding regime (exposure variable) and PCC scores between ages two-five years (outcome variables)

B. the relationship between NNS (exposure variable) and PCC scores between ages two-five years (outcome variables).

5.1. Research governance and ethics

Full ethical approval was sought from the Health Research Authority (HRA) for this strand of the study (Appendix O). Written information about the study was provided in the form of a Participant Information Sheet (PIS) for the adult and child, and an accessible information version was also made available (Appendices P-R). Informed written consent (accessible version also available) was obtained from the adult with parental responsibility (Appendices S and T).

5.2. Study Sample

The clinical sample was accessed via the clinical team in which the PhD student worked as an SLT. Parents of children who were on NHS SLT clinical caseloads between January 2018-December 2018, and September 2019-February 2021[1] were contacted by their local NHS clinical SLT service to invite them to participate in the

[1] The break in recruitment was as a result of the PhD student taking maternity leave from January-September 2019.

study. During the research appointment, a parent questionnaire was completed to confirm eligibility to participate in the study and to provide data for early feeding methods and NNS behaviours (exposure variables). Clinical speech assessment data were also collected.

5.2.1. Inclusion criteria

All children aged two-five years with a diagnosis of SSD who were on the clinical caseload of the paediatric NHS SLT team at the time of recruitment.

5.2.2. Exclusion criteria

The exclusion criteria applied in this strand of the study was the same as that applied in Strand Two, as described in section 2.2.2.

5.2.3. Participant identification and recruitment

Parents of children who had been given a diagnosis of SSD following assessment by an SLT but had not yet received direct SSD therapy were approached by a therapist about participating in the study. Interested parents were contacted and booked for a research clinic appointment to give consent and complete the assessment. The process of participant identification and recruitment for this study is described in Appendix U. The proposed recruitment process and plan were presented during a clinical team meeting of around 70 SLTs. Clinicians were invited to comment and ask questions about the proposed plan in order to inform and optimise the participant recruitment process. Key clinical and locality-specific issues were identified and resolved through this engagement activity. Written and video feedback was informally captured with individuals from the clinical team, who expressed increased confidence in supporting and recruiting to the study as a result of being involved and engaged in the design process. Throughout the recruitment period open communication channels were maintained with clinical staff to resolve issues and ask questions as needed, to maximise support for the clinical team. Electronic and hard copies of the finalised participant identification and recruitment process were disseminated throughout the clinical team. Hard copy Clinic Information Packs were created and provided to each recruiting clinic as a reference resource for clinicians. Each pack comprised a brief study background, inclusion and exclusion criteria and recruitment process flowchart for the recruiting clinician (Appendix U), copies of the parent consent (Appendix S), PIS (Appendices R and P) and accessible information versions of the consent form and PIS (Appendices Q and T). The equipment used for data collection is described in section 4.3.3.

5.3. Plan for analysis

Descriptive statistics, univariable and multivariable analyses were undertaken following the same approach as Strand Two, as described in section 2.3 and sections below.

5.3.1. Exposure variables

The exposure variables for this strand of the study were obtained using the same parent questionnaire as described in section 2.3.3. After written consent was obtained, the questionnaires were completed at the beginning of the research appointment in a clinic setting local to the parents' home.

5.3.2. Outcome variables

The outcome variables for this strand of the study were obtained using the same clinical speech assessment as described in section 2.3.4. The speech assessment was completed in a clinic setting during the research appointment. Scoring of the data was undertaken in the same way as described in section 4.3.4., using the guideline scoring document (Appendix M).

5.3.3. Potential confounding variables

This strand constitutes exploratory work with a pragmatic sampling frame. The number of potential confounding variables were limited by the complexity of the consent process, which is reflective of the challenges of undertaking research within clinical practice. A single covariate, biological sex, was easily collected from clinical records for each participant (categorical: female/male).

DAGs set out the exposure, outcome and covariate included in the analyses for each of the three parts of Strand Three of this PhD study (Figure 9 and Figure 10).

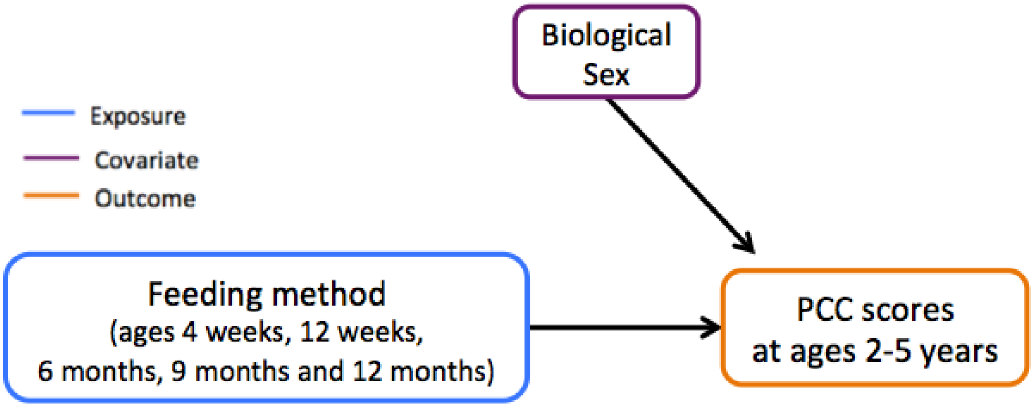

Figure 9. Directed acyclic graph (DAG) for Part A: the potential effect of feeding method on PCC scores between ages 2-5 years

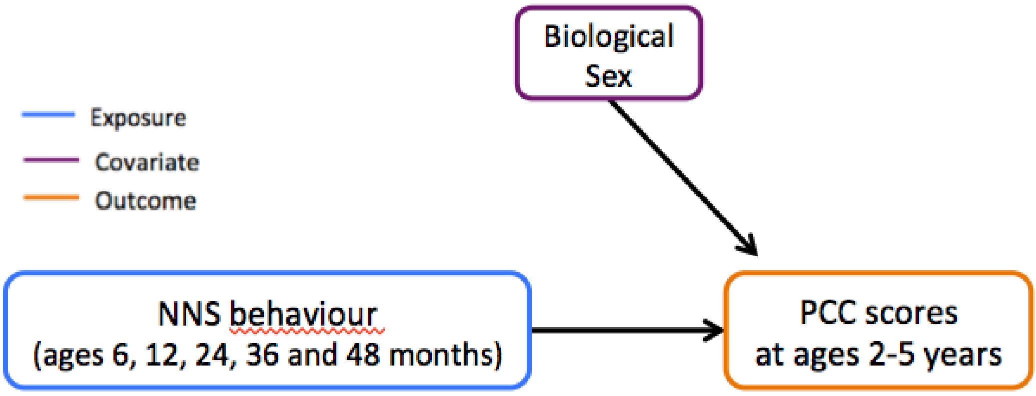

Figure 10. Directed acyclic graph (DAG) for Part B: the potential effect of NNS behaviours on PCC scores between ages 2-5 years

5.3.4. Part A: Feeding and PCC score between ages 2-5 years

In part A, least squares regression analyses considered the relationship between each of the feeding regimes (at ages four weeks, 12 weeks, six months, nine months and 12 months) and SwPCC score. The analysis included age as a variable. In this way the analysis controlled for age while allowing identification of broader associations. This approach was repeated for the CsPCC score. Unadjusted and adjusted regression models are presented.

5.3.5. Part B: NNS and PCC score between ages 2-5 years

In part B, least squares regression analyses considered the relationship between dummy or digit use (at ages 24, 36 and 48 months) and SwPCC (24, 36 and 48 months) and CsPCC scores (at ages 36 and 48 months). The same approach to analysis was taken as described for part A (section 4.3.4) and section 6.1.2.

Unadjusted and adjusted regression models are presented.

6. Patient and public involvement and engagement (PPIE)

PPIE activities to inform this study aimed to present the research topic to parents of young children to gather their thoughts and feedback on the importance of the research topic for them, and why they felt this way (NIHR, 2012). The first PPIE activity undertaken within this study was a face-to-face meeting at a children's centre. The venue was selected for its central location, family-centred facilities and high-level of use by local parents with young children. The PPIE event was advertised with posters placed in local SLT and GP clinics, early years settings, and also on social media (Appendix B). Six participants attended the 90 minute event. Information about the study was presented verbally to participants for discussion and comment (Appendix C). Parents were asked what information they would want, or expect to get, from the research. Feedback about the PPIE activity was collected from participants through brief written questionnaires (Appendix D).

To maximise public engagement and increase representativeness of the PPIE participants informing the study, an online forum was established via a website platform hosted by children's communication charity (Afasic, 2022) to enable greater accessibility to a larger and more diverse range of people. Information about the study was presented via an online discussion forum platform hosted by the charity (Appendices C and E). The online discussion board was advertised via popular social media platforms using hash tags (#) and handles (@) to maximise reach and visibility. Although the website received 129 visits, there was no active engagement with the discussion forum. Reasons for this may have included the requirement for account creation prior to using the platform and registration emails being lost in participants' spam email folders.

A final PPIE activity was undertaken directly on social media using a free polling app. The poll was advertised and shared in social media using hash tags and handles, as for the online forum, and the same questions were applied (Appendix E). The poll received 1190 visitors in the first month, with 149 completed responses by parents across the UK. A total of 61 parents registered for continued involvement in an online parent forum to support the study in the longer term.

The PPIE activities for this study enhanced our understanding of the relevance to parents of the relationship between feeding methods, non-nutritive sucking (NNS) and speech development. Details of the PPIE activities undertaken for this study have been presented at conference (Burr, 2017) (Appendix F).

Chapter Four: Results for Strand One ALSPAC Dataset

1. Overview of the chapter

This chapter presents the results from Strand One of this study, which is comprised of three parts. Part A examined the relationship between feeding regime and parental concern about speech development at age 18 months. Part B examined the relationship between feeding regime and speech error frequencies at ages 25 and 61 months. Finally, Part C examined the relationship between NNS (exposure variable) and speech error frequencies at ages 25 and 61 months (outcome variables). Brief summaries of the results for each part of the strand are provided as well as a final summary of the results of the whole strand.

2. Part A: infant feeding and parental concern about speech development

This section examines questionnaire data about infant feeding regime from the whole ALSPAC cohort to explore relationships between feeding regime and parental concern regarding speech sound development as reported at age 18 months.

2.1. Sample size

Prior to conducting the analysis, the original dataset (*n*=15,445) was examined for participants who met the inclusion criteria (see chapter three section 3.2.1.). After exclusions, 9064 (58.69%) children were identified for inclusion in the study, of whom 8606 (55.72%) (female *n*=4168, 48.43%; male *n*=4438, 51.57%) had available data for the outcome variable of interest, parental concern about speech development at age 18 months. Figure 11 illustrates the derivation of participants for this part of the study and the sample size available for feeding groups at each of the three ages included in the analysis.

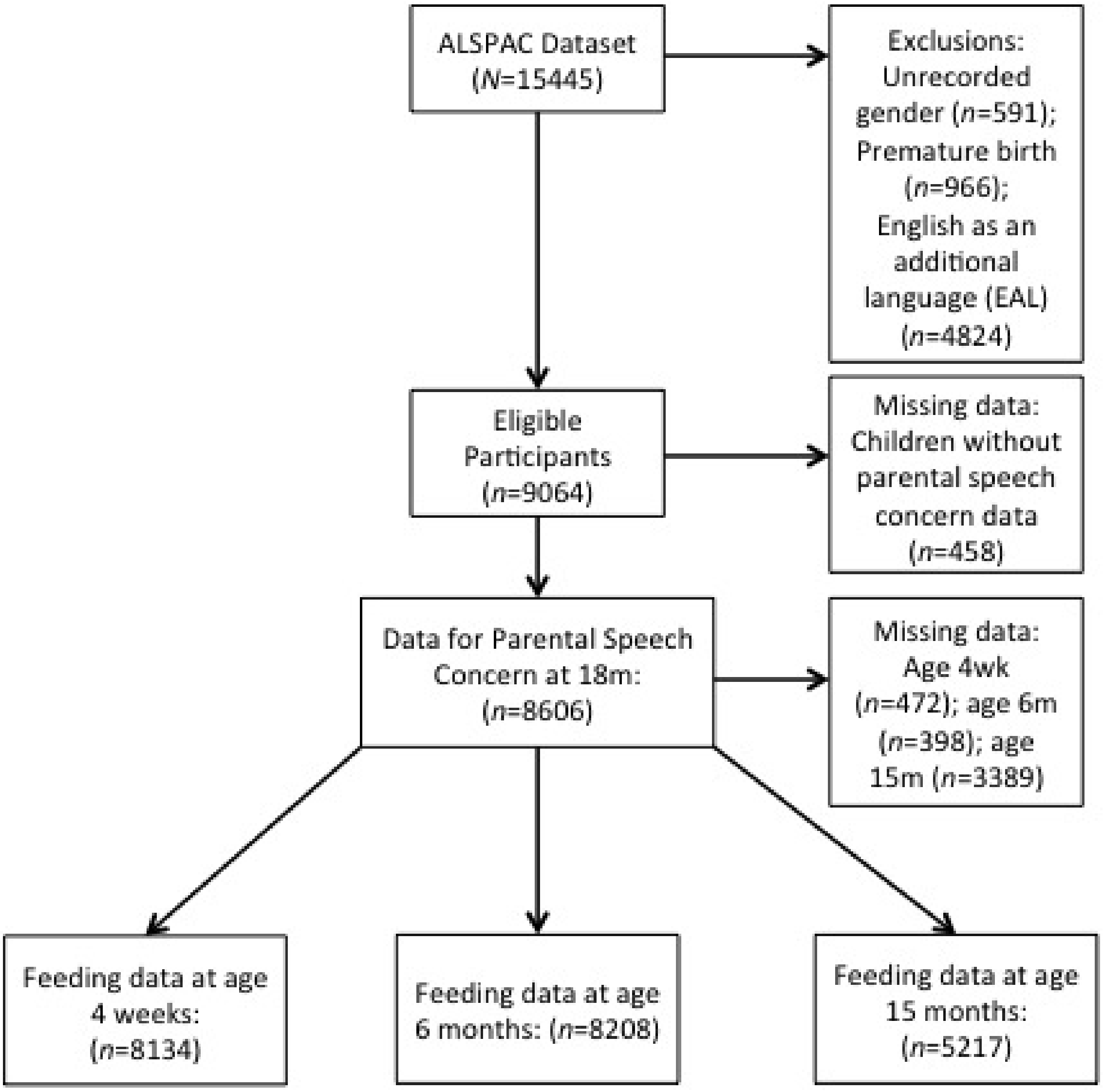

Figure 11. Derivation of participants for Strand One Part A

2.1.1. Exposure variables: feeding groups

The proportions for males and females across the feeding groups were broadly representative of the whole ALSPAC dataset (Table 10). At age 4 weeks, the largest proportion of children were exclusively breast fed (*n*=3688, 45.34%), followed by exclusive bottle feeding (*n*=3035, 37.31%) and mixed feeding (*n*=1411, 17.35%). At age 6 months the largest proportion of children were breast/mixed fed (*n*=6376, 77.68%). At age 15 months the largest proportion of children were mixed fed (*n*=2940, 54.70%).

Table 10. Exposure variables: feeding groups by age

	Feeding Group		
Age	**Breast fed**	**Mixed fed**	**Bottle fed**
4 Weeks (*n*=8134)	***n*=3688** (Female n=1834, 49.73%)	***n*=1411** (Female n=682, 48.33%)	***n*=3035** (Female n=1444, 47.58%)
6 Months (*n*=8208)	***n*=6376** (Female n=3112, 48.81%)		***n*=1832** (Female n=881, 48.09%)
15 Months (*n*=8104)	***n*=334** (Female n=157, 47.01%)	***n*=2940** (Female n=1422, 48.37%)	***n*=2101** (Female n=995, 47.36%)

2.1.2. Potential confounding variables

Summary statistics for each of the confounding variables and covariates (Figure 4) are provided (Table 11 and Table 12) for children who have available data on the outcome variable of interest (parental speech concern at age 18 months, n=8606). Children whose parents reported that they did not have a weak suck at age 4 weeks were in the majority, with 19.82% (n=1389) reported to have weak sucking at age 4 weeks. A large proportion of children were born to mothers with qualifications above O Level (n=4034, 48.04%). Children of mothers with qualifications below O Level constituted the smallest group (n=1331, 15.85%). The majority of children in the sample lived in owned or privately rented homes (n=7233, 86.08%). The summary data for maternal age showed little difference between the biological sexes (Figure 12).

Table 11. Sample size (*n*) for categorical potential confounding variables, by biological sex

Confounding Variable		Biological sex: Female *n* %	Male *n* %	Total *n* %
Weak Sucking at Age 4 Weeks	No	**3458** 49.35	**3549** 50.65	**7007** 100.00
	Yes	**626** 45.07	**763** 54.93	**1389** 100.00
Maternal education	< O Level	**631** 47.48	**700** 52.59	**1331** 100.00
	O Level	**1463** 48.24	**1570** 51.76	**3033** 100.00
	> O Level	**1973** 48.91	**2061** 51.09	**4034** 100.00
Home ownership	Owned / privately rented	**3479** 48.10	**3754** 51.90	**7233** 100.00
	Council rented / other	**581** 49.66	**589** 50.34	**1170** 100.00

Table 12. Summary statistics for continuous potential confounding variable maternal age

	Biological sex			
	Female (*n*=4168)		Male (*n*=4438)	
	Mean s.d	Median IQR	Mean s.d	Median IQR
Maternal age	28.64 4.58	29 26-32	28.85 4.68	29 26-32

Note: s.d. = standard deviation. IQR = interquartile range.

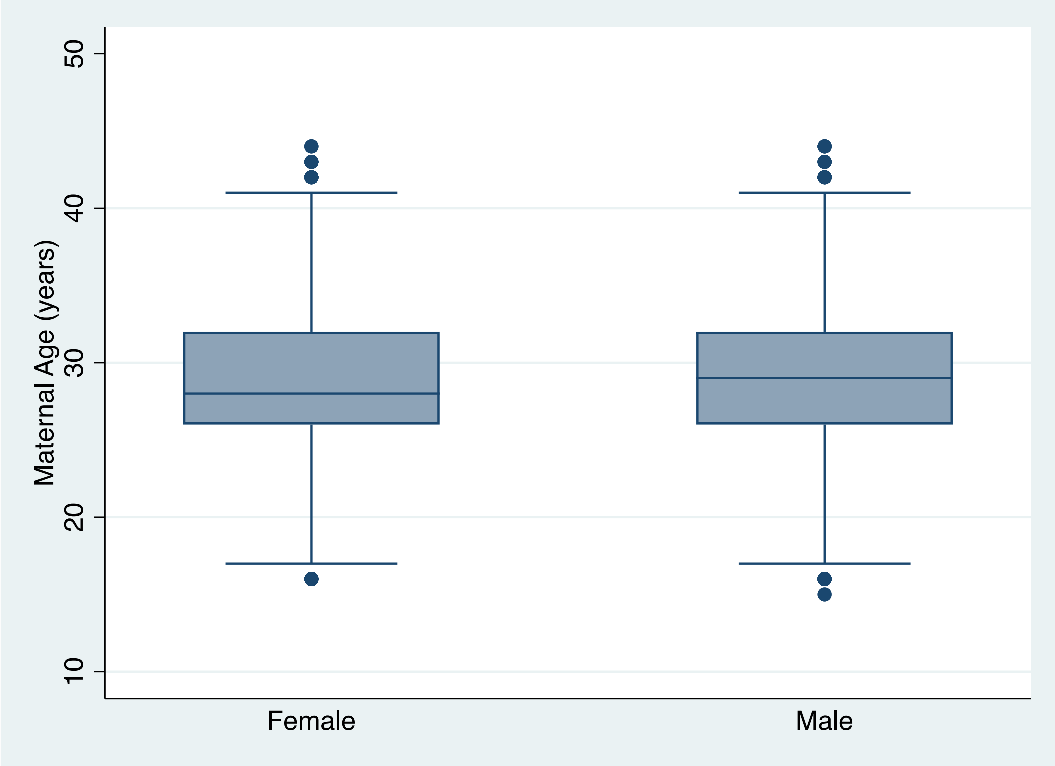

Figure 12. Box and whisker plot of maternal age by biological sex (*n*=8606)

2.1.3. Outcome variable: parental speech concern at age 18 months

Over 91% (*n*=7886, 91.63%) of parents reported no concerns about their child's speech development at age 18 months (Table 13). Of the 8.37% (n=720) of parents who were concerned, 63.44% (*n*=452) of the children were male.

Table 13. Sample (*n*) for outcome variable parental concern about speech at age 18 months

Parental speech concern at age 18 months (*n*=8606)	
No concern	**Concern**
n=7886 (female n=3900, 49.45%)	*n*=720 (female n=268, 37.22%)

2.2. Data analysis: parental speech concern at 18 months

Univariable logistic regression analysis of the potential confounder variables and covariates associated with parental concern about speech development at age 18 months indicated that biological sex (OR 1.65 [95% CI 1.41,1.93], z=6.24, p<.001) and weak sucking at age 4 weeks (OR 1.61 [95% CI 1.34,1.94], z=5.08, p<.001) also had p <.10 for inclusion in further analysis (Table 14). Maternal education (OR

1.01 [95% CI 0.90,1.12], *z*=0.09, *p*=.926) and home ownership (OR 1.12 [95% CI 0.90,1.39], *z*=1.00, *p*=.315) both had *p* >.10. To retain a measure of SES for the multivariable analysis, home ownership was retained due to the smaller likelihood ratio *p* value compared with maternal education. Maternal age was also retained (OR 0.99 [95% CI 0.97,1.00, *z*=-1.39, *p*=.164) (see section 2.2).

Table 14. Univariable logistic regression model results for potential confounder variables and covariates associated with parental concern about speech development at age 18 months (*n*=8606)

<table>
<tr><th rowspan="2">Variable
(n)</th><th rowspan="2">Category[a]</th><th colspan="3">Parental Concern about Speech at age 18 Months</th></tr>
<tr><th>OR
[95% CI]</th><th>z</th><th>p</th></tr>
<tr><td colspan="5">Demographic variables</td></tr>
<tr><td rowspan="2">Biological Sex[b]
(n=8606)</td><td>Female</td><td>1.00</td><td>-</td><td>-</td></tr>
<tr><td>Male</td><td>1.65
[1.41,1.93]</td><td>6.24</td><td><.001</td></tr>
<tr><td rowspan="2">Home ownership[b]
(n=8403)</td><td>Owned / priv rent</td><td>1.00</td><td>-</td><td>-</td></tr>
<tr><td>Council / other</td><td>1.12
[0.90,1.39]</td><td>1.00</td><td>.315</td></tr>
<tr><td colspan="2">Maternal Age[c] (n=8606)</td><td>0.99
[0.97,1.00]</td><td>-1.39</td><td>.164</td></tr>
<tr><td rowspan="3">Maternal education[b]
(n=8398)</td><td>< O Level</td><td>1.00</td><td>-</td><td>-</td></tr>
<tr><td>O Level</td><td>1.06
[0.84,1.34]</td><td>0.47</td><td>.641</td></tr>
<tr><td>> O Level</td><td>1.03
[0.82,1.29]</td><td>0.25</td><td>.805</td></tr>
<tr><td colspan="5">Early developmental variables</td></tr>
<tr><td rowspan="2">Weak Sucking 4 weeks[b]
(n=8396)</td><td>No</td><td>1.00</td><td>-</td><td>-</td></tr>
<tr><td>Yes</td><td>1.61
[1.34,1.94]</td><td>5.08</td><td><.001</td></tr>
</table>

Note: [a]For categorical variables only. [b]Categorical variable. [c]Continuous variable. Owned / Priv Rent = Owned/privately rented.

Univariable analysis for the outcome variable of feeding method at ages 4 weeks and 15 months indicated significant associations (

Table 15), which were taken forward for further model adjustment (Table 16). Feeding method at age 6 months did not show an association with parental concern about speech at age 18 months (exclusive bottle feeding: OR 1.11 [95% CI 0.93,1.34], z=1.16, p=.246) and so further adjustment of this model was not made

Table 15).

Table 15. Univariable logistic regression results for feeding and parental concern about speech at age 18 months

Exposure variable: feeding method		Outcome variable: parent concern about speech at age 18 months		
		OR [95% CI]	*z*	*p*
Age 4 weeks	Breast fed	1 [-]	-	-
	Mixed fed	1.09 [0.87,1.36]	0.72	.473
	Bottle fed	1.22 [1.02,1.45]	2.23	**.026**
Age 6 months	Breast / mixed fed	1 [-]	-	-
	Bottle fed	1.11 [0.93,1.34]	1.16	.246
Age 15 months	Breast fed	1 [-]	-	-
	Mixed fed	2.00 [1.17,3.42]	2.55	**.011**
	Bottle fed	1.92 [1.12,3.30]	2.37	**.018**

The results from the unadjusted model (Table 16) suggest that there is a strong association between feeding method at age 4 weeks and parental concern about speech development at age 18 months. Parents of children who were exclusively bottle fed at age 4 weeks were 22% more likely to be concerned about their child's speech development at age 18 months (OR 1.22 [95% CI 1.02,1.45], z=2.23, p=.026) compared with parents of children who were exclusively breast fed at age 4 weeks. This association is maintained when the model is adjusted for biological sex and home ownership (OR 1.21 [95% CI 1.01,1.44], z=2.09, p=.037) but not once weak sucking at age 4 weeks and maternal age are included in the model (OR 1.17 [95% CI 0.98,1.40], z=1.71, p=.087); OR 1.14 [95% CI 0.95,1.37], z=1.40, p=.061, respectively) (Table 16). Parents of children who were mixed fed at age 15 months were twice as likely to be concerned about their child's speech at age 18 months compared with exclusively breast fed children in the unadjusted model (OR 2.00 [95% CI 1.17,3.42], z=2.55, p=.011). This association was retained in the adjusted models, with the strongest association observed in the fully adjusted model (OR 2.05 [95% CI 1.18,3.56], z=2.53, p=.011). In contrast, the association observed in the unadjusted model between exclusively bottle fed children at age 15 months and parental speech concern at age 18 months (OR 1.92 [95% CI

1.12,3.30], z=2.37, p=.018) weakened slightly in the adjusted models with a moderate association retained in the final model (OR 1.83 [95% CI 1.04,3.23], z=2.09, p=.037). The unadjusted and adjusted regression models for the age 4 week and 15 month age groups were re-run with bottle feeding as the reference group to allow for comparison of mixed feeding to exclusive bottle feeding (Appendix V). No associations between feeding and parental concern about speech at age 18 months were identified.

Table 16. Logistic regression of feeding method at ages 4 weeks and 15 months and parental speech concern at age 18 months

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.09 [0.87,1.36]	0.72	.473	1.08 [0.86,1.36]	0.70	.484	1.06 [0.84,1.33]	0.51	.609
	Bottle fed	1.22 [1.02,1.45]	2.23	**.026**	1.21 [1.01,1.44]	2.09	**.037**	1.17 [0.98,1.40]	1.71	.087
Age 15 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	2.00 [1.17,3.42]	2.55	**.011**	2.00 [1.17,3.41]	2.53	**.011**	2.09 [1.20,3.63]	2.61	**.009**
	Bottle fed	1.92 [1.12,3.30]	2.37	**.018**	1.87 [1.09,3.22]	2.26	**.024**	1.91 [1.09,3.35]	2.25	**.024**

Table. 14. ***(Continued)***

Exposure variable: Feeding method		Model 2b: Adjusted for biological sex, home ownership and maternal age			Model 3: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks and maternal age		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.08 [0.86,1.35]	0.65	.514	1.06 [0.84,1.33]	0.47	.640
	Bottle fed	1.18 [0.98,1.42]	1.77	.077	1.14 [0.95,1.37]	1.40	.161
Age 15 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.97 [1.15,3.36]	2.47	**.014**	2.05 [1.18,3.56]	2.53	**.011**
	Bottle fed	1.81 [1.05,3.14]	2.13	**.034**	1.83 [1.04,3.23]	2.09	**.037**

Note: *N* for Age 4 Weeks: model 0 *n*=8134; model 1 *n*=7969; model 2a *n*=7969; model 2b *n*=7969; model 3 *n*=7969.
N for Age 15 Months: model 0 *n*=5217; model 1 *n*=5095; model 2a *n*=4993; model 2b *n*=5095; model 3 *n*=4993.

3. Summary

Table 17 summarises the results from the fully adjusted models for the primary analysis of interest explored in this section: feeding method at ages 4 weeks, 6 months and 15 months and parental concern about speech development at age 18 months. The presence of an arrow indicates that an association (*p*<0.05) was observed; 🡅 suggests an *increased* likelihood of parental speech concern, and 🡇 indicates *decreased* likelihood of parental speech concern. After adjusting for all confounders, increased likelihood of parental concern about speech at age 18 months was shown to be strongly associated with both mixed fed and bottle fed children at age 15 months compared with those who were exclusively breast fed at these ages (Table 17).

Table 17. Summary of observed associations from the fully adjusted logistic regression models for feeding and parental concern about speech at age 18 months

Exposure variable: Feeding method		**Outcome variable: Parental concern about speech development at age 18 months**	
		No	**Yes**
Age 4 weeks	**Breast**	-	-
	Mixed	-	-
	Bottle	-	-
Age 6 months	**Breast / Mixed**	-	-
	Bottle	-	-
Age 15 months	**Breast**	-	-
	Mixed	-	🡅 (205%)
	Bottle	-	🡅 (183%)

4. Part B: infant feeding and speech sound errors at ages 25 and 61 months

In this section, ALSPAC data from clinical speech sound assessments (10% subset) at ages 25 months and 61 months were examined with the feeding group data previously used in Part A of this strand. The following sections report the results for the feeding groups at each of the three age points (4 weeks, 6 months and 15 months), respectively, for the 10% subset of children from the original dataset explored in Part A.

4.1. Sample size

Exposure variable data on feeding were available for each of the outcome measures. Figure 13 illustrates the process of derivation of participants for this study.

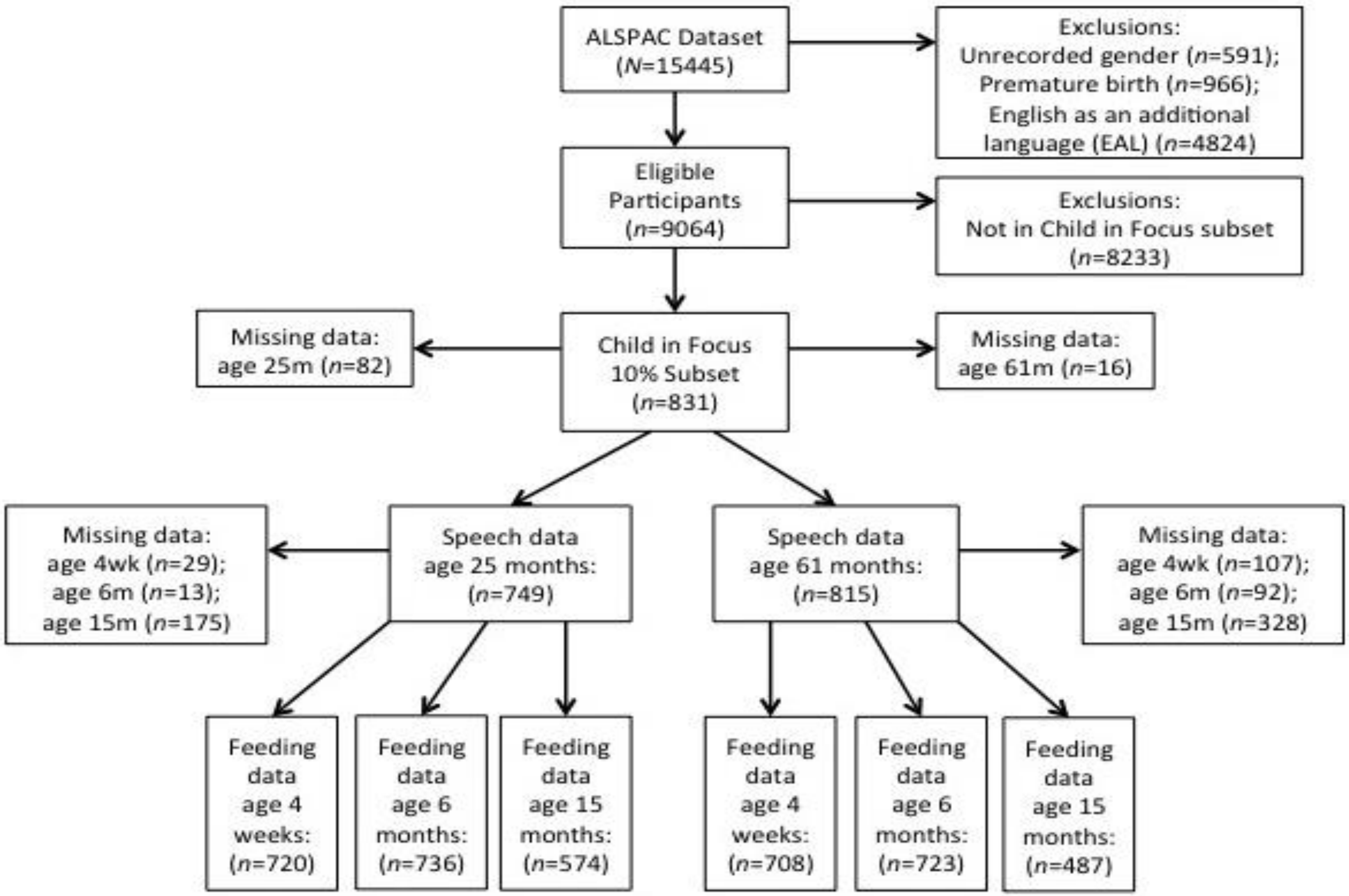

Figure 13. Derivation of participants for Strand One Part B

4.1.1. Exposure variables: feeding groups

The feeding variables for this analysis are the same as those used in Part A of this strand of the PhD study (see section 2.1.1). Table 18 shows the sample sizes by feeding group and biological sex for the Child in Focus subset. At age 4 weeks the largest proportion of children were exclusively breast fed (*n*=356, 49.38%), compared with only 6.10% (*n*=40) of children at age 15 months (Table 18).

Table 18. Feeding groups for Child in Focus subset (*n*=831)

	Feeding Group: Child in Focus Subset		
Age Point	**Exclusive Breast Fed**	**Mixed fed**	**Exclusive Bottle Fed**
4 Weeks	n=356 (Female n=169, 47.47%)	n=132 (Female n=53, 40.15%)	n=233 (Female n=110, 47.21%)
6 Months	n =594 (Female n=266, 47.21%)		n=143 (Female n=72, 50.35%)
15 Months	n=40 (Female n=17, 42.50%)	n =376 (Female n=172, 45.74%)	n=240 (Female n=119, 49.58%)

4.1.2. Potential confounding variables

Categorical confounding variable and covariate samples (see chapter three Figure 2) are described in Table 19. Within the sample, 17% (*n*=139) of children were reported to have weak sucking at age 4 weeks, with a predominance of boys (*n*=87, 62.59%) compared with girls. In both age groups, children with diagnosed, or suspected, OME (tympanogram types B (possible unilateral middle ear infection), BB (possible bilateral middle ear infection) or 'other' (e.g. some middle ear congestion) are in the minority (age 25 months: *n*=265, 39.73%; age 61 months: *n*=342, 43.51%). The largest proportion of children were born to mothers with qualifications beyond O Level (*n*=429, 52.38%) (Table 8). The largest proportion of children within the sample lived in privately owned or rented properties at birth (*n*=721, 88.03%) (Table 19). Considering expressive language skills (word combination) at age 25 months, the largest proportion of children used three-four word phrases (*n*=415, 55.70%). The proportions for biological sex groups vary across the four categories within the word combination at age 25 months variable. Compared with males, a larger proportion of females (*n*=229, 55.18%) were reported to use 3-4 word phrases at age 25 months. Lower proportions of girls were reported to use babble (*n*=4, 17.39%) or single words (*n*=33, 27.98%) at age 25 months compared with boys (Table 19).

Table 19. Sample size (*n*) for categorical potential confounding variables and covariates, by biological age (*n*=831)

Potential Confounding Variable		Biological Sex: Female *n* %	Biological Sex: Male *n* %	Biological Sex: Total *n* %
Weak Sucking at Age 4 Weeks	**No**	**323** 47.57	**356** 52.43	**679** 100.00
	Yes	**52** 37.41	**87** 62.59	**139** 100.00
OME at age 25 Months	**AA**	**182** 45.27	**120** 29.85	**402** 100.00
	B	**36** 41.86	**50** 58.14	**86** 100.00
	BB	**32** 51.61	**30** 48.39	**62** 100.00
	Other	**45** 38.46	**72** 61.54	**117** 100.00
OME at age 61 Months	**AA**	**201** 45.27	**243** 54.73	**444** 100.00
	B	**44** 53.66	**38** 46.34	**82** 100.00
	BB	**28** 49.12	**29** 50.88	**57** 100.00
	Other	**89** 43.84	**114** 56.16	**203** 100.00
Maternal Education	**< O Level**	**44** 46.32	**51** 53.68	**95** 100.00
	O Level	**135** 45.72	**160** 54.24	**295** 100.00
	> O Level	**200** 46.62	**229** 53.38	**429** 100.00
Home Ownership	**Owned / Privately Rented**	**331** 45.91	**390** 54.09	**721** 100.00
	Council Rented / Other	**46** 46.94	**52** 53.06	**98** 100.00
Word Combination at age 25 Months	**Babble**	**4** 17.39	**19** 82.61	**23** 100.00
	Single Words	**33** 27.98	**85** 72.03	**118** 100.00
	Two Words	**76** 40.21	**113** 59.79	**189** 100.00
	3-4 Word Phrases	**229** 55.18	**186** 44.82	**415** 100.00

Note: OME = otitis media with effusion (glue ear).

Continuous confounding variables and covariates are described in Table 20. Little difference in maternal age was observed between the sexes (Figure 14 and Table 20). Across the feeding age points, breast feeding mothers were consistently older than mixed feeding or bottle feeding mothers (Table 20). No significant differences were observed between males and females. Summary statistics for the transformed RDLS language comprehension score data show that, at 25 months, the mean standardised scores for females is slightly higher (*n*=337, mean=113.8, *s.d.*=15.94, median=116.50, LQ=106, UQ=122.50) compared with the mean for males (mean=110, *n*=392, *s.d.*=16.90, median=111.25, LQ=100.75, UQ=121) (Table 20). At 61 months, scores for RDLS are similar for both biological sexes (female: *n*=330, mean=105.75, *s.d.*=9.26, median=106, LQ=100, UQ=113.50; male: *n*=374, mean=104.58, *s.d.*=8.36, median=106, LQ=100, UQ=109) (Table 20). The RDLS data distributions at age 25 months and 61 months are presented in Figure 15 and Figure 16. Figure 15 indicates the 25 month RDLS comprehension standardised scores are distributed, as expected, with negative skew towards the higher scores (*n*=729, mean=111.75, *s.d.*=16.56, median=112, LQ=104.50, UQ=122.50). At age 61 months the scores show typical distribution with reduced variability (*n*=704, mean=105.13, *s.d.*=8.81, median=106, LQ=100, UQ=113.50) (Figure 16). With regard to language score at age 38 months, females had a higher mean score and lower standard deviation (mean=302.67, *s.d.*=29.17) compared with males (mean 291.53, *s.d.*=42.08) (Figure 17). The histogram shows a steep curve negatively skewed towards the higher score range. The overall mean language score is 296.71 (*n*=718, *s.d.* =37.04, median=310, LQ=288, UQ=320).

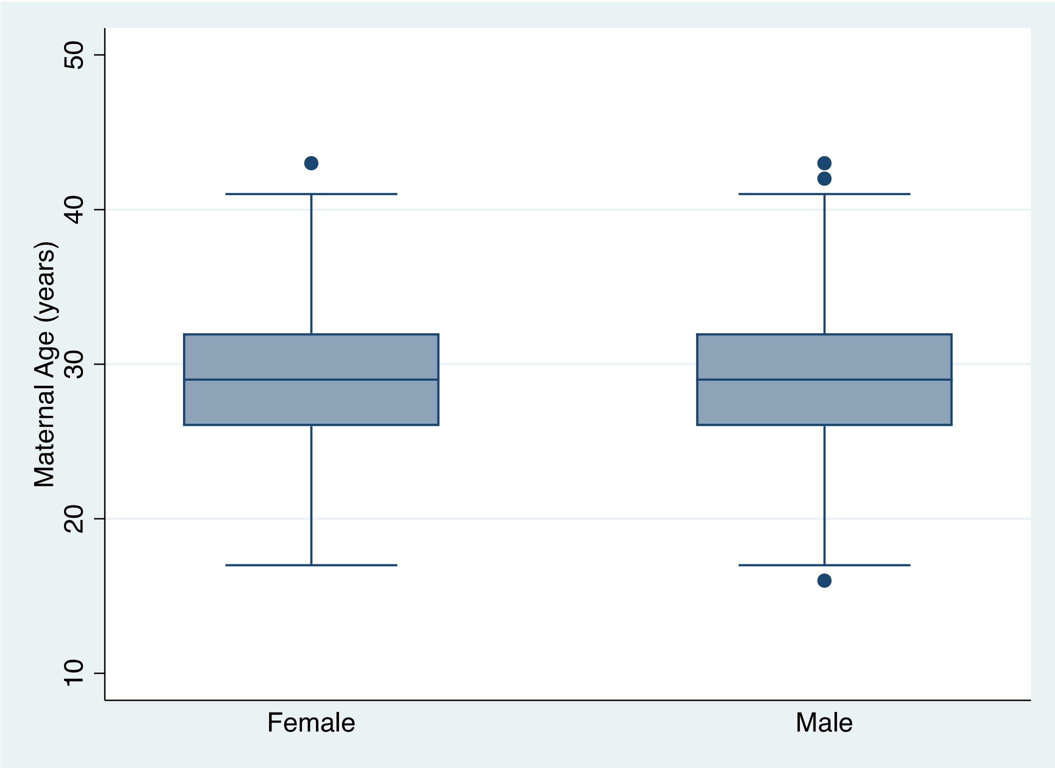

Figure 14. Box and whisker plot of maternal age for CiF subset, by biological sex (*n*=831)

Table 20. Summary statistics for continuous potential confounding variables (*n*=831)

Potential Confounding Variable		Female *n*	Female Mean s.d	Female Median IQR	Male *n*	Male Mean s.d	Male Median IQR
Maternal Age		384	29.01 4.31	29.00 26-32	447	29.68 4.32	30.00 27-32
RDLS Comprehension Score	**Age 25 Months**	337	113.80 15.94	116.50 106-122.50	392	110.00 16.90	111.25 100.75-121
	Age 61 Months	330	105.75 9.26	106.00 100-113.50	374	104.58 8.36	106.00 100-109
Language Score at age 38 Months		334	302.67 29.17	314.00 293-322	384	291.53 42.08	306.00 280-319

Note: s.d. = standard deviation. IQR = interquartile range.

