# Patterns of speech sounds after surgery: investigating infants' vocalisations following full cleft palate repair surgery.

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# Abstract

This thesis explores prelinguistic vocalisations from twenty-eight 14-month-olds with repaired cleft palate. It examines the vocalisation characteristics that are widely recognised to support the typical progression to first words in vocal development (Oller, 2000; McCune and Vihman, 2001; Ramsdell-Hudock et al., 2019) yet overlooked in clinical populations. While phonetic inventories from therapeutic assessments are valuably commonplace in practice and literature (Lohmander, Olsson and Flynn, 2011; Lee, Bessell, and Gibbon, 2019), an understanding of how infants with a repaired cleft palate resemble the established, typical production milestones is missing.

This thesis explores unresearched naturalistic, audio data from the Cleft Collective Corpus (Wren et al., 2017) by presenting detailed, phonetic evidence on what sounds infants produce in every-day settings rather than elicited settings. It implements stricter sampling criteria than literature currently offers to limit the medical impacts (e.g., cleft type, syndromic and hearing status) on speech outcomes. The research investigates twenty-eight hour-long LENA recordings to address the central research question: to what extent do the phonetic and sequential properties of syllables produced by ICPs across palatal ages post-repair resemble the typical path of vocal development? Three analyses explore vocalisation patterns, including canonicity—or speech-likeness—using mean babble level (MBL) and articulatory consistency using vocal motor schemes (VMS), as adopted by Scherer et al. (2008) and Vihman (2016) respectively. Together with measures of vocal count, phonetic inventory, and consonant-vowel sequences, the research investigates relationships between clinical timeframes and standardised production measures.

Its results emphasise the significance of palatal age on vocalisation patterns at ~14 months (especially MBLs, VMS, and contrasting vowel positions); an earlier timeframe than most research acknowledges. They capture vocalisations in their sequential contexts, i.e., the phonetic/vocalic combinations and speech-likeness of productions, rather than sounds in isolation, to reduce the distance between clinical and academic research. The results highlight that the vocal measures of babble may be a rich tool for predicting and/or recognising production milestones in infants with a cleft palate after repair. Such insight could be valuable to parents and therapists for considering intervention at earlier ages than current provisions mostly target.

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# Glossary

The list below is given to ease reading and provides a definition for common abbreviations in the thesis.

**Cleft Palate (CP):** The condition diagnosed when an infant is born with an opening in the roof of the mouth; it is a congenital abnormality that impacts the hard and/or soft palate (Fell et al., 2022). CP can occur with a unilateral cleft lip (UCLP) or bilateral cleft lip (BCLP) or on its own.

**Cleft Speech Characteristics (CSCs**): The term widely used to describe persistent non-target speech patterns and can be described and understood in relation to their phonetic and/or linguistic segments (Southby et al. 2021, Britton et al., 2014, Sell et al., 2006). Details on these examples are covered in Section 2.4.

**Consonant (C):** The configuration of and the degree of stricture between the active and passive articulators when producing a speech sound, see Section 2.2.1 for more details.

**Infant with a CP (ICPs):** The acronym used for 'infants with a cleft palate' to ease reading. The term is used to refer to ICPs independent of their repair status.

**Intravelar veloplasty:** A type of procedure used to put the muscles in a cleft palate into the typical position (for more on procedure types and details, see Naidu et al., 2022).

**Manner of articulation (MoA):** The way in which a consonant production is articulated. Manner categories in English include the following: stops with complete closure of two articulators (referred to as stops throughout to mean oral plosives); fricatives with the narrowing of two articulators and resultant friction, liquids (referred to as approximants and glides in the literature) with the approximation of two articulators and no friction in the airflow, and nasals with air flowing through the nasal cavity during articulation (see section 2.2.1 for further details). In instances of a double closure, where two different MoAs are produced simultaneously, there may be different terms used, e.g., an affricate, whereby a fricative occurs after an oral stop (O'Grady, 2013).

**Oronasal fistula:** An opening or hole between the oral and nasal cavities which can occur if there is partial breakdown of the palate repair (Fell et al., 2022).

**Palatal Age**: The term used for the number of months since surgery, e.g., if repair was carried out at 11 months, and data was collected at 15 months, the palatal age is 4 months.

**Palatoplasty:** The clinical term given to a surgical procedure of repairing the palate and closing the cleft in the mouth (and or nose and lips).

**Place of articulation (PoA):** The location in the vocal tract where the constriction between the active and passive articulators occurs.

**Relieving Incisions:** A technique carried out during palate repair surgery to relieve tension in the tissues which are being realigned in surgery.

**Speech and language therapy/therapist (SLT):** Speech and language therapy provides treatment, care, and support for children and adults who have difficulties with communication, or with drinking, eating, and swallowing. (RCSLT, 2025).

**Standard deviation (SD):** Measure for the variation from or around the mean from a set of values.

**Velopharyngeal insufficiency:** When the soft palate does not make complete closure with the pharynx in order to separate the oral and nasal cavities during speech (Abdel-Aziz, 2013, Fell et al., 2022, RCSLT, 2025). Coordination of the cavities is necessary to distinguish between oral and nasal sounds (see Section 2.2.1 for details on the articulators).

**Vowel (V):** A speech sound produced without any stricture in the oral tract (see Section 2.2.1 for details).

# 1 Introduction

This thesis investigates vocalisations from a group of infants with cleft palate (CP) following repair, a population which is known to often have persistent production difficulties through development (Wills et al., 2017, Scherer et al., 2018). The present research maintains a central thread of inquisition: to what extent do the phonetic and sequential properties of syllables produced by ICPs across palatal ages post-repair resemble the typical path of vocal development? As such, it contributes novel insight in terms of not only the phonetic details, but the sequential properties of infant vocalisations post CP repair. This section outlines the impetus for the study, including the research gap and why the research was carried out; it then illuminates the ways in which the thesis was conducted to fill the research gap; and ends with an outline of how the thesis is organised in order to ratify the central research question.