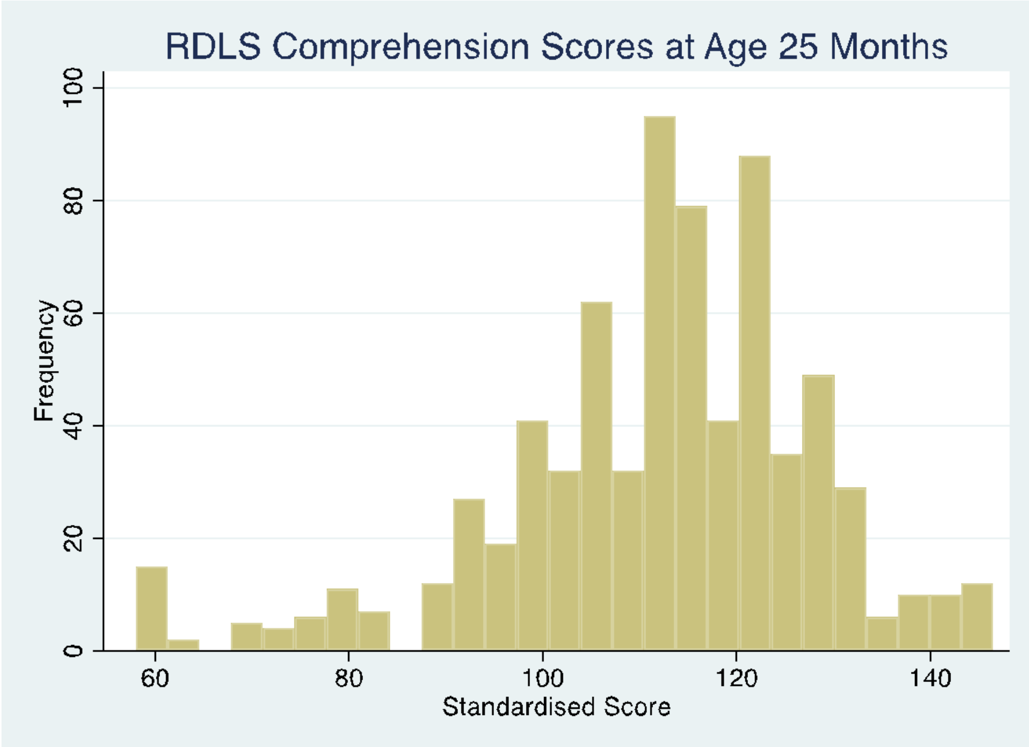

Figure 15. RDLS comprehension standardised scores at age 25 months (*n*=729)

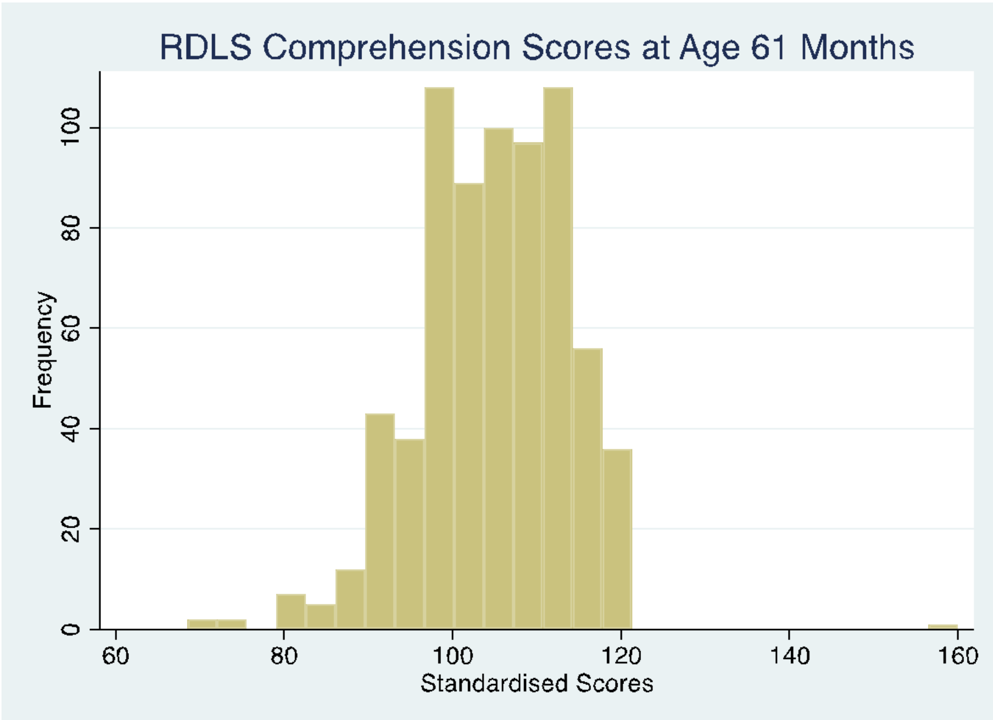

Figure 16. RDLS comprehension standardised scores at age 61 months (*n*=704)

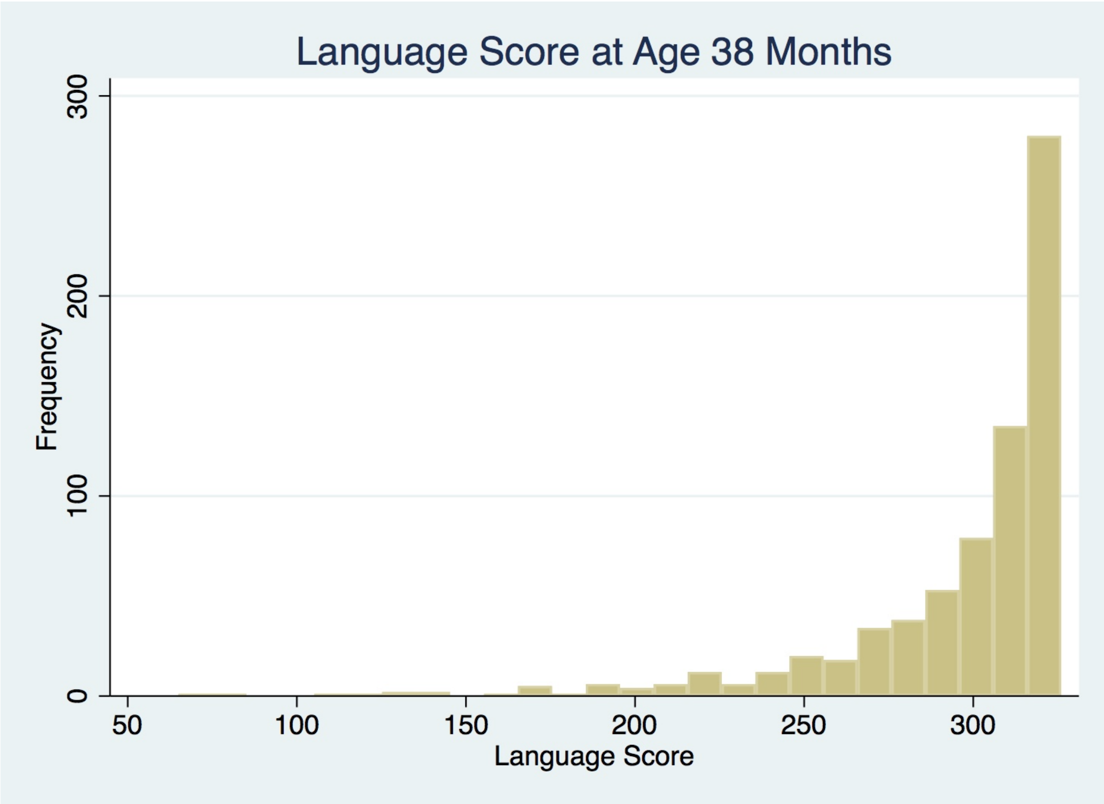

Figure 17. Language score at age 38 months (*n*=718)

4.1.3. Outcome variables: 25 month clinical speech assessment data

A total of 749 children (female *n*=345, male *n*=404) completed the speech assessment at the age 25 month assessment clinic. Speech data from the phonemically balanced single word naming task was used as the outcome data at age 25 months. Table 21 shows the maximum number of times that sound was elicited in the assessment (tokens), number of observations for that sound type, mean error frequency, standard deviation, median and lower and upper quartiles. Greatest variability in error frequencies for consonant clusters and liquids can be seen in the data at the 25 month age point (Figure 18). In contrast, velar and fricative errors exhibit a pattern of decreased variability at this age, with the majority of children achieving no, or few errors. PVC shows greatest score variability, indicated by the strong negative skew and long tail with multiple outliers (Figure 18).

Table 21. Summary statistics for speech sound error frequency at age 25 months

Speech Sound Error	No. Tokens	Mean s.d.	Median IQR
Velar	11	2.53 2.64	2 0-4
Consonant Cluster	11	5.83 3.56	6 3-9
Liquid	10	4.08 2.99	4 1-7
Fricative	12	3.12 2.83	2 1-5
Postvocalic	15	2.32 3.29	1 0-3

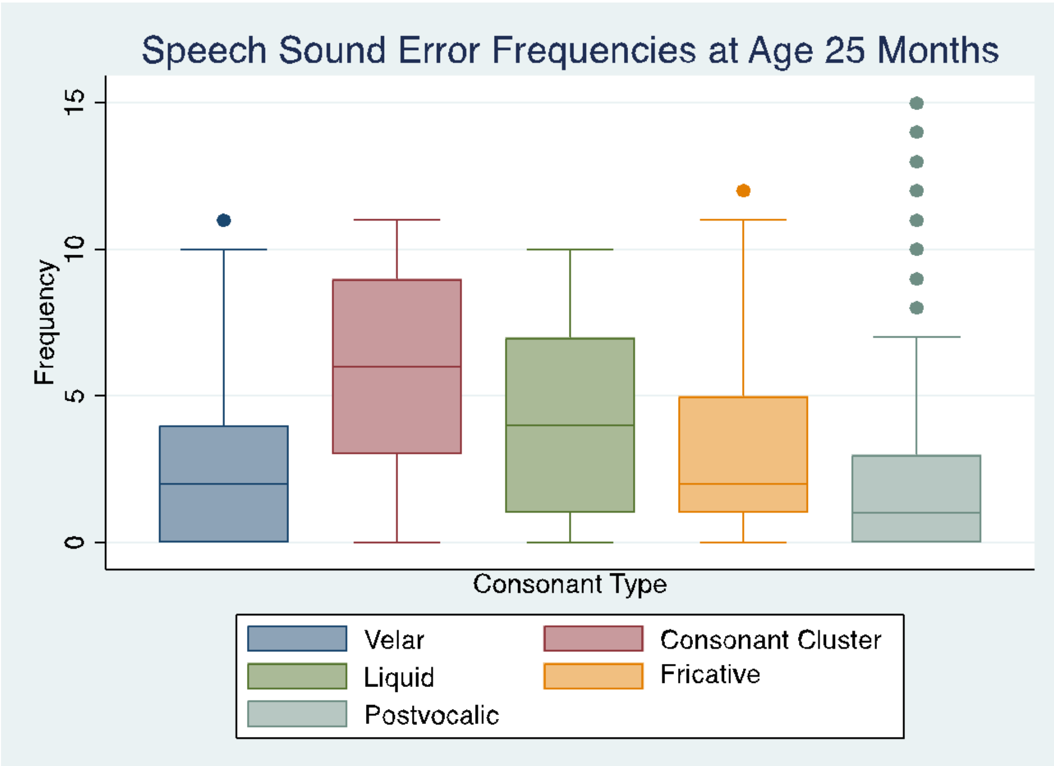

Figure 18. Box and whisker plot of speech sound error frequencies at age 25 months

4.1.4. Outcome variables: 61 month clinical speech assessment data

A total of 815 children (female *n*=380, male *n*=435) completed the speech assessment at the age 61 month assessment clinic. For each of the six speech sounds assessed, Table 22 shows the maximum number of times that sound was elicited in the assessment (tokens), number of observations for that sound type, mean error frequency, standard deviation, median and lower and upper quartiles (Figure 19).

Table 22. Summary statistics for speech sound error frequency at age 61 months

Speech Sound Error	No. Tokens	Mean s.d.	Median IQR
Velar	11	0.55 1.23	0 0-1
Consonant Cluster	15	0.90 1.65	0 0-1
Liquid	16	1.50 2.32	0 0-2
Fricative	19	0.49 1.45	0 0-1
Postvocalic	12	0.87 0.96	0 1-1
Alveolar	13	0.85 1.40	0 0-1

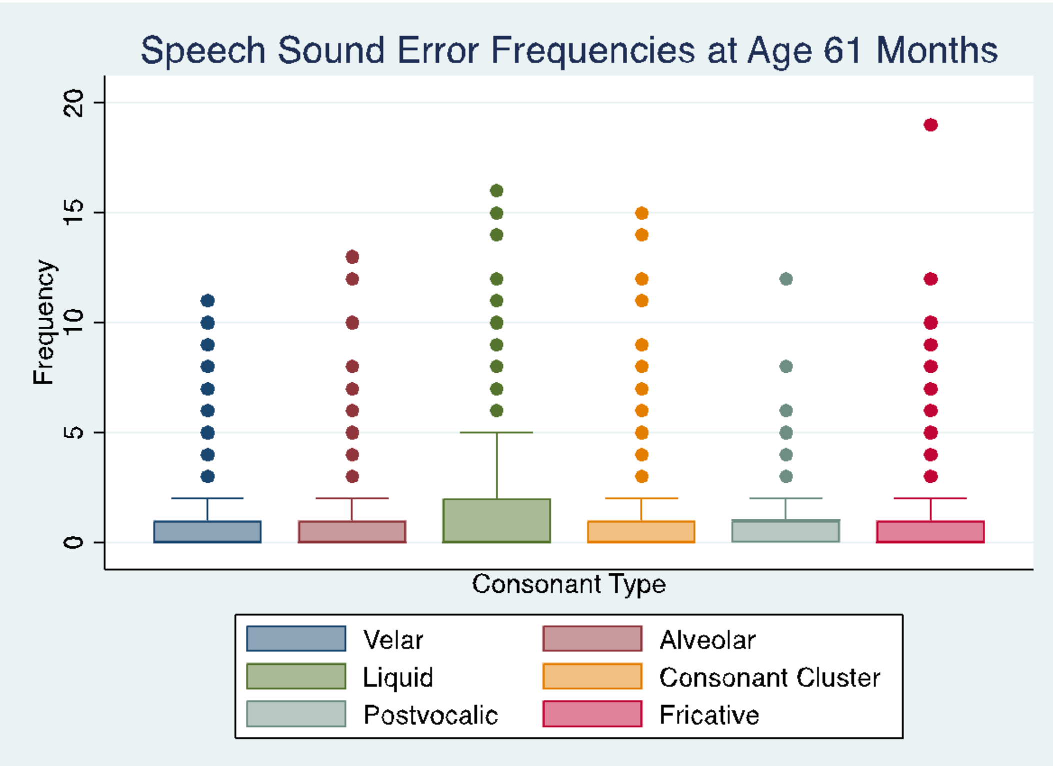

Figure 19. Box and whisker plot of speech sound error frequencies at age 61 months

With the exception of liquids, all speech sound error types at 61 months have a mean below 1, indicating a high degree of accuracy on assessment (ceiling effect). Liquid speech sounds have a higher mean (mean=1.50) and standard deviation (*s.d.*=2.32) indicating a greater degree of variability in frequency for this error type compared with the other speech outcome measures. The speech sound error outcome variables at 61 months have been included in the analysis as derived binary variables (yes/no for occurrence of consonant sound errors), as described in the methods section.

4.2. Data analysis: 25 month clinical speech assessment

Univariable analysis showed that biological sex, maternal age, RDLS at age 25 months and word combination at 25 months were the only confounders where $p<.10$ (Table 23). Only the last of these had $p<.10$ for all five consonant types. For consistency across all consonant types, all four of these confounders were included in further model adjustment for each of the five consonant types. In order to retain a measure of SES for the multivariable analysis, home ownership was also retained due to the smaller likelihood ratio p value for four out of the five consonant types compared with maternal education.

Table 23. Univariable negative binomial regression model results for potential confounders associated with speech sound error frequency at age 25 months

Variable	Category[a]	Consonant type error frequency at age 25 months								
		Velar			Consonant cluster			Liquid		
		IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*
Demographics										
Biological sex[b]	**Female**	1.00	-	-	1.00	-	-	1.00	-	-
	Male	1.00 [0.85,1.17]	0.00	.998	0.88 [0.79,0.98]	-2.37	**.018**	0.86 [0.76,0.98]	-2.36	**.018**
Home ownership status[b]	**Owned / privately rented**	1.00	-	-	1.00	-	-	1.00	-	-
	Council / other	0.86 [0.66,1.11]	-1.19	.236	0.91 [0.77,1.07]	-1.12	.264	0.93 [0.77,1.14]	-0.68	.497
Maternal age[c]		0.98 [0.97,1.00]	-1.49	.137	0.99 [0.97,1.00]	-2.14	**.032**	0.99 [0.97,1.00]	-2.06	**.039**
Maternal education[b]	**< O Level**	1.00	-	-	1.00	-	-	1.00	-	-
	O Level	0.87 [0.66,1.14]	-1.03	.302	1.05 [0.87,1.26]	0.50	.619	1.01 [0.81,1.24]	0.05	.956
	> O Level	0.96 [0.74,1.24]	-0.32	.748	1.09 [0.92,1.30]	1.02	.310	1.04 [0.85,1.27]	0.36	.720

Table 21. ***(Continued)***

Variable	Category[a]	Consonant type error frequency at age 25 months: Velar IRR [95% CI]	z	p	Consonant cluster IRR [95% CI]	z	p	Liquid IRR [95% CI]	z	p
Early developmental variables										
Weak sucking at 4 weeks[b]	**No**	1.00	-	-	1.00	-	-	1.00	-	-
	Yes	1.13 [0.91,1.40]	1.13	.259	1.09 [0.94,1.25]	1.16	.247	1.15 [0.98,1.36]	1.68	.093
OME[b]	**AA**	1.00	-	-	1.00	-	-	1.00	-	-
	B	1.08 [0.84,1.39]	0.62	.538	1.02 [0.86,1.21]	0.25	.800	1.01 [0.83,1.23]	0.09	.931
	BB	1.10 [0.81,1.48]	0.61	.545	0.99 [0.81,1.20]	-0.14	.891	0.91 [0.72,1.16]	-0.75	.456
	Other	1.12 [0.89,1.39]	0.96	.336	1.03 [0.89,1.20]	0.44	.662	1.06 [0.89,1.26]	0.65	.515
Early speech and language performance										
RDLS comprehension score at age 25m[c]		1.00 [1.00,1.01]	1.48	.140	1.01 [1.01,1.02]	7.37	**<.001**	1.01 [1.01,1.02]	6.24	**<.001**
Word combination at age 25 months[b]	**Two words**	1.00	-	-	1.00	-	-	1.00	-	-
	Babble	0.44 [0.25,0.79]	-2.74	**.006**	0.24 [0.15,0.38]	-6.02	**<.001**	0.24 [0.14,0.42]	-5.05	**<.001**
	Single words	0.95 [0.74,1.21]	-0.43	.665	0.70 [0.59,0.83]	-4.08	**<.001**	0.68 [0.55,0.83]	-3.81	**<.001**
	3-4 words	0.71 [0.59,0.85]	-3.67	**<.001**	0.98 [0.87,1.10]	-0.35	.726	0.94 [0.81,1.08]	-0.92	.359

Table 21. ***(Continued)***

Variable	Category[a]	Consonant type error frequency at age 25 months: Fricative IRR [95% CI]	z	p	Postvocalic IRR [95% CI]	z	p
Demographics							
Biological sex[b]	**Female**	1.00	-	-	1.00	-	-
	Male	1.02 [0.88,1.17]	0.22	.828	1.10 [0.89,1.36]	0.91	.361
Home ownership status[b]	**Owned / privately rented**	1.00	-	-	1.00	-	-
	Council / other	0.84 [0.67,1.06]	-1.47	.141	0.89 [0.63,1.23]	-0.72	.472
Maternal age[c]		0.98 [0.96,1.00]	-2.31	**.021**	0.96 [0.94,0.99]	-2.84	**.004**
Maternal education.[b]	**< O Level**	1.00	-	-	1.00	-	-
	O Level	1.09 [0.85,1.39]	0.67	.505	0.87 [0.61,1.25	-0.74	.458
	> O Level	1.13 [0.89,1.43]	1.01	.312	0.87 [0.62,1.22]	-0.79	.429

Table 21. ***(Continued)***

Variable	Category[a]	Consonant type error frequency at age 25 months					
		Fricative			Postvocalic		
		IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*
Early developmental variables							
Word combination at age 25 months[b]	**No**	1.00	-	-	1.00	-	-
	Yes	1.15 [0.95,1.38]	1.42	.156	1.18 [0.89,1.56]	1.16	.244
OME[b]	**AA**	1.00	-	-	1.00	-	-
	B	1.13 [0.91,1.42]	1.11	.267	0.95 [0.68,1.34]	-0.28	.780
	BB	1.07 [0.82,1.40]	0.51	.611	1.06 [0.71,1.58]	0.29	.773
	Other	1.03 [0.84,1.26]	0.30	.765	0.92 [0.68,1.25]	-0.53	.598
Early speech and language performance							
RDLS comprehension score age 25m[c]		1.01 [1.00,1.01]	3.76	**<.001**	1.00 [0.99,1.01]	-0.01	.994
Word combination at age 25 months[b]	**Two words**	1.00	-	-	1.00	-	-
	Babble	0.29 [0.16,0.51]	-4.18	**<.001**	0.36 [0.17,0.75]	-2.73	**.006**
	Single words	0.88 [0.70,1.10]	-1.12	.261	1.02 [0.74,1.40]	0.10	.919
	3-4 words	0.78 [0.66,0.92]	-3.00	**.003**	0.53 [0.42,0.67]	-5.25	**<.001**

Note: [a]For categorical variables only. [b]Categorical variable. [c]Continuous variable.
OME = otitis media with effusion (glue ear).

4.2.1. Age 25 month speech error analysis by feeding age group

Univariable analysis showed differing patterns of association between feeding and each of the consonant types at age 25 months (Table 24). No association was observed between feeding at 15 months and speech sound errors. Where the IRR $p<.10$, children who were exclusively breastfed, regardless of age group were on average 12-26% more likely to make speech sound errors compared with other feeding groups. Consonant cluster and liquid errors at age 25 months were indicated to be associated with feeding at ages 4 weeks and 6 months (Table 24). The univariable analysis was repeated with exclusive bottle feeding as the reference group to allow for comparison between bottle feeding and mixed feeding (Appendix W). Compared to children who were exclusively bottle fed at age 15 months, children who were mixed fed were around 20% more likely to make consonant cluster (IRR 1.18 [95% CI 1.01,1.38] $z=2.15$, $p=.031$) and liquid (IRR 1.22 [95% CI 1.02,1.46] $z=2.16$, $p=.031$) errors at age 25 months, before adjustment for confounders and covariates.

Table 24. Univariable negative binomial regression results for feeding and speech sound error frequency at age 25 months

Exposure variable: Feeding method		**Outcome variable: Consonant type error frequency at age 25 months**								
		Velar			**Consonant cluster**			**Liquid**		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.98 [0.79,1.22]	-0.14	.885	0.83 [0.72,0.96]	2.50	**.013**	0.84 [0.71,0.99]	-2.07	**.039**
	Bottle fed	0.97 [0.80,1.16]	-0.35	.728	0.88 [0.78,0.99]	2.59	**.037**	0.86 [0.74,0.99]	-2.12	**.034**
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.81 [0.66,1.00]	-1.94	**.052**	0.84 [0.73,0.97]	-2.46	**.014**	0.80 [0.68,0.94]	-2.72	**.007**
Age 15 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.81 [0.53,1.23]	-0.99	.323	0.99 [0.74,1.32]	-0.09	.928	1.12 [0.79,1.59]	0.66	.511
	Bottle fed	0.72 [0.46,1.13]	-1.42	.155	0.84 [0.62,1.13]	-1.16	.244	0.92 [0.64,1.33]	-0.44	.663

Table 22. ***(Continued)***

Exposure variable: Feeding method		**Outcome variable: Consonant type error frequency at age 25 months**					
		Fricative			**Postvocalic**		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.98 [0.80,1.19]	-0.22	.823	0.94 [0.70,1.25]	-0.45	.653
	Bottle fed	0.95 [0.80,1.12]	-0.64	.521	0.99 [0.78,1.27]	-0.05	.962
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.87 [0.72,1.05]	-1.49	.137	0.74 [0.56,0.97]	-2.18	**.029**
Age 15 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.99 [0.67,1.46]	-0.04	.965	1.11 [0.61,2.03]	0.34	.734
	Bottle fed	0.90 [0.60,1.35	-0.51	.613	0.77 [0.57,1.03]	0.22	.823

Note: *N* for all age 4 week models =694 except fricative (*n*=693).
N for all age 6 month models *n*=709 except fricative (*n*=708).
N for all age 15 month models *n*=437.

The following sections present the adjusted negative binomial regression results for each of the consonant type error frequencies at age 25 months where $p<.10$ in the univariable analysis (Table 24).

Velar speech sound errors at age 25 months

Table 25 presents the unadjusted and adjusted negative binomial regression models for the association between feeding method (ages 6 months) and velar speech sound errors at age 25 months. In the unadjusted model, children who were exclusively bottle fed at age 6 months were around 20% less likely (IRR 0.81 [95% CI 0.66,1.00], z=-1.94, p=.052) to make velar sound errors at age 25 months compared with exclusively breast fed children at this age. This weak association is somewhat strengthened and maintained after full model adjustment (IRR 0.80 [95% CI 0.64,0.99], z=-2.05, p=.040.

Table 25. Negative binomial unadjusted and adjusted regression models for feeding and velar speech sound error frequency at age 25 months

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks			Model 2b: Adjusted for biological sex, home ownership and maternal age		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.81 [0.66,1.00]	-1.94	.052	0.82 [0.66,1.01]	-1.84	.065	0.80 [0.65,0.99]	-2.01	**.044**	0.79 [0.64,0.98]	-2.15	**.032**

Table 23. ***(Continued)***

Exposure variable: Feeding method		**Model 3a: Adjusted for biological sex, home ownership and word combination at age 25 months**			**Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 25 months**			**Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, word combination at age 25 months and RDLS comprehension standardised score at age 25 months**		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.82 [0.67,1.01]	-1.82	.069	0.83 [0.67,1.03]	-1.67	.095	0.80 [0.64,0.99]	-2.05	**.040**

Note: *N* for Age 6 months: model 0 *n*=709; model 1 *n*=700 model 2a *n*=693; model 2b *n*=700; model 3a *n*=695; model 3b *n*=680; model 4 *n*=668.

Consonant cluster speech sound errors at age 25 months

Table 26 presents the unadjusted and adjusted negative binomial regression models for the association between feeding method (ages 4 weeks and 6 months) and consonant cluster speech sound errors at age 25 months. All feeding groups at each age point were shown, in the unadjusted analysis, to be around 20% less likely to make consonant cluster errors at age 25 months compared with exclusively breast fed children (Table 26). Following full adjustment, the association was maintained for mixed feeding at age 4 weeks (IRR 0.84 [95% CI 0.74,0.96], z=-2.47, p=.013) (Table 26). The models were rerun with bottle feeding as the reference group to allow for comparison of bottle feeding and mixed feeding at age 15 months because of the association indicated in the unadjusted model (IRR 1.18 [95% CI 1.01,1.38] z=2.15, p=.031). This association was not maintained in the fully adjusted model (IRR 1.15 [95% CI 0.99,1.33] z=1.88, p=.060) (Appendix X).

Table 26. Negative binomial unadjusted and adjusted regression models for feeding method and consonant cluster speech sound error frequency at age 25 months

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks			Model 2b: Adjusted for biological sex, home ownership and maternal age		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.83 [0.72,0.96]	2.50	**.013**	0.84 [0.72,0.97]	-2.44	**.015**	0.83 [0.71,0.95]	-2.58	**.010**	0.83 [0.72,0.96]	-2.58	**.010**
	Bottle fed	0.88 [0.78,0.99]	2.59	**.037**	0.89 [0.79,1.00]	-1.92	.054	0.88 [0.78,1.00]	-2.01	**.045**	0.86 [0.76,0.97]	-2.43	**.015**
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.84 [0.73,0.97]	-2.46	**.014**	0.84 [0.73,0.96]	-2.49	**.013**	0.83 [0.73,0.96]	-2.60	**.009**	0.82 [0.71,0.94]	-2.87	**.004**

Table 24. ***(Continued)***

Exposure variable: Feeding method		Model 3a: Adjusted for biological sex, home ownership and word combination at age 25 months			Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 25 months			Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, word combination at age 25 months and RDLS comprehension standardised score at age 25 months		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.85 [0.74,0.97]	-2.33	**.020**	0.85 [0.74,0.98]	-2.23	**.026**	0.84 [0.74,0.96]	-2.47	**.013**
	Bottle fed	0.90 [0.80,1.01]	-1.75	.081	0.95 [0.85,1.07]	-0.80	.423	0.92 [0.82,1.03]	-1.40	.161
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.85 [0.74,0.96]	-2.49	**.013**	0.91 [0.80,1.04]	-1.39	.166	0.88 [0.77,1.00]	-1.94	.052

Note: *N* for Age 4 weeks: model 0 *n*=694; model 1 *n*=686; model 2a *n*=686; model 2b *n*=686; model 3a *n*=681; model 3b *n*=667; model 4 *n*=662.
N for Age 6 months: model 0 *n*=709; model 1 *n*=700; model 2a *n*=693; model 2b *n*=700; model 3a *n*=695; model 3b *n*=680; model 4 *n*=668.

Liquid speech sound errors at age 25 months

A moderate association was indicated between feeding method at age 4 weeks and liquid speech error frequency at age 25 months (Table 27). The unadjusted model indicates that children who were mixed fed at age 4 weeks were more likely (IRR 0.84 [95% CI 0.71,0.99], z=-0.27, p=.039) to have fewer liquid errors at age 25 months compared with exclusively breast fed children. This association was maintained in the fully adjusted model (IRR 0.83 [95% CI 0.71,0.98], z=-2.22, p=.027) (Table 27). Before adjustment, children who were exclusively bottle fed at age 4 weeks were 14% less likely (IRR 0.86 [95% CI 0.74,0.99], z=2.12, p=.034) to make liquid errors, compared with exclusively breast fed children. This association did not remain after adjustment. Before adjustment, children who were exclusively bottle fed at age 6 months were 20% less likely to make liquid errors at age 25 months (IRR 0.80 [95% CI 0.68,0.94], z=2.72, p=.007). After full adjustment of the model these children were around 17% less likely to make liquid errors when all potential confounders were included in the model (IRR 0.83 [95% CI 0.71,0.97], z=-2.31, p=.021). The models were rerun with bottle feeding as the reference group to allow for comparison of bottle feeding and mixed feeding at age 15 months. The moderate associations indicated in the unadjusted model (IRR 1.22 [95% CI 1.02,1.46] z=2.16, p=.031) remained after full adjustment (IRR 1.21 [95% CI 1.01,1.44] z=2.12, p=.034) (Appendix Y).

Table 27. Negative binomial unadjusted and adjusted regression models for feeding method and liquid speech sound error frequency at age 25 months

Exposure variable: Feeding method		**Model 0: Unadjusted**			**Model 1: Adjusted for biological sex and home ownership**			**Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks**			**Model 2b: Adjusted for biological sex, home ownership and maternal age**		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.84 [0.71,0.99]	-2.07	**.039**	0.85 [0.72,1.00]	-1.96	**.049**	0.83 [0.70,0.98]	-2.19	**.029**	0.84 [0.71,0.99]	-2.09	**.037**
	Bottle fed	0.86 [0.74,0.99]	-2.12	**.034**	0.87 [0.75,1.00]	-1.97	**.049**	0.86 [0.75,0.99]	-2.09	**.037**	0.83 [0.72,0.96]	-2.49	**.013**
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.80 [0.68,0.94]	-2.72	**.007**	0.80 [0.68,0.94]	-2.76	**.006**	0.79 [0.67,0.93]	-2.86	**.004**	0.77 [0.66,0.91]	-3.12	**.002**

Table 25. ***(Continued)***

Exposure variable: Feeding method		**Model 3a: Adjusted for biological sex, home ownership and word combination at age 25 months**			**Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 25 months**			**Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, word combination at age 25 months and RDLS comprehension standardised score at age 25 months**		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.85 [0.72,1.00]	-1.94	.053	0.86 [0.73,1.01]	-1.84	.066	0.83 [0.71,0.98]	-2.22	**.027**
	Bottle fed	0.88 [0.76,1.01]	-1.83	.067	0.93 [0.81,1.07]	-1.05	.295	0.89 [0.77,1.02]	-1.68	.094
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.80 [0.68,0.94]	-2.77	**.006**	0.87 [0.74,1.01]	-1.79	.073	0.83 [0.71,0.97]	-2.31	**.021**

Note: *N* for Age 4 weeks: model 0 *n*=694; model 1 *n*=686; model 2a *n*=686; model 2b *n*=686; model 3a *n*=681; model 3b *n*=667; model 4 *n*=662.
N for Age 6 months: model 0 *n*=709; model 1 *n*=700; model 2a *n*=693; model 2b *n*=700; model 3a *n*=695; model 3b *n*=680; model 4 *n*=668.

Fricative speech sound errors at age 25 months

Univariable analysis showed no significant associations between feeding at any of the three age points and fricative speech errors at age 25 months and so no further analysis was undertaken.

Postvocalic speech sound errors at age 25 months

In the unadjusted model, exclusively bottle fed children were 25% less likely (IRR 0.74 [95% CI 0.56,0.97], z=-2.18, p=.029) to make postvocalic speech errors at age 25 months compared with breast/mixed fed children (Table 28). This association was strengthened and maintained after full adjustment (IRR 0.70 [95% CI 0.53,0.92], z=-2.56, p=.010).

Table 28. Negative binomial unadjusted and adjusted regression models for feeding method and postvocalic speech sound error frequency at age 25 months

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks			Model 2b: Adjusted for biological sex, home ownership and maternal age		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.74 [0.56,0.97]	-2.18	**.029**	0.76 [0.57,0.99]	-2.01	**.044**	0.74 [0.56,0.98]	-2.11	**.035**	0.70 [0.53,0.92]	-2.58	**.010**

Table 26. ***(Continued)***

Exposure variable: Feeding method		**Model 3a: Adjusted for biological sex, home ownership and word combination at age 25 months**			**Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 25 months**			**Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, word combination at age 25 months and RDLS comprehension standardised score at age 25 months**		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.75 [0.57,0.97]	-2.15	**.031**	0.75 [0.57,0.99]	-2.02	**.043**	0.70 [0.53,0.92]	-2.56	**.010**

Note: *N* for Age 6 months: model 0 *n*=709; model 1 *n*=700; model 2a *n*=693; model 2b *n*=700; model 3a *n*=695; model 3b *n*=680; model 4 *n*=668.

The following sections summarise, by feeding age group, the unadjusted and adjusted regression models for each consonant error type where $p<.10$ in univariable analysis of the exposure and outcome variables. The threshold $p<.05$ was applied to all multivariable analyses.

Consonant type error frequencies at age 25 months and feeding at age 4 weeks

Univariable analysis indicated an association between mixed feeding and exclusive bottle feeding at age 4 weeks and reduced likelihood of errors for consonant cluster and liquid sounds at age 25 months (Table 29). After full adjustment of the models, only the associations with mixed feeding remained (consonant cluster: IRR 0.84 [95% CI 0.74,0.96], z=-2.47, p=.013; liquids: IRR 0.83 [95% CI 0.71,0.98], z=-2.22, p=.027) (Table 29).

Table 29. Negative binomial regression models of feeding method at age 4 weeks and speech error frequencies at age 25 months (unadjusted and fully adjusted)

Consonant type error frequency at age 25 months	Model 0: Unadjusted								
	Bottle fed			Mixed fed			Breast fed		
	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*
CC	1 -	-	-	0.83 [0.72,0.96]	2.50	**.013**	0.88 [0.78,0.99]	2.59	**.037**
Liquid	1 -	-	-	0.84 [0.71,0.99]	-2.07	**.039**	0.86 [0.74,0.99]	-2.12	**.034**

Table 27. ***(Continued)***

Consonant type error frequency at age 25 months	Model 4: Fully adjusted								
	Bottle fed			Mixed fed			Breast fed		
	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*
CC	1 -	-	-	0.84 [0.74,0.96]	-2.47	**.013**	0.92 [0.82,1.03]	-1.40	.161
Liquid	1 -	-	-	0.83 [0.71,0.98]	-2.22	**.027**	0.89 [0.77,1.02]	-1.68	.094

Note: CC = consonant cluster. *N*: model 0 *n*=694; model 4 *n*=662.

Consonant type error frequencies at age 25 months and feeding at age 6 months

The overall pattern from the data is that, after full adjustment for potential confounders, children who were exclusively bottle fed at age 6 months were between 12% and 30% less likely to make speech sound errors at age 25 months compared with children who were exclusively breast fed/mixed fed at age 6 months (Table 30). The observed associations between bottle feeding and liquid errors were weakened but maintained after adjustment for potential confounders (unadjusted model: IRR 0.80 [95% CI 0.68,0.94], z=-2.72, p=.007; fully adjusted model: IRR 0.83 [95% CI 0.71,0.97], z=-2.31, p=.021). The association between bottle feeding and consonant clusters did not remain after full adjustment of the model. In contrast, the associations between bottle fed children and reduced likelihood of velar and postvocalic speech errors at age 25 months were strengthened following adjustment (unadjusted model: velar: IRR 0.81 [95% CI 0.66,1.00], z=-1.94, p=.052; postvocalic: IRR 0.74 [95% CI 0.56,0.97], z=-2.18, p=.029; fully adjusted model: velar: IRR 0.80 [95% CI 0.64,0.99], z=-2.05, p=.040; postvocalic: IRR 0.70 [95% CI 0.53,0.92], z=-2.56, p=.010) (Table 30).

Table 30. Negative binomial regression of feeding method at age 6 months and speech error frequencies at age 25 months (unadjusted and fully adjusted models) (*n*=709)

Consonant type error frequency at age 25 months	Model 0: Unadjusted						Model 4: Fully adjusted					
	Breast / mixed Fed			Bottle fed			Breast / mixed Fed			Bottle fed		
	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*
Velar	1 -	-	-	0.81 [0.66,1.00]	-1.94	.052	1 -	-	-	0.80 [0.64,0.99]	-2.05	**.040**
CC	1 -	-	-	0.84 [0.73,0.97]	-2.46	**.014**	1 -	-	-	0.88 [0.77,1.00]	-1.94	.052
Liquid	1 -	-	-	0.80 [0.68,0.94]	-2.72	**.007**	1 -	-	-	0.83 [0.71,0.97]	-2.31	**.021**
PVC	1 -	-	-	0.74 [0.56,0.97]	-2.18	**.029**	1 -	-	-	0.70 [0.53,0.92]	-2.56	**.010**

Note: CC = consonant cluster. PVC = postvocalic. *N* for velar error frequency: model 0 *n*=709; model 4 *n*=668. *N* for consonant cluster error frequency: model 0 *n*=709; model 4 *n*=668. *N* for liquid error frequency: model 0 *n*=709; model 4 *n*=668. *N* for postvocalic error frequency: model 0 *n*=709; model 4 *n*=668.

Consonant error frequencies at age 25 months and feeding at age 15 months

Univariable analysis indicated no significant associations ($p<.10$) between feeding and speech sound error frequency at age 25 months (Table 24) and so no further analysis of these variables was undertaken.

4.3. Summary

Table 31 summarises the results from the fully adjusted models for the primary analysis of interest explored in this section: feeding method at ages 4 weeks, 6 months and 15 months and speech sound error frequencies at age 25 months. The presence of an arrow indicates that an association (p<0.05) was observed; 🡅 suggests an *increased* likelihood of speech sound error, and 🡇 indicates *decreased* likelihood of speech sound error. Where significant associations are indicated, the overall pattern is of an element of protective effect of feeding (mixed or bottle) against increased likelihood of specific consonant errors. Exclusive bottle feeding at age 6 months is indicated to be associated with reduced frequencies of velar, liquid and postvocalic sound errors at age 25 months (Table 30). Mixed feeding at age 4 weeks is indicated to be associated with lower frequencies of consonant cluster and liquid sound errors (Table 29). No associations were observed between feeding method and fricative sound errors at age 25 months after adjustment for potential confounders.

Table 31. Summary of observed associations from the fully adjusted negative binomial regression models for feeding and speech sound error frequencies at age 25 months

Exposure variable: Feeding method		**Outcome variable: Speech sound error frequency at age 25 months**				
		Velar	**CC**	**Liquid**	**Fricative**	**PVC**
Age 4 weeks	**Breast**	-	-	-	-	-
	Mixed	-	🡇🡇	🡇🡇	-	-
	Bottle	-	-	-	-	-
Age 6 months	**Breast / mixed**	-	-	-	-	-
	Bottle	🡇🡇	-	🡇🡇	-	🡇🡇🡇
Age 15 months	**Breast**	-	-	-	-	-
	Mixed	-	-	(🡇🡇🡇)	-	-
	Bottle	-	-	-	-	-

Note: CC = consonant cluster. PVC = postvocalic. ( )= compared with exclusive bottle feeding
No. arrows indicates likelihood increase/decrease (one arrow <10%, two arrows=11-20%, three arrows=21-30%)

4.4. Data analysis: 61 month clinical speech assessment

Univariable analysis of the potential confounding variables with each of the consonant error types showed that all potential confounders had likelihood ratio *p* values <.10 following univariable analyses (Table 32). Only OME and the two language measures had likelihood ratios $p<.10$ for all six of the speech sound outcome measures. For consistency, all of these confounders were included in further model adjustment for each of the six consonant types. In order to retain a single measure of SES for the multivariable analysis, and to maintain consistency with the age 25 month speech error analysis, maternal education was dropped in favour of home ownership due to the lower likelihood ratio *p* value compared with maternal education.

Table 32. Univariable logistic regression model results for potential confounder variables associated with speech sound error frequency at age 61 months (*n*=815)

		Outcome variable: Consonant type error frequency at age 61 months								
		Velar			**Consonant Cluster**			**Liquid**		
Variable	**Category[a]**	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Demographics										
Biological sex[b]	**Female**	1.00	-	-	1.00	-	-	1.00	-	-
	Male	1.31 [0.97,1.76]	1.79	**.074**	1.16 [0.88,1.53]	1.07	.286	1.16 [0.88,1.52]	1.03	.303
Home ownership[b]	**Owned / priv. rented**	1.00	-	-	1.00	-	-	1.00	-	-
	Council / other	1.23 [0.78,1.93]	0.90	.368	2.17 [1.38,3.41]	3.36	**.001**	1.38 [0.89,2.12]	1.45	.146
Maternal age[c]		0.98 [0.95,1.01]	-1.17	.244	0.95 [0.92,0.98]	-3.27	**.001**	0.99 [0.96,1.02]	-0.64	.522
Maternal education[b]	**< O level**	1.00	-	-	1.00	-	-	1.00	-	-
	O Level	0.85 [0.52,1.39]	-0.66	.510	0.63 [0.39,1.04]	-1.81	**.070**	0.97 [0.61,1.56]	-0.11	.910
	> O Level	0.82 [0.51,1.32]	-0.82	.414	0.37 [0.23,0.60]	-4.05	**<.001**	1.13 [0.72,1.78]	0.54	.591

Table 30. ***(Continued)***

Variable	Category[a]	Outcome variable: Consonant type error frequency at age 61 months								
		Velar			Consonant cluster			Liquid		
		OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Early developmental variables										
Weak sucking 4 weeks[b]	**No**	1.00	-	-	1.00	-	-	1.00	-	-
	Yes	1.15 [0.78,1.70]	0.70	.486	0.83 [0.57,1.20]	-0.99	.321	1.06 [0.73,1.54]	0.33	.740
OME at 61 months[b]	**AA**	1.00	-	-	1.00	-	-	1.00	-	-
	B	1.24 [0.75,2.05]	0.83	.409	1.38 [0.85,2.23]	1.30	.193	1.65 [1.01,2.68]	2.01	**.045**
	BB	1.95 [1.11,3.43]	2.33	**.020**	1.92 [1.08,3.40]	2.23	**.026**	1.39 [0.79,2.43]	1.15	.249
	Other	1.00 [0.69,1.43]	-0.01	.988	1.25 [0.89,1.74]	1.30	.195	1.02 [0.73,1.42]	0.09	.930
Early speech and language performance										
RDLS comprehension score age 61m[c]		0.96 [0.94,0.97]	-4.79	**<.001**	0.95 [0.93,0.97]	-5.47	**<.001**	0.98 [0.96,0.99]	-2.84	**.005**
Language score at 38 months[c]		0.99 [0.99,1.00]	-3.72	**<.001**	0.99 [0.98,0.99]	-4.59	**<.001**	0.99 [0.99,1.00]	-2.58	**.010**

Table 30. ***(Continued)***

Variable	Category[a]	Fricative OR [95% CI]	Fricative *z*	Fricative *p*	Postvocalic OR [95% CI]	Postvocalic *z*	Postvocalic *p*	Alveolar OR [95% CI]	Alveolar *z*	Alveolar *p*
		Outcome Variable: Consonant type error frequency at age 61 months								
Demographics										
Biological sex[b]	**Female**	1.00	-	-	1.00	-	-	1.00	-	-
	Male	1.47 [1.08,2.00]	2.42	**.016**	1.28 [0.96,1.70]	1.70	**.088**	0.97 [0.74,1.29]	-0.18	.856
Home ownership[b]	**Owned / priv. rented**	1.00	-	-	1.00	-	-	1.00	-	-
	Council / other	1.38 [0.87,2.18]	1.39	.165	1.36 [0.86,2.15]	1.33	.183	3.49 [2.19,5.57]	5.25	**<.001**
Maternal age[c]		1.00 [0.96,1.03]	-0.23	.819	0.95 [0.91,0.98]	-3.31	**.001**	0.94 [0.91,0.97]	-3.54	**<.001**
Maternal education[b]	**< O Level**	1.00	-	-	1.00	-	-	1.00	-	-
	O Level	0.99 [0.59,1.66]	-0.04	.968	0.74 [0.44,1.23]	-1.16	.247	0.42 [0.26,0.70]	-3.37	**.001**
	> O Level	0.89 [0.54,1.47]	-0.45	.649	0.56 [0.34,0.91]	-2.33	**.020**	0.26 [0.16,0.43]	-5.39	**<.001**

Table 30. ***(Continued)***

Variable	Category[a]	Outcome variable: Consonant type error frequency at age 61 months — Fricative OR [95% CI]	*z*	*p*	Postvocalic OR [95% CI]	*z*	*p*	Alveolar OR [95% CI]	*z*	*p*
Early developmental variables										
Weak sucking 4 weeks[b]	**No**	1.00	-	-	1.00	-	-	1.00	-	-
	Yes	0.69 [0.44,1.06]	-1.68	**.093**	1.16 [0.79,1.71]	0.76	.449	1.46 [1.00,2.11]	1.98	**.047**
OME at 61 months[b]	**AA**	1.00	-	-	1.00	-	-	1.00	-	-
	B	1.63 [0.99,2.71]	1.91	**.056**	2.03 [1.20,3.44]	2.64	**.008**	1.63 [1.01,2.63]	1.99	**.047**
	BB	1.82 [1.02,3.25]	2.04	**.041**	1.41 [0.79,2.52]	1.17	.242	2.01 [1.15,3.53]	2.43	**.015**
	Other	1.00 [0.69,1.46]	0.01	.991	1.69 [1.19,2.40]	2.93	**.003**	1.31 [0.94,1.84]	1.59	.112
Early speech and language performance										
RDLS comprehension score age 61m[c]		0.97 [0.95,0.99]	-2.97	**.003**	0.97 [0.95,0.99]	-3.41	**.001**	0.94 [0.92,0.96]	-6.17	**<.001**
Language Score at 38 months[c]		0.99 [0.98,0.99]	-5.42	**<.001**	0.99 [0.99,1.00]	-3.07	**.002**	0.99 [0.99,1.00]	-3.07	**.002**

Note: [a]For categorical variables only. [b]Categorical variable. [c]Continuous variable.
Biologic. Sex = Biological Sex. Maternal Educ. = Maternal Education. OME = otitis media with effusion (glue ear).

4.4.1. Age 61 month speech error analysis by feeding age group

Table 33 provides results of the univariable analysis, which indicated no association between feeding regime at any age and liquid or fricative sound errors at age 61 months. Increased likelihood of velar, consonant cluster and postvocalic sound errors were indicated to be associated with exclusive bottle feeding at age 4 weeks. Increased likelihood of alveolar errors was indicated to be associated with exclusive bottle feeding at all ages. Analysis at univariable level indicated a protective effect for breastfeeding against speech errors at age 61 months. The analyses were rerun with bottle feeding as the reference group to allow for comparison between exclusive bottle feeding and mixed feeding (Appendix Y). Compared with children who were exclusively bottle fed at age 4 weeks, children who were mixed fed were around 50% less likely to make postvocalic (OR 0.54 [95% CI 0.35,0.84], z=2.71, p=.007) or alveolar (OR 0.50 [95% CI 0.32,0.78], z=3.07, p=.002) sound errors at age 61 months. Children who were mixed fed at age 15 months were 59% less likely to make alveolar errors at age 61 months, compared with exclusively bottle fed children (OR 0.59 [95% CI 0.40,0.87], z=2.66, p=.008) (Appendix Y).

Table 33. Univariable logistic regression model for feeding and speech sound error frequency at age 61 months

Exposure variable: Feeding method		Outcome variable: Consonant type error frequency at age 61 months								
		Velar			CC			Liquid		
		OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.06 [0.68,1.66]	0.25	.805	1.07 [0.71,1.60]	0.33	.742	0.84 [0.56,1.25]	-0.87	.385
	Bottle fed	1.67 [1.17,2.37]	2.83	**.005**	1.38 [0.99,1.93]	1.90	**.057**	1.08 [0.77,1.50]	0.44	.660
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	1.11 [0.75, 1.64]	0.51	.610	1.27 [0.88,1.84]	1.28	.201	0.90 [0.62,1.30]	-0.58	.564
Age 15 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.86 [0.39,1.90]	-0.37	.715	1.16 [0.56,2.42]	0.39	.693	0.60 [0.29,1.26]	-1.35	.178
	Bottle fed	1.29 [0.57,2.91]	0.62	.538	1.62 [0.76,3.48]	1.24	.215	0.58 [0.27,1.26]	-1.37	.171

Table 31. ***(Continued)***

Exposure variable: Feeding method		Outcome variable: Consonant type error frequency at age 61 months								
		Fricative			Postvocalic			Alveolar		
		OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.83 [0.52,1.33]	-0.77	.439	0.81 [0.54,1.21]	-1.04	.299	1.01 [0.67,1.53]	0.05	.960
	Bottle fed	1.23 [0.85,1.76]	1.10	.272	1.49 [1.05,2.12]	2.24	**.025**	2.02 [1.44,2.83]	4.07	**<.001**
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	1.05 [0.70,1.58]	0.24	.808	1.31 [0.89,1.94]	1.38	.168	1.91 [1.32,2.78]	3.40	**.001**
Age 15 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.50 [0.62,3.59]	0.91	.365	1.41 [0.68,2.94]	0.92	.358	1.73 [0.79,3.78]	1.37	.171
	Bottle fed	1.69 [0.69,4.16]	1.14	.253	1.67 [0.78,3.59]	1.32	.188	2.91 [1.30,6.54]	2.59	**.010**

Note: n for all age 4 week models *n*=709.
n for all age 6 month models *n*=724.
n for all age 15 month models *n*=488.

The following sections present the results, by consonant type error frequency, for feeding groups where the likelihood ratio from the univariable analysis of the exposure and outcome variables was p <.10 (Table 33). The threshold p<.05 was applied to all multivariable analyses.

Velar speech sound error frequency at age 61 months

In the unadjusted model, children who were exclusively bottle fed at age 4 weeks were 67% more likely (OR 1.67 [95% CI 0.56,0.97], z=2.83, p=.005) to make velar errors at age 61 months compared with exclusively breast fed children (Table 34). This association was not maintained in the fully adjusted model (OR 1.27 [95% CI 0.82,1.96], z=1.08, p=.282). The unadjusted and adjusted models were re-run with bottle feeding as the reference group to allow for comparison of mixed feeding to bottle feeding (Appendix Z). No association was observed between feeding at age 4 weeks and velar errors at age 61 months in the adjusted model. Compared with children who were exclusively bottle fed at age 15 weeks, mixed fed children were around 33% less likely to make velar sound errors at age 61 months before adjustment for confounders (OR 0.67 [95% CI 0.45,1.00], z=-1.94, p=052). This association did not remain after full adjustment of the model (OR 0.85 [95% CI 0.51,1.42], z=-0.63, p=530) (Appendix Z).

Table 34. Logistic unadjusted and adjusted regression models for feeding at age 4 weeks and velar speech sound error frequency at age 61 months (*n*=709)

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.06 [0.68,1.66]	0.25	.805	1.05 [0.67,1.65]	0.23	.820	1.05 [0.67,1.65]	0.22	.825
	Bottle fed	1.67 [1.17,.37]	2.83	**.005**	1.63 [1.14,2.34]	2.67	**.008**	1.63 [1.14,2.34]	2.66	**.008**

Table 32. ***(Continued)***

Exposure variable: Feeding method		Model 2b: Adjusted for biological sex, home ownership and maternal age			Model 2c: Adjusted for biological sex, home ownership and OME age 61 months			Model 3a: Adjusted for biological sex, home ownership and language score at age 38 months		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	1 [-]	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.06 [0.67,1.66]	0.23	.815	1.00 [0.63,1.58]	-0.02	.985	1.08 [0.68,1.72]	0.32	.747
	Bottle fed	1.64 [1.14,2.37]	2.65	**.008**	1.61 [1.11,2.34]	2.51	**.012**	1.55 [1.06,2.25]	2.28	**.022**

Table 32. *(Continued)*

Exposure variable: Feeding method		Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 61 months			Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, OME age 61 months, language score at age 38 months and RDLS comprehension standardised score at age 61 months		
		OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.96 [0.60,1.55]	-0.17	.867	0.95 [0.58,1.58]	-0.18	.857
	Bottle fed	1.19 [0.80,1.77]	0.87	.383	1.18 [0.77,1.81]	0.78	.437

Note: *n* for Age 4 weeks: model 0 *n*=709; model 1 *n*=701; model 2a *n*=701; model 2b *n*=701; model 2c *n*=668; model 3a *n*=675; model 3b *n*=601; model 4 *n*=554.

Consonant cluster speech sound error frequency at age 61 months

In the unadjusted model, children who were exclusively bottle fed at age 4 weeks were indicated to be more likely (OR 1.38 [95% CI 0.99,1.93], z=1.90, p=.057) to make consonant cluster errors at age 61 months compared with exclusively breast fed children (Table 35). This weak association was not maintained in the fully adjusted model (OR 1.02 [95% CI 0.68,1.52], z=0.08, p=.938) (Table 35). The unadjusted and adjusted models for feeding were re-run with bottle feeding as the reference group to allow for comparison of mixed feeding to bottle feeding (Appendix Z). No association was observed between feeding at age 4 weeks and consonant clusters error frequency at age 61 months. A weak association was observed in the unadjusted model with children who were mixed fed at age 15 months (OR 0.72 [95% CI 0.49, 1.05], z=-1.71, p=.088), compared to those who were exclusively bottle fed at this age. This association did not remain in the fully adjusted model (OR 1.10 [95% CI 0.68, 1.80], z=0.40, p=.691) (Appendix Z).

Table 35. Logistic unadjusted and adjusted regression models for feeding at age 4 weeks and consonant cluster speech sound error frequency at age 61 months (*n*=709)

Exposure variable: Feeding method		**Model 0: Unadjusted**			**Model 1: Adjusted for biological sex and home ownership**			**Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.07 [0.71,1.60]	0.33	.742	1.09 [0.72,1.63]	0.40	.691	1.10 [0.73,1.66]	0.45	.650
	Bottle fed	1.38 [0.99,1.93]	1.90	**.057**	1.30 [0.93,1.83]	1.52	.129	1.31 [0.93,1.84]	1.55	.122

Table 33. ***(Continued)***

Exposure variable: Feeding method		Model 2b: Adjusted for biological sex, home ownership and maternal age			Model 2c: Adjusted for biological sex, home ownership and OME age 61 months			Model 3a: Adjusted for biological sex, home ownership and language score at age 38 months		
		OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.06 [0.70,1.60]	0.28	.782	1.07 [0.71,1.63]	0.34	.737	1.17 [0.77,1.78]	0.72	.469
	Bottle fed	1.19 [0.84,1.69]	0.99	.324	1.33 [0.93,1.89]	1.58	.114	1.18 [0.83,1.68]	0.91	.362

Table 33. ***(Continued)***

Exposure variable: Feeding method		Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 61 months			Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, OME age 61 months, language score at age 38 months and RDLS comprehension standardised score at age 61 months		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.04 [0.67,1.62]	0.18	.857	1.12 [0.70,1.79]	0.49	.627
	Bottle fed	1.04 [0.71,1.52]	0.21	.831	1.02 [0.68,1.52]	0.08	.938

Note: *n* for Age 4 weeks: model 0 *n*=709; model 1 *n*=701; model 2a *n*=701; model 2b *n*=701; model 2c *n*=668; model 3a *n*=675; model 3b *n*=601; model 4 *n*=554.

Postvocalic speech sound error frequency at age 61 months

In the unadjusted model, children who were bottle fed at age 4 weeks were more likely (OR 1.49 [95% CI 1.05,2.12], z=2.24, p=.025) to make postvocalic errors at age 61 months compared with exclusively breast fed children (Table 36). This association was not maintained in the adjusted model (OR 1.04 [95% CI 0.69,1.57], z=0.18, p=.860). The unadjusted and adjusted models for feeding at age 4 weeks were re-run with bottle feeding as the reference group to allow for comparison of mixed feeding to bottle feeding (Appendix Z). In the unadjusted model children who were mixed fed at age 4 weeks were around 46% less likely to make postvocalic errors at age 61 months compared with exclusively bottle fed children (OR 0.54 [95% CI 0.35,0.84], z=-2.71, p=.007). After full adjustment of the model this association did not remain (OR 0.78 [95% CI 0.47,1.31], z=-0.94, p=.347) (Appendix Z). No association was observed between feeding at age 15 months and postvocalic sound errors at age 61 months.

Table 36. Logistic unadjusted and adjusted regression models for feeding at age 4 weeks and postvocalic speech sound error frequency at age 61 months (*n*=709)

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.81 [0.54,1.21]	-1.04	.299	0.80 [0.53,1.21]	-1.04	.297	0.80 [0.53,1.20]	-1.08	.278
	Bottle fed	1.49 [1.05,2.12]	2.24	**.025**	1.42 [0.99,2.02]	1.93	.054	1.41 [0.99,2.02]	1.91	.057

Table 34. ***(Continued)***

Exposure variable: Feeding method		**Model 2b: Adjusted for biological sex, home ownership and maternal age**			**Model 2c: Adjusted for biological sex, home ownership and OME age 61 months**			**Model 3a: Adjusted for biological sex, home ownership and language score at age 38 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.79 [0.52,1.19]	-1.14	.256	0.75 [0.49,1.14]	-1.33	.182	0.78 [0.51,1.18]	-1.17	.241
	Bottle fed	1.33 [0.92,1.90]	1.53	.127	1.38 [0.95,2.00]	1.71	.088	1.28 [0.89,1.84]	1.32	.186

Table 34. ***(Continued)***

Exposure variable: Feeding method		Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 61 months			Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, OME age 61 months, language score at age 38 months and RDLS comprehension standardised score at age 61 months		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	0.84 [0.54,1.31]	-1.75	.450	0.76 [0.48,1.21]	-1.15	.249
	Bottle fed	1.13 [0.77,1.65]	0.60	.545	1.04 [0.69,1.57]	0.18	.860

Note: *n* for Age 4 weeks: model 0 *n*=709; model 1 *n*=701; model 2a *n*=701; model 2b *n*=701; model 2c *n*=668; model 3a *n*=675; model 3b *n*=601; model 4 *n*=554.

Alveolar speech sound errors at age 61 months

In the unadjusted model, exclusively bottle fed children at ages 4 weeks (OR 2.02 [95% CI 1.44,2.83], z=4.07, p<.001) and 6 months (OR 1.91 [95% CI 1.32,2.78], z=3.40, p=.001) were twice as likely to make alveolar speech sound errors at age 61 months compared with breast fed children (Table 37). These associations were not maintained after full adjustment of the models (Table 37). In the unadjusted model, exclusively bottle fed children at 15 months were almost three times more likely to make alveolar speech sound errors at age 61 months (OR 2.91 [95% CI 1.30,6.54], z=2.59, p=.010). Note the wide confidence interval for this result, which indicates a larger margin of error. After adjustment for confounders, the association remained (OR 3.27 [95% CI 1.21,8.84], z=2.34, p=.019). Note the wide confidence interval.

After full adjustment for confounders, an association was observed between children who were mixed fed at age 15 months and increased likelihood of alveolar errors at age 61 months (OR 3.06 [95% CI 1.17,8.00], z=2.28, p=.022). Note the wide confidence interval, which suggests indicates a larger margin of error. This association was not present in the unadjusted model (Table 37).

The unadjusted and adjusted models were re-run with exclusive bottle feeding as the reference group to allow for comparison between mixed feeding and bottle feeding (Appendix Z). In the unadjusted models mixed fed children at ages 4 weeks and 15 months (OR 0.50 [95% CI 0.32,0.78], z=-3.07, p=.002; OR 0.59 [95% CI 0.40,0.87], z=2.66, p=.008, respectively) were around 50% less likely to make alveolar sound errors at age 61 months compared with exclusively bottle fed children. Neither of these associations remained after full adjustment of the models.

Table 37. Logistic unadjusted and adjusted regression models for feeding and alveolar speech sound error frequency at age 61 months

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.01 [0.67,1.53]	0.05	.960	1.03 [0.68,1.58]	0.17	.865	1.01 [0.67,1.55]	0.07	.947
	Bottle fed	2.02 [1.44,2.83]	4.07	**<.001**	1.87 [1.32,2.65]	3.53	**<.001**	1.86 [1.31,2.63]	3.48	**<.001**
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	1.91 [1.32,2.78]	3.40	**.001**	1.74 [1.19,2.56]	2.83	**.005**	1.70 [1.16,2.51]	2.69	**.007**
Age 15 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.73 [0.79,3.78]	1.37	.171	1.98 [0.87,4.49]	1.64	.101	1.88 [0.83,4.29]	1.51	.131
	Bottle fed	2.91 [1.30,6.54]	2.59	**.010**	2.96 [1.27,6.90]	2.52	**.012**	2.85 [1.22,6.66]	2.41	**.016**

Table 35. ***(Continued)***

Exposure variable: Feeding method		Model 2b: Adjusted for biological sex, home ownership and maternal age			Model 2c: Adjusted for biological sex, home ownership and OME age 61 months			Model 3a: Adjusted for biological sex, home ownership and language score at age 38 months		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.02 [0.67,1.56]	0.11	.909	1.01 [0.65,1.55]	0.03	.979	1.08 [0.70,1.67]	0.36	.722
	Bottle fed	1.79 [1.26,2.55]	3.24	**.001**	1.83 [1.28,2.63]	3.30	**.001**	1.72 [1.20,2.46]	2.96	**.003**
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle fed	1.67 [1.13,2.46]	2.58	**.010**	1.69 [1.13,2.52]	2.57	**.010**	1.56 [1.05,2.33]	2.18	**.029**
Age 15 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.91 [0.84,4.32]	1.55	.122	2.49 [1.05,5.87]	2.08	**.038**	2.06 [0.89,4.80]	1.68	.093
	Bottle fed	2.72 [1.16,6.37]	2.30	**.021**	3.67 [1.51,8.94]	2.87	**.004**	2.87 [1.19,6.91]	2.35	**.019**

Table 35. ***(Continued)***

Exposure variable: Feeding method		**Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 61 months**			**Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, OME age 61 months, language score at age 38 months and RDLS comprehension standardised score at age 61 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	1.06 [0.67,1.66]	0.24	.810	1.01 [0.63,1.63]	0.05	.958
	Bottle fed	1.52 [1.04,2.24]	2.14	**.033**	1.37 [0.90,2.09]	1.49	.137
Age 6 months	**Breast / mixed fed**	1 [-]	-	-	1 [-]	-	-
	Bottle fed	1.54 [1.01,2.35]	1.98	**.047**	1.26 [0.79,2.01]	0.99	.323
Age 15 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	2.23 [0.91,5.46]	1.76	**.**078	3.06 [1.17,8.00]	2.28	**.022**
	Bottle fed	2.55 [1.02,6.42]	1.99	**.046**	3.27 [1.21,8.84]	2.34	**.019**

Note: *n* for Age 4 weeks: model 0 *n*=709; model 1 *n*=701; model 2a *n*=701; model 2b *n*=701; model 2c *n*=668; model 3a *n*=675; model 3b *n*=601; model 4 *n*=554. *n* for Age 6 months: model 0 *n*=724; model 1 *n*=715; model 2a *n*=708; model 2b *n*=715; model 2c *n*=682; model 3a *n*=688; model 3b *n*=610; model 4 *n*=559. *n* for Age 15 months: model 0 *n*=488; model 1 *n*=483; model 2a *n*=475; model 2b *n*=483; model 2c *n*=459; model 3a *n*=460; model 3b *n*=416; model 4 *n*=375.

The following sections summarise, by feeding age group, the unadjusted and adjusted regression models for each consonant error type where $p<.10$ in univariable analysis of the exposure and outcome variables. The threshold $p<.05$ was applied to all multivariable analyses.

Consonant error frequencies at age 61 months and feeding at age 4 weeks

The unadjusted model indicates an association between exclusive bottle feeding at age 4 weeks and higher speech sound error frequencies for velar (OR 1.67, 95% CI 1.17,2.37, z 2.83, $p=.005$), consonant cluster (OR 1.38, 95% CI 0.99,1.93, z 1.90, $p=.057$), postvocalic (OR 1.49, 95% CI 1.05,2.12, z 2.24, $p=.025$) and alveolar (OR 2.02, 95% CI 1.44,2.83, z 4.07, $p<.001$) consonants at age 61 months (Table 38). These associations were not maintained in the fully adjusted model (Table 38).

Table 38. Logistic regression of feeding method at age 4 weeks and speech error frequencies at age 61 months (unadjusted and adjusted models)

Consonant type error frequency at age 61 months	Model 0: Unadjusted								
	Breast fed			Mixed fed			Bottle fed		
	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Velar	1 -	-	-	1.06 [0.68,1.66]	0.25	.805	1.67 [1.17,2.37]	2.83	**.005**
CC	1 -	-	-	1.07 [0.71,1.60]	0.33	.742	1.38 [0.99,1.93]	1.90	.057
PVC	1 -	-	-	0.81 [0.54,1.21]	-1.04	.299	1.49 [1.05,2.12]	2.24	**.025**
Alveolar	1 -	-	-	1.01 [0.67,1.53]	0.05	.960	2.02 [1.44,2.83]	4.07	**<.001**

Table 36. ***(Continued)***

Consonant type error frequency at age 61 months	Model 4: Fully adjusted								
	Breast fed			Mixed fed			Bottle fed		
	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Velar	1 -	-	-	0.95 [0.58,1.58]	-0.18	.857	1.18 [0.77,1.81]	0.78	.437
CC	1 -	-	-	1.12 [0.70,1.79]	0.49	.627	1.02 [0.68,1.52]	0.08	.938
PVC	1 -	-	-	0.76 [0.48,1.21]	-1.15	.249	1.04 [0.69,1.57]	0.18	.860
Alveolar	1 -	-	-	1.01 [0.63,1.63]	0.05	.958	1.37 [0.90,2.09]	1.49	.137

Note: CC = consonant cluster. PVC = postvocalic. *n* for all model 0 *n*=709. *n* for all model 4 *n*=554.

Consonant type error frequencies at age 61 months and feeding at ages 6 and 15 months

Comparisons between consonant type error frequencies associated with feeding at ages 6 and 15 months were not possible as only alveolar errors were shown to be associated, as described above (Table 33 and Table 38).

4.5. Summary

Table 39 summarises the results from adjusted models for the primary analysis of interest explored in this section: feeding method at ages 4 weeks, 6 months and 15 months and speech sound error frequencies at age 61 months. The presence of an arrow indicates that an association (p<0.05) was observed; ↑ suggests an *increased* likelihood of speech sound error, and ↓ indicates *decreased* likelihood of speech sound error. Children who were mixed fed or exclusively bottle fed at age 15 months were shown to be almost three times more likely to make alveolar speech sound errors at age 61 months (OR 2.89 [95% CI 1.11,7.58], z 2.16, p=.030 and (OR 2.90 [95% CI 1.06,7.96], z 2.07, p=.039, respectively), compared with children who were exclusively breast fed at age 15 months.

Table 39. Summary of observed associations from the fully adjusted logistic regression models for feeding method and speech sound error frequencies at age 61 months

Exposure variable: Feeding method		Outcome variable: Speech sound error frequency at age 61 months					
		Velar	**CC**	**Liquid**	**Fricative**	**PVC**	**Alveolar**
Age 4 weeks	**Breast**	-	-	-	-	-	-
	Mixed	-	-	-	-	-	-
	Bottle	-	-	-	-	-	-
Age 6 months	**Breast/ mixed**	-	-	-	-	-	-
	Bottle	-	-	-	-	-	-
Age 15 months	**Breast**	-	-	-	-	-	-
	Mixed	-	-	-	-	-	↑306%
	Bottle	-	-	-	-	-	↑327%

Note: CC = consonant cluster. PVC = postvocalic.

5. Part C – NNS and speech sound error frequencies at ages 25 and 61 months

In this section, questionnaire data on NNS from the whole cohort are examined together with the clinical speech assessment data (at ages 25 and 61 months) used in part B to explore the relationship between NNS and speech development. The following sections report the results for the NNS groups at each of the age points (4 weeks, 15 months,24 months and 38 months) respectively for the 10% subset of children from the original dataset explored in Part A of Strand One.

5.1. Sample size

Exposure variable data on NNS were available for each of the outcome measures. Figure 20 illustrates the process of derivation of participants for this study.

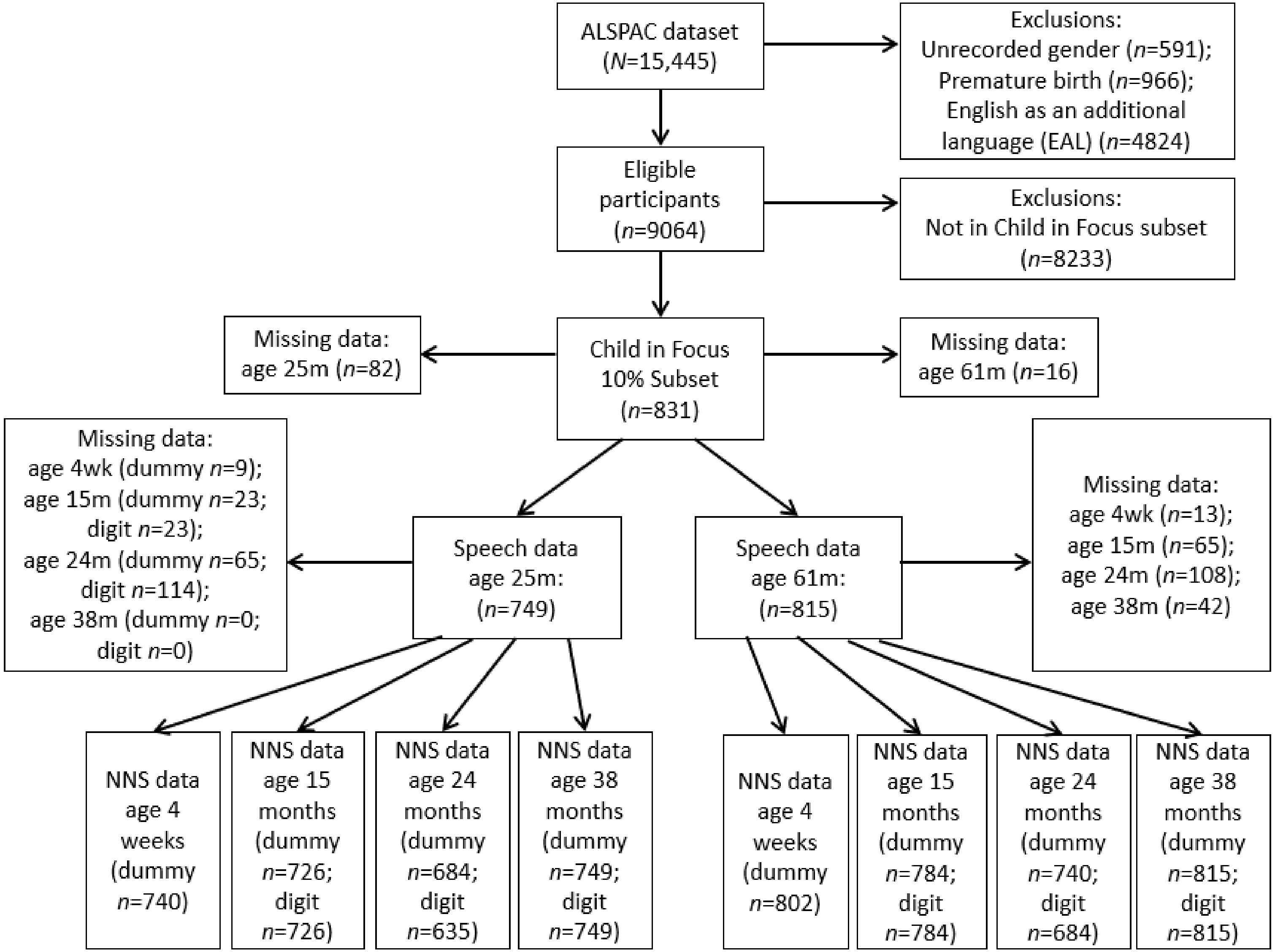

Figure 20. Derivation of participants for Strand One Part C

5.1.1. Exposure variables: NNS groups

The NNS variables for this analysis have been determined from existing variables within the ALSPAC dataset (Table 40 and Table 41). Data on NNS behaviour at age 4 weeks are only available for dummy use, and not digit sucking, as these data were not collected in the original ALSPAC study. Table 41 shows that, in both the 25 month and 61 month analyses, there is a higher proportion of children at age 24 months who suck either a dummy or digit most of the time compared to age 15 months. The proportion of occasional NNS behaviours shows a pattern of decrease between the age 15 and 24 month measures.

Table 40. Sample size (*n*) for dummy use at age 4 weeks by speech data available at ages 25 and 61 months

Dummy use at age 4 weeks	Age 25 month analysis *n* %	Age 61 month analysis *n* %
No	322 43.51	346 43.14
Yes	418 56.49	456 56.86

Table 41. Sample size (*n*) for NNS groups by speech data available at ages 25 and 61 months

NNS age point	NNS groups: Child in focus subset											
	Age 25 months analysis *n* %						Age 61 months analysis *n* %					
	Dummy sucking			Digit sucking			Dummy sucking			Digit sucking		
	N	S	M	N	S	M	N	S	M	N	S	M
15 months	454 62.53	220 30.30	52 7.16	560 77.13	143 19.69	23 3.17	482 61.48	249 31.76	53 6.76	606 77.30	153 19.52	25 3.19
24 months	451 72.28	173 27.72	60 9.62	493 77.64	107 16.85	35 5.51	481 65.00	196 26.48	63 8.51	536 78.36	111 16.22	37 5.41
38 months	-	-	-	-	-	-	674 82.70	117 14.36	24 2.94	667 81.84	113 13.87	35 4.29

Note: N = Never. S = Sometimes. M = Mostly.

5.1.2. Potential confounding variables

The potential confounding variables used in this analysis are presented in Part B (see section 4.1.2).

5.1.3. Outcome variables: 25 month clinical speech assessment data

The summary statistics for the age 25 month speech sound error score data are detailed in Part B (see section 4.1.3).

5.1.4. Outcome variables: 61 month clinical speech assessment data

The summary statistics for the age 61 month speech sound error score data are detailed in Part B (see section 4.1.4).

5.2. Data analysis: 25 month clinical speech assessment

Univariable analysis of the potential confounding variables is detailed in section 4.2

5.2.1. Age 25 month speech sound error analysis by NNS group

Univariable analysis of the relationship between the NNS groups and each of the consonant types at age 25 months indicated that velar sound errors are the only outcome shown to be potentially associated (p<.10) with NNS behaviours (Table 42). In the unadjusted models, children who frequently sucked a dummy at age 24 months (IRR 0.74 [95% CI 0.54,1.01], z=-1.89, p=.059) or sometimes sucked their digit at age 24 months (IRR 0.74 [95% CI 0.58,0.94], z=-2.42, p=.016) were around 25% less likely to make velar sound errors at age 25 months compared with children who did not engage in these NNS behaviours at age 24 months (Table 43). Both these associations were maintained, and were strengthened, after full adjustment for potential confounders (dummy 'mostly' age 24 months: IRR 0.68 [95% CI 0.49,0.94], z=-2.34, p=.019; digit 'sometimes' age 24 months: IRR 0.74 [95% CI 0.58,0.94], z=-2.43, p=.015).

Table 42. Univariable negative binomial regression results for NNS and speech sound error frequency at age 25 months

Exposure variable: NNS behaviour		Outcome Variable: Consonant type error frequency at age 25 months								
		Velar			Consonant cluster			Liquid		
		IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Yes	1.03 [0.87,1.21]	0.34	.732	0.99 [0.89,1.10]	-0.21	.832	1.01 [0.89,1.15]	0.20	.840
Dummy age 15 months	**N**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	S	1.02 [0.85,1.21]	0.17	.868	1.00 [0.89,1.13]	-0.02	.987	1.02 [0.89,1.17]	0.30	.761
	M	0.85 [0.61,1.18]	-0.98	.328	1.08 [0.88,1.33]	0.72	.472	1.16 [0.91,1.48]	1.20	.230
Digit age 15 months	**N**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	S	0.90 [0.73,1.10]	-1.02	.307	0.99 [0.87,1.14]	-0.07	.942	1.01 [0.87,1.19]	0.17	.867
	M	0.91 [0.57,1.46]	-0.38	.707	0.98 [0.72,1.34]	-0.12	.906	1.03 [0.72,1.47]	0.14	.887
Dummy age 24 months	**N**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	S	1.11 [0.91,1.34]	1.03	.304	1.05 [0.93,1.20]	0.80	.426	1.07 [0.93,1.25]	0.94	.349
	M	0.74 [0.54,1.01]	-1.89	**.059**	0.99 [0.82,1.21]	-0.07	.944	1.08 [0.86,1.35]	0.65	.519
Digit age 24 months	**N**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	S	0.74 [0.58,0.94]	-2.42	**.016**	1.03 [0.88,1.20]	0.32	.748	1.03 [0.86,1.24]	0.32	.752
	M	1.06 [0.72,1.55]	0.28	.780	1.06 [0.82,1.37]	0.42	.671	1.11 [0.82,1.49]	0.65	.515

Table 40. ***(Continued)***

Exposure variable: NNS behaviour		Outcome Variable: Consonant type error frequency at age 25 months					
		Fricative			Postvocalic		
		IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-
	Yes	0.96 [0.83,1.11]	-0.52	.602	1.12 [0.91,1.39]	1.06	.289
Dummy age 15 months	**N**	1 [-]	-	-	1 [-]	-	-
	S	0.96 [0.82,1.13]	-0.49	.626	1.14 [0.90,1.45]	1.12	.261
	M	0.97 [0.73,1.29]	-0.20	.840	0.91 [0.59,1.40]	-0.42	.675
Digit age 15 months	**N**	1 [-]	-	-	1 [-]	-	-
	S	0.87 [0.72,1.04]	-1.53	.125	0.97 [0.74,1.27]	-0.25	.801
	M	0.86 [0.57,1.32]	-0.67	.500	0.86 [0.46,1.61]	-0.47	.639
Dummy age 24 months	**N**	1 [-]	-	-	1 [-]	-	-
	S	0.99 [0.83,1.17]	-0.14	.886	1.20 [0.93,1.55]	1.41	.158
	M	0.87 [0.66,1.13]	-1.04	.299	0.79 [0.53,1.18]	-1.14	.252
Digit age 24 months	**N**	1 [-]	-	-	1 [-]	-	-
	S	0.96 [0.78,1.19]	-0.38	.702	0.90 [0.65,1.24]	-0.66	.506
	M	0.98 [0.69,1.39]	-0.10	.919	1.10 [0.65,1.84]	0.34	.732

Note: N = Never. S = Sometimes. M = Mostly. *n* for all dummy age 4 week models *n*=713, except fricative (*n*=712). *n* for all dummy age 15 month models *n*=701, except fricative (*n*=700). *n* for all digit age 15 month models *n*=701, except fricative (*n*=700). *n* for all dummy age 24 month models *n*=660. *n* for all digit age 24 month models *n*=616, except fricative (*n*=615).

Table 43. Negative binomial unadjusted and adjusted regression models for NNS and velar speech sound error frequency at age 25 months

Exposure variable: NNS behaviour		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks		
		IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*	IRR [95% CI]	*z*	*p*
Dummy age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.11 [0.91,1.34]	1.03	.304	1.09 [0.90,1.33]	0.92	.358	1.10 [0.90,1.33]	0.95	.342
	Mostly	0.74 [0.54,1.01]	-1.89	.059	0.73 [0.53,1.01]	-1.90	.057	0.73 [0.53,1.00]	-1.93	.053
Digit age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.74 [0.58,0.94]	-2.42	**.016**	0.73 [0.57,0.93]	-2.55	**.011**	0.73 [0.57,0.93]	-2.53	**.011**
	Mostly	1.06 [0.72,1.55]	0.28	.780	1.06 [0.72,1.54]	0.28	.782	1.07 [0.73,1.57]	0.35	.723

Table 41. ***(Continued)***

Exposure variable: NNS behaviour		Model 2b: Adjusted for biological sex, home ownership and maternal age			Model 3a: Adjusted for biological sex, home ownership and word combination at age 25 months		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Dummy age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.08 [0.90,1.33]	0.77	.442	1.08 [0.89,1.30]	0.78	.435
	Mostly	0.71 [0.52,0.98]	-2.07	**.038**	0.69 [0.50,0.94]	-2.34	**.019**
Digit age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.73 [0.57,0.93]	-2.48	**.013**	0.72 [0.56,0.91]	-2.71	**.007**
	Mostly	1.05 [0.72,1.53]	0.25	.801	0.91 [0.62,1.33]	-0.50	.620

Table 41. ***(Continued)***

Exposure variable: NNS behaviour		Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 25 months			Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, word combination at age 25 months and RDLS comprehension standardised score at age 25 months		
		IRR [95% CI]	***z***	***p***	**IRR [95% CI]**	***z***	***p***
Dummy age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.08 [0.89,1.31]	0.74	.462	1.06 [0.87,1.28]	0.56	.573
	Mostly	0.75 [0.54,1.03]	-1.76	.079	0.68 [0.49,0.94]	-2.34	**.019**
Digit age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.74 [0.58,0.95]	-2.37	**.018**	0.74 [0.58,0.94]	-2.43	**.015**
	Mostly	1.14 [0.77,1.67]	0.64	.519	1.01 [0.69,1.49]	0.06	.954

n for Dummy Age 24 months: model 0 *n*=660; model 1 *n*=651; model 2a *n*=645; model 2b *n*=651; model 3a *n*=646; model 3b *n*=633; model 4 *n*=622. *n* for Digit Age 24 Months: model 0 *n*=616; model 1 *n*=608; model 2a *n*=602; model 2b *n*=608; model 3a *n*=604; model 3b *n*=590; model 4 *n*=580.

5.3. Summary

Table 44 summarises the results from the primary analysis of interest explored in this section, NNS (ages 4 weeks, 15 months and 24 months) and speech sound error frequencies at age 25 months. The presence of an arrow indicates that an association (p<0.05) was observed; 🡅 suggests an *increased* likelihood of speech sound error, and 🡇 indicates *decreased* likelihood of speech sound error. A potential protective effect was found of NNS behaviours at age 24 months against likelihood of velar sound errors at age 25 months. Children who sucked a dummy most of the time at age 24 months were around 32% less likely than children who never sucked a dummy at this age to make velar sound errors at age 25 months (IRR 0.68 [95% CI 0.49,0.94], z=-2.34, p=.019) (Table 43). Children who sometimes sucked their finger or thumb at age 24 months were 1.35 times more likely not to make velar speech sound errors at age 25 months (IRR 0.74 [95% CI 0.58,0.94], z=-2.42, p=.016) compared with children who never sucked their finger/thumb (Table 43).