## 1.1 The Motivation for this Thesis

Vocalisation across the first months of life involves developmental milestones that serve as noteworthy precursors to speech (the parameters of which are given in Section 2.2). Research on the production of syllables in a babble and pre-babble context in typically developing infants is a growing field of research (Oller et al., 2021; Kalashnikova and Carreiras, 2022), especially emphasising the production of well-formed canonical syllables as essential for developing the articulatory ability for acquiring adult-like phonological elements (Ganger and Brent, 2004, Nathani, Ertmer and Stark, 2006) that words are built from. When infants progress from babble to words (from ~10 months), they are efficient in many early production behaviours, for instance, they reuse early syllable sequences and sound structures from babble (Faytak, 2018), which is beneficial for extending production repertoire. This resourcefulness requires the implicit reuse of motor patterns across parallel structures in early word forms (Chodroff and Wilson, 2017), which highlights the benefits of producing stable early vocal structures. Together, these studies foreground the importance of simplistic CV vocal structures (known as babble) for reaching later vocal and speech milestones and for transitioning into first words. In typical development research, a wide mix of vocalisation variables are used to measure and predict such vocalisation behaviours and stages (such as vocabulary size), and as such the implementation of standardised vocalisation measures is commonplace in linguistic research on typically developing populations.

Recent demographics on the UK population reported that 1 in 600 babies are born with cleft lip and/or palate (CLP), up to half of whom encounter persistent challenges in their speech

(Fell et al., 2022; Williams, Harding, and Wren, 2021; Shaw et al., 2019; and Sell et al. 2015). Such production difficulties include but are not limited to misarticulations, weak or absent pressure consonants, nasalisation, and glottalisation, all of which can contribute to lower overall intelligibility in communication (Wills et al., 2017; Frey, Kaiser, and Scherer, 2018; Naros et al., 2022). While typical babble research continues to expand, due to sample complexity and the number of individuals affected by CP, the research on the development of babble in atypical populations, including infants with a CP (henceforth ICPs) remains, by comparison, very limited.

Although babble in this population has been studied to some degree previously (Hardin et al., 2023, Scherer et al. 2018), standardised vocal measures are rarely applied to research paradigms and have not been used in conjunction with the necessary clinical criteria. Thus, a main obstacle of published research on ICPs is that the studies group together complex clinical variables that are known to influence speech outcomes (see Section 2.2.3.1). This thesis therefore tackles this research gap by using a set of consistent vocal measures (given in Section 1.2), whilst also implementing stricter sampling and exclusion criteria, as well as grouping the sample by the number of months since surgery. A central motivation of this thesis therefore amplifies the importance of studying atypical populations using consistent measures, rather than assuming differences from the very outset.

Another catalyst for this thesis is that the most frequent explorations of ICPs are dominated by inventories of isolated sounds. While phonetic inventories from therapeutic assessments are valuable and commonplace in medical practice and clinical literature (Lohmander, Olsson and Flynn, 2011; Lee, Bessell, and Gibbon, 2019), they do not provide a rich enough collection of data to analyse babble as it occurs naturally in a string of syllables. Furthermore, existing linguistic and clinical research often reports on the phonetic inventories that ICPs produce post repair as well as the longer-term speech development through childhood and adolescence. However, there continues to be less knowledge of what vocalisation patterns sound like earlier than these timeframes or how sounds are used in combination to form vocalisation units (or syllables), especially in the early months after CP repair. This narrow timeframe is necessary to explore because the process of babble (re)emergence may begin instantly or at least very soon post operatively.

Given that ICPs have delayed access to some of the typical articulators (such as the alveolar ridge), it is perhaps unsurprising that they encounter speech delays in pre-school years (Jones, Chapman, and Hardin-Jones, 2005) which, for some, even persist through childhood (Murray et al., 2008). However, the understanding of atypical production patterns *during* the emergence of the sequences required to form first words is currently inadequate. Understanding babble at this sequential level alongside a phonetic profile helps to measure to what degree the atypical trajectory aligns with the typical trajectory, which in itself is necessary to understand when, where, and whether treatment may be useful. As such, this thesis includes an exploration of consonant/vowel combinations and transitions. It taps into not only the isolated sounds that ICPs produce, but also the orders in which they produce them, to examine whether this is where these infants diverge from typical patterns. Such divergences would illustrate a contrast in how ICPs may build their early words.

As stated, the current research into naturalistic babble of ICPs is limited, especially in samples that factor in palatal age; this thesis contributes to that research gap by separating the sample into palatal ages and implementing strict exclusion criteria. There is literature on ICPs acquiring Korean that points to a delay in the onset of canonical babble when compared to typically developing infants (Ha and Oller, 2022), but research has yet to explore what these phonetic properties look like across English-acquiring infants in sufficiently robust detail. As such, the existing work from other languages, albeit limited, encourages more research to better understand why so many ICPs experience difficulty reaching the typical speech milestones even after CP repair. One possible explanation may be that, within the prelinguistic productions of ICPs, the vocal characteristics resemble the typical development milestones less, impacting their ability to progress in the typical ways. Thus, the purpose of this thesis is to explore the phonetic, sequential, and combinatory vocalisation properties of 14-month-old ICPs, from a real-life setting, and investigate how they compare and differ with the typical timeline.

## 1.2 The Present Study

To address the research gaps, this thesis a) explores naturalistic data, b) includes selective medical variables in the sample, c) implements palatal age, and d) uses standardised babble measures for CP research. Firstly, the naturalistic nature of the data benefits the thesis by offering evidence of infants' production rehearsal in an every-day setting, rather than from clinical settings. The naturalistic context fills the research gap by contributing findings on phonetic vocalisation measures (e.g., vocalisation length and vocal count). The novel outcomes on emergent vocalisations post repair work towards an understanding of the similarities and differences to the typical trajectory, which is at the heart of informing clinical intervention and assessment.

The selection of **l**anguage **en**vironment **a**nalysis (LENA) audio data from the corpus has not been explored before, let alone analysed at a fine-grain production level. LENA is a recording device worn as a vest on the infant to record and capture infant production behaviours alongside the speech in a child's immediate environment (Richards et al., 2017). To add, the data analysis captured by LENA in the corpus also offers insight into earlier timeframes post repair than most of the literature does, as it captures vocalisations at home between clinical appointments, and could be useful to researchers exploring other elements of the corpus (including medical data and speech and language therapist reports). The thesis therefore analysis unresearched audio data from the Cleft Collective Corpus (Wren et al., 2017) by presenting evidence on what infants produce in real-life settings rather than elicited ones.

The thesis also includes consistent and selectively sampled medical variables. Specifically, is examines palatal age, that is, the vocal output of infants with a mean of five months after surgery in cases where there were no further medical complications, e.g., syndromes, hearing difficulties, or additional surgeries. The analysis of vocalisations from infants (with an age range of 13-19 months and a mean age range of 10 months at surgery) examined the characteristics widely recognised to support the typical progression to first words and later stages in vocal development (Oller, 2000; McCune and Vihman, 2001; Ramsdell-Hudock et al., 2019) that are otherwise overlooked in clinical populations. The sample builds up a comprehensive profile of these infants' phonetic repertoire by investigating the Cleft Collective Corpus (Wren et al. 2017) whose surgery timings are all comparable to the clinical timeline in the UK as they were carried out by 12 months (Fell et al., 2022, Zajac et al., 2021). The sample also adds insight into variation across palatal ages, to explore how time since repair could influence ICPs' vocal production. Existing explorations of production characteristics following CP repair have so far mainly assessed phonetic inventories; this work, on the other hand, will extend the research by carrying out an analysis of sound combinations and babble formations evident in infant vocalisations from hour-long, at home recordings.