Table 44. Summary of observed associations for the adjusted negative binomial regression models for NNS and speech sound error frequencies at age 25 months

Exposure variable: NNS behaviour		Outcome variable: Speech sound error frequency at age 25 months				
		Velar	CC	Liquid	Fricative	PVC
Dummy age 4 weeks	Yes	-	-	-	-	-
Dummy age 15 months	Sometimes	-	-	-	-	-
	Mostly	-	-	-	-	-
Digit age 15 months	Sometimes	-	-	-	-	-
	Mostly	-	-	-	-	-
Dummy age 24 months	Sometimes	-	-	-	-	-
	Mostly	🡇🡇🡇🡇	-	-	-	-
Digit age 24 months	Sometimes	🡇🡇🡇	-	-	-	-
	Mostly	-	-	-	-	-

Note: N = CC = Consonant cluster. PVC = postvocalic.
No. arrows indicates likelihood increase/decrease (one arrow <10%, two arrows=11-20%, three arrows=21-30%, four arrows=31-40%).

The following sections present the results for the analysis of the association between NNS and speech sound error frequencies at age 61 months.

5.4. Data analysis: 61 month clinical speech assessment

Univariable analysis of the potential confounding variables is described in section 4.4.

5.4.1. Age 61 month speech error analysis by NNS group

Univariable analysis of the relationship between the NNS groups and each of the consonant types at age 61 months indicated that consonant cluster, fricative, postvocalic and alveolar sounds had likelihood ratios $p<.10$ (Table 45). The following sections explore the model adjustment for these outcomes. The threshold of $p<.05$ was used in all multivariable analyses to identify significant associations.

Table 45. Univariable logistic regression models for NNS and speech sound error frequency at age 61 months

Exposure variable: NNS behaviour		Outcome variable: Consonant type error frequency at age 61 months								
		Velar			Consonant cluster			Liquid		
		OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Yes	1.01 [0.75,1.36]	0.07	.944	1.39 [1.05,1.84]	2.29	**.022**	1.12 [0.85,1.48]	0.78	.435
Dummy age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.98 [0.71,1.36]	-0.10	.917	1.06 [0.78,1.44]	0.37	.709	0.98 [0.72,1.33]	-0.14	.888
	Mostly	0.97 [0.53,1.78]	-0.10	.917	1.28 [0.72,2.26]	0.85	.395	1.28 [0.72,2.26]	0.85	.395
Digit age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.92 [0.62,1.34]	-0.45	.653	1.11 [0.78,1.59]	0.60	.550	0.93 [0.65,1.33]	-0.38	.705
	Mostly	1.62 [0.72,3.64]	1.18	.240	0.96 [0.43,2.15]	-0.09	.927	0.68 [0.30,1.54]	-0.92	.358

Table 43. ***(Continued)***

Exposure variable: NNS behaviour		Outcome variable: Consonant type error frequency at age 61 months								
		Velar			Consonant cluster			Liquid		
		OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Dummy age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.90 [0.63,1.29]	-0.57	.566	0.98 [0.71,1.37]	-0.09	.928	1.14 [0.81,1.58]	0.75	.451
	Mostly	1.12 [0.65,1.95]	0.41	.684	1.34 [0.79,2.27]	1.07	.283	0.91 [0.54,1.54]	-0.34	.730
Digit age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.17 [0.76,1.80]	0.71	.476	1.21 [0.80,1.82]	0.91	.364	0.79 [0.52,1.19]	-1.13	.257
	Mostly	1.31 [0.66,2.62]	0.78	.437	0.81 [0.41,1.59]	-0.61	.543	1.22 [0.62,2.37]	0.57	.565
Dummy age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.98 [0.64,1.50]	-0.08	.936	1.04 [0.71,1.55]	0.22	.827	0.99 [0.67,1.47]	-0.03	.973
	Mostly	1.80 [0.79,4.08]	1.40	.160	1.21 [0.54,2.75]	0.46	.642	0.88 [0.39,2.00]	-0.29	.769
Digit age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.11 [0.73,1.69]	0.49	.625	1.23 [0.83,1.84]	1.02	.309	0.79 [0.53,1.18]	-1.16	.247
	Mostly	0.84 [0.40,1.79]	-0.45	.655	1.11 [0.56,1.19]	0.30	.762	1.37 [0.69,2.73]	0.91	.364

Table 43. ***(Continued)***

Exposure variable: NNS behaviour		**Outcome variable: Consonant type error frequency at age 61 months**								
		Fricative			**Postvocalic**			**Alveolar**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Yes	1.23 [0.90,1.68]	1.30	.193	1.21 [0.91,1.61]	1.32	.188	1.69 [1.27,2.25]	3.61	**<.001**
Dummy age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.24 [0.89,1.73]	1.25	.210	0.93 [0.68,1.28]	-0.43	.667	1.14 [0.84,1.56]	0.86	.391
	Mostly	0.96 [0.51,1.83]	-0.12	.906	0.80 [0.45,1.42]	-0.77	.441	1.99 [1.11,3.53]	2.34	**.019**
Digit age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.96 [0.65,1.43]	-0.18	.859	1.26 [0.87,1.82]	1.22	.222	1.27 [0.89,1.81]	1.30	.193
	Mostly	0.78 [0.31,1.98]	-0.52	.601	1.19 [0.52,2.73]	0.40	.687	0.42 [0.16,1.06]	-1.85	**.065**

Table 43. ***(Continued)***

Exposure variable: NNS behaviour		Outcome variable: Consonant type error frequency at age 61 months								
		Fricative			**Postvocalic**			**Alveolar**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.25 [0.87-1.80]	1.20	.230	0.76 [0.54-1.06]	-1.63	.103	1.07 [0.77,1.49]	0.39	.694
	Mostly	1.38 [0.79-2.42]	1.13	.258	0.96 [0.56-1.65]	-0.15	.882	1.67 [0.99,2.84]	1.91	**.056**
Digit age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.30 [0.84,2.02]	1.16	.247	1.22 [0.80,1.87]	0.93	.354	1.31 [0.87,1.97]	1.30	.195
	Mostly	1.14 [0.55,2.37]	0.36	.718	1.38 [0.68,2.81]	0.89	.373	0.91 [0.46,1.79]	-0.27	.785
Dummy age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.45 [0.96,2.20]	1.75	**.080**	0.79 [0.53,1.17]	-1.19	.234	1.06 [0.72,1.58]	0.30	.765
	Mostly	1.11 [0.45,2.71]	0.22	.824	0.85 [0.37,1.94]	-0.39	.700	2.66 [1.12,6.29]	2.22	**.026**
Digit age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.23 [0.80,1.89]	0.94	.346	0.90 [0.60,1.35]	-0.51	.612	1.12 [0.75,1.67]	0.55	.585
	Mostly	1.21 [0.58,2.51]	0.50	.617	2.16 [0.97,4.84]	1.88	**.060**	1.24 [0.63,2.45]	0.62	.538

Note: N = never, S = sometimes, M = mostly. *n* for all dummy age 4 week models *n*=803. *n* for all dummy age 15 month models *n*=785. *n* for all digit age 15 month models *n*=785. *n* for all dummy age 24 month models *n*=741. *n* for all digit age 24 month models *n*=685. *n* for all dummy age 38 month models *n*=816. *n* for all digit age 38 month models *n*=816.

Consonant cluster speech sound errors at age 61 months

The unadjusted model indicated that children who used a dummy at age 4 weeks were 1.39 times more likely to make consonant cluster errors at age 61 months than children who did not use a dummy at age 4 weeks (OR 1.39 [95% CI 1.05,1.84], z=2.29, p=.022) (Table 46). This association was not maintained after adjustment (OR 1.09 [95% CI 1.77,1.53], z=0.49, p=.624) (Table 46).

Table 46. Unadjusted and adjusted logistic regression models for NNS at age 4 weeks and consonant cluster speech sound error frequency at age 61 months

Exposure variable: NNS behaviour		**Model 0: Unadjusted**			**Model 1: Adjusted for biological sex and home ownership**			**Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Yes	1.39 [1.05,1.84]	2.29	**.022**	1.30 [0.98,1.73]	1.82	.069	1.29 [0.97,1.72]	1.77	.076

Table 44. ***(Continued)***

Exposure variable: NNS behaviour		**Model 2b: Adjusted for biological sex, home ownership and maternal age**			**Model 2c: Adjusted for biological sex, home ownership and OME age 61 months**			**Model 3a: Adjusted for biological sex, home ownership and language score at age 38 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Yes	1.21 [0.91,1.62]	1.30	.193	1.28 [0.96,1.72]	1.66	.096	1.24 [0.92,1.66]	1.41	.159

Table 44. ***(Continued)***

Exposure variable: NNS behaviour		**Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 61 months**			**Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, OME age 61 months, language score at age 38 months and RDLS comprehension standardised score at age 61 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-
	Yes	1.25 [0.91,1.71]	1.40	.163	1.09 [0.77,1.53]	0.49	.624

Note: *n* for Dummy age 4 weeks: model 0 *n*=803; model 1 *n*=793; model 2a *n*=793; model 2b *n*=793; model 2c *n*=756; model 3a *n*=762; model 3b *n*=682; model 4 *n*=628.

Fricative speech sound errors at age 61 months

Before adjustment for confounders, children who sometimes used a dummy at age 38 months were indicated to be 1.45 times more likely (OR 1.45 [95% CI 0.96,2.20], z=1.75, p=.080) to make fricative sound errors at age 61 months compared with children who never used a dummy (Table 47). After adjustment for confounders, this association was not maintained (Table 47).

Table 47. Unadjusted and adjusted logistic regression models for NNS and fricative speech sound error frequency at age 61 months

Exposure variable: NNS behaviour		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.45 [0.96,2.20]	1.75	.080	1.48 [0.97,2.24]	1.82	.069	1.53 [1.00,2.34]	1.98	**.047**
	Mostly	1.10 [0.45,2.71]	0.22	.824	0.98 [0.38,2.54]	-0.04	.965	1.00 [0.38,2.61]	0.00	.998

Table 45. ***(Continued)***

Exposure variable: NNS behaviour		**Model 2b: Adjusted for biological sex, home ownership and maternal age**			**Model 2c: Adjusted for biological sex, home ownership and OME age 61 months**			**Model 3a: Adjusted for biological sex, home ownership and language score at age 38 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.47 [0.97,2.24]	1.81	.070	1.54 [1.00,2.37]	1.98	**.048**	1.51 [1.00,2.37]	1.85	.064
	Mostly	0.98 [0.38,2.54]	-0.05	.964	1.03 [0.38,2.75]	0.05	.959	0.95 [0.36,2.54]	-0.10	.922

Table 45. ***(Continued)***

Exposure variable: NNS behaviour		**Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 61 months**			**Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, OME age 61 months, language score at age 38 months and RDLS comprehension standardised score at age 61 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.51 [0.96,2.33]	1.80	.072	1.58 [0.98,2.56]	1.87	.061
	Mostly	0.96 [0.30,3.03]	-0.08	.940	1.14 [0.34,3.81]	0.21	.837

n for Dummy age 38 months: model 0 *n*=816; model 1 *n*=804; model 2a *n*=793; model 2b *n*=804; model 2c *n*=765; model 3a *n*=773; model 3b *n*=690; model 4 *n*=628.

Postvocalic speech sound errors at age 61 months

Before adjustment for confounders children who frequently sucked their digit at age 38 months were indicated to be 2.16 times more likely to make postvocalic errors at age 61 months (OR 2.16 [95% CI 0.97,4.84], z=1.88, p=.060) compared with children who did not exhibit this behaviour (Table 48). After full adjustment of the model the association was not maintained (Table 48).

Table 48. Unadjusted and adjusted logistic regression models for NNS and postvocalic speech sound error frequency at age 61 months

Exposure variable: NNS behaviour		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Digit age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.90 [0.60,1.35]	-0.51	.612	0.93 [0.62,1.39]	-0.36	.717	0.94 [0.63,1.42]	-0.28	.782
	Mostly	2.16 [0.97,4.84]	1.88	.060	2.24 [0.99,5.03]	1.94	.052	2.09 [0.92,4.74]	1.76	.079

Table 46. ***(Continued)***

Exposure variable: NNS behaviour		**Model 2b: Adjusted for biological sex, home ownership and maternal age**			**Model 2c: Adjusted for biological sex, home ownership and OME age 61 months**			**Model 3a: Adjusted for biological sex, home ownership and language score at age 38 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Digit age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.99 [0.66,1.50]	-0.03	.977	0.87 [0.66,1.50]	-0.66	.507	0.93 [0.61,1.40]	-0.36	.719
	Mostly	2.26 [0.92,4.74]	1.96	**.050**	1.80 [0.78,4.19]	1.37	.171	2.47 [1.09,5.57]	2.17	**.030**

Table 46. ***(Continued)***

Exposure variable: NNS behaviour		**Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 61 months**			**Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, OME age 61 months, language score at age 38 months and RDLS comprehension standardised score at age 61 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***
Digit age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	0.95 [0.61,1.48]	-0.24	.814	1.01 [0.63,1.64]	0.06	.956
	Mostly	2.62 [1.00,6.82]	1.97	**.049**	2.46 [0.91,6.66]	1.77	.077

n for Digit age 38 months: model 0 *n*=816; model 1 *n*=804; model 2a *n*=793; model 2b *n*=804; model 2c *n*=765; model 3a *n*=773; model 3b *n*=690; model 4 *n*=628.

Alveolar speech sound errors at age 61 months

Alveolar sounds were the consonant type found to be most associated with NNS behaviours before adjustment for confounders. Compared with children who did not engage in NNS behaviours, children who used a dummy at age 4 weeks were 1.69 times more likely (OR 1.69 [95% CI 1.27,2.25], z=3.61, p<.001) to make alveolar errors at age 61 months (Table 49). Children who sucked a dummy most of the time at age 15 months were almost twice as likely (OR 1.99 [95% CI 1.11,3.53], z=2.34, p=.019) to make alveolar errors at 61 months, while children who mostly sucked their digit at age 15 months were 2.38 times *less* likely (OR 0.42 [95% CI 0.16,1.06], z=-1.85, p=.065) to make alveolar errors (before adjustment for confounders). Children who sucked a dummy most of the time at age 24 months were 1.67 times more likely (OR 1.67 [95% CI 0.99,2.84], z=1.91, p=.056) to make alveolar errors, with a stronger effect seen for those who mostly sucked a dummy at age 38 months (OR 2.66 [95% CI 1.12,6.29], z=2.22, p=.026). After adjustment for confounders, only the association with digit sucking at age 15 months remained (OR 1.59 [95% CI 1.03,2.46], z=2.09, p=.037).

Table 49. Unadjusted and adjusted logistic regression models for NNS and alveolar speech sound error frequency at age 61 months

Exposure variable: NNS behaviour		Model 0: Unadjusted			Model 1: Adjusted for biological sex and home ownership			Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks		
		OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*	OR [95% CI]	*z*	*p*
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Yes	1.69 [1.27,2.25]	3.61	**<.001**	1.57 [1.17,2.10]	3.02	**.003**	1.59 [1.19,2.13]	3.10	**.002**
Dummy age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.14 [0.84,1.56]	0.86	.391	1.15 [0.84,1.57]	0.85	.395	1.17 [0.85,1.62]	0.98	.325
	Mostly	1.99 [1.11,3.53]	2.34	**.019**	1.66 [0.91,3.04]	1.65	.099	1.67 [0.91,3.05]	1.65	.098
Digit age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.27 [0.89,1.81]	1.30	.193	1.30 [0.90,1.87]	1.41	.160	1.32 [0.91,1.90]	1.46	.143
	Mostly	0.42 [0.16,1.06]	-1.85	.065	0.46 [0.18,1.18]	-1.61	.108	0.50 [0.19,1.28]	-1.45	.147

Table 47. ***(Continued)***

Exposure variable: NNS behaviour		**Model 0: Unadjusted**			**Model 1: Adjusted for biological sex and home ownership**			**Model 2a: Adjusted for biological sex, home ownership and weak sucking at age 4 weeks**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.07 [0.77,1.49]	0.39	.694	1.08 [0.77,1.52]	0.43	.666	1.10 [0.78,1.55]	0.52	.604
	Mostly	1.67 [0.99,2.84]	1.91	.056	1.37 [0.79,2.38]	1.11	.268	1.38 [0.79,2.43]	1.13	.257
Dummy age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.06 [0.72,1.58]	0.30	.765	1.06 [0.71,1.59]	0.28	.779	1.05 [0.70,1.59]	0.25	.804
	Mostly	2.66 [1.12,6.29]	2.22	**.026**	2.42 [1.00,5.89]	1.95	.051	2.42 [0.98,5.80]	1.91	.056

Table 47. ***(Continued)***

Exposure variable: NNS behaviour		Model 2b: Adjusted for biological sex, home ownership and maternal age			Model 2c: Adjusted for biological sex, home ownership and OME age 61 months			Model 3a: Adjusted for biological sex, home ownership and language score at age 38 months		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Yes	1.48 [1.10,2.00]	2.59	**.010**	1.55 [1.14,2.09]	2.83	**.005**	1.57 [1.16,2.13]	2.92	**.004**
Dummy age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.10 [0.85,1.62]	0.58	.559	1.17 [0.84,1.62]	0.94	.345	1.17 [0.85,1.63]	0.96	.340
	Mostly	1.49 [0.81,2.75]	1.25	.200	1.70 [0.91,3.20]	1.66	.096	1.73 [0.94,3.18]	1.77	.076
Digit age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.40 [0.96,2.02]	1.76	.078	1.30 [0.89,1.90]	1.35	.177	1.29 [0.89,1.88]	1.34	.180
	Mostly	0.43 [0.17,1.12]	- 1.73	.083	0.47 [0.18,1.12]	-1.57	.117	0.56 [0.22,1.46]	-1.18	.238

Table 47. ***(Continued)***

Exposure variable: NNS behaviour		**Model 2b: Adjusted for biological sex, home ownership and maternal age**			**Model 2c: Adjusted for biological sex, home ownership and OME age 61 months**			**Model 3a: Adjusted for biological sex, home ownership and language score at age 38 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.10 [0.78,1.55]	0.52	.604	1.11 [0.78,1.58]	0.59	.557	1.11 [0.79,1.58]	0.61	.543
	Mostly	1.38 [0.79,2.43]	1.13	.257	1.33 [0.74,2.36]	1.95	.340	1.40 [0.79,2.46]	1.16	.245
Dummy age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.03 [0.69,1.54]	0.14	.892	1.04 [0.69,1.57]	0.19	.849	1.09 [0.72,1.65]	0.42	.675
	Mostly	2.42 [0.99,5.91]	1.94	.053	2.46 [0.95,6.33]	1.86	.063	2.44 [1.00,5.96]	1.95	.051

Table 47. ***(Continued)***

Exposure variable: NNS behaviour		**Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 61 months**			**Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, OME age 61 months, language score at age 38 months and RDLS comprehension standardised score at age 61 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 4 weeks	**No**	1 [-]	-	-	1 [-]	-	-
	Yes	1.43 [1.04,1.98]	2.19	**.029**	1.38 [0.98,1.96]	1.82	.069
Dummy age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.16 [0.82,1.64]	0.83	.407	1.22 [0.84,1.77]	1.04	.299
	Mostly	1.45 [0.74,2.87]	1.08	.281	1.45 [0.71,2.97]	1.01	.311
Digit age 15 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.48 [0.99,2.23]	1.89	.058	1.59 [1.03,2.46]	2.09	**.037**
	Mostly	0.44 [0.17,1.19]	-1.62	.106	0.46 [0.16,1.29]	-1.48	.138

Table 47. ***(Continued)***

Exposure variable: NNS behaviour		**Model 3b: Adjusted for biological sex, home ownership and RDLS comprehension standardised score at age 61 months**			**Model 4: Adjusted for biological sex, home ownership, weak sucking at age 4 weeks, maternal age, OME age 61 months, language score at age 38 months and RDLS comprehension standardised score at age 61 months**		
		OR [95% CI]	***z***	***p***	**OR [95% CI]**	***z***	***p***
Dummy age 24 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.11 [0.76,1.62]	0.55	.582	1.19 [0.80,1.79]	0.87	.386
	Mostly	1.36 [0.79,2.46]	1.00	.319	1.37 [0.71,2.66]	0.94	.349
Dummy age 38 months	**Never**	1 [-]	-	-	1 [-]	-	-
	Sometimes	1.02 [0.65,1.58]	0.07	.945	1.03 [0.64,1.64]	0.11	.913
	Mostly	2.23 [0.78,6.42]	1.49	.136	2.53 [0.79,8.09]	1.56	.119

n for Dummy age 4 weeks: model 0 *n*=803; model 1 *n*=793; model 2a *n*=793; model 2b *n*=793; model 2c *n*=756; model 3a *n*=762; model 3b *n*=682; model 4 *n*=628. *n* for Dummy age 15 months: model 0 *n*=785; model 1 *n*=776; model 2a *n*=767; model 2b *n*=776; model 2c *n*=737; model 3a *n*=746; model 3b *n*=665; model 4 *n*=606. *n* for Digit age 15 months: model 0 *n*=785; model 1 *n*=776; model 2a *n*=767; model 2b *n*=776; model 2c *n*=737; model 3a *n*=746; model 3b *n*=665; model 4 *n*=606. *n* for Dummy age 24 months: model 0 *n*=741; model 1 *n*=732; model 2a *n*=724; model 2b *n*=700; model 2c *n*=704; model 3a *n*=628; model 3b *n*=628; model 4 *n*=576. *n* for Dummy age 38 months: model 0 *n*=816; model 1 *n*=804; model 2a *n*=793; model 2b *n*=804; model 2c *n*=765; model 3a *n*=773; model 3b *n*=690; model 4 *n*=628.

5.5. Summary

Table 50 summarises the results from the fully adjusted models for the primary analysis of interest explored in this section: NNS (ages 4 weeks, 15, 24 and 38 months) and speech sound error frequencies at age 61 months. The presence of an arrow indicates that an association ($p<0.05$) was observed; 🡅 suggests an *increased* likelihood of speech sound error, and 🡇 indicates *decreased* likelihood of speech sound error. Only one association between the outcome and exposure variables remained after full model adjustment. Children who occasionally sucked their digit at age 15 months were more likely to make alveolar sound errors at age 61 months (Table 49).

Table 50. Summary of observed associations for the adjusted logistic regression models for NNS and speech sound error frequencies at age 61 months

Exposure variable: NNS behaviour		Outcome variable: Speech sound error frequency at age 61 months					
		Velar	**CC**	**Liquid**	**Fricative**	**PVC**	**Alveolar**
Dummy age 4 weeks	**Yes**	-	-	-	-	-	-
Dummy age 15 months	**S**	-	-	-	-	-	-
	M	-	-	-	-	-	-
Digit age 15 months	**S**	-	-	-	-	-	🡅59%
	M	-	-	-	-	-	-
Dummy age 24 months	**S**	-	-	-	-	-	-
	M	-	-	-	-	-	-
Digit age 24 months	**S**	-	-	-	-	-	-
	M	-	-	-	-	-	-
Dummy age 38 months	**S**	-	-	-	-	-	-
	M	-	-	-	-	-	-
Digit age 38 months	**S**	-	-	-	-	-	-
	M	-	-	-	-	-	-

Note: CC = Consonant cluster. PVC = Postvocalic. S = Sometimes. M = Mostly.

5.6. Summary of Strand One

For each of the three parts of Strand One of the study, the results indicate some significant association ($p<.05$) between the exposure and outcome variables of interest (Table 51 and Table 52).

5.6.1. Feeding and parental concern about speech development at age 18 months

Part A found evidence that, after adjustment for confounding variables, parents of children who were mixed fed (OR 2.05 [95% CI 1.18,3.56], z=2.53, p=.011) or exclusively bottle fed (OR 1.83 [95% CI 1.04,3.23], z=2.09, p=.037) at age 15 months were around twice as likely to be concerned about their child's speech development at age 18 months, compared with children who were exclusively breast fed at age 15 months (Table 51).

5.6.2. Feeding and speech sound error frequencies at ages 25 and 61 months

Part B found some evidence for a potential protective effect of exclusive bottle feeding (compared with exclusive breast feeding or mixed feeding) at age 6 months for velar (IRR 0.80 [95% CI 0.64,0.99], z=-2.05, p=.040), liquid (IRR 0.83 [95% CI 0.71,0.97], z=-2.31, p=.021) and postvocalic (IRR 0.70 [95% CI 0.53,0.92], z=-2.56, p=.010) sound error frequencies at age 25 months after adjustment for confounders (Table 30). No associations were observed between feeding method and fricative sound errors at age 25 months after adjustment for potential confounders. Evidence of an association between increased likelihood of alveolar errors at age 61 months and feeding at age 15 months was indicated (Table 37). Children who were mixed fed (OR 2.89 [95% CI 1.11,7.58], z=2.16, p=.030) or exclusively bottle fed (OR 2.90 [95% CI 1.06,7.96], z=2.07, p=.039) at age 15 months were shown to be almost three times more likely to make alveolar speech sound errors at age 61 months, compared with children who were exclusively breast fed at age 15 months (Table 37 and Table 52).

5.6.3. NNS and speech sound error frequencies at ages 25 and 61 months

Part C found that, after full adjustment for confounders, only velar sound error frequency at age 25 months was associated with NNS (Table 43). Some evidence was found of a potential protective effect of frequent dummy use (IRR 0.68 [95% CI 0.49,0.94], z=-2.34, p=.019) and occasional digit sucking (IRR 0.74 [95% CI 0.58,0.94], z=-2.43, p=.015) at age 24 months against higher frequency of velar sound errors at age 25 months (Table 43). No further significant associations between NNS and speech errors at age 25 months were indicated. Occasional digit sucking at age 15 months (OR 1.59 [95% CI 1.03,2.46], z=2.09, p=.037) was indicated to be associated with increased likelihood of alveolar errors at age 61 months (Table 52).

Table 51. Summary of observed associations from the fully adjusted logistic regression models for feeding and parental concern about speech at age 18 months

Exposure variable: Feeding method		**Outcome Variable: Parental concern about speech development at age 18 months**	
		No	**Yes**
Age 4 weeks	**Breast**	-	-
	Mixed	-	-
	Bottle	-	-
Age 6 months	**Breast / mixed**	-	-
	Bottle	-	-
Age 15 months	**Breast**	-	-
	Mixed	-	🡅 (205%)
	Bottle	-	🡅 (183%)

Table 52. Summary of observed associations for the adjusted models for feeding, NNS and speech sound error frequencies at ages 25 and 61 months

Exposure variable: Feeding / NNS		Outcome Variable: Speech sound error frequency										
		Velar		CC		Liquid		Fricative		PVC		Alveolar
		25m	61m	25m	61m	25m	61m	25m	61m	25m	61m	61m
Feeding age 4 weeks	Breast	-	-	-	-	-	-	-	-	-	-	-
	Mixed	-	-	↓↓	-	↓↓	-	-	-	-	-	-
	Bottle	-	-	-	-	-	-	-	-	-	-	-
Feeding age 6 months	Breast/ mixed	-	-	-	-	-	-	-	-	-	-	-
	Bottle	↓↓	-	-	-	↓↓	-	-	-	↓↓↓	-	-
Feeding age 15 months	Breast	-	-	-	-	-	-	-	-	-	-	-
	Mixed	-	-	-	-	(↓↓↓)	-	-	-	-	-	↑ 306%
	Bottle	-	-	-	-	-	-	-	-	-	-	↑ 327%

Table 50. ***(Continued)***

Exposure variable: Feeding / NNS		**Outcome variable: Speech sound error frequency**										
		Velar		**CC**		**Liquid**		**Fricative**		**PVC**		**Alveolar**
		25m	**61m**	**25m**	**61m**	**25m**	**61m**	**25m**	**61m**	**25m**	**61m**	**61m**
Dummy age 4 weeks	**Yes**	-	-	-	-	-	-	-	-	-	-	-
Dummy age 15 months	**Sometimes**	-	-	-	-	-	-	-	-	-	-	-
	Mostly	-	-	-	-	-	-	-	-	-	-	
Digit age 15 months	**Sometimes**	-	-	-	-	-	-	-	-	-	-	↑ 59%
	Mostly	-	-	-	-	-	-	-	-	-	-	-
Dummy age 24 months	**Sometimes**	-	-	-	-	-	-	-	-	-	-	-
	Mostly	↓↓↓↓	-	-	-	-	-	-	-	-	-	-
Digit age 24 months	**Sometimes**	↓↓↓	-	-	-	-	-	-	-	-	-	-
	Mostly	-	-	-	-	-	-	-	-	-	-	-
Dummy age 38 months	**Sometimes**	-	-	-	-	-	-	-	-	-	-	-
	Mostly	-	-	-	-	-	-	-	-	-	-	-
Digit age 38 months	**Sometimes**	-	-	-	-	-	-	-	-	-	-	-
	Mostly	-	-	-	-	-	-	-	-	-	-	-

Note: CC = consonant cluster. PVC = postvocalic. ( )= compared with exclusive bottle feeding. No. arrows indicates likelihood increase/decrease (one arrow <10%, two arrows=11-20%, three arrows=21-30%, four arrows=31-40%, figures >40% are specified).

Chapter Five: Results for Strand Two ALSPAC-G2 Dataset

1. Overview of chapter

This chapter presents the results from Strand Two of this study, which is comprised of two parts. Part A examined relationship between feeding regime and PCC scores at ages 24, 36 and 48 months. Part B examined the relationship between NNS and PCC scores at ages 24, 36 and 48 months. Brief summaries of the results for each part of the strand are provided as well as a final summary of the results of the whole strand.

2. Part A: feeding and speech sound errors at ages 24, 36 and 48 months

In this section ALSPAC-G2 data from clinical speech sound assessments at ages 24, 36 and 48 months were examined with feeding group data.

2.1. Sample size

Exposure variable data on feeding were available for each of the outcome measures. Figure 21 illustrates the process of derivation of participants for this study. Children with unrecorded gestational age data (*n*=67) were included in the sample. This is because prevalence of premature births between 2010-2017 was 7-8% meaning that only 5 of the 67 children were likely to have been born before 37 weeks gestation (Office for National Statistics, 2020). To exclude all children with unrecorded data would have substantially reduced the sample size and the statistical power for calculations. During the course of the data collection period some children participated in more than one of the assessment clinics as they became eligible for an older age group (*n*=26). To avoid a learning effect on the assessment materials and bias within the sample, only data for the first assessment clinic was retained. The final sample size of 122 participants included 57 females (46.72%).

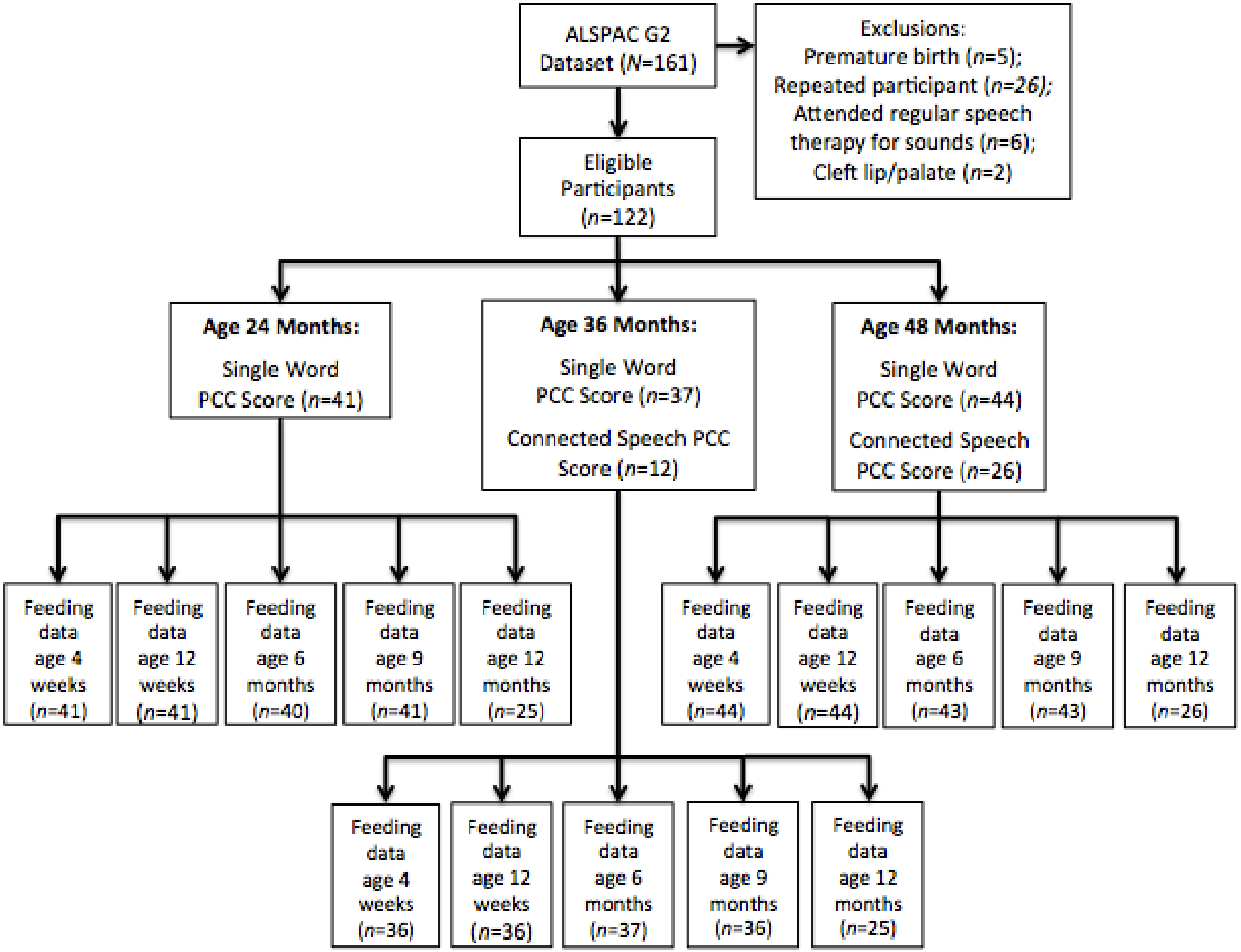

Figure 21. Derivation of participants for Strand Two Part A

2.1.1. Exposure variables: feeding groups

The proportions for males and females across the feeding groups are broadly in line with the wider sample with regard to exclusive bottle feeding (Table 53). A larger proportion of females were exclusively breast fed across the age groups, while a smaller proportion were mixed fed at ages 4 weeks, and 9 months old (Table 53).

Table 53. Exposure variables: feeding groups by age

	Feeding groups		
Age point	**Exclusive breast fed**	**Mixed fed**	**Exclusive bottle fed**
4 weeks	n=51 (Female n=28, 54.90%)	n=38 (Female n=14, 36.84%)	n=32 (Female n=15, 46.88%)
12 weeks	n=18 (Female n=10, 55.56%)	n=17 (Female n=9, 52.94%)	n=23 (Female n=10, 43.48%)
6 months	n=26 (Female n=15, 57.69%)	n=17 (Female n=8, 47.06%)	n=77 (Female n=33, 42.86%)
9 months	n=20 (Female n=12, 60.00%)	n=12 (Female n=4, 33.33%)	n=88 (Female n=41, 46.59%)
12 months	n=56 (Female n=29, 51.79%)		n=20 (Female n=9, 45.00%)

2.1.2. Potential confounding variables

Confounding variables and covariates for Strand Two Part A are illustrated in chapter three (Figure 7). The majority of children in the sample lived in owned or privately rented accommodation (*n*=56, 75.68%), with balanced biological sex groups (Table 54). The largest proportion of children had mothers educated to vocational level (*n*=44, 45.83%). More females than males had mothers educated to AS/A Level or above (*n*=19, 54.29%). The largest proportion of children were born to mothers aged 23 years (*n*=42, 34.43%). Note here that age 25 years is the oldest specified age because of the period of time between the original ALSPAC study in 1990-1991 and this period of data collection for the ALSPAC G2 study. As described in chapter four, maternal age was included as a potential confounding variable in the analysis as a result of evidence from Roulstone *et al* (2009), in a related study using the same data, which indicated a potential association with speech sound development. Despite the small age range of mothers in this sample, the variable was retained for consistency of analysis with the original ALSPAC dataset. 60% of males had OME at age 12 months (*n*=10) compared with 44.44% of males who had OME at age 48 months (*n*=4). Of the 26% of children who were not yet combining two words at age 24 months, two thirds were male (*n*=6). All children who were not combining syllables at age 12 months were male (*n*=5, 5.95%).

Table 54. Summary statistics for categorical potential confounding variables and covariates for Strand Two Part A

Potential confounding variable / covariate		Biological sex Female *n* %	 Male *n* %	 Total *n* %
Home ownership	**Owned/privately rented**	27 48.21	29 51.79	**56** 100.00
	Council rented/ other	9 50.00	9 50.00	**18** 100.00
Maternal education	**≤ GCSE**	8 47.06	9 52.94	**17** 100.00
	Vocational	18 40.91	26 59.09	**44** 100.00
	AS/A Level	10 52.63	9 47.37	**19** 100.00
	≥ Degree	9 56.25	7 43.75	**16** 100.00
Maternal age	**21 years**	4 40.00	10 60.00	**14** 100.00
	22 years	16 47.06	18 52.94	**34** 100.00
	23 years	21 50.00	21 50.00	**42** 100.00
	24 years	14 58.33	10 41.67	**24** 100.00
	25+ years	2 25.00	6 25.00	**8** 100.00
Ear Infection at 12 months	**No**	34 54.84	28 45.16	**62** 100.00
	Yes	4 40.00	10 60.00	**14** 100.00
Ear Infection at 48 months	**No**	19 46.34	22 53.66	**41** 100.00
	Yes	5 55.56	4 44.44	**9** 100.00
Word combination at 24 months	**Yes**	48 48.00	52 52.00	**100** 100.00
	No	3 33.33	6 66.67	**9** 100.00
Syllable combination at 12 months	**Yes**	40 50.63	39 49.37	**79** 100.00
	No	0 0.00	5 100.00	**5** 100.00

2.1.3. Outcome variables: clinical speech assessment data

Single word PCC (SwPCC) scores

Table 55 and Figure 22 presents the summary statistics for the overall outcome variable SwPCC score. Mean scores for SwPCC increase with age, as expected in typical development (Figure 23, Figure 24 and Table 56). Mean scores for females are higher than for males across the age groups (Table 56). A high degree of score variability was observed among younger children (Figure 23 and Figure 24).

Table 55. SwPCC score summary statistics

Overall SwPCC score		
n	**Mean s.d**	**Median IQR**
122	67.92 23.73	72.51 51.61-87.27

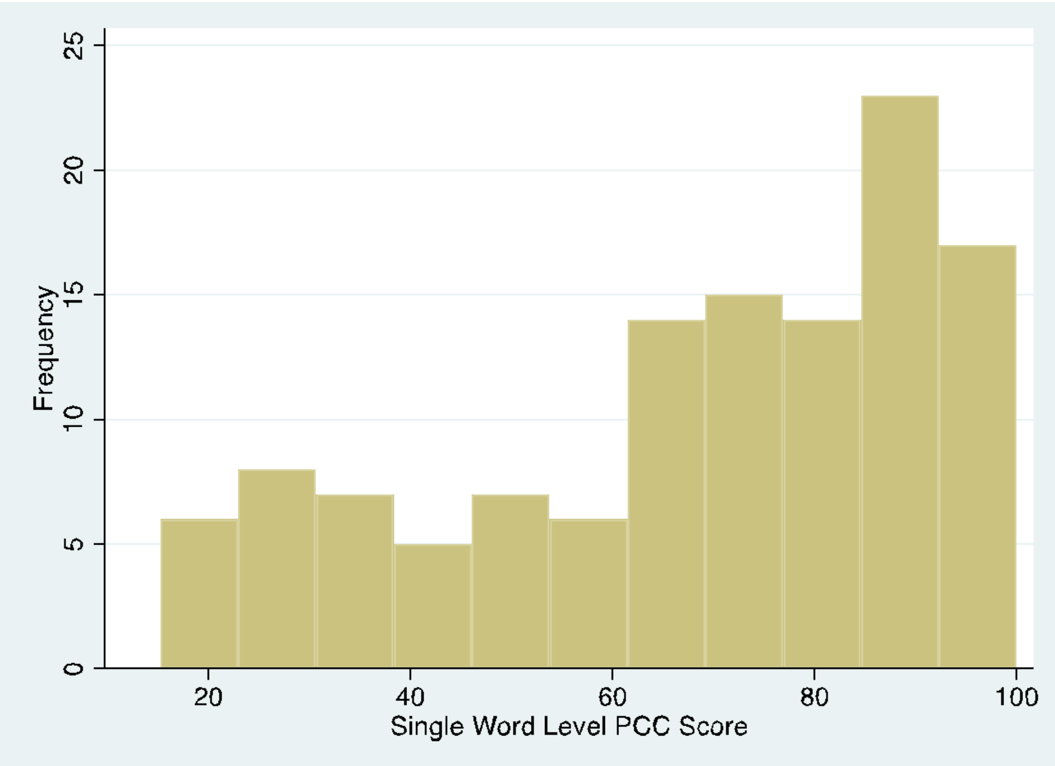

Figure 22. Histogram of SwPCC scores (*n*=122)

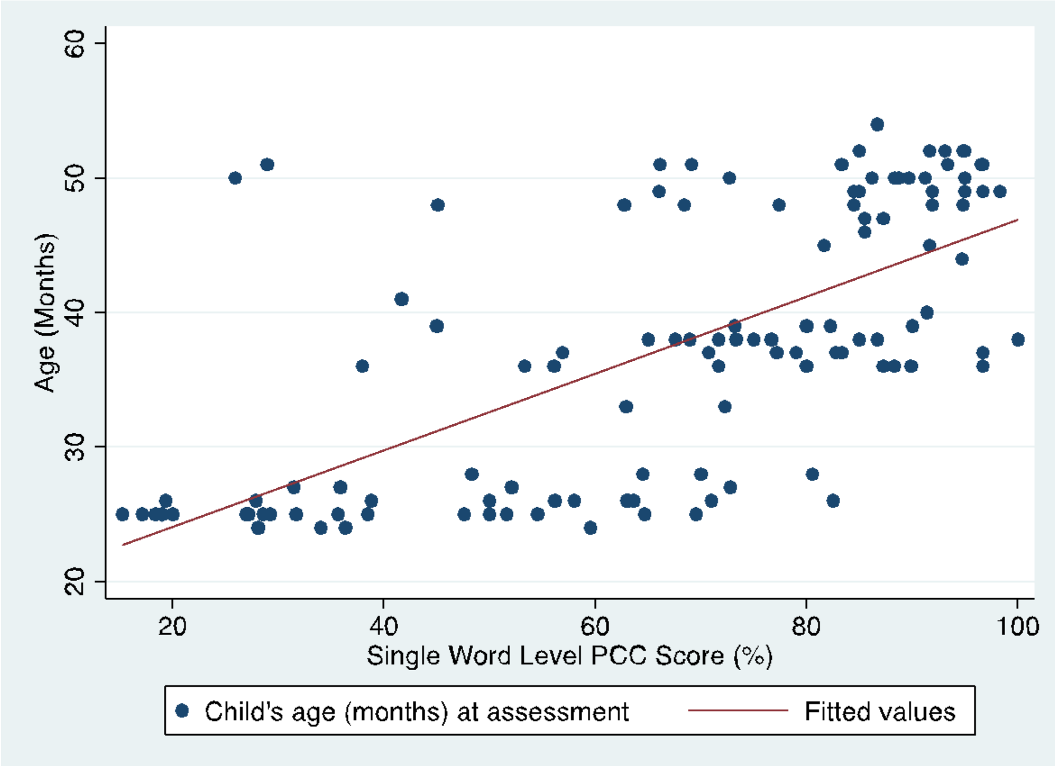

Figure 23. Scatter plot of SwPCC scores and age with line of best fit (*n*=122)

Table 56. SwPCC score summary statistics, by age group

	SwPCC score								
	Age 24 months			Age 36 months			Age 48 months		
	n	**Mean s.d**	**Median IQR**	***n***	**Mean s.d**	**Median IQR**	***n***	**Mean s.d**	**Median IQR**
Whole sample	41	45.18 19.21	47.62 28.57-63.00	37	74.72 14.95	76.67 68.97-85.00	44	83.38 16.64	88.52 82.50-94.79
Female	19	50.80 18.05	52.08 34.04-64.47	19	79.20 10.98	79.03 71.67-88.33	19	89.18 8.40	91.94 85.00-95.00
Male	22	40.33 19.23	35.75 26.92-56.18	18	70.00 17.30	72.44 56.90-85.00	25	78.97 19.91	85.48 69.09-93.10

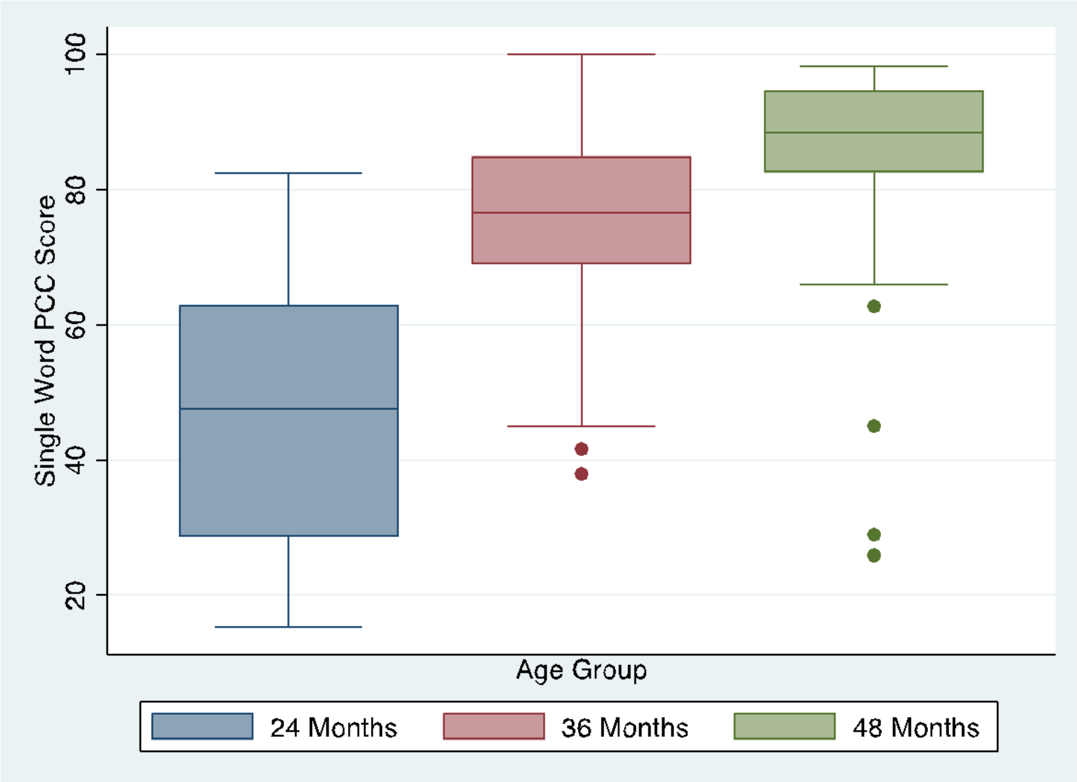

Figure 24. Box and whisker plot of SwPCC scores at ages 24 months (*n*=410), 36 months (*n*=37) and 48 months (*n*=44)

Connected speech PCC (CsPCC) scores

Table 57 presents the summary statistics for overall connected speech PCC (CsPCC) score and Figure 25 presents these data in a histogram. Mean CsPCC scores were shown to increase with age, as expected in typical development (Figure 26, Figure 27 and Table 58). Females achieved higher mean CsPCC scores than males (Table 58).

Table 57. Overall CsPCC score summary statistics

Overall CsPCC score		
n	**Mean s.d**	**Median IQR**
38	70.48 19.79	73.33 61.90-83.87

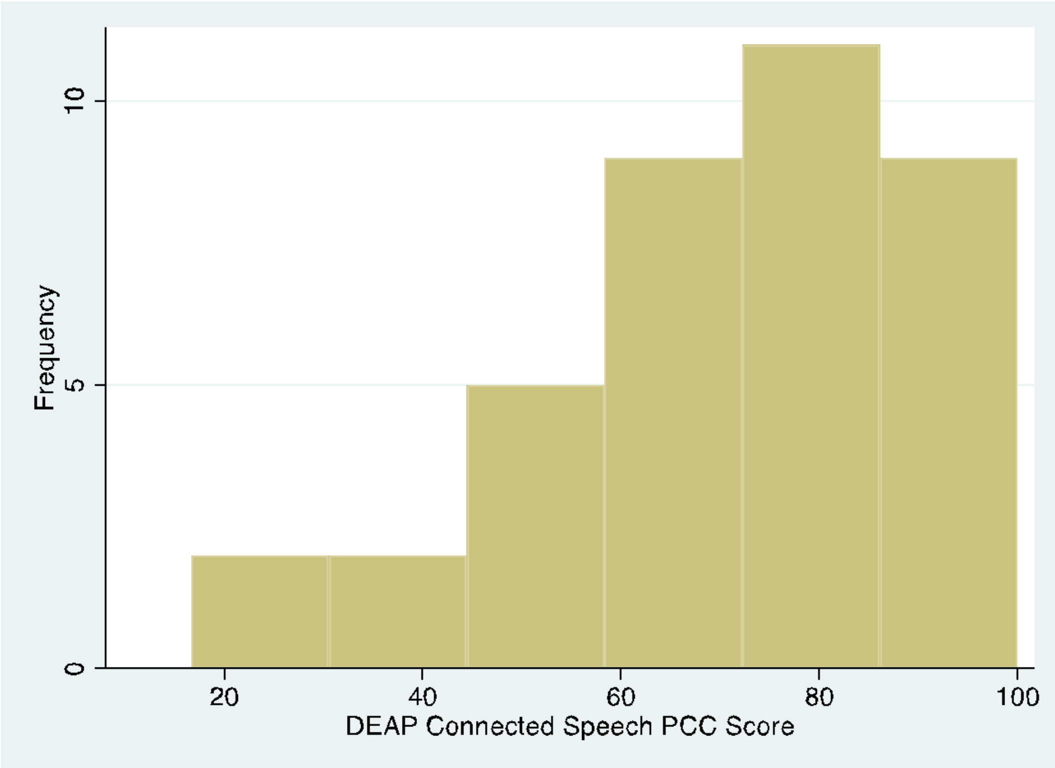

Figure 25. Histogram of overall CsPCC scores (*n*=38)

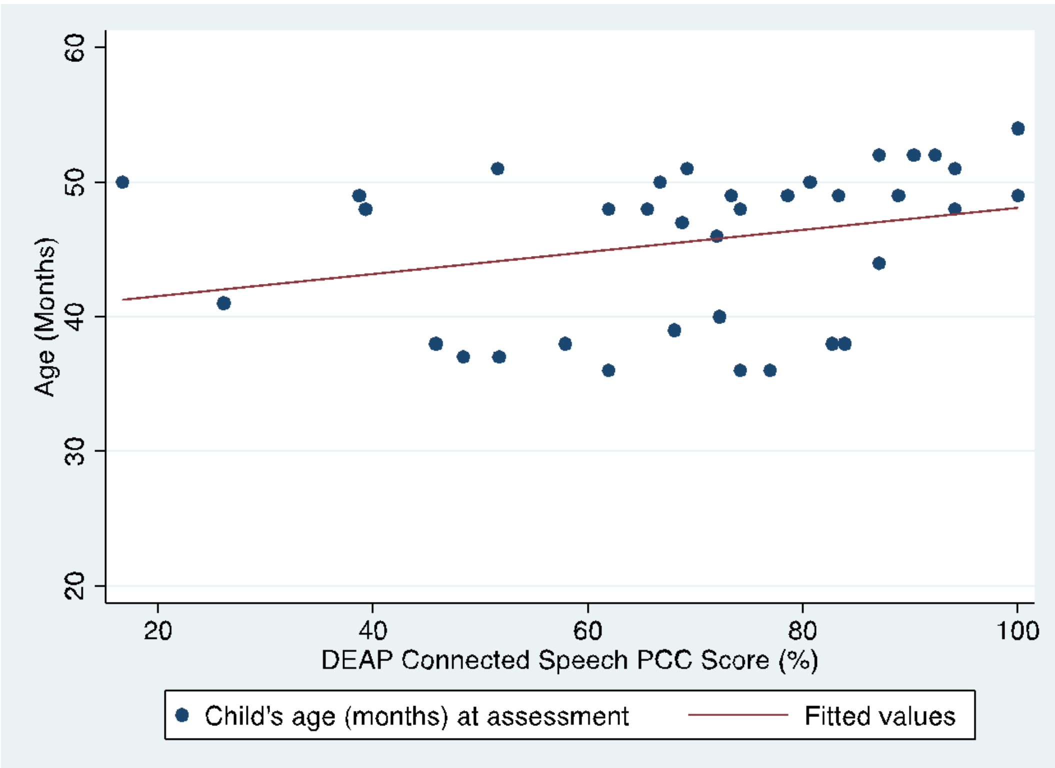

Figure 26. Scatter plot of CsPCC scores and age with line of best fit (*n*=38)

Table 58. CsPCC score summary statistics for ages 36 and 48 months

	CsPCC score					
	Age 36 months			Age 48 months		
	n	Mean s.d	Median IQR	*n*	Mean s.d	Median IQR
Whole sample	12	62.48 17.26	64.95 50.06-75.56	26	74.17 20.09	76.38 66.67-88.89
Female	6	69.43 11.49	71.10 61.90-76.92	14	77.74 14.66	79.61 73.33-87.10
Male	6	55.53 20.19	53.14 45.83-72.22	12	70.01 25.06	70.62 56.76-93-22

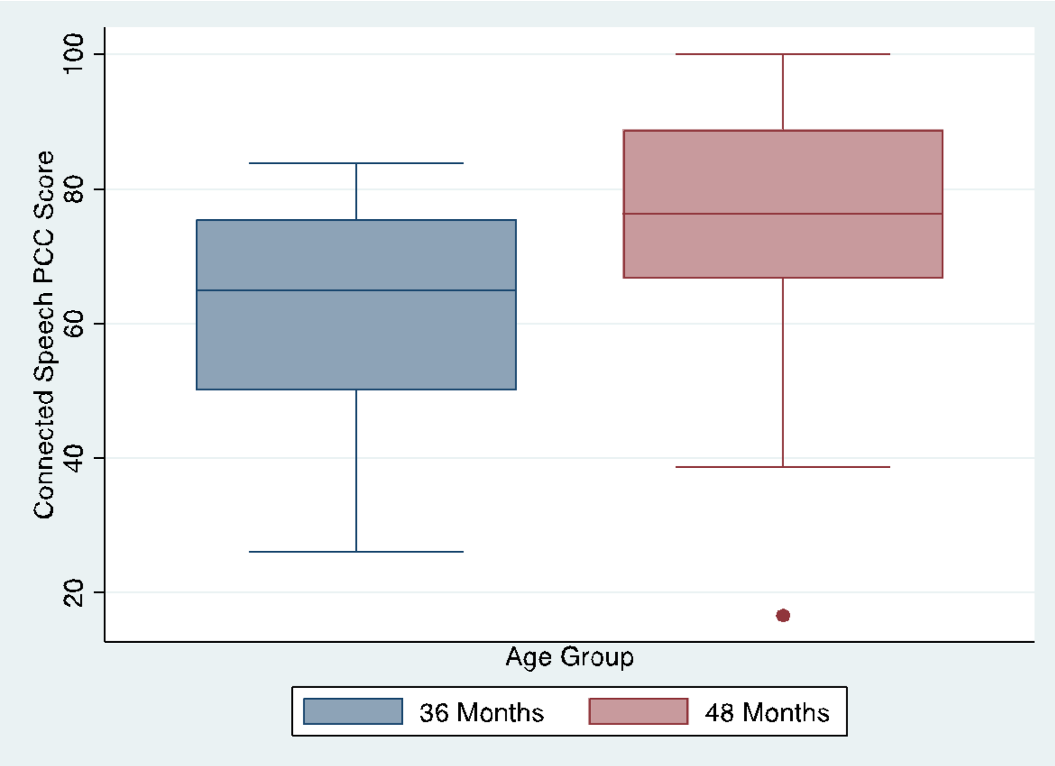

Figure 27. Box and whisker plot of CsPCC scores at ages 36 months (*n*=12) and 48 months (*n*=26)

2.2. Data analysis: PCC scores

The following sections present first the analysis of the overall SwPCC score outcome data, and then PCC scores for each individual age group. This approach will then be repeated for the CsPCC score outcome data.

2.2.1. Data analysis: overall SwPCC score

Univariable analysis of potential confounders associated with SwPCC score showed that age group, biological sex and maternal age had *p* values <.10 (Table 59). In order to retain a measure of SES for the multivariable analysis, home ownership was also retained due to the lower likelihood ratio *p* value compared with maternal education.

Table 59. Univariable regression model results for potential confounders associated with overall SwPCC score

		Outcome variable: SwPCC score		
Variable	**Category**	**Coef. [95% CI]**	***t* [df]**	***p***
Demographics				
Assessment age group	**24 months**	1.00	-	-
	36 months	29.54 [21.88,37.21]	7.63 [119]	**<.001**
	48 months	38.20 [30.86,45.54]	10.31 [119]	**<.001**
Biological sex	**Female**	1.00	-	-
	Male	-9.65 [-18.03,-1.27]	-2.28 [120]	**.024**
Home ownership status	**Owned / privately rented**	1.00	-	-
	Council / other	5.26 [-8.07,18.59]	0.79 [72]	.434
Maternal age	**21 years**	1.00	-	-
	22 years	-1.76 [-15.92,12.41]	-0.25 [118]	.807
	23 years	-14.24 [-28.00,-0.47]	-2.05 [118]	**.043**
	24+ years	-21.01 [-35.30,-6.71]	-2.91 [118]	**.004**
Maternal education	≤ GCSE	1.00	-	-
	Vocational	4.43 [-9.28,18.14]	0.64 [92]	.523
	AS/A Level	-0.49 [-16.53,15.54]	-0.06 [92]	.951
	≥ Degree	0.27 [-16.46,17.00]	0.03 [92]	.975
Ear infection at12 months	**No**	1.00	-	-
	Yes	-6.31 [-20.55,7.92]	-0.88 [74]	.380
Ear infection at 48 months	**No**	1.00	-	-
	Yes	6.77 [-9.10,22.65]	0.86 [48]	.395
Early developmental variables				
Syllable combination at 12 months	**Yes**	-	-	-
	No	8.49 [-14.79,31.76]	0.73 [82]	.470
Word combination at age 24 Months	**Yes**	1.00	-	-
	No	0.81 [-15.69,17.31]	0.10 [107]	.923

Note: See Appendix AA for full table of model *n* values. df = degrees of freedom.

Univariable analysis of the relationship between feeding groups and overall SwPCC score showed an association between SwPCC and feeding at age 4 weeks and age 12 months (Table 60). In both cases children who were exclusively bottle fed at these ages achieved lower overall PCC scores (age 4 weeks: *coef.*= -11.30 [*95% CI* -21.78, -0.82], *t*= -2.14, *df*=118, *p*=.035; age 12 months: *coef.*= -18.76 [*95% CI* -30.59, -6.94], *t*= -3.16, *df*=74, *p*=.002) on average compared with children who were exclusively breast fed at these ages. No associations were found when the univariable analysis was rerun with bottle feeding as the reference group to allow for comparison between mixed feeding and bottle feeding (Appendix AB).

Table 60. Univariable regression model results for feeding groups and overall SwPCC score

Exposure variable: Feeding method		Outcome variable: SwPCC score		
		Coef. [95% CI]	*t* [df]	*p*
Age 4 weeks	Breast fed	1 [-]	-	-
	Mixed fed	-7.74 [-17.70,2.22]	-1.54 [118]	.127
	Bottle fed	-11.30 [-21.78,-0.82]	-2.14 [118]	**.035**
Age 12 weeks	Breast fed	1 [-]	-	-
	Mixed fed	0.64 [-11.54,12.82]	0.10 [118]	.918
	Bottle fed	-3.25 [-13.26,6.76]	-0.64 [118]	.522
Age 6 months	Breast fed	1 [-]	-	-
	Mixed fed	-10.83 [-25.49,3.84]	-1.46 [117]	.146
	Bottle fed	-1.09 [-11.76,9.57]	-0.20 [117]	.840
Age 9 months	Breast fed	1 [-]	-	-
	Mixed fed	0.12 [-17.22,17.47]	0.01 [117]	.989
	Bottle fed	3.83 [-7.94,15.59]	0.64 [117]	.521
Age 12 months	Breast/mixed	1 [-]	-	-
	Bottle	-18.76 [-30.59,-6.94]	-3.16 [74]	**.002**

Note: *n* for age 4 weeks and 12 weeks models *n*=121. *n* for age 6 month and 9 month models *n*=120. *n* for 12 month model *n*=76.

In the unadjusted model, children who were exclusively bottle fed at age 4 weeks obtained a PCC score 11 points lower on average (*coef.*=-11.30 [95% CI -21.78,-0.82], *t*=-2.14, *df*=118 *p*=.035) than children who were exclusively breast fed at that age (Table 61). Note the wide confidence interval for this coefficient. Children who were exclusively bottle fed at age 12 months obtained a PCC score 18.76 points lower on average (*coef.*=-18.76 [95% CI -30.59,-6.94], *t*=-3.16, *df*=74 *p*=.002) compared with children who were exclusively breast fed at this age. Neither of these effects were maintained after adjustment of the model for confounders (Table 61).

Table 61. Unadjusted and adjusted regression models for feeding method and overall SwPCC score

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1a: Adjusted for age group and biological sex		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-7.74 [-17.70,2.22]	-1.54 [118]	.127	-3.95 [-10.97,3.07]	-1.11 [115]	.269
	Bottle fed	-11.30 [-21.78,-0.82]	-2.14 [118]	**.035**	-6.44 [-13.84,0.96]	-1.72 [115]	**.088**
Age 12 months	**Breast/ mixed fed**	1 [-]	-	-	1 [-]	-	-
	Bottle fed	-18.76 [-30.59,-6.94]	-3.16 [74]	**.002**	-7.19 [-15.82,1.45]	-1.66 [71]	.101

Table 59. ***(Continued)***

Exposure variable: Feeding method		**Model 1b: Adjusted for age group, biological sex and home ownership**			**Model 2: Adjusted for age group, biological sex, home ownership and maternal age**		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-4.37 [-13.96,5.21]	-0.91 [66]	.365	-2.95 [-12.94,7.04]	-0.59 [63]	.557
	Bottle fed	-1.55 [-12.18,9.07]	-0.29 [66]	.772	-0.73 [-11.64,10.19]	-0.13 [63]	.895
Age 12 months	**Breast/ mixed fed**	1 [-]	-	-	1 [-]	-	-
	Bottle fed	0.89 [-11.65,13.44]	0.14 [44]	.887	0.23 [-12.70,13.15]	0.04 [41]	.972

Note: *n* for age 4 weeks: model 0 (*n*=121); model 1a (*n*=121); model 1b (*n*=73); model 2 (*n*=73). *n* for age 12 months: model 0 (*n*=76); model 1a (*n*=76); model 1b (*n*=50); model 2 (*n*=50).

2.2.2. Data analysis: SwPCC score by age group

Univariable analysis of feeding groups and SwPCC score at each age group (24, 36 and 48 months) indicated coefficients with *p*<.10 for all feeding age groups except age 12 months (Table 62). Across all feeding age groups, children who were mixed fed or exclusively bottle fed obtained, on average, lower SwPCC scores at age 24 months compared with children who were exclusively breast fed (Table 62). At age 36 months, SwPCC scores obtained by children who were exclusively bottle fed at ages 4 weeks, 12 weeks and 6 months were lower, on average, compared with exclusively breast fed children. In contrast, SwPCC scores were *higher* at age 48 months among children who were exclusively bottle fed at ages 12 weeks, 6 months and 9 months, compared with exclusively breast fed children at the same ages. The significance of this association was strongest for bottle fed children at age 9 months, who, on average, achieved a SwPCC score at age 48 months 18.88 points higher than children who were exclusively breast fed at age 9 months (*coef.*= 18.88 [95% CI 3.39,34.38], *t*=2.46, *df*=40 *p*=.018).

Table 62. Univariable regression model results for feeding groups and SwPCC score, by age group

Exposure variable: Feeding method		Outcome variable: SwPCC score								
		Age 24 months			Age 36 months			Age 48 months		
		Coef. [95% CI]	*t* [df]	*p*	Coef. [95% CI]	*t* [df]	*p*	Coef. [95% CI]	*t* [df]	*p*
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-13.36 [-27.31,0.59]	-1.94 [38]	**.060**	-0.07 [-13.05,12.91]	-0.01 [33]	.992	-2.45 [-13.76,8.87]	-0.44 [41]	.665
	Bottle fed	-13.26 [-27.79,1.28]	-1.85 [38]	**.073**	-10.35 [-21.58,0.89]	-1.87 [33]	**.070**	4.17 [-10.71,19.05]	0.57 [41]	.575
Age 12 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-23.52 [-40.84,-6.20]	-2.75 [38]	**.009**	-11.35 [-26.11,3.41]	-1.56 [33]	.127	10.25 [-2.97,23.48]	1.57 [41]	.125
	Bottle fed	-13.46 [-25.70,-1.21]	-2.22 [38]	**.032**	-12.81 [-24.57,-1.05]	-2.22 [33]	**.034**	10.40 [-1.78,22.58]	1.72 [41]	**.092**
Age 6 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-27.34 [-45.46,-9.23]	-3.06 [37]	**.004**	-13.55 [-30.86,3.76]	-1.59 [34]	.121	4.00 [-13.84,21.85]	0.45 [40]	.653
	Bottle fed	-15.36 [-28.45,-2.28]	-2.38 [37]	**.023**	-11.81 [-24.46,0.83]	-1.90 [34]	**.066**	12.58 [-0.62,25.78]	1.93 [40]	**.061**

Table 60. ***(Continued)***

		Outcome variable: SwPCC score								
Exposure variable: Feeding method		**Age 24 months**			**Age 36 months**			**Age 48 months**		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 9 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-9.51 [-31.97,12.95]	-0.86 [38]	.397	-11.36 [-30.94,8.22]	-1.18 [33]	.246	14.01 [-9.66,37.68]	1.20 [40]	.239
	Bottle fed	-13.81 [-27.86,0.25]	-1.99 [38]	**.054**	-8.16 [-23.27,6.96]	-1.10 [33]	.280	18.88 [3.39,34.38]	2.46 [40]	**.018**
Age 12 months	**Breast/mixed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Bottle	-8.91 [-25.63,7.80]	-1.10 [23]	.281	-9.03 [-22.91,4.84]	-1.35 [23]	.191	-3.79 [-23.96,16.38]	-0.39 [24]	.701

Note: See Appendix AC for table of *n* values for each model.

Separate tables are presented for the unadjusted and adjusted regression analyses for feeding and SwPCC score at age 24 months (Table 63), 36 months (Table 64) and 48 months (Table 65).

Infant feeding and SwPCC score at age 24 months

After full adjustment for confounders none of the associations observed in the univariable analysis remained at the $p<.05$ significance level (Table 63).

Table 63. Unadjusted and adjusted regression models for feeding method and SwPCC score at age 24 months

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1a: Adjusted for biological sex		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-13.36 [-27.31,0.59]	-1.94 [38]	.060	-9.30 [-25.39,6.79]	-1.17 [37]	.249
	Bottle fed	-13.26 [-27.79,1.28]	-1.85 [38]	.073	-11.65 [-26.53,3.23]	-1.59 [37]	.121
Age 12 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-23.52 [-40.84,-6.20]	-2.75 [23]	**.009**	-23.20 [-40.10,-6.31]	-2.78 [22]	**.008**
	Bottle fed	-13.46 [-25.70,-1.21]	-2.22 [23]	**.032**	-12.20 [-24.23,-0.16]	-2.05 [22]	**.047**
Age 6 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-27.34 [-45.46,-9.23]	-3.06 [37]	**.004**	-26.24 [-44.20,-8.28]	-2.96 [36]	**.005**
	Bottle fed	-15.36 [-28.45,-2.28]	-2.38 [37]	**.023**	-13.03 [-22.20,4.22]	-1.98 [36]	.055
Age 9 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-9.51 [-31.97,12.95]	-0.86 [38]	.397	-5.78 [-28.68,17.12	-0.51 [37]	.612
	Bottle fed	-13.81 [-27.86, 0.25]	-1.99 [38]	.054	-11.38 [-25.74,2.98]	-1.61 [37]	.117

Table 61. ***(Continued)***

Exposure variable: Feeding method		**Model 1b: Adjusted for biological sex and home ownership**			**Model 2: Adjusted for biological sex, home ownership and maternal age**		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	9.21 [-30.89,12.47]	-0.88 [22]	.388	-7.32 [-30.73,16.08]	-0.65 [20]	.521
	Bottle fed	-4.85 [-24.78,15.08]	-0.50 [22]	.619	-3.75 [-24.36,16.86]	-0.38 [20]	.708
Age 12 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-18.53 [-40.79,-3.72]	-1.73 [14]	.098	-15.2833 [-39.87,1.95]	-1.30 [13]	.208
	Bottle fed	-16.26 [-28.97,-3.56]	-1.45 [14]	.160	-11.95 [-28.95,5.06]	-1.47 [13]	.158
Age 6 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-24.88 [-47.86,-1.90]	-2.25 [21]	**.035**	-24.24 [-48.52,-0.04]	-2.09 [19]	.050
	Bottle fed	-12.84 [-31.47,-5.79]	-1.43 [21]	.167	-14.76 [-33.90,-4.37]	-1.61 [19]	.123
Age 9 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-12.39 [-42.70,-17.92]	-0.85 [22]	.406	-3.48 [-37.24,-30.27]	-0.22 [20]	.832
	Bottle fed	-11.34 [-30.82,-8.13]	-1.21 [22]	.240	-11.21 [-30.83,8.41]	-1.19 [20]	.247

Note: n for age 4 weeks: model 0 (*n*=41); model 1a (*n*=41); model 1b (*n*=27); model 2 (*n*=27). *n* for age 12 weeks: model 0 (*n*=41); model 1a (*n*=41); model 1b (*n*=27); model 2 (*n*=27). *n* for age 6 months: model 0 (*n*=40); model 1a (*n*=40); model 1b (*n*=26); model 2 (*n*=26). *n* for age 9 months: model 0 (*n*=41); model 1a (*n*=41); model 1b (*n*=27); model 2 (*n*=27).

Infant feeding and SwPCC score at age 36 months

After full adjustment for confounders, associations observed between feeding and SwPCC score at age 36 months were maintained for the age 6 months feeding group (Table 64). At age 36 months, children who were mixed fed (*coef.*=-24.13 [95% CI -44.91,-3.35], *t*=-2.47, *df*=15, *p*=.026) or exclusively bottle fed (*coef.*=-21.67 [95% CI -40.02,-3.32], *t*=-2.52, *df*=15, *p*=.024) at age 6 months obtained a SwPCC score, on average, more than 20 points lower than children who were exclusively breast fed at age 6 months (Table 64).

Table 64. Unadjusted and adjusted regression models for feeding method and SwPCC score at age 36 months

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1a: Adjusted for biological sex		
		Coef. [95% CI]	*t* [df]	*p*	Coef. [95% CI]	*t* [df]	*p*
Age 4 weeks	Breast fed	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-0.07 [-13.05,12.91]	-0.01 [33]	.992	2.33 [-10.09,14.75]	0.38 [32]	.705
	Bottle fed	-10.35 [-21.58,0.89]	-1.87 [33]	.070	-9.69 [-20.29,0.91]	-1.86 [32]	.072
Age 12 weeks	Breast fed	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-11.35 [-26.11,3.41]	-1.56 [33]	.127	-9.26 -23.70,5.17]	-1.31 [32]	.201
	Bottle fed	-12.81 [-24.57,-1.05]	-2.22 [33]	**.034**	-11.35 [-22.81,0.12]	-2.02 [32]	.052
Age 6 months	Breast fed	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-13.55 [-30.86,3.76]	-1.59 [34]	.121	-10.45 [-28.20,7.30]	-1.20 [33]	.240
	Bottle fed	-11.81 [-24.46,0.83]	-1.90 [34]	.066	-8.99 [-22.20,4.22]	-1.38 [33]	.176

Table 62. ***(Continued)***

Exposure variable: Feeding method		**Model 1b: Adjusted for biological sex and home ownership**			**Model 2: Adjusted for biological sex, home ownership and maternal age**		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-4.52 [-20.78,11.73]	-0.59 [17]	.565	-2.26 [-19.42,14.90]	-0.28 [14]	.782
	Bottle fed	-8.23 [-23.13,6.68]	-1.16 [17]	.260	-11.35 [-27.65,4.95]	-1.49 [14]	.158
Age 12 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-18.00 [-34.09,-1.91]	-2.36 [17]	**.031**	-17.28 [-36.50,1.95]	-1.93 [14]	.074
	Bottle fed	-16.26 [-28.97,-3.56]	-2.70 [17]	**.015**	-15.47 [-31.83,0.89]	-2.03 [14]	.062
Age 6 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-20.60 [-37.13,-4.07]	-2.62 [18]	**.017**	-24.13 [-44.91,-3.35]	-2.47 [15]	**.026**
	Bottle fed	-19.12 [-32.56,-5.69]	-2.99 [18]	**.008**	-21.67 [-40.02,-3.32]	-2.52 [15]	**.024**

Note: *n* for age 4 weeks: model 0 (*n*=41); model 1a (*n*=36); model 1b (*n*=22); model 2 (*n*=22). *n* for age 12 weeks: model 0 (*n*=41); model 1a (*n*=36); model 1b (*n*=22); model 2 (*n*=22). *n* for age 6 months: model 0 (*n*=40); model 1a (*n*=37); model 1b (*n*=23); model 2 (*n*=23).

Infant feeding and SwPCC score at age 48 months

After full adjustment for confounders, only the association observed in the unadjusted model between feeding at age 9 months and SwPCC score at age 48 months remained (Table 65). On average, children who were exclusively bottle fed at age 9 months obtained a SwPCC score at age 48 months 24.64 points higher (*coef.*=24.64 [95% CI 3.88,45.40], t=2.52, df=16, p=.023) compared with children who were exclusively breast fed aged 9 months (Table 65).

Table 65. Unadjusted and adjusted regression models for feeding method and SwPCC score at age 48 months

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1a: Adjusted for biological sex		
		Coef. [95% CI]	*t* [df]	*p*	Coef. [95% CI]	*t* [df]	*p*
Age 12 weeks	Breast fed	1 [-]	-	-	1 [-]	-	-
	Mixed fed	10.25 [-2.97,23.48]	1.57 [41]	.125	9.07 [-3.92,22.07]	1.41 [40]	.166
	Bottle fed	10.40 [-1.78,22.58]	1.72 [41]	.092	7.51 [-4.86,19.88]	1.23 [40]	.227
Age 6 months	Breast fed	1 [-]	-	-	1 [-]	-	-
	Mixed fed	4.00 [-13.84,21.85]	0.45 [40]	.653	1.64 [-15.84,19.12]	0.19 [39]	.850
	Bottle fed	12.58 [-0.62,25.78]	1.93 [40]	.061	10.38 [-2.62,23.39]	1.62 [39]	.114
Age 9 months	Breast fed	1 [-]	-	-	1 [-]	-	-
	Mixed fed	14.01 [-9.66,37.68]	1.20 [40]	.239	12.86 [-10.26,35.97]	1.12 [39]	.267
	Bottle fed	18.88 [3.39,34.38]	2.46 [40]	**.018**	16.40 [1.03,31.77]	2.16 [39]	**.037**

Table 63. ***(Continued)***

Exposure variable: Feeding method		Model 1b: Adjusted for biological sex and home ownership			Model 2: Adjusted for biological sex, home ownership and maternal age		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 12 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	11.56 [-7.61,30.73]	1.26 [19]	.222	7.83 [-18.58,34.24]	0.63 [16]	.539
	Bottle fed	11.37 [-7.61,30.73]	1.27 [19]	.221	11.53 [-8.96,32.01]	1.19 [16]	.250
Age 6 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	11.98 [-12.12,36.07]	1.04 [19]	.311	8.84 [-24.12,41.80]	0.57 [16]	.578
	Bottle fed	13.25 [-4.65,31.14]	1.55 [19]	.138	12.52 [-7.86,32.90]	1.30 [16]	.211
Age 9 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	16.98 [-11.75,45.72]	1.24 [19]	.231	11.76 [-20.80,44.32]	0.77 [16]	.455
	Bottle fed	24.44 [5.50,43.38]	2.70 [19]	**.014**	24.64 [3.88,45.40]	2.52 [16]	**.023**

Note: *n* for age 12 weeks: model 0 (*n*=44); model 1a (*n*=44); model 1b (*n*=24); model 2 (*n*=24). *n* for age 6 months: model 0 (*n*=43); model 1a (*n*=43); model 1b (*n*=24); model 2 (*n*=24). *n* for age 9 months: model 0 (*n*=43); model 1a (*n*=43); model 1b (*n*=24); model 2 (*n*=23).

2.2.3. Data analysis: overall CsPCC score

Univariable analysis of potential confounders associated with overall CsPCC score indicated that age group, maternal education and word combination at age 24 months had p values <.10 (Table 66). Biological sex was retained because of the weight of published evidence for the association with speech sound development. Although maternal education showed some weak association with the outcome variable (≥ degree level: *coef.*=-25.31 [95% CI -51.35, 0.74], *t*=-2.01, *df*=23, *p*=.056), home ownership was retained as the measure of SES the multivariable analysis in order to maintain a consistent approach throughout the study. Confounders and covariates age group, biological sex, home ownership and word combination at age 24 months were taken forward for multivariable analysis, for which the threshold p<.05 was applied.

Table 66. Univariable regression model results for potential confounders associated with overall CsPCC score

		Outcome variable: CsPCC score		
Variable	**Category[a]**	**Coef. [95% CI]**	***t* [df]**	***p***
Demographics				
Age group	**36 months**	1.00	-	-
	48 months	11.69 [-1.95,25.32]	1.74 [36]	**.091**
Biological sex[b]	**Female**	1.00	-	-
	Male	-10.06 [-22.84,2.71]	-1.60 [36]	.119
Home ownership status[b]	**Owned / privately rented**	1.00	-	-
	Council / other	-12.27 [-30.36,5.82]	-1.41 [21]	.173
Maternal age[c]	**21 years**	1.00	-	-
	22 years	7.29 [-18.29,32.87]	0.58 [34]	.566
	23 years	9.72 [-17.17,36.61]	0.73 [34]	.468
	24+ years	-1.82 [-24.47,25.83]	-0.13 [34]	.894
Maternal education[a]	≤ GCSE	1.00	-	-
	Vocational	-13.55 [-36.45,9.35]	-1.22 [23]	.233
	AS/A Level	-18.90 [-47.75,9.96]	-1.35 [23]	.189
	≥ Degree	-25.31 [-51.35,0.74]	-2.01 [23]	**.056**
Ear infection at 12 months	**No**	1.00	-	-
	Yes	-6.69 [-28.48,15.10]	-0.64 [22]	.531
Ear infection at 48 months	**No**	1.00	-	-
	Yes	-4.98 [-33.85,23.89]	-0.36 [18]	.721
Syllable combination at 12 months	**Yes**	1.00	-	-
	No	-2.17 [-25.40,21.06]	-0.19 [24]	.849
Word combination at age 24 months	**Yes**	1.00	-	-
	No	-19.76 [-38.87,-0.65]	-2.11 [31]	**.043**

Note: See Appendix AD for full Table of model *n* values.

Univariable analysis of the relationship between feeding groups and overall CsPCC score indicated that only feeding at age 4 weeks was associated with CsPCC score where $p>.10$ (Table 67). On average, children who were either mixed fed or exclusively bottle fed at age 4 weeks achieved *higher* overall CsPCC scores in (mixed fed: *coef.*=15.99 [95% CI 2.91,29.07], t=2.48, *df*=34, p=.018; bottle fed: *coef.*=20.83 [95% CI -0.05,41.70], t=2.03, *df*=34, p=.051) compared with children who were exclusively breast fed at age 4 weeks. No associations were found when the univariable analysis was rerun with bottle feeding as the reference group to allow for comparison between mixed feeding and bottle feeding (Appendix AE).

Table 67. Univariable regression model results for feeding groups and overall CsPCC score

Exposure variable: Feeding method		Outcome variable: Overall CsPCC score		
		Coef. [95% CI]	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-
	Mixed fed	15.99 [2.91,29.07]	2.48 [34]	**.018**
	Bottle fed	20.83 [-0.05,41.70]	2.03 [34]	**.051**
Age 12 weeks	**Breast fed**	1 [-]	-	-
	Mixed fed	7.49 [-11.89,26.88]	0.79 [34]	.438
	Bottle fed	14.93 [-4.29,34.14]	1.58 [34]	.124
Age 6 months	**Breast fed**	1 [-]	-	-
	Mixed fed	4.38 [-19.93,28.70]	0.37 [35]	.717
	Bottle fed	14.20 [-7.13,35.53]	1.35 [35]	.185
Age 9 months	**Breast fed**	1 [-]	-	-
	Mixed fed	-8.84 [-35.46,17.78]	-0.67 [35]	.505
	Bottle fed	14.65 [-5.38,34.69]	1.48 [35]	.147
Age 12 months	**Breast / mixed**	1 [-]	-	-
	Bottle	-13.37 [-45.13,18.39]	-0.87 [22]	.392

Note: n for age 4 weeks and 12 weeks models *n*=37. *n* for age 6 month and 9 month models *n*=38. *n* for 12 month model *n*=24.

After adjustment for confounders, the association observed in Table 67 between exclusively bottle fed children and CsPCC score was not maintained (Table 68). In the case of those who were mixed fed at age 4 weeks the association with CsPCC score strengthened after full adjustment for confounders. On average, mixed fed children obtained a CsPCC score 22.10 points higher (*coef.*=22.10 [95% CI 5.41,38.78], t=2.89, df=12, p=.014) compared with children who were exclusively breast fed at age 4 weeks.

Table 68. Unadjusted and adjusted regression models for feeding method and overall CsPCC score

Exposure variable: Feeding method		**Model 0: Unadjusted**			**Model 1a: Adjusted for age group and biological sex**			**Model 1b: Adjusted for age group, biological sex and home ownership**		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-	1 [-]	-	-
	Mixed fed	15.99 [2.91,29.07]	2.48 [34]	**.018**	10.76 [-4.09,25.63]	1.48 [32]	.150	15.86 [-3.61,35.33]	1.73 [16]	.103
	Bottle fed	20.83 [-0.05,41.70]	2.03 [34]	.051	18.32 [-2.59,39.24]	1.78 [32]	.084	16.12 [-8.74,40.98]	1.37 [16]	.188

Table 66. ***(Continued)***

Exposure variable: Feeding method		Model 2: Adjusted for age group, biological sex and word combination age 24 months			Model 3: Adjusted for age group, biological sex, home ownership and word combination age 24 months		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	14.43 [-0.78,29.65]	1.95 [26]	.062	22.10 [5.41,38.78]	2.89 [12]	**.014**
	Bottle fed	5.44 [-21.58,32.46]	0.41 [26]	.682	5.10 [-18.49,28.69]	0.47 [12]	.646

Note: n for age 4 weeks: model 0 (*n*=37); model 1a (*n*=37); model 1b (*n*=22); model 2 (*n*=32); model 3 (*n*=19).

2.2.4. Data analysis: CsPCC score by age group

Regression analysis of feeding groups and CsPCC score at ages 36 and 48 months was not possible due to small group sizes. Detailed description of the data is limited by small group sizes and the requirement to preserve anonymity by only reporting group sizes where $n>5$. Shriberg and Kwiatkowski (1982) proposed a PCC score severity rating matrix, which has been used here to describe the CsPCC data (Table 69). Of the children aged 48 months, 19.23% ($n=5$) achieved a CsPCC score rated moderate-severe or severe, compared with 50% ($n=6$) of children aged 36 months. Due to small group sizes, it is not possible to determine patterns between feeding methods and CsPCC scores.

Table 69. PCC score severity rating matrix

PCC score severity rating matrix	
Mild	85-100%
Mild-moderate	65-85%
Moderate-severe	50-65%
Severe	<50%

Note: Adapted from Shriberg & Kwiatkowski (1982).

2.3. Summary

Table 70 summarises the results from the adjusted models for the primary analysis of interest explored in this section: feeding method (ages 4 weeks, 12 weeks, 6 months, 9 months and 12 months) and PCC scores at ages 24, 36 and 48 months). The presence of an arrow indicates that an association ($p<0.05$) was observed; 🡅 suggests an *increased* likelihood of speech sound error, and 🡇 indicates *decreased* likelihood of speech sound error. Compared with exclusive breast feeding at ages 12 weeks and 6 months, mixed or exclusive bottle feeding were associated with lower SwPCC scores at age 36 months (Table 70). In contrast, mixed and bottle feeding are indicated to have protective effects, with higher CsPCC scores for mixed and bottle fed children at 12 weeks, 6 months and 9 months.