In addition, the thesis implements stricter sampling criteria than the literature currently offers to limit the potential medical influences. The benefit of this sampling process is to shed light on vocalisation patterns in a context with more strict sampling of variables (e.g., cleft type, number of relieving incisions, and babbling level). Thus, the findings extend the binary nature of phonetic inventories to capture vocalisations in their syllable contexts rather than only in isolation, i.e., the phonetic and vocalic combinations and speech-likeness of productions, to reduce the distance between clinical and academic research.

Among other sample variables, the thesis focuses on palatal age (i.e., the number of months since surgery) to boost our understanding of its impact on vocalisation features of ICPs within a timeframe (of 1-9 months post-CP repair). Three research gaps were critically explored in the data to assess whether (and how) CP repair production characteristics resemble the typical trajectory documented in English-acquiring infants in the literature (see Section 2). More specifically, the research aims are to explain variation in vocal development across the sample in relation to the use of speech sounds and sequential combinations. It includes three groups of palatal ages (1-3 months, 4-5 months, and 6-9 months after repair); it includes one type of cleft (CP); and uses standardised vocalisation measures (vocal count, vocal motor schemes, mean babble level, and phonetic inventories).

Lastly, the thesis contributes to the research field by incorporating standard, replicable measures that are frequent in typical infant research. Of the published studies (reviewed in depth in Chapter 2), the consonant repertoires of infants following CP repair are mostly reduced to isolated lists of phonetic production abilities, from elicited contexts, after the point of first words and do not sufficiently consider sample characteristics (these factors are laid out in Section 4.1.4). The present research carries out three analyses on these phonetic and sequential properties and elucidates whether more standardised, phonetic vocalisation measures provide any novel insight into emergent vocalisations post repair. The three central production measures represent concepts in vocal development: mean babble level (MBL) being the measure for canonicity (i.e., timeliness during speech sound transitions and the articulatory components in vocalisations), vocal motor schemes being the measure for consistency of consonant production, and vocal count being a measure for the amount of vocalisation rehearsal (Oller, 2000; McCune and Vihman, 2001, Ha and Oller, 2022).

The research explores these concepts, along with the sequential characteristics of consonant, vowel, and syllable patterns within sequential contexts, i.e., the positioning and types of consonants within syllable units and babble types before first words. The analysis of vocalised sequences and transitional probabilities (i.e., the likelihood of sounds occurring together) will help to explore the recombinability of phonetic segments, which are at the heart of an eventual phonological system (Oller 2000, p. 16). Thus, the analyses outcomes here could help to explain variation in vocal development within infants' sequential combinations of speech sounds and the impact this may have on them progressing to their first words.

In addition, absent or deviant productions could give useful insight on whether infants' vocal tendencies in natural contexts align with those addressed by common speech and language therapy (SLT) focal points as well as those that are next in the vocal timeline, such as elicited patterns at 2 + years of age. The thesis considers whether phonetic sequences give new insight on how infants might advance to their next vocal stages and whether this is an area that may be deviant from the typical patterns.

The thesis overall explores whether (and to what extent) the listed vocal patterns echo those documented along the typical speech trajectory. Further, it discusses whether the actual production of sounds in naturalistic environments aligns with reported clinical outcomes and published literature, (i.e., from documented babble from ICPs who are older and/or have had more months after surgery). Its overall contribution adds weight to the importance of studying productions of ICPs with more standardised measures, which are already commonplace in typical vocal development research. This present avenue of research contributes to our understanding of the population at a more fine-grained and in a stricter sample; as such, it questions the extent to which the phonetic and sequential properties of vocalisations produced at 14- months-old with a repaired CP resemble the typical path of vocal development.

The analysis of the vocal patterns across different palatal ages brings new insight into a ICPs. It helps offer explanations for why these infants tend to have persistent differences to the typical vocal patterns that may impact how they advance from prelinguistic, canonical vocalisations to early words. Moreover, the outcomes indicate the extent to which these infants' patterns align with clinical intervention goals, that is, whether the vocalisations produced by ICPs reflect patterns that support or disrupt development timeframes in typical development. Thus, this thesis advocates the importance of more consistent babble measures in future research and the importance of considering resemblances with development stages in order to understand vocalisations of ICPs on the whole.

### 1.2.1 The Research Questions

The central research question at the heart of this thesis is *to what extent do the phonetic and sequential properties of syllables produced by ICPs across palatal ages post-repair resemble the typical path of vocal development?* The following three subsidiary research questions are also examined (in an analysis chapter in turn) and they collate to inform the central research question and to add to the contributions of the larger thesis, too.

- ◊ RQ2: How do the vocalisation measures of vocal count, vocalisation length, and canonicity vary with palatal age, and does the inclusion of these measures reveal new insights into the typical/CP trajectory of known vocalisation patterns in infancy?
- ◊ RQ3: What are the compositional and organisational components of syllables produced by ICPs (i.e., the phonetic properties of babbled 'consonants' and 'vowels')?
- ◊ RQ4: To what extent do the sequential features of non-canonical, canonical, and true canonical syllables show consistencies with published CP patterns and therapeutic aims post-repair? Does the visualisation of transitional probabilities – a method for

visualising phonetic and sequential details from vocalisation transcriptions – benefit the analysis of and reveal new insights into CP production patterns.

The ways in which the research questions are integrated into the present study are given next in Section 1.3, where the order of chapters and sections is expanded on.

## 1.3 Thesis Structure

To follow are five chapters which in turn contribute to contextualising, exploring, and answering the research questions. The literature review in Chapter 2 first presents and critiques the published work on the typical trajectory of infant vocalisation and the vocal production behaviours involved across the first two years of life, including the progression to first words (Section 2.2). Sections 2.1 and 2.2 both bring forward the research gaps (also given in Section 1.1) within the wider literary context. Section 2.2.3.1 also critically explores what is already known about ICPs, initially at a clinical level, and then Section 2.4 explores this at a linguistic level. The section includes a review of what is currently understood about how the population begins to vocalise (both before and after repair), and evaluations about how well these infants may map onto the typical trajectory. As a result, it establishes a baseline for comparing similarities, differences, and absences with the typical trajectory. The reviewed literature on ICPs illustrates how identifying absent or deviant productions (i.e., identifying the early speech sounds that do not follow the typical developmental sequence) can help determine whether infants' vocal tendencies in natural contexts align with those in more regulated, clinical contexts (as is reviewed in Section 2.4.5).

Sections 2.5 to 2.6.1 respond to the gaps in the literature (as brought forward in sections 2.2 and 2.2.3.1). Specifically, they provide more detail on how research overlooks the phonetic context of syllables. For instance, the section considers the importance of vowels when determining the maturity of vocalisations, and their integration with research designs, and how consonants are explored in infant production forms (e.g., the classification of pre-canonical, canonical, variegated babble) in clinical research. As such, these pre-word, phonetic features are established as a significant chain in the vocal development stages throughout the chapter, further motivating the focus and formation of the following methodology and analyses chapters. In summary, the literature review builds an understanding about what, how, and why certain vocal patterns occur through infancy, yet it also sets the parameters to which CP vocalisation has been explored to date, and, crucially, what is missing from the literature. It introduces and justifies why the thesis extends existing explorations of cleft repair characteristics. It also motivates the analysis focus on consonant-vowel combinations, and babble formations evident in 14-month-old infant vocalisations from hour-long, naturalistic recordings. Consequently, the chapter provokes the research questions (given above) and corresponding hypotheses (given below) that are at the heart of the conducted research.

The methodology is separated into two chapters. Chapter 3 is a presentation of two pilot studies, which were carried out to evaluate, inform and finalise stages in the full methodology, captured in the subsequent chapter. Pilot One included trialling parametric transcriptions of typical child vocalisations (see Section 3.1.1) and Pilot Two included piloting the transcription approach for a case study of one infant with a CP (see Section 3.1.2). The two pilots were both conducted ahead of the full study. Chapter 4 is a descriptive report of the data, ethics, methodological decisions, and finalised procedure. Section 4.1 gives an overview of the pre-existing corpus, which was the primary source of data for the thesis. It describes how the data were originally collected and sourced (4.1.1). It also expands on the process of gaining access to a sample from the corpus, and importantly the ethical requirements to do so (4.1.2). To expand, Section 4.1.2 provides a full account of the ethics procedure undertaken ahead of accessing the corpus data from the Cleft Collective (Wren et al., 2017) and ahead of transcription. The procedure included ethics forms, an application to the ethics committee at Cardiff University, and adhering to the ethical guidelines from the team in charge of the data at Bristol University. All these stages were necessary for working with data from clinically vulnerable participants. The chapter also includes the sample selection process, details of eligibility criteria, and data preparation processes (4.1.3 - 4.1.6).

The next parts of the Methodology outline and details the finalised methodological procedure adopted in the main study. Specifically, this includes the processes for transcribing the audio data (4.2), including the vocalisation inclusion criteria, guidance on discerning and excluding vocalisation types. It also includes detail on the processes of coding and converting the data (4.3), and crucially, the finalised sample of twenty-eight infants (given in Section 4.4) with detail on how and why they were selected (4.4.1 - 4.4.2).The methodology chapter therefore contains a stepwise, detailed description of the data coding procedure and conventions as well as the data preparation and analyses processes undertaken in R (scripts all available at Langner 2024). Taking these sections together, the Methodology provides a comprehensive outline of the practical stages leading up to the analyses illustrating its replicability for future work. Therefore, it addresses how the dataset and measures (given in Section 4.3.2) facilitate the exploration of the phonetic and structural properties of vocalisations produced by ICPs post repair at 14 months. Lastly in the methodology, Section 4.4 overviews the participant features, which were finalised following the pilot research.

The Analysis consists of four sections: it opens with the Analysis overview (see Section 5.1), which foregrounds the data analysis procedure in relation to how it addresses the research questions (in Section 5.1.1) and then presents an introduction to the vocalisation outcomes in Section 5.1.2. The remainder of the chapter is composed of three separate analysis sections, which serve to address the three subsidiary research questions in turn by exploring three relevant hypotheses. Analysis I responds to research question 2 and explores *Hypothesis 1*, which predicts that vocal count and MBLs, will be lower than typical amounts at 14 months, but also lower than measures that typically occur earlier. Analysis II explores research question 3, whereby *Hypothesis 2* expects that the most common formations of vocalisations will be composed of fricative-, liquid-, and vowel-initial syllables (with fewer stops and fewer velars). Plus, central vowels will be more common than front and back vowels across the sample. Lastly, Analysis III tackles research question and *Hypothesis 3,* which makes the prediction that palatal age will relate to (and perhaps even predict) vocalisation measures at 14 months and it also expects that these measures will be a better predictor of syllable inventories and babbling ability than palatal age. The three predictions are expanded on and motivated in the literature review (see Section 2.6.1).

Section 5.1 overviews the central tendencies of vocalisation measures and it sets the foundation for the rest of the analyses. Each analysis then explores the concerned vocalisation patterns, including canonicity—or speech-likeness—using MBL alongside articulatory stability and consistency using vocal motor schemes (VMS), as adopted by Scherer et al. (2008) and Vihman (2016) respectively. Analysis I explores the data with a descriptive and inferential analysis of vocalisation measures, all of which are then explored in relation to vocal count, vocalisation lengths, and MBL across palatal and chronological ages.[1] Section 5.2.2 analyses vocal count across the sample to assess variability across infants and in relation to the infants' age. Then vocalisation length is considered across palatal ages (see 5.2.3) to establish any relationships with the length of vocalisations. Also in this section, the results of MBL are introduced and analysed against ages (see Section 5.2.5) as well as in relation to extreme data points from the other two vocal measures (5.2.6).

Together with measures of vocal count, phonetic inventory, and consonant-vowel sequences, Section 5.2 therefore investigates the relationships between clinical timeframes and standardised production measures. Its results explore the significance of palatal age on vocalisation patterns at ~14 months (in relation to canonicity, VMS, and contrasting vowel

[1] See section 2.4.2 for definitions of palatal and chronological age.

positions), at an earlier timeframe than most research acknowledges. Analysis I examines whether the implementation of palatal groups was valuable for assessing the three centrally relevant measures (vocal count, vocalisation length, and MBL), and analyses the relationship between palatal age with vocal count and with MBL. It also considers the variability within the palatal groups depending on the number of months post-surgery, alongside if and when variability stabilises following surgery. In sum, the section provides findings on the relationship between vocal measures and chronological age versus palatal age, however the following analyses continue this exploration.