Table 70. Summary of observed associations from the fully adjusted logistic regression models for feeding and PCC scores at ages 24, 36 and 48 months

Exposure variable: Feeding method		Outcome variable: PCC score				
		SwPCC score				CsPCC score
		Overall	24 Months	36 Months	48 Months	Overall
Age 4 weeks	Breast	-	-	-	-	-
	Mixed	-	-	-	-	↑↑↑
	Bottle	-	-	-	-	-
Age 12 weeks	Breast	-	-	-	-	-
	Mixed	-	-	-	-	-
	Bottle	-	-	-	-	-
Age 6 months	Breast	-	-	-	-	-
	Mixed	-	-	↓↓↓	-	-
	Bottle	-	-	↓↓↓	-	-
Age 9 months	Breast	-	-	-	-	-
	Mixed	-	-	-	-	-
	Bottle	-	-	-	↑↑↑	-
Age 12 months	Breast / mixed	-	-	-	-	-
	Bottle	-	-	-	-	-

Note: No. arrows indicates average percentage points (%pts) increase/decrease (one arrow <10 points, two arrows=11-20 points, three arrows=21-30 points, four arrows=31-40 points, figures >40 points are specified).

3. Part B: NNS and speech sound errors at ages 24, 36 and 48 months

In this section ALSPAC-G2 data from clinical speech sound assessments at ages 24, 36 and 48 months were examined with NNS group data.

3.1. Sample size

Exposure variable data on NNS and PCC score outcome measures were collected for each participant. Figure 28 illustrates the process of derivation of participants for this study. Participants with unrecorded data for gestational age were managed as per Part A section 3.1.1. The final sample size of 122 participants included 57 females (46.72%). There are significant missing data resulting in smaller exposure and outcome groups for the analysis. Group sizes where *n*<5 cannot be reported for reasons of potential loss of anonymity.

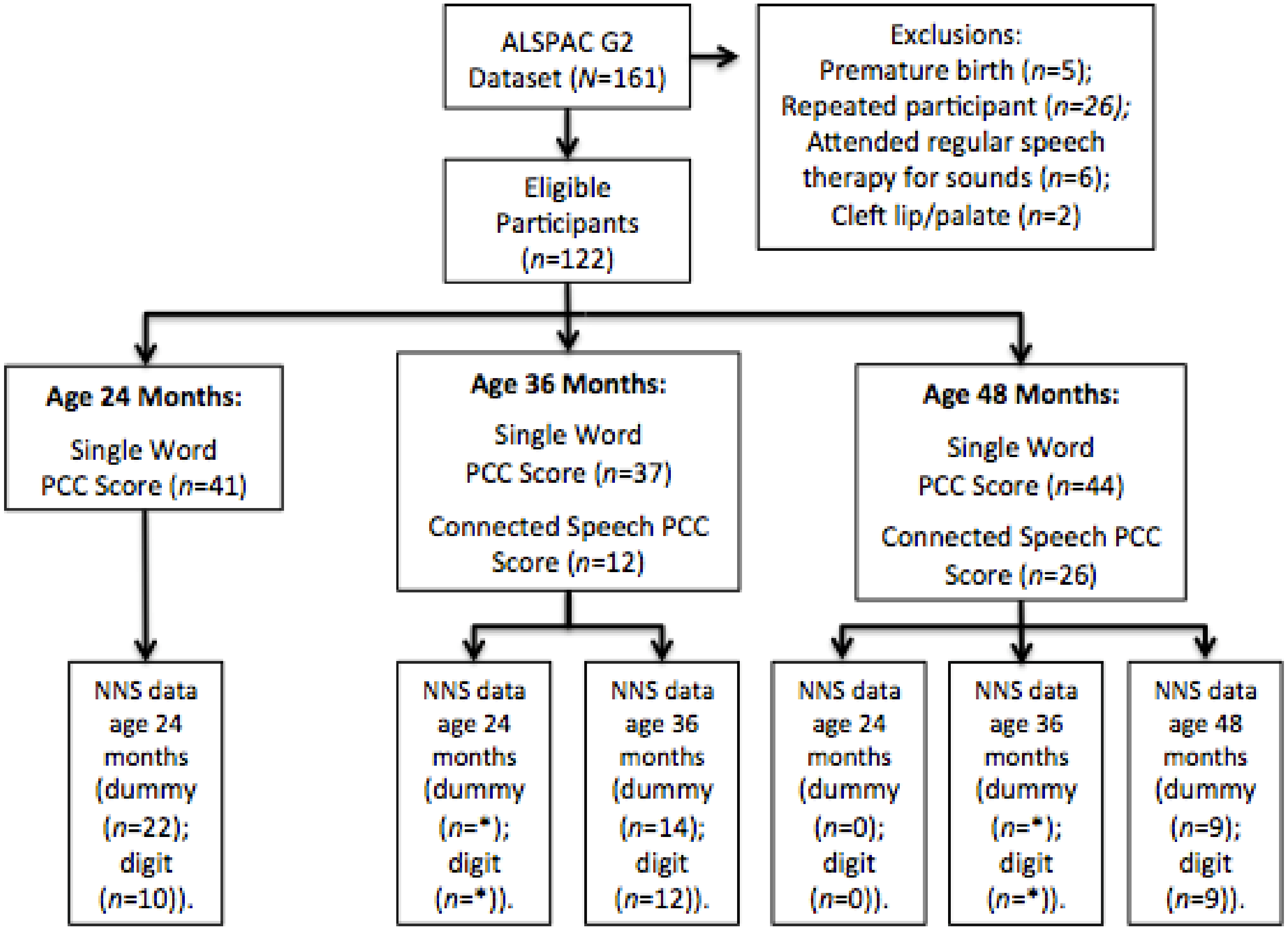

Figure 28. Derivation of participants for Strand Two Part B

3.1.1. Exposure variables: NNS groups

Due to small group sizes (range *n*=0–*n*=19) (Figure 28) and the risk to loss of anonymity, the NNS data could not be presented in a table by group and biological sex. For each of the NNS age groups (ages 24, 36 and 48 months), *n*<5 for at least one of the group categories (never, sometimes, mostly).

3.1.2. Potential confounding variables

The potential confounding variables and covariates for this part of the study are the same as those described in Section 3.1.1.2.

3.1.3. Outcome variables: clinical speech assessment data - PCC scores

The SwPCC and CsPCC scores used as the outcomes of interest in this study are described in section 3.1.1.3.

3.2. Data analysis: PCC scores

Regression analysis was not possible due to insufficient exposure variable data. The following sections present a description of the SwPCC score outcome data, the SwPCC scores for each age group, using the standard score and percentile rank data from the DEAP (Dodd *et al*, 2002) and TPT (McIntosh & Dodd, 2011) assessment manuals. The age groups have been combined to create the overall SwPCC score, as per Strand Two (see section 2.2.1). A similar approach to that adopted in Part A of this strand, was used for the CsPCC score outcome data, where the data was described using the PCC score severity rating matrix (Shriberg & Kwiatkowski, 1982) (Table 69).

3.2.1. Data analysis: overall SwPCC score

Almost 30% of children who sucked a dummy or their digit at least some of the time at ages 24, 36 and 48 months, achieved a SwPCC standardised score below 7 (*n*=27, 29.67%; *n*=25, 29.41%, respectively). This indicates below typical performance, as approximately two-thirds of all children achieve standard scores between 7 and 13 (Dodd *et al*, 2002, p.20; McIntosh & Dodd, 2011, p.31). The majority of children with SwPCC score data (*n*=13, 81.25%) who were reported not to suck a dummy at age 36 months obtained SwPCC standardised scores of at least 8 (25^{th} percentile or higher). A similar trend was observed for children who were reported never to suck a dummy at age 48 months, of which 87.50% (*n*=14) obtained an SwPCC standardised score of at least 8 (25^{th} percentile or higher).

3.2.2. Data analysis: SwPCC score by age group

Summary statistics could not be generated because group sizes *n*<10 with several empty groups (*n*=0).

3.2.3. Data analysis: overall CsPCC score

Summary statistics could not be generated because group sizes *n*<10, with many empty groups (*n*=0).

3.3. Summary

Due to small sample sizes, it was not possible to perform regression analysis on the data. Almost a third of children who sucked a dummy or digit at ages 2-4 years achieved a standardised SwPCC score below 7, which is the lower end of the expected score range for typical speech development. Findings from the CsPCC data with regard to NNS were not possible due to small group sizes.

4. Summary of Strand Two

The results of this strand of the study indicate some association between early feeding regime and speech sound development in early childhood (Table 70).

4.1. Infant feeding and PCC scores at ages 2-4 years

Part A of this strand found evidence that children who were mixed fed (*coef.*=-24.13 [95% CI -44.91,3.35], *t*=-2.47, *df*=15, *p*=.026) or exclusively bottle fed (*coef.*=-21.67 [95% CI -40.02,3.32], *t*=-2.52, *df*=15, *p*=.024) at age 6 months were likely to achieve a SwPCC score at age 36 months around 20 points lower compared with exclusively breast fed children (Table 64). In contrast, children who were exclusively bottle fed at age 9 months were more likely (*coef.*=24.64 [95% CI 3.88,45.40], *t*=2.52, *df*=16, *p*=.023) to achieve a higher SwPCC score at age 48 months compared with exclusively breast fed children (Table 65). With regard to

CsPCC score, children who were mixed fed at age 4 weeks obtained a CsPCC score, on average, 22.10 points higher compared with children who were exclusively breast fed at this age (*coef.*=22.10 [95% CI 5.41,38.78], *t*=2.89, *d.f.*=12, *p*=.014) (Table 68). Further analysis of potential associations between feeding methods and CsPCC data was not possible due to insufficient sample size.

4.2. NNS and PCC scores at ages 2-4 years

In Part B of this strand, formal statistical analysis of an association between NNS and SwPCC or CsPCC scores was not possible due to insufficient data (Figure 28). Informal analysis indicated that almost 30% of children who sucked a dummy or their digit at least some of the time at ages 24, 36 and 48 months, achieved a SwPCC standardised score below 7 (*n*=27, 29.67%; *n*=25, 29.41%, respectively). Children who never sucked a dummy at age 36 months or 48 months obtained SwPCC standardised scores of at least 8 (25^{th} percentile or higher (*n*=13, 81.25%; *n*=14, 87.50%, respectively). Analysis of potential associations between NNS and CsPCC was not possible due to insufficient sample size.

Chapter Six: Results for Strand Three: NHS Clinical Data

1. Overview of the chapter

This chapter presents the results from Strand Three of this study, which is comprised of three parts. Part A examined the relationship between feeding regime and PCC scores between ages 2 and 5 years. Part B examined the relationship between NNS and PCC scores between ages 2 and 5 years. Brief summaries of the results for each part of the strand are provided as well as a final summary of the results of the whole strand.

2. Part A: infant feeding and speech sound errors between ages 2-5 years

This section examines questionnaire and clinical assessment data about infant feeding regime from NHS clinical patients to explore relationships between feeding regime and speech sound development between ages 2-5 years.

2.1. Sample size

Exposure variable (feeding) data and outcome variable (SwPCC and CsPCC PCC scores) data were collected for each participant. Figure 29 illustrates the process of derivation of participants for this study. The final sample size of 52 participants included 19 females (36.54%). 15.38% of children in the sample were aged under 36 months and completed the Toddler Phonology Test (TPT) assessment (*n*=8). The majority of participants were aged 36 months or over and completed the Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd, 2005). Due to the small data sample, the analysis is presented as children age <36 months and >36 months.

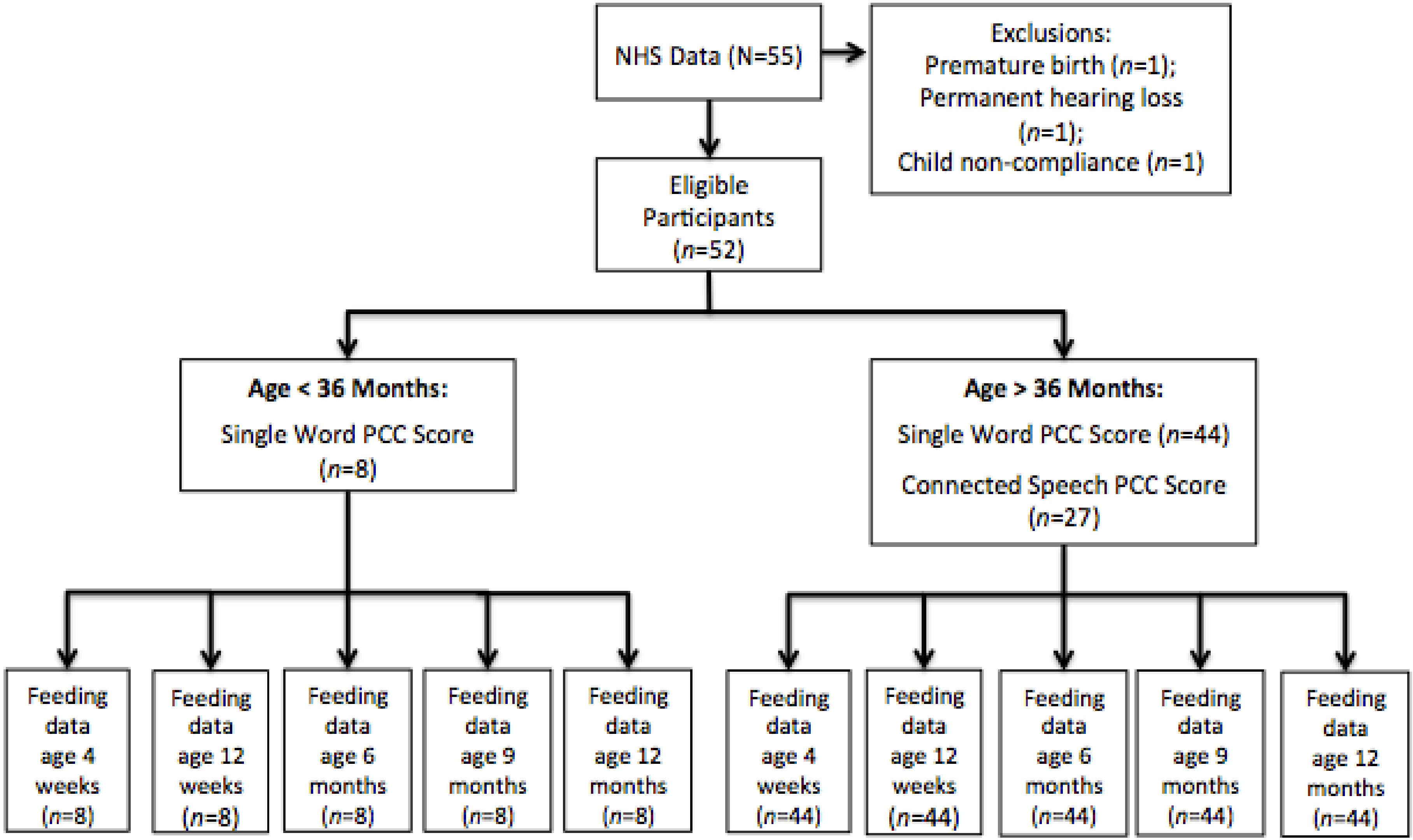

Figure 29. Derivation of participants for Strand Three Part A

2.1.1. Exposure variables: feeding groups

Biological sex could not be included in Table 71, because group sizes <5 risked loss of data anonymity. Higher proportions of females than males were exclusively bottle fed across the age groups, and higher proportions of males were exclusively breast fed. The largest proportion of children were breast fed at age 4 weeks, while exclusive bottle feeding constituted the largest proportions at ages 12 weeks, 6 months and 9 months (Table 71).

Table 71. Exposure variables: feeding groups by age

	Feeding groups		
Age point	**Exclusive breast fed**	**Mixed fed**	**Exclusive bottle fed**
4 weeks	*n*=27	*n*=6	*n*=19
12 weeks	*n*=22	*n*=*	*n*=26
6 months	*n*=20	*n*=5	*n*=27
9 months	*n*=12	*n*=7	*n*=32

Note: *group size *n*<5.

2.1.2. Potential confounding variables

Limited data were available for confounding variables. Data were collected on the child's age at assessment (months) (Table 72) and biological sex (Table 73) (see also chapter three Figure 6). The age data showed normal distribution with the largest proportion of children aged around 46 months (Figure 30). The proportion of females who completed the TPT and DEAP clinical assessments reflected the proportion of the overall sample (Table 73).

Table 72. Summary statistics for potential confounding variable: age (months) of child at assessment

Age of child at assessment (months)		
n	**Mean s.d**	**Median IQR**
52	43.77 7.51	45 38-48

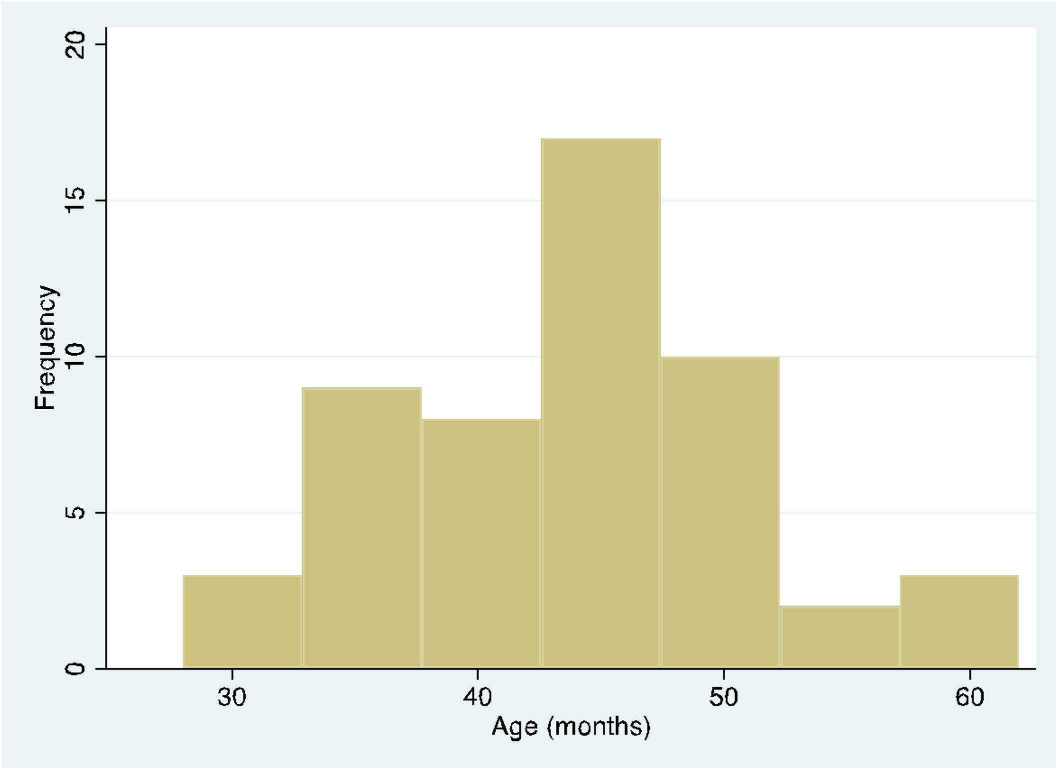

Figure 30. Histogram of participant age at assessment (months) (*n*=52)

Table 73. Sample (*n*) for covariate biological sex

Assessment age group	
<Age 36 months	**>Age 36 months**
8 (Female n=3, 37.50%)	44 (Female n=16, 36.36%)

2.1.3. Outcome variables: clinical speech assessment data PCC scores

Single word PCC (SwPCC) scores

Table 74 presents the summary statistics for the overall outcome variable SwPCC score. The data appeared normally distributed with slightly higher proportions of children achieving scores below the overall mean (Table 74, Figure 31, Figure 32 and Table 75). This pattern is expected within a population of children known to have SSD. The majority of children in the sample (n=38, 73.08%) obtained a standardised SwPCC score of 3 (1st percentile), indicating SSD of significant clinical concern.

Table 74. SwPCC score summary statistics

Overall SwPCC score		
n	Mean s.d	Median IQR
52	40.49 17.04	40.16 31.58-50.58

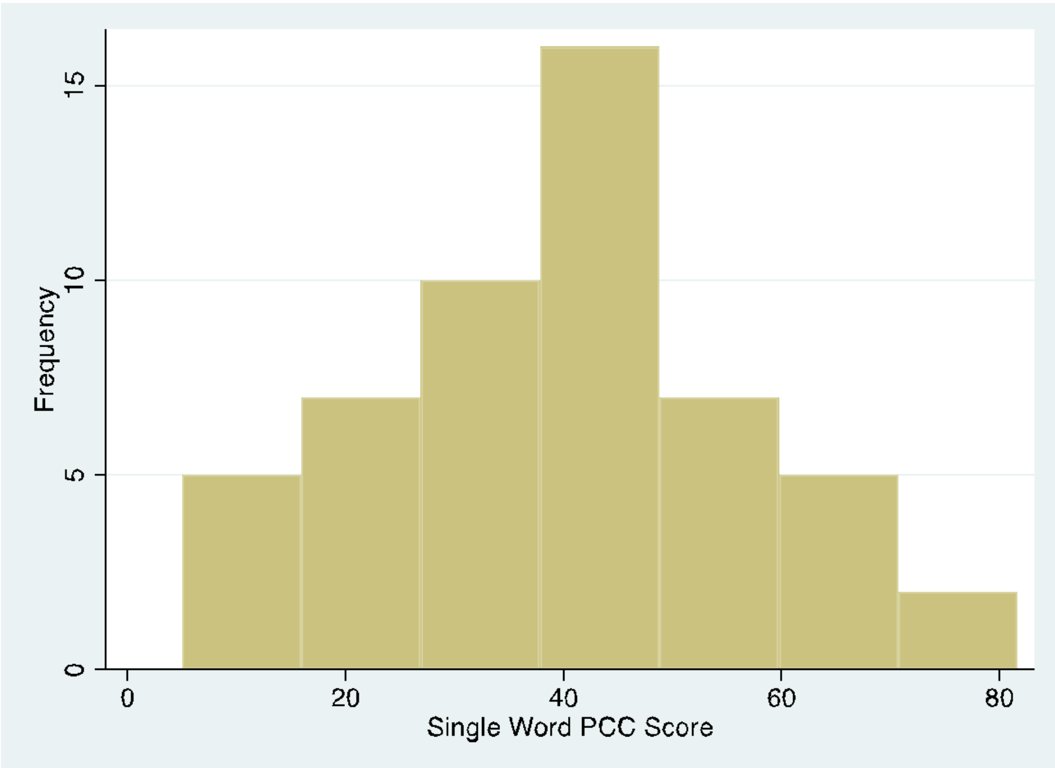

Figure 31. Histogram of SwPCC raw scores (*n*=52)

In line with expectations of typical development, mean SwPCC scores generally increased with age (Figure 32 and Figure 33). Mean SwPCC scores for females aged under 3 years were on average 6% higher than for males (females *mean*=29.24; male *mean*=23.26), but little difference in means was observed between the sexes in children over age 3 years (females *mean*=43.54; males *mean*=43.03). The disparity between group sizes should be noted (under 36 months *n*=8; over 36 months *n*=44) (Table 75). Gender proportions (*n*) are not noted in the table due to risk to loss of data anonymity.

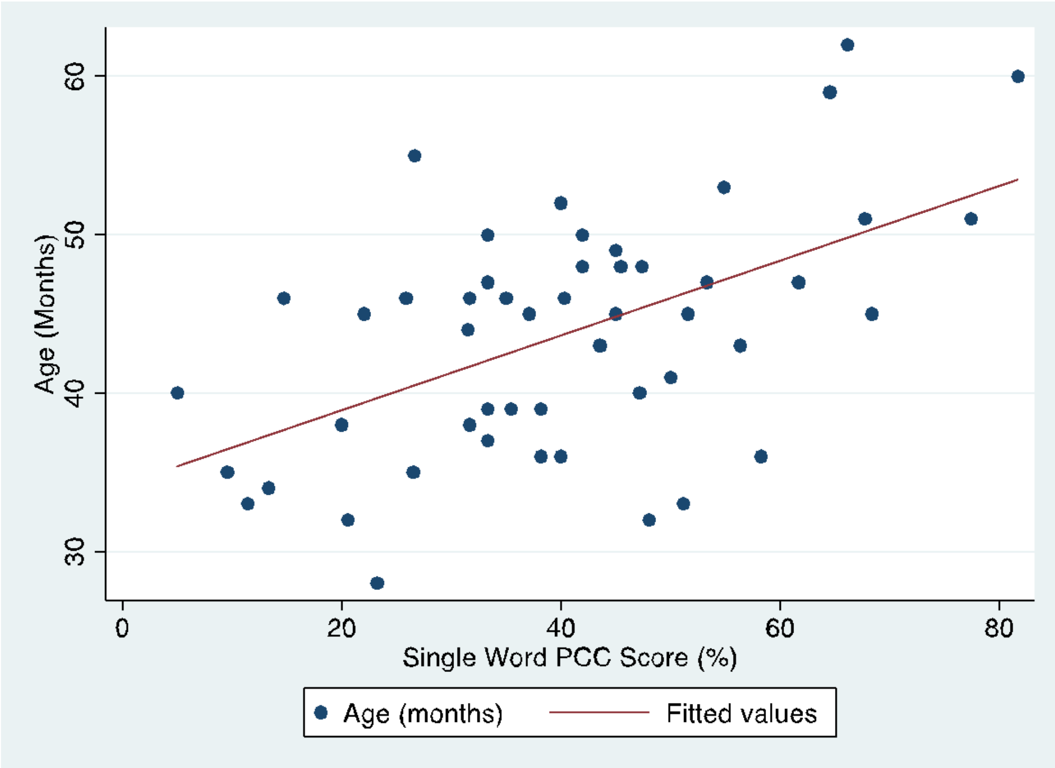

Figure 32. Scatter plot of SwPCC scores and age (months) with line of best fit (*n*=52)

Table 75. SwPCC score summary statistics, by age group

	SwPCC score					
	<= Age 35 months			**>= Age 36 months**		
	n	**Mean s.d**	**Median IQR**	***n***	**Mean s.d**	**Median IQR**
Whole sample	8	25.48 16.02	21.89 12.38-37.29	44	43.22 15.90	41.94 33.33-52.47

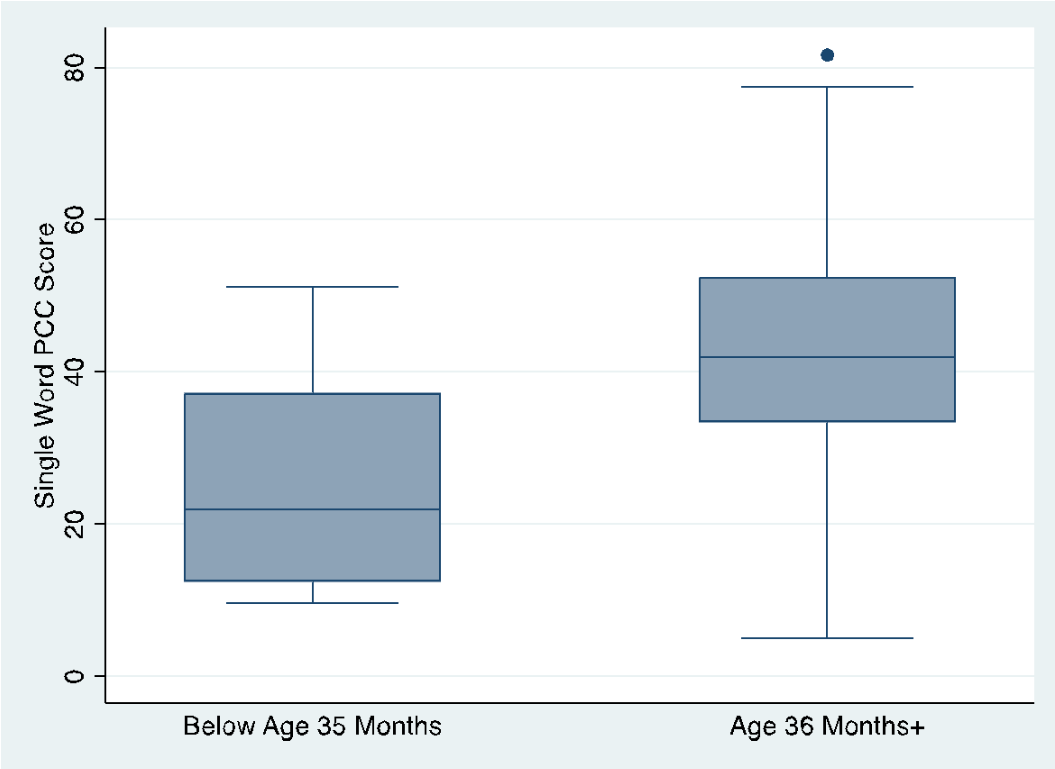

Figure 33. Box and whisker plot of SwPCC scores for below age 35 months (*n*=8) and age 36 months and older (*n*=44)

CsPCC score

Table 76 presents the summary statistics for the overall outcome variable CsPCC score. The mean age of children for whom these data were available was 45.77 months (range=36-62 months, s.d.=6.28, IQR=40.50-49.50). The data appear normally distributed with a high proportion of scores clustered around the mean (mean=37.18) (Figure 34 and Figure 35). Two children achieved CsPCC scores below 10%, indicated by dots on **Error! Reference source not found.**. CsPCC s cores are shown to increase with age, as expected (Figure 36).

Table 76. CsPCC score summary statistics

Overall CsPCC score		
n	**Mean s.d**	**Median IQR**
27	37.18 15.48	39.29 31.25-47.37

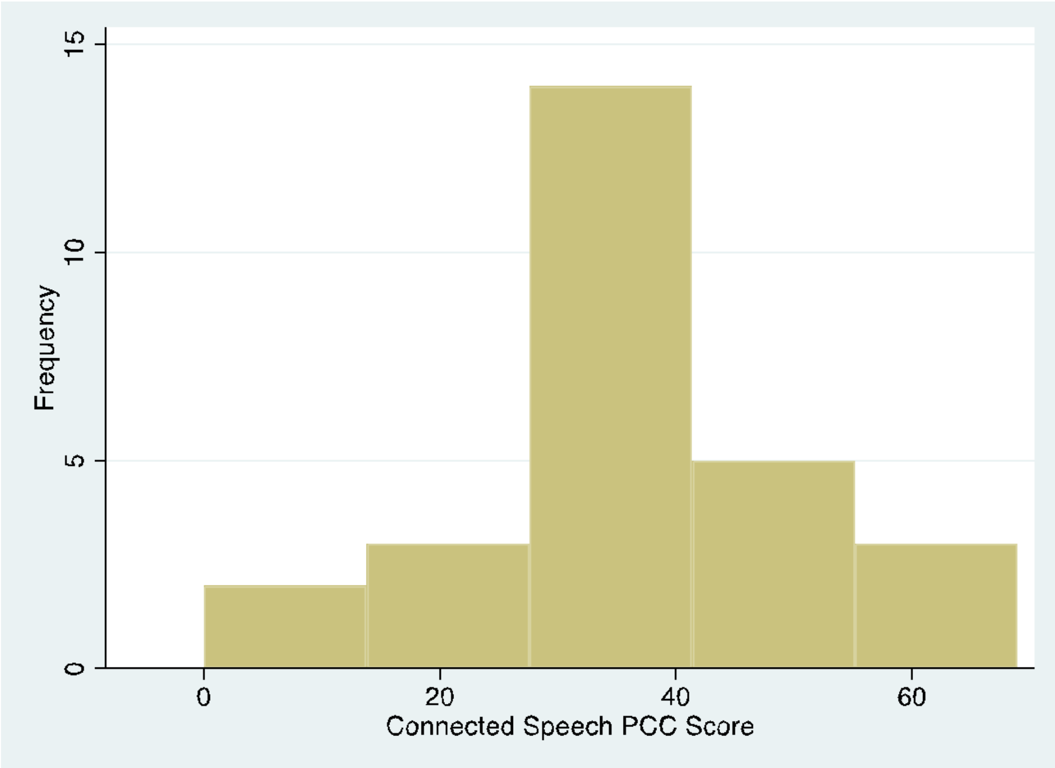

Figure 34. Histogram of overall CsPCC scores (*n*=27)

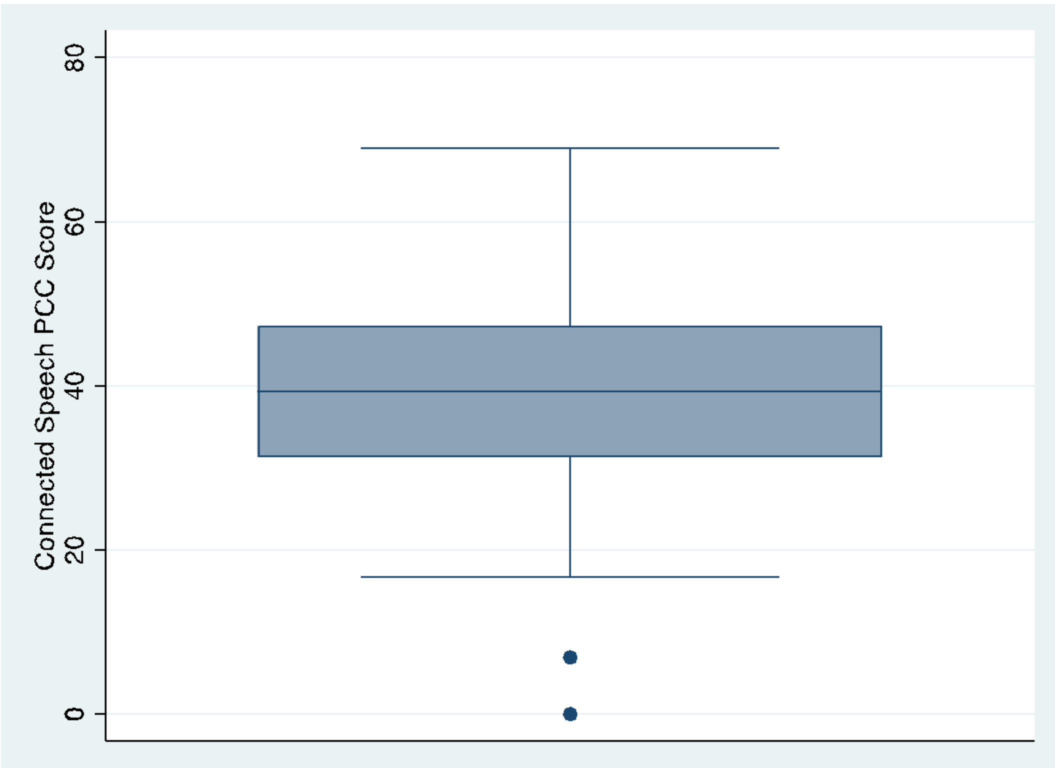

Figure 35. Box and whisker plot of CsPCC scores in children over age 36 months (*n*=27)

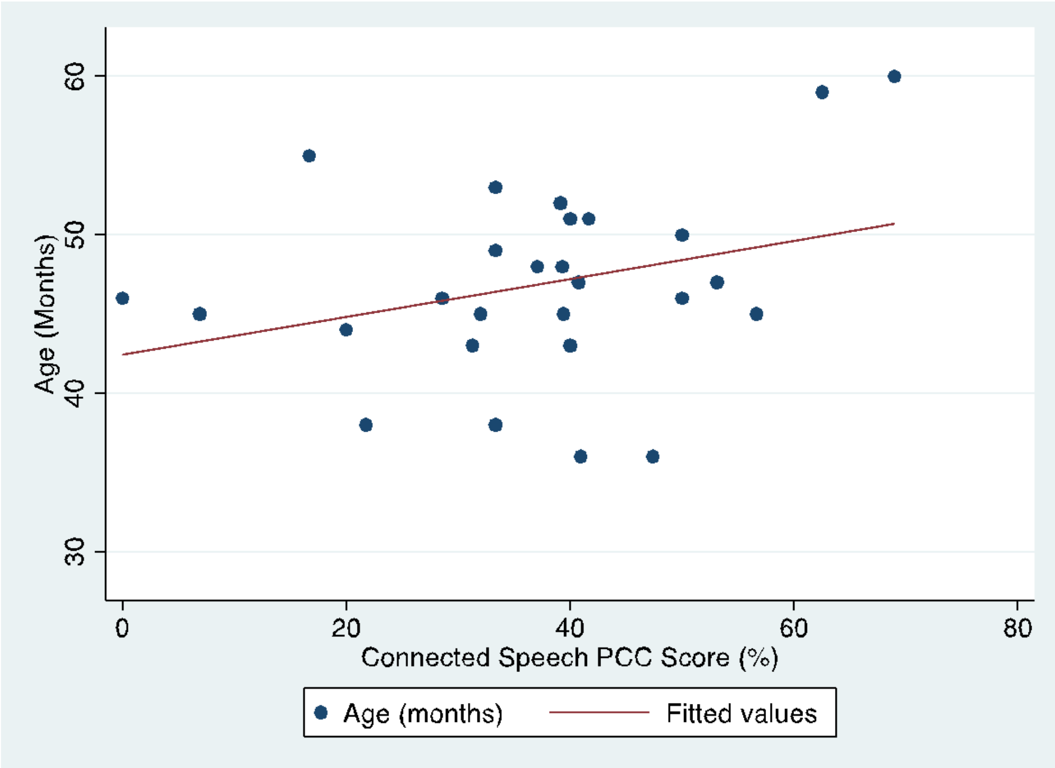

Figure 36. Scatter plot of CsPCC scores and age in months with line of best fit (*n*=27)

2.2. Data analysis: PCC scores

The following sections present the analysis of the overall SwPCC score outcome data, and then the overall CsPCC score data. Due to small group sizes, it was not possible to analyse the data by age group.

2.2.1. Data analysis: overall SwPCC score

Univariable analysis of potential confounders associated with SwPCC score showed that biological age had a significant association, as expected with typical speech development (Table 77). Biological sex was retained due to the weight of published evidence for its association with speech sound development.

Table 77. Univariable regression model results for potential confounders associated with overall SwPCC score

		Outcome variable: Overall SwPCC score		
Variable	**Category[a]**	**Coef. [95% CI]**	***t* [df]**	***p***
Assessment age (months)		1.21	4.48	**<.001**
Biological sex[b]	**Female**	1.00	-	-
	Male	-1.26 [-11.20,-8.69]	-0.25 [50]	.801

Univariable analysis of the relationship between overall SwPCC score and feeding groups showed very weak associations where $p>.10$ (Table 78). On average, children who were exclusively bottle fed at age 4 weeks or age 9 months achieved SwPCC scores around 9 points lower than exclusively breast fed children at these ages before adjustment for confounders (*Coef.*=-9.14 [95% CI -19.24,0.96], t=-1.82, *d.f.*=49, p=.075; *Coef.*=-9.68 [95% CI -21.18,1.82], t=-1.69, *d.f.*=48, p=.097, respectively). The univariable analysis was rerun with bottle feeding as the reference group to allow for comparison of mixed feeding with bottle feeding. No associations were observed (Appendix AF). When the models (Table 78) were adjusted for age and biological sex, no further significant observations were observed (Table 79).

Table 78. Univariable regression model results for feeding groups and overall SwPCC score

Exposure variable: Feeding method		Outcome variable: Overall SwPCC score		
		Coef. [95% CI]	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-
	Mixed fed	-0.06 [-15.28,15.16]	-0.01 [49]	.994
	Bottle fed	-9.14 [-19.24,0.96]	-1.82 [49]	**.075**
Age 12 weeks	**Breast fed**	1 [-]	-	-
	Mixed fed	-10.66 [-29.15,7.82]	-1.16 [49]	.252
	Bottle fed	-7.12 [16.97,2.73]	-1.45 [49]	.153
Age 6 months	**Breast fed**	1 [-]	-	-
	Mixed fed	-9.58 [-26.52,7.37]	-1.14 [49]	.262
	Bottle fed	-8.08 [-18.08,1.92]	-1.62 [49]	.111
Age 9 months	**Breast fed**	1 [-]	-	-
	Mixed fed	-10.21 [-26.37,5.95]	-1.27 [48]	.210
	Bottle fed	-9.68 [-21.18,1.82]	-1.69 [48]	**.097**

Note: n for age 4 week, 12 weeks and 6 month models (n=52). n for age 9 month models (n=51).

Table 79. Unadjusted and adjusted regression models for feeding and overall SwPCC score

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1a: Adjusted for biological sex		
		Coef. [95% CI]	*t* [df]	*p*	Coef. [95% CI]	*t* [df]	*p*
Age 4 weeks	Breast fed	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-0.06 [-15.28,15.16]	-0.01 [49]	.994	-0.12 [-15.50,15.17]	-0.02 [48]	.983
	Bottle fed	-9.14 [-19.24,0.96]	-1.82 [49]	.075	-9.65 [-19.98,0.67]	-1.88 [48]	.066
Age 9 months	Breast fed	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-10.21 [-26.37,5.95]	-1.27 [48]	.210	-9.99 [-26.43,6.46]	-1.22 [47]	.228
	Bottle fed	-9.68 [-21.18,1.82]	-1.69 [48]	.097	-9.80 [-21.47,1.87]	-1.69 [47]	.098

Table 77. ***(Continued)***

Exposure variable: Feeding method		Model 1b: Adjusted for age			Model 2: Adjusted for biological sex and age		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-3.67 [-17.20,9.85]	-0.55 [48]	.588	-3.86 [-17.43,9.72]	-0.57 [47]	.570
	Bottle fed	-2.57 [-12.08,6.94]	-0.54 [48]	.589	-3.17 [-12.80,6.47]	-0.66 [47]	.512
Age 9 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-7.31 [-21.15,6.53]	-1.06 [47]	.293	-6.63 [-20.66,7.40]	-0.95 [46]	.346
	Bottle fed	-7.60 [-17.45,2.25]	-1.55 [47]	.127	-7.90 [-17.83,2.03]	-1.60 [46]	.116

Note: n for age 4 weeks models (n=52). n for age 9 months models (n=51).

2.2.2. Data analysis: overall CsPCC score

Univariable analysis of potential confounders associated with CsPCC score indicated that neither the child's age nor biological sex were significantly associated with the outcome (Table 80). As these are the only potential confounders that were available for inclusion in the analysis, and the weight of published evidence associating age and sex with speech sound development, both were retained for further analysis.

Table 80. Univariable regression model results for potential confounders associated with overall CsPCC score

		Outcome variable: Overall CsPCC score		
Variable	**Category[a]**	**Coef. [95% CI]**	***t* [df]**	***p***
Assessment age (months)		0.79 [-0.22,1.79]	1.61 [25]	.119
Biological sex[b]	**Female**	1.00	-	-
	Male	-4.03 [-16.88,8.82]	-0.65 [25]	.524

Note: n for all models (*n*=27)

Univariable analysis of the relationship between overall SwPCC score and feeding groups showed some associations where $p>.10$ (Table 81). Within each feeding age group, mixed and exclusively bottle fed children achieved lower scores, on average, compared to exclusively breast fed children at these ages. In each case the CIs are wide, but those for mixed fed children are closer to 0 than the coefficient CIs for exclusively bottle fed children. This means that, for the latter, the wide CI indicates low certainty of the result, but that it is not likely to include the null hypothesis that there is not an association. The univariable analysis was rerun with bottle feeding as the reference group to allow for comparison of mixed feeding with bottle feeding. No associations were observed (Appendix AG).