The second analysis in Section 5.3 comprises a mixed methods analysis of the sample. It first examines the phonetic repertoire within vocalisations (including inventory size, 5.3.1) and phonetic inventory characteristics (5.3.2) to provide a basis for comparing with the existing literature on phonetic inventories. It then examines vocalisations at deeper phonetic levels by considering the vocalic elements (see Section 5.3.2.1) and then the consonantal elements (see Section 5.3.2.2) across infants and palatal groups. These phonetic details combine to provide an in-depth view of the phonetic characteristics and are considered in relation to the other standardised measures throughout the rest of Analysis II. These comparisons are made with vocal motor schemes in Section 5.3.2.3 and then with MBL (5.3.3) and inventory size (5.3.3.1). Lastly, in the second analysis, syllable inventories, or phonetic sequences are explored; Section 5.3.4 explores the most common sequences across infants, and it explores absent patterns too, to assess how sounds are used in combination most (and least) across the vocalisations.

As a result, Analysis II investigates the relationships between the vocalisation variables (namely, MBL, vocal count, consonant inventory size, and vocal motor scheme repertoire) and highlights whether there was interaction between MBL and consonant inventory size in the data. As such, Section 5.3 reveals the relationship between the consistency at which consonants were produced, and the size of phonetic inventories at 14 months, in addition to what the results looked like through different palatal ages. It demonstrates findings in relation to Hypothesis 2 regarding the later to emerge sounds, as well as mixed outcomes in relation to the literary findings.

The third part (Analysis III) considers the vocalisation data in relation to sequential features of vocalisations. It explores the patterning of sound categories to build a detailed, phonetic profile of the sample's vocalisation patterns. The first part of Analysis III considers sequential elements in turn: Section 5.4.1 analyses consonant and vowel harmony, which is an indicator of articulatory coordination and systematicity; Section 5.4.2 explores the phonetic sequences of vocalisations, and specifically analyses the combinations of sounds across mono-, bi- and tri-syllables. The second part of Analysis III considers these elements in relation to the variables highlighted as influential in Analyses I and II, including MBL scores (5.4.2.1), and palatal age (5.4.2.3). Lastly, Section 5.4.3 introduces and analyses the entire data set of vocalisations using transitional probabilities, which is also considered across MBLs and palatal ages (5.4.3.1 and 5.4.3.2 respectively) in order to analyse the larger scale trends across these categories to reflect on which typical vocal stages the ICPs' vocalisations resembled most.

Analysis III considers whether any of the sequential features of vocalisations varied with MBLs and provides potential explanations for the revealed sound combination patterns. It also reveals how systematic the productions were and compares this aspect to typical production patterns. This final analysis assesses whether transitional probabilities could be valuable for visualising the details from vocalisation transcriptions and encourages this method for revealing new insight into production patterns of ICPs following repair.

Following the analyses, in Chapter 6 is an interpretation and elaboration on the results; it critically discusses the findings from the analyses and presents potential explanations for them. Specifically, it examines the results in line with the three subsidiary research questions in turn (6.1.1, 6.1.2, and 6.1.3) and then it addresses and fulfils the main research question (see Section 6.2). The findings motivate discussion about whether phonetic measures of babble may be a rich tool for predicting and/or recognising production milestones in ICPs. Such insight could be valuable to parents and therapists for considering intervention at earlier ages than current provisions have targeted so far. The discussion also explores whether and why the phonetic elements found may have occurred and compares the results to the typical patterns of development, particularly regarding a high and low presences of sounds and sound combinations. The discussion provides evidence on how ICPs' vocalisations could be explored using standardised measures, for instance, the use of vocal motor schemes, and what this may mean for the presence of mechanistic processes in ICPs that may occur in the typical trajectory, too, even though such behaviours occur at a delayed rate.

Lastly, Chapter 7 acknowledges and reflects on the limitations of the thesis. Informed by the entire research process, the chapter acknowledges the mitigation strategies made by research choices as well as recommendations for future research. Finally, the Reflections offer a conclusion to the whole thesis. As a whole, this thesis ratifies the central research and aims to give a deeper understanding of the potential ways that production difficulties emerge (and maybe even persist) in infants following successful CP repair.

# 2 Literature Review

This chapter critically reviews linguistic and clinical literature, both of which contributed to the overarching research questions and methodological processes. It presents a series of sections (between 2.2 - 2.4) which come together to reveal and demonstrate the research gaps (see Section 1.1). It critiques literature on the typical trajectory of infant vocal development, on the medical timeline of ICPs, and on what is currently understood about this populations' vocal development (pre and post repair). More specifically, it explores how vocal production behaviours advance across the first two years of life, to set a baseline for comparing similarities, differences, and absences that may be evident in the pre- and post-repair vocalisations of ICPs.

Section 2.1 presents the research parameters that set the foundation and highlight the importance for studying vocal development in this population. Section 2.2 reviews the typical speech trajectory of English-speaking populations through infancy; it explores the processes of sound production, the emergence of vocalisation, and the transition from rudimentary vocalisations to mature vocalisations to early words. This section provides a foundation on vocalisation patterns in early infancy and builds an understanding about what, how, and why patterns may occur; and, further, which of them are most systematic and most idiosyncratic across infants. This foundation will serve to compare the central elements involved in monolingual, English-acquiring babies, and will later be used to explore the prelinguistic (and pre-phonological) patterns of development in this atypical population of ICPs.

Section 2.3 presents the clinical aspects regarding ICPs, such as types of CP as well as the medical repair timeline in the UK, and Section 2.4 reviews what is currently understood about how they begin to vocalise (both before repair, without repair, and after repair) and what is known about how well these infants map onto the typical trajectory. Section 2.4.5 presents the timeframes and goals that therapy practice aims to meet, illustrating some of the long-term difficulties that ICPs face as well as the common 'errors' that earlier therapy practices target. Finally in the chapter, Section 2.5 provides the research context which is a culmination of responses to the reviewed literature, which include the research questions and three hypotheses that are informed by this chapter.

## 2.1 Research Parameters

The first months and years of life are fundamental in typical vocal development and later speech advances (Oller, 2000). The vocalisation patterns that occur through early infancy are the first instances in which babies use purposeful oral production; the vocalisations they produce develop from (and potentially before) birth and undertake a variety of forms over this timeframe. Longstanding literature documents vocal patterns and developmental stages and provides a foundation upon which to explore how the typical baby transitions from non-speech vocalisations into early word forms. Many such studies view the role of babble as a crucial building block for phonological development (Bruderer et al., 2015; Davis and Redford, 2019; Keren-Portnoy et al., 2010; McAllister Byun and Tessier, 2016; Menn and Vihman, 2011; Vihman, 2017; Zamuner et al., 2018; Cychosz, Munsonc, and Edwards, 2021) and are expanded on below (see Section 2.2).

These persistent production factors can include different severities of atypical patterns that impact the end state of atypical vocal features and, further, interaction opportunities. For instance, these difficulties can have impacts on verbal communication and intelligibility in 17- to 37- month old toddlers (Frey, Kaiser, and Scherer, 2018) as well as later in childhood development (Murray et al., 2008; Shaw et al., 2019), including how conversation partners perceive their speech: twenty percent of 5-year-olds' speech was evaluated as extremely challenging to understand by naïve listeners (Sell, Harding, and Grunwell, 1999). There is plenty of work, too, illustrating that these production difficulties (including substitutions, glottalisation, misarticulations, etc) persist into adulthood (Wren, 2017, Southby, 2021), impacting the 'final state' of speech features as well as social aspects (Chetpakdeechit et al., 2009). Collectively, these long-term findings have not explored the prior stages as extensively. As such, the existing literature encourages further linguistic research to better understand what explanations could be behind the characteristics of ICPs, including their persistent speech difficulties, and to provide a clearer indication of why they occur despite successful repair of the palate.

## 2.2 The Typical Trajectory

This section reviews typical vocal development in early infancy. It explores the process of sound production, at the articulatory level, the typical emergence of vocalisation, and the transition infants make from babble to first words. This section elucidates key definitions for and stages of vocalisation to provide a foundation for comparison with the output sounds of ICPs, which are expanded on later in relation to typical infants (see Section 2.4).

### 2.2.1 The Process of Sound Production

The process of sound production involves three biological systems: respiration (in the chest), phonation in the throat, and articulation in the head (Collins and Mees, 2008, p. 30). The initiation, development, and execution of movements are largely understood under the term phonetics, where speech sounds are considered as physical things that humans produce (O' Grady, 2013, p., 2). This section lays out the process of how sounds are typically produced, it then speculates how productions may be altered for atypically developing infants to hypothesise what and where production difficulties and compensations infants may encounter in the present study.

In the respiration phase, air is taken into the lungs and diaphragm, and the air is pushed through the oesophagus. Once the airstream reaches the vocal folds, if the vocal folds are apart, the sound is voiceless, however, if the vocal folds are close or resting together the sound is voiced and this is where the phonation stage occurs (Collins and Mees, 2008, p. 32). Once the airstream is (or is not) phonated–or vibrating–it reaches the articulation phase, whereby the major articulators (from the glottis to the lips and nose) are responsible for producing a range of different sounds (Kent, 2021). During this articulation phase, the airstream is interrupted and depending on where and how this interruption occurs determines the type of speech sound generated (Wayland, 2018, p. 9). Different organs of speech cause this interruption, and they are divided into the passive articulators (which remain mostly still) and the active articulators (which move) during articulation. Figure 2.1 depicts the positioning of these articulators in the speech organs.

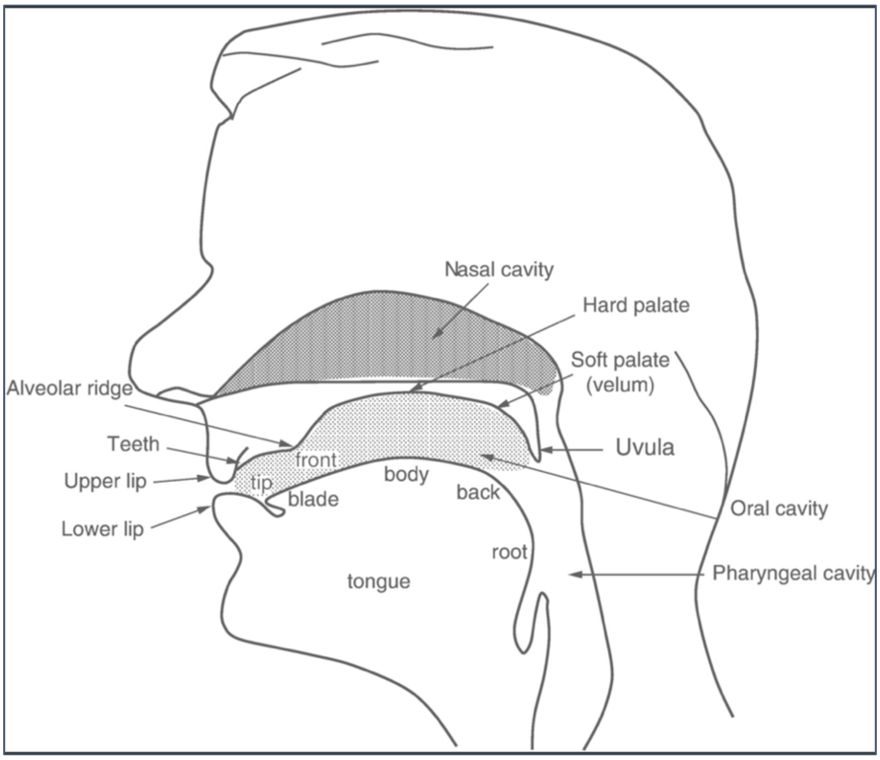



*Figure 2.1: Diagram of the Passive and Active Articulators (from Wayland, 2018, p. 7)*

During consonant productions, the still, passive articulators (alveolar ridge, nasal cavity, hard palate, soft palate, oral cavity, and pharyngeal cavity) interact with the active articulators (the lips, teeth, and tongue) to provide a place of articulation. To continue, sounds are described by where they are produced; Figure 2.2 illustrates details of the passive and active articulators, which move together to create speech sounds. These placements include the following (from front to back of the) articulatory areas: bilabial, labio-dental, dental, alveolar, post-alveolar, palatal, velar, uvular, pharyngeal, glottal (Schwartz et al., 2012).