Table 81. Univariable regression model results for feeding groups and overall CsPCC score

Exposure variable: Feeding method		Outcome variable: Overall CsPCC score		
		Coef. [95% CI]	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-
	Mixed fed	-6.69 [-21.22,7.84]	-0.95 [24]	.352
	Bottle fed	-19.04 [-31.40,-6.68]	-3.18 [24]	**.004**
Age 12 weeks	**Breast fed**	1 [-]	-	-
	Mixed fed	-14.78 [-35.91,6.35]	-1.44 [24]	.162
	Bottle fed	-17.68 [-28.76,-6.61]	-3.30 [24]	**.003**
Age 6 months	**Breast fed**	1 [-]	-	-
	Mixed fed	-17.21 [-32.83,-1.59]	-2.27 [24]	**.032**
	Bottle fed	-20.71 [-31.81,-9.60]	-3.85 [24]	**.001**
Age 9 months	**Breast fed**	1 [-]	-	-
	Mixed fed	-17.62 [-33.46,-1.77]	-2.29 [24]	**.031**
	Bottle fed	-23.30 [-35.83,-10.77]	-3.84 [24]	**.001**

Note: *n* for all models (*n*=27). *n* for age 9 month models (*n*=51).

After full adjustment of the models for biological sex and age at assessment, associations observed in the univariable analysis were maintained (Table 82). Across the feeding age groups, children who were exclusively bottle fed achieved CsPCC scores 18-20% lower than those achieved by children who were exclusively breast fed at the same age (Table 82). The strongest of these associations were observed among children who were exclusively bottle fed beyond age 6 months (bottle fed age 6 months: *Coef.*=-19.90 [95% CI -31.67,-8.13], t=-3.51, df=22, p=.002; age 9 months: *Coef.*=-21.38 [95% CI -34.67,-8.09], t=-3.34, df=22, p=.003).

Table 82. Unadjusted and adjusted regression models for feeding and overall CsPCC score

Exposure variable: Feeding method		Model 0: Unadjusted			Model 1a: Adjusted for biological sex		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-6.69 [-21.22,7.84]	-0.95 [24]	.352	-5.66 [-20.20,8.88]	-0.80 [23]	.429
	Bottle fed	-19.04 [-31.40,-6.68]	-3.18 [24]	**.004**	-19.97 [-32.36,-7.59]	-3.34 [23]	**.003**
Age 12 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-14.78 [-35.91,6.35]	-1.44 [24]	.162	-16.40 [-37.38,4.57]	-1.62 [23]	.119
	Bottle fed	-17.68 [-28.76,-6.61]	-3.30 [24]	**.003**	-18.80 [-29.85,-7.75]	-3.52 [23]	**.002**
Age 6 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-17.21 [-32.83,-1.59]	-2.27 [24]	**.032**	-16.75 [-32.37,-1.13]	-2.22 [23]	**.037**
	Bottle fed	-20.71 [-31.81,-9.60]	-3.85 [24]	**.001**	-21.23 [-32.36,-10.10]	-3.94 [23]	**.001**
Age 9 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-17.62 [-33.46,-1.77]	-2.29 [24]	**.031**	-17.02 [-33.51,-0.52]	-2.13 [23]	**.044**
	Bottle fed	-23.30 [-35.83,-10.77]	-3.84 [24]	**.001**	-23.05 [-35.91,-10.19]	-3.71 [23]	**.001**

Table 80. ***(Continued)***

Exposure variable: Feeding method		**Model 1b: Adjusted for age**			**Model 2: Adjusted for biological sex and age**		
		Coef. [95% CI]	***t* [df]**	***p***	**Coef. [95% CI]**	***t* [df]**	***p***
Age 4 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-6.76 [-31.96,3.61]	-0.94 [23]	.355	-5.73 [-20.60,9.13]	-0.80 [22]	.355
	Bottle fed	-17.79 [-31.96,-3.61]	-2.60 [23]	**.016**	-18.81 [-33.03,-4.59]	-2.74 [22]	**.012**
Age 12 weeks	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-12.00 [-34.78,10.78]	-1.09 [23]	.287	-13.64 [-36.24,8.97]	-1.25 [22]	.224
	Bottle fed	-16.35 [-28.17,-4.53]	-2.86 [23]	**.009**	-17.47 [-29.26,-5.68]	-3.07 [22]	**.006**
Age 6 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-15.83 [-32.11,-0.44]	-2.01 [23]	.056	-15.25 [-31.52,1.02]	-1.94 [22]	.065
	Bottle fed	-19.45 [-31.23,-7.67]	-3.42 [23]	**.002**	-19.90 [-31.67,-8.13]	-3.51 [22]	**.002**
Age 9 months	**Breast fed**	1 [-]	-	-	1 [-]	-	-
	Mixed fed	-16.46 [-32.50,-0.41]	-2.13 [23]	**.044**	-15.65 [-32.39,-1.09]	-1.94 [22]	.065
	Bottle fed	-21.77 [-34.70,-8.84]	-3.48 [23]	**.002**	-21.38 [-34.67,-8.09]	-3.34 [22]	**.003**

Note: *n* for age 4 weeks models (*n*=52). *n* for age 9 months models (*n*=51).

2.3. Summary

Table 83 summarises the results from the adjusted models for the primary analysis of interest explored in this section: feeding method (ages 4 weeks, 12 weeks, 6 months and 9 months) and PCC scores achieved between the ages of 2 and 5 years. The presence of an arrow indicates that an association (*p*<0.05) was observed; 🡅 suggests an *increased* likelihood of speech sound error, and 🡇 indicates *decreased* likelihood of speech sound error. Compared with exclusive breast feeding, exclusive bottle feeding in all age groups was indicated to be associated with lower CsPCC scores (Table 82 and Table 83).

Table 83. Summary of observed associations from the fully adjusted logistic regression models for feeding and PCC scores

Exposure variable: Feeding method		Outcome variable: PCC score	
		Single word	Connected speech
Age 4 weeks	Breast	-	-
	Mixed	-	-
	Bottle	-	🡇🡇
Age 12 weeks	Breast	-	-
	Mixed	-	-
	Bottle	-	🡇🡇
Age 6 months	Breast	-	-
	Mixed	-	-
	Bottle	-	🡇🡇
Age 9 months	Breast	-	-
	Mixed	-	-
	Bottle	-	🡇🡇🡇

Note: No. arrows indicates average percentage points (%pts) increase/decrease (one arrow <10 points, two arrows=11-20 points, three arrows=21-30 points).

3. Part B: NNS and speech sound errors between ages 2-5 years

This section examines questionnaire and clinical assessment data from NHS clinical data about NNS behaviours in early childhood to explore relationships between NNS and speech sound development between ages 2-5 years.

3.1. Sample size

Exposure variable (NNS) data were collected for each of the outcome measures (SwPCC and CsPCC scores). Figure 37 illustrates the process of derivation of participants for this study. The final sample size of 52 participants included 19 females (36.54%).

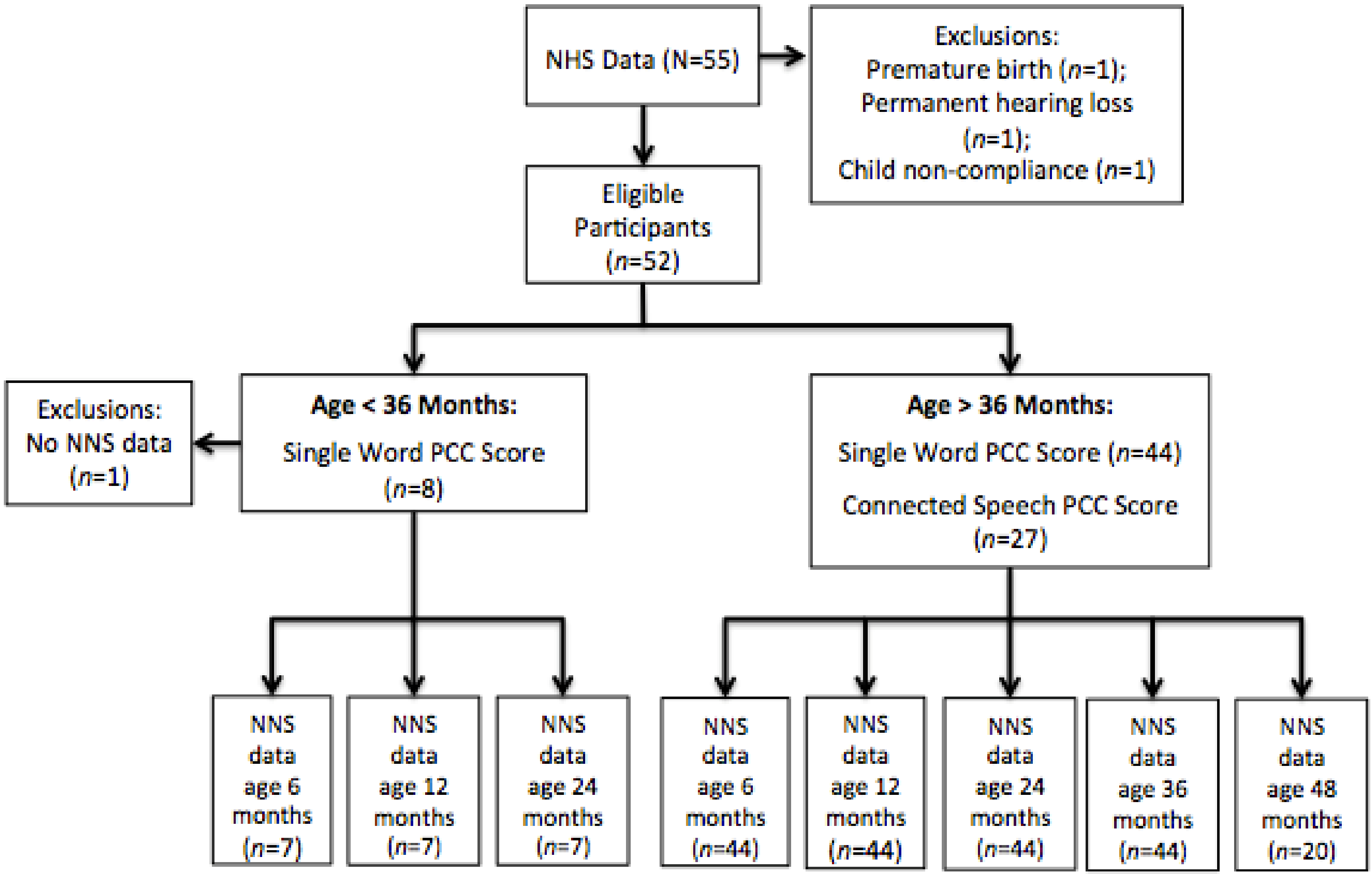

Figure 37. Derivation of participants for Strand Three Part B

3.1.1. Exposure variables: NNS groups

Due to small (some *n*=0) group sizes for ages 24, 36 and 48 months, only the exposure variables dummy sucking at ages 6 months and 12 months were used in the analysis (Table 84).

Table 84. Exposure variable: NNS groups by age

Age point	Exposure variable: Dummy sucking		
	Never	**Sometimes**	**Mostly**
6 months	*n*=25 (female n=7, 28.00%)	*n*=14 (female n=6, 42.86%)	*n*=12 (female n=6, 50%)
12 months	*n*=27 (female n=7, 25.93%)	*n*=12 (female n=5, 41.67%)	*n*=12 (female n=7, 58.33%)

Note: n values for dummy sucking groups: 6 months (*n*=51); 12 months (*n*=51).

3.1.2. Potential confounding variables

The confounding variables used in the analysis are described in section 4.1.1.2.

3.1.3. Outcome variables: PCC scores

The outcome variables used in the analysis are described in section 4.1.1.3.

3.2. Data analysis: PCC scores

The following sections present the analysis of the overall SwPCC score outcome data. Due to small sample sizes, it was not possible to analyse SwPCC scores by age group. This approach was then repeated for the CsPCC score outcome data.

3.2.1. Data analysis: SwPCC score

Formal analysis of NNS and overall SwPCC score was not possible due to small group sizes. Mean overall SwPCC scores (Table 74) did not differ significantly from mean SwPCC scores for each of the NNS groups (dummy sucking at ages 6 and 12 months) (Table 85).

Table 85. Summary statistics for SwPCC score, by dummy use at ages 6 and 12 months

Exposure variable: NNS behaviour		Outcome variable: SwPCC score		
		n **%**	**Mean s.d**	**Median IQR**
Dummy 6 months	**Never**	25 49.02	41.19 17.96	41.94 26.67,51.61
	Sometimes	14 27.45	39.22 19.40	34.17 31.48,47.17
	Mostly	12 23.53	42.17 12.43	45.46 33.33,50.58
Dummy 12 months	**Never**	27 52.94	41.57 17.31	41.94 26.67,51.61
	Sometimes	12 23.53	34.15 18.94	33.33 26.76,36.05
	Mostly	12 23.53	46.05 12.73	47.71 35.76,55.60

3.2.2. Data analysis: CsPCC score

Formal analysis of NNS and overall CsPCC score was not possible due to small group sizes. Informal analysis using the PCC score severity rating matrix (Table 69) indicated that none of the participants obtained a CsPCC score rated mild. The majority of children (*n*=23, 85.19%) obtained a CsPCC score rated severe (CsPCC score <50%). Almost half of the children (*n*=11, 47.83%) with severe CsPCC score did not suck a dummy at ages 6 or 12 months.

3.3. Summary

Detailed analysis of the association between NNS behaviour and PCC scores was severely limited by insufficient data. Mean overall SwPCC scores (Table 74) were found not to differ significantly from mean SwPCC scores for each of the NNS groups (Table 85). No significant association was found between NNS and CsPCC scores.

4. Summary of Strand Three

The results of this strand of the study indicate tentative associations between early feeding regime, NNS and speech sound development in early childhood (**Error! Reference source not found.**). Data analysis was restricted by small sample sizes.

4.1. Infant feeding and PCC scores between ages 2-5 years

After full adjustment of the regression models in Part A of this strand, no associations were identified between early feeding regimes and SwPCC scores achieved between ages 2 and 5 years. Compared with exclusive breast feeding, exclusive bottle feeding in all exposure age groups was indicated to be associated with lower CsPCC scores between ages 2 and 5 years (Table 79). No associations were indicated when mixed feeding was compared to exclusive bottle feeding.

4.2. NNS and PCC scores between ages 2-5 years

Regression analysis of the association between NNS and PCC scores between ages 2-5 years was not possible do to insufficient sample sizes. Informal analysis of the data did not indicate significant associations between the exposure and outcome variables of interest.

Chapter Seven: Discussion

1. Overview of chapter

This chapter presents a summary of the findings for each of the three strands of this study with regard to how they address the objectives. A discussion of these findings in the context of relevant theoretical mechanisms and existing evidence is presented. The strengths and limitations of this study are described, and clinical implications and directions for future research are outlined. Finally, the contribution to knowledge is described.

2. Summary of results

This study has found that, within normative and clinical samples, different patterns of feeding and NNS are associated with varying speech outcomes in early childhood. Key findings are summarised in the following sections.

2.1. Feeding and speech sound development

The primary research question of this study asked whether there is a relationship between infant feeding regimes and speech sound development in the first five years of life. The results varied across the samples and the different speech outcome measures used.

Strand One found that mixed or bottle feeding were strongly associated with increased parental concern about speech development at age 18 months. Distinct feeding patterns were also observed to be associated with different consonant sound error frequencies. Exclusive breast feeding (at any age) was associated with higher frequency of sound errors at age 25 months, but lower frequency of particular sound errors at age 61 months, specifically alveolar sounds. Children who were not exclusively breast fed at age 15 months were almost three times more likely to make alveolar speech sound errors at age 61 months, compared with children who were exclusively breast fed. This is curious, because of the time difference between the feeding age point and speech assessment. Although children who were mixed or bottle fed at age 15 months may have continued to use a bottle to some extent beyond age 15 months, the likelihood is this would have ceased around the age of three years, and certainly by age four years, as solid food becomes the primary method of nutritional intake. It is notable that early feeding method is indicated to be so strongly associated with a high likelihood of increased speech errors at age five years. Data for alveolar errors were not available within the ALSPAC dataset for the age 25 month analysis, which may otherwise have indicated a similar association with feeding and alveolar errors earlier in speech sound development.

Findings from Strand Two indicated that there is a difference in the pattern of speech sound acquisition for children depending on their infant feeding regime. It is not that one is better or worse than the other. Rather, the patterns change when sounds emerge and reach maturity. Contrasting findings, with regard to age, were observed. SwPCC scores differed over time, with younger children showing a degree of protection from exclusive breast feeding and older children showing similar protection from bottle feeding. Confidence intervals for these data are wide and so the reliability of these results may be questionable. Possible influences on these outcomes may be the age and stage of child development within the sample, with increasing stability of speech sound development within the age 48 month group. These findings are different to those observed for the connected speech percentage consonants correct (CsPCC) scores, which instead found that only mixed feeding at age four weeks was indicated to be associated with overall CsPCC scores. It is important to note that the reliability of these findings are limited by a small sample size and so no firm conclusions can be drawn.

Strand Three offered more consistent findings within the clinical sample. Among children known to have SSD, exclusive bottle feeding was indicated to be strongly associated with poorer overall CsPCC scores. This association was strengthened with increased duration of exclusive bottle feeding. Although a small sample size meant that examination of this association by age group would have yielded unreliable results, age was included as a covariate in the analysis and so the influence of age-related development was accounted for as far as possible.

The findings for a relationship between feeding and speech sound development were mixed. The strongest associations suggest that longer duration of breastfeeding is associated with reduced parental concern about speech development at age 18 months and markedly reduced alveolar errors at age five years.

2.2. NNS and speech sound development

A secondary research question asked whether there was a relationship between NNS and speech sound development in the first five years of life. Strand One found an association between NNS patterns in early childhood and speech sound development at age two years. Both dummy and digit sucking were strongly associated with reduced velar sound errors at age two years. No strong associations were observed between NNS and speech sound development at age five years. Due to small sample sizes for Strands Two and Three, it was not possible to explore the association between NNS and PCC scores.

The findings for a relationship between NNS and speech sound development indicate that, although NNS may be an influential factor in speech sound development at age 25 months, this influence may not be observed at age five years.

2.3. Feeding, NNS and SSD

This analysis asked whether, within a population of children diagnosed with SSD, different patterns of speech disorder are observed in children with different histories of infant feeding regime and NNS. This question differs from those examined in sections 2.1 and 2.2. in that the focus is on a sample of children known to have SSD (clinical sample) rather than a normative sample (ALSPAC and ALSPAC-G2). In addition, rather than looking for a relationship between sucking and any speech sound outcome, this question sought to specifically examine different patterns of SSD associated with different sucking histories. Due to the impact of the Covid19 pandemic on recruitment for the NHS strand of this study, it was not possible to answer this question due to the lack of data to power the statistical analysis of feeding and speech sound error patterns (see section 7.1).

3. Associations between feeding, NNS and early speech sound development in the context of existing literature

In this section the findings are considered in the context of existing theoretical mechanisms and the current evidence base for the association between feeding, NNS and speech sound development in early childhood. The influence of other known risk factors for SSD with regard to the findings of this study on the association between feeding, NNS and speech sound development are examined.

3.1. Associations between feeding, NNS and early speech sound development in the context of theoretical mechanisms

The hypothesis of this study was that different patterns of feeding and NNS in infancy and early childhood influence the prelinguistic stage of speech development, such that different patterns of speech development may be observed between ages two-five years. In the following sections, the findings reported in this thesis will be considered in relation to the theories regarding sucking mechanisms, early somatosensory and motor development, and early speech sound development in childhood.

3.1.1. Sucking mechanisms for breast, bottle feeding and NNS

In view of the wealth of evidence that advocates for the numerous benefits of breastfeeding to support optimal, healthy child development, it may reasonably have been assumed that the findings of this study would likewise indicate better speech sound outcomes for exclusively breastfed children. In contrast, data from two-year-olds presented in this study demonstrated the opposite. This may be because much of the evidence that advocates for the benefits of breast feeding focusses on breast milk as the important factor, rather than the feeding mechanism itself. The findings of this thesis suggest that, while we know that breast milk is important for healthy development, the mechanism of breast feeding may have a different effect on early speech sound development, with greater sound errors observed at age two.

We know that, in contrast to the largely stable and consistent materials required for bottle feeding, breast feeding involves a greater number of changeable variables and organic challenges, which can cause the feeding process to vary day-to-day and feed-to-feed (Elad *et al*, 2014; Alex, Bhandary and McGuire, 2020). These changes could be considered to afford breast fed babies a more dynamic and varied feeding experience, compared to bottle fed babies, which could account for the differences in speech sound error rates observed at age two years in this study.

This theoretical basis may also explain why feeding methods (mixed and bottle feeding) and NNS, which involve less variability in sucking mechanism (Eishima, 1991; Mizuno and Ueda, 2006; Elad *et al*, 2014; Harding, 2014) were observed in the analysis of this thesis to be associated with reduced speech sound errors in early development.

3.1.2. Early somatosensory and motor experience

Extending what we know about the evidence for differences in the sucking mechanisms for breast and bottle feeding (Eishima, 1991; Mizuno and Ueda, 2006; Elad *et al*, 2014; Harding, 2014), it is reasonable to consider that these different sucking processes involve diverse somatosensory and motor experiences. These different experiences could be conceived to lay down different foundations of learning at the level of representation, which would underpin subsequent speech sound development (Stackhouse and Wells, 1997; Dodd and McIntosh, 2010; Haggard and de Boer, 2014; The Phonology Project, 2022). This would likely lead to bottle and breast fed children presenting with different patterns of speech sound development, in line with the findings of this thesis. For example, more stable sucking mechanisms associated with NNS and bottle feeding may contribute to a less varied foundation of oro-motor experience from which the child develops their early speech motor programmes.

The results from the analysis in this study suggest that bottle feeding may have some protective effect against specific consonant sound errors at age 25 months (i.e., velar, liquid and PVC). In the case of velar errors, this association may be linked to the suppression of the tongue tip/blade during bottle feeding sucking, and therefore greater oro-motor and somatosensory awareness development for movement involving the back of the tongue, which is required for velar sound production (Shotts, McDaniel and Neeley, 2008; Burr *et al*, 2020; Haggard and de Boer, 2014). This rationale may go some way to explaining the finding that children who were exclusively bottle fed or mixed fed at age 15 months were more than three times more likely to make alveolar errors at age 61 months. It may be the case that persistent and prolonged suppression of the tongue tip/blade during bottle feeding was detrimental to typical alveolar sound development (Dodd *et al*, 2004; Shotts, McDaniel and Neeley, 2008; Burr *et al* 2020; Strutt, Khattab and Willoughby, 2021).

This theory can also be applied to NNS and for children who may periodically use a bottle like a dummy (Fox, Dodd and Howard, 2002). The more time children spend with a dummy or digit in their mouth, the more time the anterior part of the tongue spends being suppressed and largely immobile. Children at age 25 months typically talk and use sounds much of their waking time, and, within this NNS group, are likely to be doing so while the anterior portion of the tongue is supressed by a dummy/digit (Strutt, Khattab and Willoughby, 2021). This leads to a reduction in opportunities for sound production practice with the anterior part of the tongue (Shotts, McDaniel and Neeley, 2008; Burr *et al* 2020; Strutt, Khattab and Willoughby, 2021) and the obstructive presence of the dummy in the mouth could mean the resulting articulation difficulty may become an ingrained pattern in the child's phonology (Steeve *et al*, 2008; *Strutt*, Khattab and Willoughby, 2021).

3.1.3. Variability in early child speech sound development

Findings reported in this thesis are consistent with what we know about early child speech sound development. Greater variability of speech sound production is observed at age two years compared with later development at age five years, when the system has begun to stabilise (Stoel-Gammon and Dunn, 1985; Grunwell, 1987; Vihman, 1996; Dodd *et al*, 2003, Broomfield and Dodd, 2004; Roulstone *et al*, 2009). It is unfortunate that alveolar sound error data were not available for age 25 month analysis of the ALSPAC data, as this may have offered an opportunity to examine this theory more precisely within the present study. In particular, investigation of the assertion by Smith and Gerber (1993) that, if feeding were influential in speech sound development at age five years, this influence would also be observed at age two years.

The findings from Strands One and Two indicate that different types of consonant sounds may be affected in different ways by alternative patterns of feeding. This notion also relates to age, because the typical ages when different sounds are mastered vary by consonant type (e.g., Grunwell, 1981; Stoel-Gammon and Dunn, 1985; Grunwell, 1987; Smit *et* al 1990; Vihman, 1996; Dodd *et al* 2003; Broomfield and Dodd, 2004; McLeod and Crowe, 2018). Early developmental variation and 'noise' at age 25 months may explain differences in sound error types between the different groups (Vihman, 1996; Roulstone *et al,* 2009). Speech sound development norms presented by McIntosh and Dodd (2011, p.60) suggest that at about age 25 months 90% of children will have alveolar, velar and liquid consonant sounds, and some fricatives (/s/, /z/, /h/ and perhaps /ʃ/, /f/). Dodd *et al* (2002, p.65) state that 90% of children aged 61 months would be expected to have all sounds that were assessed in this study, except fricative 'th' (voiced /ð/ and voiceless /θ/ variants) and liquid sound 'r' /ɹ/. This means that, while greater variation is observed in the age 25 month data compared to the age 61 month data, the consistent pattern is for higher error scores (at age 25 months) among exclusively breast fed children, compared to those who were mixed or bottle fed. Therefore, it is less likely that the patterns observed in the associations between feeding method and speech sound development in this study can be explained by variation in speech development at age 25 months and increased sound system stabilisation by age five years.

3.2. Consideration of findings in relation to existing evidence

Direct comparison of the findings of this study with others in this area of research is challenged by the limited number of studies in this field and methodological variability (Burr *et al*, 2020). Crucially, this research differs from previous studies identified in the systematic review, because none included clinical assessment of children at age two years (Burr *et al*, 2020).

3.2.1. Parent concern about speech development at age 18 months

The present study found an association between parent concern about child speech development at age 18 months to be associated with mixed or bottle feeding at age 15 months. These findings align with those of Dee *et al* (2007), who found that parents of children who were breast fed for at least three months were less likely to be concerned about their child's speech development (Dee *et al*, 2007). The authors also found that the degree of parental speech concern decreased for children who were breast fed for at least nine months. Conversely, some evidence suggests that parents who do not exclusively breast feed their children may be more likely to experience guilt linked to their feeding choice and be more likely to be anxious about their child's speech development (Knaak, 2010; Ludlow *et al*, 2012; Radzyminski and Callister, 2016). Radzyminski and Callister (2016, p.19) suggested that, "*because breast feeding is considered the superior source of feeding and nutrition,* [...] *mothers who choose* [bottle feeding] *may have increased guilt or stress associated with that decision.*" It follows that these mothers may be more likely to be concerned about their child's speech development, compared with mothers who breast fed, as indicated by the findings of this study.

Within normative samples, the findings of this study suggest some potential indicators of SSD with regard to feeding and NNS. Longer durations of mixed feeding and exclusive bottle feeding were associated with increased parental concern about speech development at age 18 months. Clinically, parental concern is acknowledged as a key factor in identification of childhood SSD (Roulstone, 1995; Roulstone, 1997; Zhang and Tomblin, 2000; Bishop and Hayiou-Thomas, 2008). Previous research supports these findings and suggests that, in the context of other risk factors, feeding method may be a potential indicator of possible SSD risk in association with reported parental concern about speech development.

3.2.2. Early identification of SSD

Although Pereira *et al* (2017) included parents of children aged one to three years in their study, the authors chose not to ask these parents about their child's speech development. A growing evidence base advocates for the potential for early identification of SSD in children as young as age two years (Roulstone *et al*, 2002; McIntosh and Dodd, 2008; McIntosh and Dodd, 2011; Dodd, 2014a; 2014b; Claessen *et al*, 2017). Early intervention for children with SSD at age five years is crucial to reduce the impact on outcomes in childhood and later life (Hesketh, 2004; Nathan *et al*, 2004; Bryan, Freer and Furlong, 2007; Elliott, 2011; Roulstone *et al*, 2011; McAllister, Collier and Shepstone, 2013; Wren, 2021). The complex mix of factors including high developmental variability and pressures on clinical services present challenges for early assessment and intervention.

3.2.3. PCC scores

The findings of this study, with regard to PCC scores, find mixed support in the published literature. This study found that, in a normative sample, exclusive bottle feeding was associated with lower PCC scores at age three years, but higher PCC scores at age four years. These findings are in contrast to those of Smith and Gerber (1993), who found no association between feeding and PCC scores in a broadly similar population sample of children aged three-four years who had never been referred to SLT.

Within a sample of children known to have SSD, Baker *et al* (2018) found that longer duration of breastfeeding was associated with higher SwPCC scores among children aged four-five years. Their findings are parallel to those from this study, which showed that, in a clinical sample of children aged two-five years, higher CsPCC scores were associated with exclusive breastfeeding, and the strength of the association increased with feeding duration. No association was indicated with SwPCC scores for this group.

Expectations for typical development would anticipate increased PCC scores with age and exposure to early education settings (Roulstone, 1995; Roulstone, 1997; Roulstone *et al*, 2011). This does not necessarily explain the specific association with feeding (i.e., exclusive bottle feeding). This finding is not supported by other studies, which found either a detrimental effect of bottle feeding on speech development, or no effect (Burr *et al*, 2020). It may be that public health messaging about feeding may have led parents of exclusively bottle fed children to be more concerned about their child's development, and therefore to support proactively speech and language development (e.g., through increased modelling or seeking professional support) (Knaak, 2010; Ludlow *et al*, 2012; Radzyminski and Callister, 2016).

3.2.4. NNS and SSD

An association between NNS duration and reduced velar sound errors at age 25 months was indicated in the findings of this study. Clinical SLTs might anticipate that children who persistently suck a dummy or their thumb would be more likely to make velar sounds in their speech, than alveolar sounds, and may also be more likely to present with an atypical 'backing' pattern of speech (Broomfield and Dodd, 2004; Dodd *et al* 2017; Strutt, Khattab and Willoughby, 2021). A child who presents with 'backing' changes sounds made at the front of the mouth (e.g., alveolar consonants 't' and 'd') to sounds made further back in the mouth (e.g., velar consonants 'k' and 'g'), so that, for example, *dog* becomes *gog* (McLeod and Baker, 2017). Persistent dummy use is considered to result in anterior tongue blade suppression and subsequent increase of compensatory strategies to use velar sounds in place of the suppressed alveolar sounds (Shotts, McDaniel and Neeley, 2008; Burr *et al* 2020; Strutt, Khattab and Willoughby, 2021). If this is the case, a child would be expected to have greater opportunity to practice and produce velar sounds, and likely use them more accurately, as observed in this study, and in place of the suppressed alveolar sounds (i.e. backing). As data on alveolar sound errors were not available at age two for analysis, it was not possible to further examine the latter part of this theory.

Fox, Dodd and Howard (2002) found dummy use to be a risk factor for SSD only when it was included with bottle feeding and thumb sucking. Given the current evidence, a potential cumulative impact of persistent sucking behaviours which involve reduced movement of the anterior portion of the tongue (Eishima, 1991; Shotts, McDaniel and Neeley, 2008; Burr *et al* 2020; Strutt, Khattab and Willoughby, 2021) exerting a negative influence on speech sound development is certainly plausible. Unfortunately, combined analysis of feeding and NNS was not possible in this study due to time limitations.

Insufficient sample sizes meant that results from the examination of the association between NNS and PCC scores within the present study were unreliable. Published evidence on the association between dummy use and PCC scores is limited. Strutt, Khattab and Willoughby (2021) found no significant association when examining these variables (SwPCC) using the same speech assessment administered in this study (DEAP). The authors found that errors were lower among older children, as expected developmentally (Strutt, Khattab and Willoughby, 2021)

4. Strengths of this study

The present study is one of very few studies within this field of research to explore the association between infant feeding, NNS and specific consonant sound errors at ages two to five years. This study is also novel in considering this association from a specific motoric perspective of sucking on speech development, rather than from a nutritional or more generalised perspective of feeding. As such, this study goes some way to addressing gaps in the available evidence, as cited by other studies (e.g., Barbosa *et al*, 2009; Pereira *et al*, 2017; Baker *et al*, 2018; Strutt, Khattab and Willoughby, 2021). The following section outlines further strengths of this study with regard to methodology.

4.1. Patient and public involvement and engagement (PPIE)

PPIE activities undertaken in preparation for this study were successful in creating an online community of parents of young children willing to engage with the study for its duration (e.g. via online polls or web chats) in order to inform different phases of the study, such as dissemination. One of the challenges during this process has been to maintain contact and momentum of interest with, and from, that online community. The approach from the outset was to try to create a two-way information exchange, such that members of the group would feel they were receiving something in return for their interest in and engagement with the study. Links were shared to interesting articles and evidence relating to child development were shared via the online platform, which often received 'likes' and positive comments from members of the group.

4.2. Methodology

This study has examined data from two large birth cohort studies (ALSPAC and ALSPAC-G2), as well as exploring data from a clinical sample of children aged two-five years with a diagnosis of SSD. This has supported comparison of findings between the different sample groups within the study. The breadth and depth of the ALSPAC dataset used in this study enabled the inclusion of key measures for confounding factors in the children's early life experiences, as well as the primary measures of interest.

4.3. Inclusion and exclusion criteria

While the study applied inclusion and exclusion criteria to the ALSPAC dataset, it was not possible to exclude children with genetic syndromes, which may otherwise have impacted their speech sound development. This is because measures for these data were not available within the dataset. As this is a population study, the proportion of the sample with genetic syndromes would be small and unlikely to alter the results. Nevertheless, it is important that all children are included in studies of this nature to ensure the research is inclusive and does not omit specific groups. The samples used for this study therefore could be considered more representative of the population of interest that others where exclusion criteria prevent children participating.

4.4. Assessment and outcome measures

The broad range of assessment applied in this study has enabled the collection of different types of speech outcome data. These have included parent reported outcomes, PCC scores, single word and single sound measures. Connected speech samples, as well as single word samples were gathered, which is something highlighted by other studies as important to understanding the nature of the relationship between NNS and speech development (Garber and Reynolds, 1994; Strutt, Khattab and Willoughby, 2021) and child speech development more widely (Howard, Wells and Local, 2008; Wren *et al*, 2012; McLeod, Harrison and McCormack, 2012). The breadth of speech sound measures collected in this study have enabled diverse examination of the relationship between feeding, NNS and speech sound development, which is unique in this field of research.

This study included speech assessment data from children as young as age two years, which is an age group not included in the studies described in the systematic review. There is growing evidence that key development measures in early childhood are instrumental in the early identification of SSD, and subsequent reduction of its impact for the child’s social, developmental and educational outcomes (Johnson, Beitchman and Brownlie, 2010; Dodd, 2014a; 2014b; Eadie *et al*, 2014; *Wren et al*, 2016). Therefore, the inclusion of younger children in this study is important and beneficial.

A further strength of the measurement approach of this study is the chosen assessment. This study used a standardised speech assessment (DEAP) that is widely accessible to clinical SLTs and researchers. This means that that this work can be easily replicated, within either a research or clinical context. This is important because it ensures the research remains clinically grounded and linked to the reality of clinical practice. By using the Articulation and Oro-motor Assessment subtest of the DEAP, the study was able to use a recognised clinical assessment procedure based on motor speech principles that aligns with the theoretical underpinning of this work to examine children's speech and gather data for the study.

4.5. Recruitment training for fieldworkers and clinicians

For Strand Two of this study a high level of training was provided to the ALSPAC-G2 fieldworker team to ensure accurate administration of the DEAP and TPT assessments for data collection. This included face-to-face training on cueing young children in to picture naming tasks, levels of response prompting (e.g. initial sound, initial syllable, whole word modelling for imitation) (Dodd, 2002). Additional written and video training materials were provided to the team to support on-demand follow-up training for syllable and single sound modelling for the relevant subsections of the Articulation and Oro-motor Assessment subtest. Open channels of communication were maintained with the fieldworker team throughout the study. This ensured that any issues could be resolved quickly to maintain the flow of high quality data collection. It also meant that the team could be confident that continued support was easily accessible and available to them at all times.

A similar proactive approach to supporting recruitment was adopted with the clinical SLT team. A range of measures were employed to maximise and simplify participant identification and recruitment by the clinical team for Strand Three of this study. A dynamic support package was implemented to enable the clinical team to embed the process of identifying and approaching potential research participants in their daily clinical practice (chapter three, section 5.2.3.). This included a workshop event at the start of the study to present the proposed protocol for participant identification and recruitment, and to invite comments and feedback from the team of 70 SLTs with the aim of optimising the recruitment approach. From this event changes and improvements to the protocol were made, which would not have been possible without the local and logistical knowledge and experience of the SLTs at each of the clinics across the trust. Further face-to-face presentations at whole-team and locality team meetings throughout the study provided updates and top-up training to the clinical team. This ensured that a two-way channel of communication was open with the clinical team throughout the study. The added benefit of this was to enhance the profile of clinically-based research within the SLT team and this has inspired interest among clinical colleagues to seek further research training and development opportunities within their clinical roles. The process and learning from this approach to enhanced engagement of the clinical team in the planning, design and implementation of this PhD study was published as an invited article in the Royal College of Speech and Language Therapists professional magazine (Burr, 2019).

5. Limitations of this study

The key limitations within this study are summarised as common themes across the three study strands in the following sections.

5.1. Patient and public involvement and engagement (PPIE)

Maintaining regular contact with the online parent group was challenging because of the competing pressures and activities during the PhD, and the impact of the pandemic. Although there was initial interest and interactions with posts on the online group, the number of responses from parents to posts diminished quite quickly after the set-up of the online group. One of the key issues with the PPIE approach in this study was that the PPIE activity was not sufficiently embedded within the methodology for the study. On reflection, more meaningful and proactive ways for parents and members of the public to be involved with the study could have been identified. For example, inviting parents and children to share their experiences of clinical assessment to inform the approach. With regard to dissemination, next steps will include reaching out to the online parent group, and other parents, members of the public and health, social care and education professionals to inform the strategy for publicising the findings of this study. This will ensure that they have maximum impact for children and families.

5.2. Inclusion and exclusion criteria

Limited data were available for Strands One and Two for the required exclusion criteria (e.g. developmental verbal dyspraxia, learning disability, genetic conditions) and so it is not known whether children with these additional significant confounding factors were included in the sample.

5.3. Participant identification and recruitment

A number of procedural issues were identified with the ALSPAC-G2 data collection in Strand Two of this study. Following consultation with PhD supervisors, it was determined that data on isolated and sequenced movements from the DEAP assessment could not be used for analysis. The reliability of the data was in question because video recordings of the assessments had not been made, which could have otherwise supported secondary data checking by the researcher, and the fieldworkers were not qualified SLTs.

To obtain a stand-alone PCC score for connected speech within a phonemically balanced speech sample, the data from the connected speech section of the DEAP assessment was scored as per the assessment manual. The Phonology Assessment subtest of the DEAP, from which comparative PCC scores for single word targets would have been generated, was not completed. The Articulation and Oro-motor Assessment subtest was selected as a more appropriate stimulus to obtain speech sound measures with an articulatory, rather than phonological focus.

5.4. Assessment procedures

The age 25 month speech data in the ALSPAC sample used in Strand One were collected by testers who were not trained in phonetic transcription and audio/video recording was not available for these assessments. This limits the reliability of the data accuracy because detail may have been missed or inaccurately recorded.

During analysis of the Strand Two ALSPAC-G2 data, a number of persistent modelling issues were identified. These rendered some of the data unusable because of the potential influence incorrect modelling may have had on the child's response. Common modelling errors included /w/ modelled with bilabial fricative [ɸ], and single consonants (C) modelled incorrectly as consonant-vowel (CV) syllables with an additional 'schwa' sound (e.g. /k/ modelled as [kə] or 'kuh').

Administrative errors led to some data not being used for the study. There was some loss of data due to speech assessments being carried out on children of the wrong age within the ALSPAC-G2 study. In addition, the variable 'weak sucking at age four weeks' was omitted from the parent questionnaire for the ALSPAC-G2 data collection. To ensure high-quality assessment administration and to minimise data loss, the learning from this study highlights the need for experienced, trained individuals for speech sound data collections. Although qualified and experienced staff in this case would be the gold standard, this can be impractical to achieve because of the increased research costs and shortage of available staff. Researchers need to carefully consider the financial and ethical implications of collecting potentially unreliable data when planning a study.

For Strand Three, the research protocol specified that the assessment had to be administered in clinical conditions to optimise the consistency of assessment audio recordings for transcription. Participant accessibility to the study was maximised where possible by offering families appointments at local clinics to minimise both burden of travel and time for participants. A small number of potential participants were not able to take part in the study because of difficulties accessing their local clinic. This is a common challenge for routine clinical practice and is not unique to research recruitment. Greater uptake of recruitment may have been achieved by offering potential participants assessments in their own homes.

5.5. Sample Size

CsPCC score data samples were small, which limited the ability to carry out regression analysis. Standardised scores and percentile ranks used for SwPCC score data, taken from the DEAP manual (Dodd *et al*, 2006), were not appropriate to apply to CsPCC scores because they were not standardised for this outcome measure. To provide a guideline for describing the CsPCC data, a published rating matrix was applied (Shriberg and Kwiatkowski, 1982). This matrix was originally intended for use with a minimum of five-10 minute conversational speech samples containing at least 200 utterances with children aged four years and one month to age eight years and six months (Shriberg and Kwiatkowski, 1982). In the absence of more appropriate frameworks, the matrix was applied as a guideline only.

5.6. Missing data

Missing data presented a challenge in this study, which affected the different strands of the study in different ways. Throughout the study advice was sought from a statistician on missing data within each of the three datasets. Within the STATA programme, missing data values are marked as a (.), and so are easy to identify and account for within the analysis. No undertaking was made in the analysis to explore the missing data to look for possible systematic bias, which could have affected the analysis. Missing data due to human error, as described in section 5.4. of this chapter, did have a significant impact on the resulting sample sizes for the study.

5.7. Plan for analysis

Within the ALSPAC study data used in Strand One, the outcome variable parental concern about speech development at age 18 months was a generic term used within the parent questionnaire. The term did not specify concern about speech sounds, and therefore it can be assumed that parents who indicated 'yes' for this question, may have been concerned about a wide range of speech and language needs. This means that the sample may have included children with other types of speech problem, such as language delay or stammering, which could have impacted on their speech sound development.