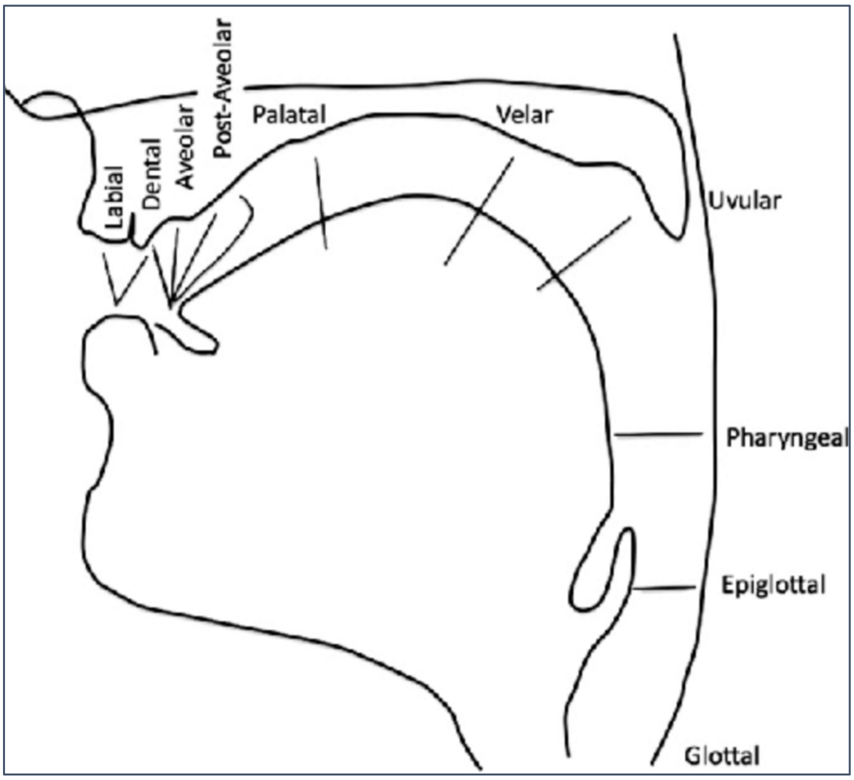



*Figure 2.2: Diagram of Placements of Articulation (from Schwartz et al., 2012, p. 14)*

Additionally, by phonetics it is important to describe the different ways that sounds are produced. This is widely referred to as the manner of articulation and involves the way that the airstream is interrupted to generate a consonant. Specifically, these categories in English include stops (the complete closure caused by the contact between two articulators), fricatives (the narrowing of space between two articulators resulting in a turbulent airstream), approximants/liquids (the approximation of two articulators, with no friction in the airflow). Stops themselves are subdivided into oral and nasal consonants. In the case of nasals the velum is lowered allowing air to flow through the nasal cavity despite the stop in the oral cavity (Davies and Kirkness, 2003). There is a physical distinction between oral and nasal stops. Throughout this thesis, the term 'stop' is used to mean the 'oral stop' and does not merge nasal stops into this category. Nasals are categorised throughout the thesis as nasal stops because nasal stops, taps, approximants and glides exist across many languages (Ohala and Sole, 2008). In summary, while being continuous sounds, all nasal consonants are -continuant; this is owing to the stopping of the mouth (see Mielke, 2008, p. 53, and pp. 73-77; Gussenhoven, 2017, p. 80; and Chomsky and Halle, 1968, p. 33). In cases where more than one sound occurs simultaneously (like when the stop occurs with a fricative in a simultaneous movement), this is known as an affricate.

During vowel production, the tongue is the only active articulator, and the phonation setting is voiced. Different formations (or placements) of the tongue in the oral cavity are altered to change the airflow in the articulatory system resulting in different vowel sounds (or resonances). The categories of vowels, similarly to consonants, are therefore determined by a range of tongue placements, but specifically are understood along two axes: front to back and open to close. Figure 2.3 captures three vowels at the end of both, labelled axes (/a/, /i/, and /u/) and these three realisations are often referred to as the corner vowels.

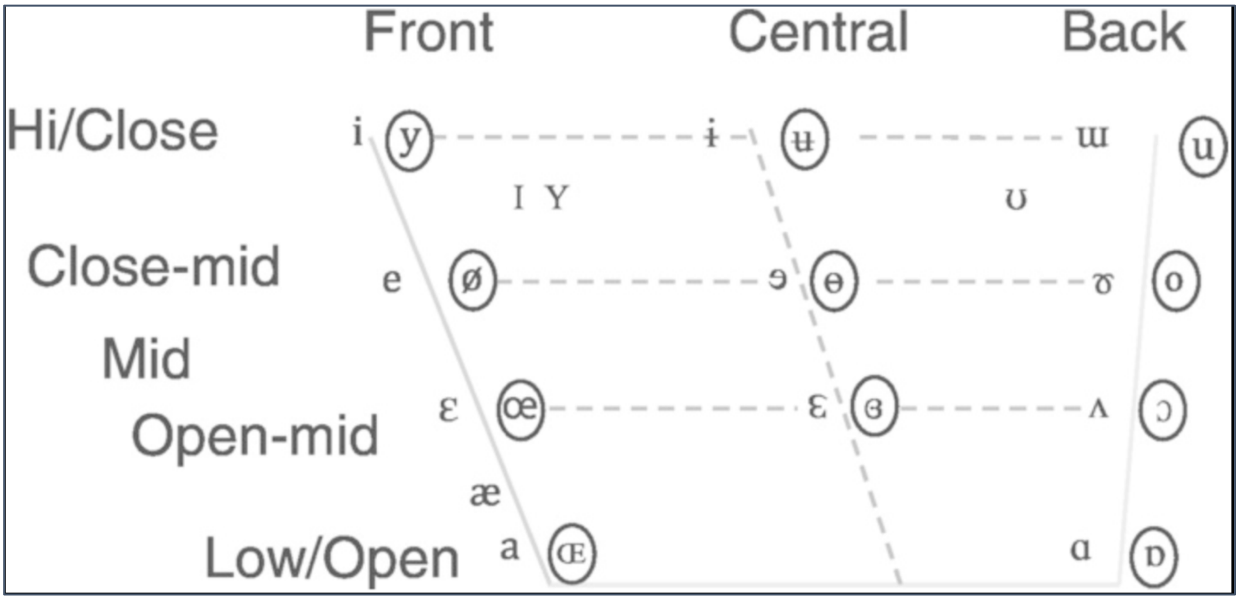



*Figure 2.3: Diagram of Vowel Categories (from Wayland, 2018, p. 27)*

The circled symbols on the left-hand side of the line illustrate that the lips were spread during articulation, those on the right illustrate that the lips were rounded, both settings impact the articulated vowel quality. During the articulation of vowels, the airstream is continuous, meaning that more than one vowel can be produced after another (for instance, a diphthong /ei/ which consists of a front, close-mid vowel, followed by a front, close vowel). Both vowel and consonant productions can be analysed at very fine phonetic levels using acoustic analyses and information on analysing sounds at the wave form level are given in relation to the pilot research (see Section 3.1.1.3). The options for vowel productions have numerous combinations along the two continuums, and the options for consonant productions are many. The range of sounds humans can make also include consonant gestures (such as trills and taps) and more vowel combinations that are not reviewed here because they are not meaningful sounds in English. In sum, in speech, these consonants and vowels comprise an inventory of clear and recognisable speech sounds. As such, there are a finite selection of consonant and vowel articulations largely defined by their belonging to a specific language system. Together, they form a variety of recognisable syllables, which are categorised by their resonance and formation during production. Section 4.2.1.5 provides a thorough description of how infant syllables are defined through the present thesis, including details of their phonetic composition, along with the timing of transitions between consonant and vowel elements.