Across all three strands of this study, the data collected were insufficient to support in-depth analysis of the impact of NNS intensity and duration on speech sound development: measures lacking in the current available evidence (Strutt, Khattab and Willoughby, 2021).

Data on hearing loss before the age of 18 months were not available for Strand One Part A because newborn hearing screens were not in practice at the time of the ALSPAC study in the 1990s. Due to the complexity of the consenting process, comprehensive data on potential confounding variables were not collected in the NHS clinical sample. Only data on biological sex could be easily obtained from clinical records. Collection of additional data, such as social economic status, maternal history and child language development would have risked significantly greater burden and impact on the parent and child, with regard to time and potential anxiety and assessment fatigue (e.g., Field and Behrman, 2004). This is reflective of the challenges of undertaking research in clinical practice.

Within Strands Two and Three of this study, data on diadochokinetic (DDK) rates were collected during the DEAP assessment, and information on the child's production was captured by audio recording for subsequent scoring by a qualified SLT. Analysis of the clinical speech assessments identified typical and atypical sound errors but, due to time constraints, these data have not been analysed.

The risk of bias when collecting parent reported measures is well documented. Within this study, effects of bias may have been present with regard to parent guilt and social desirability bias around feeding choices and dummy use (Whitmarsh, 2008; Ludlow *et al*, 2012; Strutt, Khattab and Willoughby, 2021). Recall bias may have been a factor due to the requirement for parents to report feeding methods and NNS behaviours that had taken place up to five years ago (Smith and Gerber 1993).

6. Impact of Covid-19

Towards the end of the recruitment period for Strand Three the Covid-19 pandemic resulted in recruitment being temporarily paused while all non-essential face-to-face patient contact was ceased in line with local and national NHS and government guidance. As virtual consultations became more established, an application for substantial amendment was submitted and approved by the HRA for recruitment to be conducted using virtual platforms (Appendix AH). Despite the amendment, no further recruitment was achieved. This may have been due to an increased focus on clinical needs and priorities by clinicians and families. The evidence for the negative impact of the pandemic on non-essential patient contacts and health research activities is well documented (Yanow and Good, 2020; Bratan *et al*, 2021; Sohrabi *et al*, 2021).

In hindsight, offering families the option to participate in the study virtually would have significantly increased accessibility and flexibility of appointments, which may have resulted in substantially greater recruitment. When this study began in 2017, virtual appointments were much less common and the technological support within the NHS for remote contacts within healthcare was under-developed. In the wake of the pandemic, substantial technological advances, rapid culture change and published evidence now underpin virtual healthcare approaches, which can also support research participation (Mold *et al* 2021; RCPCH, 2021). In the case of this study, careful consideration would still need to have been given to the potential technological limitations on sound and audio quality, which may have impacted high-quality data collection for research (Car *et al*, 2020). The limitations that virtual contacts may impose on research accessibility for some participants is a key consideration of these innovative approaches (Volkmer and Broomfield, 2022).

Chapter Eight: Conclusion

1. Overview of chapter

This chapter outlines the contribution to knowledge made by this study. Clinical implications of the findings are presented, as well as implications for wider healthcare and public health. Further areas for research in this field are described and final remarks on this study are provided.

2. Contribution to knowledge

The main contribution of this work is the lack of evidence of any major impact of bottle feeding and NNS on child speech sound development. However, different patterns of sucking behaviours early in life have been indicated to be associated with different patterns of speech sound development at ages 2 and 5 years.

This study has found some evidence that any effect of early feeding method on speech sound development may be more enduring than that of early NNS behaviours. It has examined, and provided evidence for, how different sucking patterns in infancy may influence the development of different consonant sounds in children as young as age two years, although these influences do not appear to persist later in childhood. Evidence of an association between mixed or bottle feeding and a reduction in some consonant sound errors at age two years has been indicated. The evidence from this study suggests an association between longer duration of exclusive breastfeeding and significantly lower frequency of alveolar consonant errors at age five years, compared to mixed and bottle feeding. Despite having some impact at age two years, NNS behaviours, regardless of duration, have been shown not to impact speech sound development at age five years.

3. Clinical implications

The findings of this study support the inclusion of feeding and NNS questions within the clinical case history, together with other relevant risk factors (Wren *et al*, 2016) to support the clinician to develop a broad picture of the child's SSD risk profile. Clinicians need to consider the mounting evidence for the influence that early somatosensory and motor experiences may have on a child's early speech sound development and be familiar with the theoretical frameworks for these with regard to potential SSD (Stackhouse and Wells, 1997; Shriberg *et al*, 2010).

The findings of this study, together with those from other studies support the message that, while there is suggestion of an association between different feeding methods or NNS behaviours on child speech sound development, further interpretation cannot be made with regard to causality based on the findings and methodology of this study. The findings do indicate that persistent use of bottle feeding and dummy sucking over a longer period of time may have a detrimental impact on speech sound development. For many parents, these findings will constitute reassuring messages, and provide important information that will enable them to make informed choices about their child's care. For some children the findings of this study may mean that feeding and NNS might form part of a wider profile of risk for SSD persisting in to later childhood and requiring specialist SLT intervention (Wren *et al*, 2019). This is why gathering detailed information about early feeding regimes and NNS behaviours as part of a comprehensive case history is necessary to inform SLT clinical assessment, diagnosis and intervention planning. These are key messages that can be disseminated to a broad range of professionals in health, social care and education to ensure that parents have the information they need to make an informed choice about NNS behaviours and how they feed their baby.

4. Implications for wider healthcare

The findings of this study constitute new evidence within this field of research, which could add support to local and national public health strategies and campaigns to promote breastfeeding. The findings of this study have potential implications for public health messaging around infant feeding and dummy use. Based on the results of this study, the key message for parents is that the way babies are fed and whether they suck their thumb or a dummy does not have a major impact on how they develop their sounds for speech in the first five years of life. There are some indications from this study that longer duration of exclusive bottle feeding may be linked to atypical patterns of speech sound development (alveolar sound errors). These findings require further examination before they can reliably inform public health messaging and clinical practice (see section 5).

The wider message from this research is that the picture is not clear, and while there are indications of associations between feeding, NNS and early speech sound development, no major impact has been identified. Crucially, this research can reinforce universal and targeted care packages delivered by health visitors and midwives by increasing awareness of early feeding methods as part of a wider profile of early risk factors for SSD. This will provide families with information about the impacts of feeding and NNS to empower them to make informed decisions about how they care for their children. For clinical SLTs, the findings from this study, together with the available evidence, reinforce the importance of gathering detailed information on early feeding and NNS as part of a child's case history to inform assessment, diagnosis and intervention. Identifying and isolating the influential factors in the association between feeding, NNS and speech sound development is highly challenging, because of the complexity of the unique, wider developmental process that each child experiences. For this reason, it is important for researchers and clinicians to consider the wider picture of speech sound development for any given child. Professionals can use evidence from a profile of potential risk factors, such as early feeding and NNS, and the child's own intrinsic dynamics, to inform their understanding of the comprehensive developmental experience for that child.

5. Implications for research and future directions

The present study has built on the limited, but developing, body of evidence about the association between early feeding and NNS behaviours and speech sound development in children. The findings of this study have indicated that different patterns of feeding and NNS may be associated with different patterns of speech sound development between ages two-five years. Exploring the patterns of speech development for different feeding regimes and NNS groups in terms of typical/atypical errors is important to determine clinical significance of associations indicated by the findings of this research, and related studies (e.g., Baker *et al*, 2019; Strutt, Khattab and Willoughby, 2021). Future research should also consider:

- Whether there a combined effect of feeding regime and NNS behaviour on speech sound development
- How the results of this study compare with those that involve larger samples

of children from typical populations and clinical samples of children known to have SSD to explore the association between feeding, NNS and speech sound development

- Whether clinical assessment of a wider range of speech sounds at age two years could help to identify early predictors of persistent SSD later in childhood
- Whether, within a clinical population, different patterns of feeding and NNS are associated with different types of SSD. If so, whether different SLT assessments and interventions are warranted for children with different types of SSD, based on their feeding and/or NNS history

Exploration of the latter question could include a longitudinal study design of a clinical cohort of children identified as presenting with a profile of higher SSD risk at age two years, based on known risk factors within the published literature (e.g. Wren *et al*, 2019). These children would undergo comprehensive speech sound assessment at age two years, which would be repeated at age five years. Any loss to follow-up as a result of discharge from the SLT service due to resolved SSD would be documented. A third follow-up at age eight years for children who continue to require SLT services would provide information on the association between early feeding, NNS and persistent SSD at age eight years (Wren *et al*, 2019). This knowledge is currently missing from the current published literature and would be very valuable in helping to understand developmental speech patterns as a function of feeding and NNS. If indications for more targeted assessment and intervention were found, this could have positive benefits for health economics within NHS SLT services and the wider social economy.

More work is needed in this area to explore these questions for further research with larger samples, including clinical samples of children diagnosed with SSD. Although expensive, longitudinal studies, particularly birth cohort studies, such as the ALSPAC study, offer a valuable opportunity for this area of research. Longitudinal studies with clinical populations are also important for advancing our understanding of the relationship between feeding, NNS and SSD in childhood. Researchers also need to invest more time and resources to maximise and optimise engagement in clinical research from clinical teams. Clinicians are ideally placed to support and facilitate research in this area because they have the local and service-level knowledge to support key aspects of research delivery, including participant identification and recruitment (Burr, 2019). The relationships SLTs have with children and their families can foster interest and enthusiasm in PPIE and research participation, which enriches and strengthens the quality of the research, and its impact on healthcare for patients.

Future research should also consider the substantial developments in telehealth as a result of the Covid-19 pandemic when determining appropriate methodological approaches. Researchers must fully consider the right of the individual to participate in clinical research, the need to ensure diversity of research participants and the responsibility of the researcher to ensure maximum accessibility to research participation without compromising data quality or reliability (Volkmer and Broomfield, 2022). These considerations must be examined and balanced with methodological requirements for perceived optimal conditions for data collection.

6. Final remarks

The parents who supported the development of the aims of this study wanted to know whether SSD can be linked, to some extent, to a particular type of feeding or NNS. This study has found that, depending on how children were fed as babies and their NNS behaviours, there are differences in patterns of speech sound development. Further research should investigate whether children who experience persistent dummy or bottle sucking over a prolonged period of time may be more likely to present with atypical speech sound development. The findings from this thesis provide evidence that healthcare professionals can use to support comprehensive and targeted clinical assessment and intervention, and to empower parents to make informed decisions about how they care for their children.

References

Afasic. Available from: https://www.afasic.org.uk/. [Accessed 07 February 2016].

Alcock, K. (2006) The development of oral motor control and language. *Down's Syndrome, Research and Practice* [online]. 11 (1), pp.1-8. [Accessed 14 February 2022].

Alex, A., Bhandary, E., and McGuire, K. P. (2020) Anatomy and Physiology of the Breast during Pregnancy and Lactation. *Advances in experimental medicine and biology* [online]. 1252, pp.3–7. [Accessed 21 June 2021].

Audacity [software]. Available from: www.audacityteam.org. [Accessed 10 March 2017].

Avon Longitudinal Study of Parents and Children (ALSPAC) (1991) Available from: https://www.bristol.ac.uk/alspac/. [Accessed 10 February 2017].

Avon Longitudinal Study of Parents and Children (ALSPAC) (2021) *About Children of the 90s Factsheet*. Available from: http://www.bristol.ac.uk/media-library/sites/alspac/documents/About%20Children%20of%20the%2090s%20Factsheet%202021.pdf . [Accessed 19 August 2022].

Baker, E., Masso, S., McLeod, S. and Wren, Y. (2018) Pacifiers, Thumb Sucking, Breastfeeding, and Bottle Use: Oral Sucking Habits of Children with and without Phonological Impairment. *Folia Phoniatrica et Logopaedica* [online]. 70. [Accessed 24 March 2019].

Barbosa, C., Vasquez, S., Parada, M.A., Gonzalez, J.C.V., Jackson, C., Yanez, N.D., Gelaye, B. and Fitzpatrick, A.L. (2009) The relationship of bottle feeding and other sucking behaviors with speech disorder in Patagonian preschoolers. *BMC Pediatrics* [online]. 9 (66). [Accessed 17 March 2018].

Barca, L. (2021) Toward a speech-motor account of the effect of Age of Pacifier Withdrawal. *Journal of Communication Disorders* [online]. 90. [Accessed 20 November 2021].

Belfort, M. B., Rifas-Shiman, S. L., Kleinman, K. P., Guthrie, L. B., Bellinger, D. C., Taveras, E. M., Gillman, M. W., and Oken, E. (2013) Infant feeding and childhood cognition at ages 3 and 7 years: Effects of breastfeeding duration and exclusivity. *JAMA pediatrics* [online]. 167 (9), pp.836–844. [Accessed 10 April 2016].

Bishop, D.V.M. and Hayiou-Thomas, M.E. (2008) Heritability of specific language impairment depends on diagnostic criteria. *Genes, Brain and Behaviour* [online]. 7 (3), pp.365–372. [Accessed 15 February 2022].

Bowen, C. (2015). *Children's speech sound disorders*. 2nd ed. Chichester: Wiley-Blackwell.

Bratan, T., Aichinger, H., Brkic, N., Rueter, J., Apfelbacher, C., Boyer, L. and Loss, J. (2021) Impact of the COVID-19 pandemic on ongoing health research: an ad hoc survey among investigators in Germany. *BMJ Open* [online]. 11 (12). [Accessed 28 January 2022].

Broomfield, J. and Dodd, B. (2004) Children with speech and language disability: caseload characteristics. *International Journal of Communication Disorders* [online]. 39 (3), pp.303-324. [Accessed 14 March 2019].

Bryan, K., Freer, J. and Furlong, C. (2007) Language and communication difficulties in juvenile offenders. *International Journal of Language and Communication Disorders* [online]. 42 (5), pp.505–520. [Accessed 21 April 2016].

Bunton, K. (2008) Speech versus Nonspeech: Different Tasks, Different Neural Organization. *Seminars in Speech and Language* [online]. 29 (4), pp.267–275. [Accessed 14 February 2022].

Burr, S. (2017) *The Benefits of Using Social Media for PPI Activities* [poster]. Available from: https://www.researchgate.net/publication/344333249_The_Benefits_of_Using_Social_Media_for_PPI_Activities. [Accessed 10 September 2017].

Burr, S. (2019) Creating shared ownership: empowering clinical SLTs to engage in recruitment for clinical research. *Royal College of Speech and Language Therapists (RCSLT) Bulletin magazine.* Issue 807.

Burr, S., Harding, S., Wren, Y. and Deave, T. (2020) The Relationship between Feeding and Non-Nutritive Sucking Behaviours and Speech Sound Development: A Systematic Review. *Folia Phoniatrica et Logopaedica* [online]. 73 (2), pp.75–88. [Accessed 28 March 2021).

Buxton, K.E., Gielen, A.C., Faden, R.R., Brown, C.H., Paige, D.M. and Chwalow, A.J. (1991) Women intending to breastfeed: predictors of early infant feeding experiences. *American Journal of Preventative Medicine* [online]. 7 (2), pp.101-106. [Accessed 15 February 2022].

Campbell, T., Dollaghan, C., Rockette, H., Paradise, J., Feldman, H., Shriberg, L., Sabo, D.L. and Kurs-Lasky, M. (2003) Risk Factors for Speech Delay of Unknown Origin in 3-Year-Old Children. *Child Development* [online]. 74 (2), pp.346-357. [Accessed 12 March 2016].

Car, J., Koh, G.C.-H., Foong, P.S. and Wang, C.J. (2020) Video consultations in primary and specialist care during the covid-19 pandemic and beyond. *British Medical Journal* [online]. 371. [Accessed 25 January 2022].

Churcher, S. (2016) *Early intervention for speech disorder: Not just desirable but essential?* Winston Churchill Memorial Trust Travel Fellowship Report. Available from: https://media.churchillfellowship.org/documents/Churcher_S_Report_2016_Final.pdf [Accessed 29 March 2022].

Claessen, M., Beattie, T., Roberts, R., Leitao, S., Whitworth, A. and Dodd, B. (2017) Is two too early? Assessing toddlers' phonology. *Speech, Language and Hearing* [online]. 20 (2), pp.91–101. [Accessed 20 January 2022].

Clark, H.M. (2008) The role of strength training in speech sound disorders. *Seminars in speech and language* [online]. 29 (4), pp.276-83. [Accessed 15 June 2018].

Dee, D.L., Li, R., Lee, L.-C. and Grummer-Strawn, L.M. (2007) Associations Between Breastfeeding Practices and Young Children's Language and Motor Skill Development. *Pediatrics* [online]. 119 (1), pp.92-98. [Accessed 21 October 2020].

Dodd, B., Hua, Z., Crosbie, S. and Holm, A. (2002) *Diagnostic Evaluation of Articulation and Phonology (DEAP)* [Manual].

Dodd, B., Hua, Z., Crosbie, S. and Holm, A. (2006) *Diagnostic Evaluation of Articulation and Phonology (DEAP).*

Dodd, B. (2014a) Differential Diagnosis of Pediatric Speech Sound Disorder. *Current Developmental Disorders Reports* [online]. 1, pp.189–196. [Accessed 10 May 2017].

Dodd, B. (2014b) Assessment and intervention for two-year olds at risk of phonological disorder. In: Bowen, C., ed. (2014) *Children's Speech Sound Disorders*. Chichester: John Wiley and Sons, Ltd, Chichester.

Dodd, B., Holm, A., Hua, Z. and Crosbie, S. (2003) Phonological development: a normative study of British English-speaking children. *Clinical Linguistics & Phonetics* [online]. 17 (8), pp.617-643. [Accessed 09 January 2017].

Dodd, B and McIntosh, B. (2010) Two-year-old phonology: impact of input, motor and cognitive abilities on development. *Journal of Child Language* [online]. 37, pp.1027-1046. [Accessed 15 February 2022].

Dodd, B., Ttofari-Eecen, K., Brommeyer, K., Ng, K., Reilly, S. and Morgan, A. (2017) Delayed and disordered development of articulation and phonology between four and seven years. *Child Language Teaching and Therapy* [online]. 34 (2), pp.87–99. [Accessed 09 January 2020].

Eadie, P., Morgan, A., Ukoumunne, O.C., Ttofari Eecen, K., Wake, M. and Reilly, S. (2015) Speech sound disorder at 4 years: prevalence, comorbidities, and predictors in a community cohort of children. *Developmental Medicine and Child Neurology* [online]. 57 (6), pp.578–584. [Accessed 05 January 2021].

Eishima, K. (1991) The analysis of sucking behaviour in newborn infants. *Early Human Development* [online]. 27 (3), pp.163–173. [Accessed 17 November 2021].

Elad, D., Kozlovsky, P., Blum, O., Laine, A.F., Po, M.J., Botzer, E., Dollberg, S., Zelicovich, M. and Ben Sira, L. (2014) Biomechanics of milk extraction during breast-feeding. *Proceedings of the National Academy of Sciences of the United States of America* [online]. 111 (14), pp.5230–5235. [Accessed 17 November 2021].

Elliott, N. (2011) *An investigation into the communication skills of long-term unemployed young men*. Dissertation [online]. PhD. University of Glamorgan. Available from: https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.553779. [Accessed 05 April 2017].

Enderby, P., Pickstone, C., John, A., Fryer, K., Cantrell, A. and Papaioannou, D. (2009) *Resource Manual for Commissioning and Planning Services for SLCN*. Available from: https://www.rcslt.org/wp-content/uploads/media/Project/RCSLT/resource-manual-commissioning-planning-slcn.pdf. [Accessed 05 March 2016].

Evans-Morris, S. (1998) *Feeding and speech relationships*. Available from: https://www.new-vis.com/_files/ugd/57f349_24e417533836400f9d2b9126990ad9f0.pdf. [Accessed 17 May 2017].

Felsenfeld, S., Broen, P.A. and McGue, M. (1994) A 28-year follow-up of adults with a history of moderate phonological disorder: educational and occupational results. *Journal of Speech, Language and Hearing Research* [online]. 37 (6), pp.1341–1353. [Accessed 18 May 2018].

Field, M.J. and Behrman, R.E. (2004) The necessity and challenges of clinical research involving children. In: Field, M.J. and Behrman, R.E., eds. *Ethical Conduct of Clinical Research Involving Children*. Washington: National Academic Press.

Fox, A.V., Dodd, B. and Howard, D. (2002) Risk factors for speech disorders in children. *International Journal of Language and Communication Disorders* [online]. 37 (2), 117–131. [Accessed 17 May 2012].

Garber, N. and Reynolds, M. (1994) An examination of alveolar stop retraction during pacifier use. *International Journal of Orofacial Myology and Myofunctional Therapy* [online]. 20 (1), pp.22–26. [Accessed 14 March 2020].

Geddes, D.T., Kent, J.C., Mitoulas, L.R. and Hartmann, P.E. (2008) Tongue movement and intra-oral vacuum in breastfeeding infants. *Early Human Devleopment* [online]. 84, pp.471-477. [Accessed 15 February 2022].

Geddes, D.T. and Sakalidis, V.S. (2015) Ultrasound imaging of breastfeeding – a window to the inside: Methodology, normal appearances, and application. *Journal of Human Lactation. Special Report: State of the Science* [online]. 32 (2), pp.340-349. [Accessed 24 July 2018].

Golding, J. and the ALSPAC Study Team. (2004) The Avon Longitudinal Study of Parents and Children (ALSPAC) – study design and collaborative opportunities. *European Journal of Endocrinology* [online]. 151, pp119-123. [Accessed 19 August 2022].

Groot, M.E., Lekkerkerk, M.C., and Steenbekkers, L.P. (1998) *Mouthing behaviour of young children: an observational study.* Available from: https://edepot.wur.nl/384470 [Accessed 14 March 2022].

Grunwell, P. (1981) The development of phonology: a descriptive profile. *First Language* [online]. 2 (6), pp.161–191. [Accessed 09 January 2017].

Grunwell, P. (1987) Phonological assessment, evaluation and explanation of speech disorders in children. *Clinical Linguistics and Phonetics* [online]. 2 (3), pp.221-252. [Accessed 03 January 2022].

Haggard, P. and de Boer, L. (2014) Oral somatosensory awareness. *Neuroscience & Biobehavioral Reviews* [online]. 47, pp.469–484. [Accessed 02 March 2021].

Hambly, H., Wren, Y., McLeod, S. and Roulstone, S. (2013) The influence of bilingualism on speech production: A systematic review. *International Journal of Language & Communication Disorders* [online]. 48 (1), pp.1–24. [Accessed 27 July 2017].

Harding, C. (2014) Non-nutritive sucking for infants: what are the issues? *Infant Journal* [online]. 10 (2), pp. 50-53. [Accessed 14 October 2020].

Harrison, L.J. and McLeod, S. (2010) Risk and Protective Factors Associated With Speech and Language Impairment in a Nationally Representative Sample of 4- to 5-Year-Old Children. *Journal of Speech, Language and Hearing Research* [online]. 53 (2), pp.508–529. [Accessed 15 May 2017].

Hayiou-Thomas, M.E. (2008) Genetic and environmental influences on early speech, language and literacy development. *Journal of Communication Disorders* [online]. 41 (5), pp.397–408. [Accessed 15 May 2017].

Hesketh, A. (2004) Early literacy achievement of children with a history of speech problems. *International Journal of Language & Communication Disorders* [online]. 39 (4), pp.453–468. [Accessed 15 May 2017].

Hitchcock, E. R., Harel, D., and Byun, T. M. (2015) Social, Emotional, and Academic Impact of Residual Speech Errors in School-Aged Children: A Survey Study. *Seminars in speech and language* [online]. 36 (4), pp.283–294. [Accessed 10 April 2018].

Howard. S., Wells, B. and Local, J. (2008) Connected Speech. In: Ball, M.J., Perkins, M.R., Müller, n. and Howard, S. eds. *Handbook of Clinical Linguistics*. Oxford: Blackwell Publishing Ltd.

Huang, J., Vaughn, M. G., and Kremer, K. P. (2016) Breastfeeding and child development outcomes: an investigation of the nurturing hypothesis. *Maternal & child nutrition* [online]. 12 (4), pp.757–767. [Accessed 10 April 2016].

Jędrychowski, W.A. *et al* (2011) Effect of exclusive breastfeeding on the development of children's cognitive function in the Krakow prospective birth cohort study. *European Journal of Pediatrics* [online]. 171*,* pp.151-158. [Accessed 10 April 2016].

Johnson C., Beitchman J. and Brownlie E. (2010) Twenty-year follow-up of children with and without speech-language impairments: family, educational, occupational, and quality of life outcomes. *American Journal of Speech Language Pathology* [online]. 19 (1), pp.51–65. [Accessed 18 January 2021].

Juberg, D.R., Alfano, K., Coughlin, R.J. and Thompson, K.M. (2001) An Observational Study of Object Mouthing Behavior by Young Children. *Pediatrics* [online]. 107 (1), pp.135–142. [Accessed 20 January 2022].

Khazipov, R., Sirota, A., Leinekugel, X., Holmes, G.L., Ben-Ari, Y. and Buzsáki, G. (2004) Early motor activity drives spindle bursts in the developing somatosensory cortex. *Nature* [online]. 432, pp.758–761. [Accessed 20 January 2022].

Knaak, S.J. (2010) Contextualising risk, constructing choice: Breastfeeding and good mothering in risk society. *Health, Risk & Society* [online]. 12 (4), pp.345–355. [Accessed 13 January 2022].

Kramer, M.S. and Kakuma, R. (2004) The Optimal Duration of Exclusive Breastfeeding. In: Pickering, L.K., Morrow, A.L., Ruiz-Palacios, G.M. and Schanler, R.J. eds. *Protecting Infants through Human Milk, Advances in Experimental Medicine and Biology*. pp.63–77. US: Springer [Accessed 22 March 2019].

Lawlor, D. A. *et al* (2019) The second generation of The Avon Longitudinal Study of Parents and Children (ALSPAC-G2): a cohort profile. *Wellcome open research* [online]. 4, 36. [Accessed 03 May 2022].

Lee, H. *et al* (2016) Effect of Breastfeeding Duration on Cognitive Development in Infants: 3-Year Follow-up Study. *Journal of Korean medical science* [online]. 31(4), pp.579–584. [Accessed 10 April 2016].

Lewis, B.A., Freebairn, L.A. and Taylor, H.G. (2000a) Follow up of children with early expressive phonology disorders. *Journal of Learning Disabilities* [online]. 33, pp.433-444. [Accessed 29 March 2022].

Lewis, B.A., Freebairn, L.A. and Taylor, H.G. (2000b) Academic outcomes in children with histories of speech sound disorders. *Journal of Communication Disorders* [online]. 33, pp.11-30. [Accessed 29 March 2022].

Lewis, B.A., Freebairn, L.A. and Taylor, H.G. (2002) Correlates of spelling abilities in children with early speech sound disorders. *Reading and Writing: An Interdisciplinary Journal*. [online]. 15, pp.389-407.

Ludlow, V., Newhook, L.A., Newhook, J.T., Bonia, K., Goodridge, J.M. and Twells, L. (2012) How formula feeding mothers balance risks and define themselves as 'good mothers.' *Health, Risk & Society* [online]. 14 (3), pp.291–306. [Accessed 14 January 2022].

McAllister, J., Collier, J. and Shepstone, L. (2013) The impact of adolescent stuttering and other speech problems on psychological well-being in adulthood: evidence from a birth cohort study. *International Journal of Language and Communication Disorders* [online]. 48 (4), pp.458–468. [Accessed 14 May 2020].

McIntosh, B. and Dodd, B. (2008) Two-year-olds' phonological acquisition: Normative data. *International Journal of Speech-Language Pathology* [online]. 10 (6), pp.460–469. [Accessed 20 January 2022].

McIntosh, B. and Dodd, B. (2011) *Toddler Phonology Test (TPT).* London: Pearson Publishing.

McKinnon, D. H., McLeod, S., and Reilly, S. (2007) The prevalence of stuttering, voice, and speech-sound disorders in primary school students in Australia. *Language, speech, and hearing services in schools* [online]. 38 (1), pp.5–15. [Accessed 14 October 2018]

McLeod, S., and Baker, E. (2017) *Children's speech: An evidence-based approach to assessment and intervention*. (Always learning). Boston: Pearson.

McLeod, S. and Crowe, K. (2018) Children's Consonant Acquisition in 27 Languages: A Cross-Linguistic Review. *American Journal of Speech-Language Pathology* [online]. 27 (4), pp.1546–1571. [Accessed 20 January 2022].

McLeod, S., Harrison, L.J. and McCormack, J. (2012) The intelligibility in context scale: validity and reliability of a subjective rating measure. *Journal of Speech Language Hearing and Research* [online]. 5 (2), pp.648–56. [Accessed 14 November 2021].

Mizuno, K. and Ueda, A. (2006) Changes in sucking performance from non-nutritive sucking to nutritive sucking during breast- and bottle-feeding. *Pediatric Research* [online]. 59 (5), pp.728-731. [Accessed 20 May 2018].

Mold, F., Cooke, D., Ip, A., Roy, P., Denton, S. and Armes, J. (2021) COVID-19 and beyond: virtual consultations in primary care—reflecting on the evidence base for implementation and ensuring reach: commentary article. *BMJ Health Care Informatics* [online]. 28 (1). [Accessed 14 November 2021].

Moral, A., Bolibar, I., Seguranyes, G., Ustrell, J.M., Sebastia, G., Maritenez-Barba, C., and Rios, J. (2010) Mechanics of sucking: comparison between bottle feeding and breastfeeding. *BMC Pediatrics* [online]. 10 (6). [Accessed 04 Feb 2018].

Muir, C., O'Callaghan, M.J., Bor, W., Najman, J.M and, Williams, G.M. (2011) Speech concerns at 5 years and adult educational and mental health outcomes: Speech concerns and outcomes. *Journal of Paediatrics and Child Health* [online]. 47 (7), pp.423–428. [Accessed 12 March 2016].

Nathan, L., Stackhouse, J., Goulandris, N. and Snowling, M.J. (2004) The development of early literacy skills among children with speech difficulties: a test of the "critical age hypothesis." *Journal of Speech, Language and Hearing Research* [online]. 47 (2), pp.377–391.

National Institute for Health Research (NIHR). (2012) *Briefing notes for researchers: public involvement in NHS, public health and social care research.* Available from: https://www.invo.org.uk/wp-content/uploads/2014/11/9938_INVOLVE_Briefing_Notes_WEB.pdf. [Accessed 12 April 2016].

Neiva, F.C.B., Cattoni, D.M., Araújo Ramos, J.L. de. and Issler, H. (2003) Early weaning: implications to oral motor development. *Jornal de Pediatria* [online]. 79 (1), pp.7-12. [Accessed 04 March 2018].

Oddy, W.H., Li, J., Robinson, M. and Whitehouse, A.J.O. (2012) The Long-Term Effects of Breastfeeding on Development. *Contemporary Pediatrics* [online]. [Accessed 27 January 2021].

Oller, D.K. (1980) The emergence of the sounds of speech in infancy. In: Yenikomshian, G., Kavanagh, J.F. and Ferguson, C.A. eds., *Child Phonology, 1: Production.* New York: Academic Press.

Paden, E.P., Novak, M.A. and Beiter, A.C. (1987) Predictors of phonologic inadequacy in young children prone to otitis media. *Journal of Speech and Hearing Disorders* [online]. 52, pp.232-242. [Accessed 20 May 2019].

Palmer, B. (1998) The Influence of Breastfeeding on the Development of the Oral Cavity: A Commentary. *Journal of Human Lactation* [online]. 14 (2), pp.93–98. [Accessed 27 January 2021].

Parrell, B. and Houde, J. (2019) Modelling the role of sensory feedback in speech motor control and learning. *Journal of Speech, Language and Hearing Research* [online]. 62 (8), pp.2963-2985. [Accessed 29 March 2022].

Pereira, T.S., Oliveira, F. de. and Cardoso, M.C. de A.F. (2017) Associação entre hábitos orais deletérios e as estruturas e funções do sistema estomatognático: percepção dos responsáveis. *CoDAS* [online]. 29 (3). [Accessed 17 January 2018].

Pollock, J. (2013) *Oral motor skills in breastfeeding infants.* Available from: https://www.springfieldul.org/Custom/Library/1/documents/2013-02-05/OralMotorSkillsinBreastfeedingInfants.pdf. [Accessed 23 February 2018].

Poore, M.A. and Barlow, S.M. (2009) Suck Predicts Neuromotor Integrity and Developmental Outcomes. *Perspectives on Speech Science and Orofacial Disorders* [online]. 19 (1), pp.44–51. [Accessed 23 December 2021].

Radzyminski, S. and Callister, L.C. (2016) Mother's Beliefs, Attitudes, and Decision Making Related to Infant Feeding Choices. *The Journal of Perinatal Education* [online]. 25 (1), pp.18–28. [Accessed 14 December 2021].

Reilly, S., Wake, M., Ukoumunne, O., Bavin, E., Prior, M., & Cini, E., Conway, L., Eadie, P. and Bretherton, L. (2010) Predicting Language Outcomes at 4 Years of Age: Findings From Early Language in Victoria Study. *Pediatrics* [online]. 126 (6), pp.1530-1537. [Accessed 20 March 2016].

Reynell, J. (1969) *Reynell Developmental Language Scales (RDLS).* UK: NFER Publishing Co. Ltd.

Ritchie, F. (2019) *10 is the safest number that there's ever been.* Available from: https://uwe-repository.worktribe.com/output/7457485/10-is-the-safest-number-that-theres-ever-been [Accessed 08 January 2022].

Roulstone, S. (1997) What's driving you? A template which underpins the assessment of preschool children by speech and language therapists. *International Journal of Language and Communication Disorders* [online]. 32 (3), pp.299–315. [Accessed 23 January 2022].

Roulstone, S. (1995) *The child, the process and the expertise: identification of priority children from preschool referrals to speech and language therapy.* Dissertation [online]. PhD. Brunel University. Available from: https://bura.brunel.ac.uk/bitstream/2438/5450/1/FulltextThesis.pdf. [Accessed 20 January 2022].

Roulstone, S. Loader, S., Northstone, K., Beveridge, M. and The ALSPAC Team. (2002) The Speech and Language of Children Aged 25 Months: Descriptive Data from the Avon Longitudinal Study of Parents and Children. *Early Child Development and Care*. [online]. 172 (3), pp.259-268. [Accessed 16 April 2018].

Roulstone, S. Miller, L.L., Wren, Y. and Peters, T.J. (2009) The natural history of speech impairment of 8-year-old children in the Avon Longitudinal Study of Parents and Children: Error rates at 2 and 5 years. *International Journal of Speech-Language Pathology* [online]. 11 (95), pp.381-391. [Accessed 12 June 2017].

Roulstone, S., Law, J., Rush, R., Clegg, J. and Peters, T. (2011) *Investigating the role of language in children's early educational outcomes* [online]. London: Department for Education. [Accessed 14 October 2019].

Royal College of Paediatrics and Child Health (RCPCH). (2021) *Principles for conducting virtual consultations with children and young people* [online]. Available from: https://www.rcpch.ac.uk/resources/principles-conducting-virtual-consultations-children-young-people. [Accessed 17 January 2022].

Ruark, J.L. and Moore, C.A. (1997) Coordination of lip muscle activity by 2-year-old children during speech and non-speech tasks. *Journal of Speech, Language and Hearing Research* [online]. 40 (6), pp.1373-85. [Accessed 15 April 2018].

Ruff, H.A. (1984) Infants' manipulative exploration of objects: Effects of age and object characteristics. *Developmental Psychology* [online]. 20 (1), pp.9–20. [Accessed 01 February 2022].

Ruff, H.A. and Dubiner, K. (1987) Stability of Individual Differences in Infants' Manipulation and Exploration of Objects. *Perceptual and Motor Skills* [online]. 64 (3), pp.1095–1101. [Accessed 14 December 2021].

Sices, L., Taylor, H.G., Freebairn, L. Hansen, A. and Lewis, B. (2007) Relationship between speech-sound disorders and early literacy skills in preschool-age children: impact of comorbid language impairment. *Journal of Developmental and Behavioral Pediatrics* [online]. 28 (6), pp.438-447. [Accessed 29 March 2022].

Shotts, L.L., McDaniel, D.M. and Neeley, R.R. (2008) The impact of prolonged pacifier use on speech articulation: a preliminary investigation. *Contemporary Issues in Communication Science and Disorders* [online]. 35, pp.72-75. [Accessed 14 February 2022].

Shriberg, L. and Kwiatkowski, J. (1982) Phonological Disorders III; a procedure for assessing severity of involvement. *Journal of Speech and Hearing Disorders* [online]. 47 (3), pp.256-270. [Accessed 27 March 2021].

Shriberg, L.D. *et al* (2010) Extensions to the Speech Disorders Classification System (SDCS). *Clinical Linguistics & Phonetics* [online]. 24 (10), pp.795–824. [Accessed 10 January 2022].

Smit, A.B., Hand, L., Freilinger, J.J., Bernthal, J.E. and Bird, A. (1990) The Iowa Articulation Norms Project and its Nebraska Replication. *Journal of Speech and Hearing Disorders* [online]. 55 (4), pp.779–798. [Accessed 03 March 2018].

Smith, L. and Gerber, E. (1993) Infant feeding and phonologic development. *International Journal of Pediatric Otorhinolaryngology* [online]. 28 (1), pp.41-49. [Accessed 10 April 2016].

Sohrabi, C., Mathew, G., Franchi, T., Kerwan, A., Griffin, M., Soleil C Del Mundo, J., Ali, S.A., Agha, M. and Agha, R. (2021) Impact of the coronavirus (COVID-19) pandemic on scientific research and implications for clinical academic training – A review. *International Journal of Surgery* [online]. 86, pp.57–63. [Accessed 14 January 2022].

Stackhouse, J. and Wells, B. (1997) *Children's speech and literacy difficulties*. London: Whurr

Stark, R.E. (1980) Stages of speech development in the first year of life. In: Yenikomshian, G., Kavanagh, J.F. and Ferguson, C.A. eds., *Child Phonology, 1: Production.* New York: Academic Press.

StataCorp. (2017) *Stata Statistical Software: Release 15*. College Station, TX: StataCorp LLC.

Steeve, R.W., Moore, C.A., Green, J.R., Reilly, K.J. and Ruark McMurtrey, J. (2008) Babbling, chewing and sucking: oromandibular coordination at 9-months. *Journal of Speech, Language and Hearing research* [online]. 51, pp.1390-1404. [Accessed 09 February 2022].

Stoel-Gammon, C. and Dunn, C. (1985) Normal and Dsiordered Phonology in Children. Michigan, US: University Park Press.

Strutt, C., Khattab, G. and Willoughby, J. (2021) Does the duration and frequency of dummy (pacifier) use affect the development of speech? *International Journal of Language & Communication Disorders* [online]. 56 (3), pp.512–527. [Accessed 12 December 2021].

The Phonology Project (2022) *Speech Disorders Classification System (SDCS).* Available from: https://phonology.waisman.wisc.edu/. [Accessed 04 January 2022].

Thelen, E. and Smith, L.B. (2007) Dynamic Systems Theories. In: Damon, W. and Lerner, R.M., eds. (2007) *Handbook of Child Psychology*. USA: John Wiley & Sons, Inc.

van Geert, P. (2000) The Dynamics of General Developmental Mechanisms: From Piaget and Vygotsky to Dynamic Systems Models. *Current Directions in Psychological Science* [online]. 9 (2), pp.64–68. [Accessed 12 February 2022].

Vieira, V.C., de Araújo, C.M. and Jamelli, S.R. (2016) Speech development and infant feeding: possible implications. *Review CEFAC* [online]. 18 (6), pp.1359-1369 [Accessed 10 February 2018].

Vihman, M. (1996) *Phonological Development: the origins of language in the child*. Oxford: Blackwell Publishers.

Volkmer, A. and Broomfield, K. (2022) Seldom Heard Voices in Service User Involvement: The how and why of meaningful collaboration. Havant: J&R Press.

Watson, M.M., and Lof, G.L. (2008) Epilogue: what we know about nonspeech oral motor exercises. *Seminars in speech and language* [online]. 29 (4), pp.339-44. [Accessed 17 June 2018].

Weiss, P.P.W. (2003) *Sucking on the Breast and on the Bottle*. Available from: https://nebula.wsimg.com/a03e8aeb7de27e300b93eafca5d2dffa?AccessKeyId=CB80718871C9FF21998F&disposition=0&alloworigin=1. [Accessed 12 March 2018].

Whitmarsh, J. (2008) The good, the bad and the pacifier: unsettling accounts of early years practice. *Journal of Early Childhood Research* [online]. 6 (2), pp.145–162. [Accessed 21 January 2022].

Wilson, E., Green, J., Yunusova, Y. and Moore, C. (2008) Task Specificity in Early Oral Motor Development. *Seminars in Speech and Language* [online]. 29 (4), pp.257–266. [Accessed 30 June 2019].

Wilson, E., and Nip, I.S. (2010) Physiologic Studies Provide New Perspectives on Early Speech Development. *Perspectives on Speech Science and Orofacial Disorders* [online]. 20, pp.29-36. [Accessed 05 May 2018].

Woolridge, M.W. (1986) The 'anatomy' of infant sucking. *Midwifery* [online]. 2 (4), pp.164–171. [Accessed 14 April 2017].

Wren, Y. McLeod, S., White, P., Miller, P. and Roulstone, S. (2012) Speech characteristics of 8-year-old children: Findings from a prospective population study. *Journal of Communication Disorders* [online]. 46 (1), pp.53-69. [Accessed 19 November 2018].

Wren, Y., Miller, L.L., Peters, T.J., Emond, A. and Roulstone, S. (2016) Prevalence and Predictors of Persistent Speech Sound Disorder at Eight Years Old: Findings From a Population Cohort Study. *Journal of Speech Language and Hearing Research* [online]. 59 (4), pp.647-673. [Accessed 03 September 2017].

Wren, Y., Pagnamenta, E., Peters, T. Emond, A., Northstone, K., Miller, L.L. and Roulstone, S. (2021) Educational outcomes associated with persistent speech disorder. *International Journal of Communication Disorders* [online]. 56 (2), pp.299-312. [Accessed July 2021].

Yanow, S.K. and Good, M.F. (2020) Nonessential Research in the New Normal: The Impact of COVID-19. *The American Journal of Tropical Medicine and Hygiene* [online]. 102 (6), pp.1164–1165. [Accessed 12 January 2022].

Zhang, X. and Tomblin, B.J. (2000) The association of intervention receipt with speech-language profiles and social-demographic variables. *American Journal of Speech-Language Pathology* [online]. 9 (4), pp.345-357. [Accessed 19 September 2019].