The definition of non-speech sounds, by extension, can be understood as those sounds that fall outside of these parameters. However, some are more relevant to rudimentary and emergent infant productions, which include articulations not realised with recognisable production quality (during the manner of respiratory and/or phonation phase (Iverson, 2010, p. 233). These sounds—including reflexive vocalisations, coo and goo vocalisations, and vocal play vocalisations—are often deemed to be protophones (Bloom et al., 1993, Oller, 2000, Laing and Bergelson, 2020), which also fall under the category of non-speech sounds. These vocalisations occur in the run up to canonical babble and are largely referred to as proto-words and pre-linguistic sounds, which indicate that they have resemblances with the sounds of a language (including language specific vowels and consonants) but are not mature enough to be deemed speech sounds.

### 2.2.2 The Typical Emergence of Vocalisation

Literature documents variability across individual infants as to which speech sounds and early words are typically produced first (Vihman and Keren-Portnoy, 2013). Despite this variation, across studies there is systematicity regarding the vocal structures that emerge earliest and the forms they take (Stark, 1980, Oller, 2000, Nathani, Ertmer and Stark, 2006). These forms are organised in stages and loosely attributed to a period of months rather than exact, chronological ages, and this appears to be the most logical and constructive way of categorising the vocalisation staged. While this approach complicates how straightforward it is to compare an individual's development with the exact, typical monthly timeframes, it provides a reasonably comprehensive order and shape of stages to compare with, which is presented next.

The earliest stage to emerge in infant vocalisations is **reflexive vocalisations,** which includes crying and fussing sounds that indicate discomfort (Oller, 2000). These vocalisations are fixed to non-speech categories (Nathani, Ertmer, and Stark, 2006): non-verbal vocal expressions (such as crying, laughter), and vegetative sounds (such as burps, hiccups, etc.), including others (e.g., grunts) which subsequently disappear altogether (Oller, 2000). These are innate, non-speech sounds which do not depend on the environment or social reinforcement (Long et al., 2020) and are perhaps most universal as they are present across most infants. These reflexive vocalisations typically occur between 0 and 2 months of age; they signify the earliest stage of vocal output and combine vital processes for respiration and phonation development (Iverson, 2010, p. 233). The processes include anatomical matters because reflexive productions, such as crying, require the control of air flow and breath, alongside voicing and pitch and also require coordination of the respiratory and laryngeal systems (ibid). Such movements are necessary for speech production, therefore reflexive vocalisations offer an opportunity for early motoric learning and musculature control in the first stage of vocal development, despite being inherently non-speech-like.

The reflexive stage is proceeded by **cooing and laughter vocalisations** (at 2-4 months)**,** which are the sounds first produced in pleasurable interaction with another but may subsequently be elicited in situations that do not involve interaction. The features of these early vocalisations have been described as ‘protophones’ (Oller, 2000), a term which is now commonplace in vocal development literature (e.g., Ramsell-Hudock et al., 2019 and Werwach et al., 2021). These protophones primarily consist of vowel-like vocalizations with high instability and high variability (Bloom et al., 1993, Laing and Bergelson, 2020, p. 5). Originally termed ‘quasivowels’ by Oller (2000, p. 187), in the first months, these vowel-like protophones comprise several vocalization characteristics-including pitch range and acoustic resonance-and progress along a continuum becoming more speech-like (in resonance and clarity) towards the end of the first year of life. The high variability documented at this vocal stage can be measured in relation to the patterns of vocal fold vibration and involves three main categories: vowel vocalisations (or ‘vocants’), produced at mid-pitch-or in other words a baseline/resting pitch range-for the infant (Buder et al., 2008); squeals, produced at twice or more as high a pitch to mid-pitch; and growls, produced at least twice as low as the resting-pitch (Jhang and Oller 2017, p. 3, Stark et al., 1975). The combination of these three vocal settings marks a shift from protophones, as there is experimentation from a baseline (mid-pitch) in growls and squeals, indicating the first instances of potential vocal exploration.

Cries are also very common in these months, but the ratio of cries to protophones declines in the first year (Oller et al., 2021, p. 4). Unlike reflexive vocalisations, there is a more explicit functional difference to cries and laughter, which are captured by inherently negative (cry) or positive (laugh) noises (Jhang, and Oller, 2017, p. 1). Consequently, these two non-speech-like signals exemplify the first instances of vocal production as a consequential form of communication, as the infant produces a noise to the effect of an environmental response, and it marks the potential shift from innate animal-like sounds, to intentional, communicative ones.

However, while cries and laughter indicate communicative function, in this stage it is likely that the other protophones do, too (e.g., squeals). Experimental research from three 20-

minute interactional contexts (free play with caregivers, feeding time, and solitary time) found that, between 2 and 4 months, the amount of protophones a child uses tends to substantially outnumber cries and vegetative noises (Nathani, Ertmer, and Stark, 2006). One speculation as to why protophones are used substantially more than vegetative and cry vocalisations is informed by Jhang and Oller (2017), who present empirical motivation for protophones being functionally flexible in a way that infant cries and laughter are not. While the function (or affect) of crying and laughing are deemed inherently positive or negative (p. 3), the higher frequency of non-cries suggests a spontaneous nature to vocalisation behaviours because, unlike cries, they signal a more purposeful, flexible instinct to vocalise rather than solely to indicate the extremes of (dis)comfort.

A further motivation of vocalisations being spontaneous and intentional is that across the entire first year, babies produce these non-linguistic protophones in social environments as well as when in non-interactive environments (Locke, 2006, Elbers and Ton, 1985, Vihman et al., 1985). Protophones have consistently stable vocalisation rates, regardless of whether the infant is alone or interacting with an adult (Laing and Bergelson, 2020, Oller et al., 2019), indicating them to be an inherent vocalisation process. Given that babies produce these sounds in flexible environments (also see Locke, 2006, Elbers and Ton, 1985, Vihman et al., 1985), it becomes apparent that—at as early as the first months—pre-canonical vocalisations serve many preparatory functions. One difference when considering the intention of these vocalisations is that, unlike growls and squeals, signals from cries and laughter indicate properties of communicative function as well as spontaneity and even an ‘endogenous nature’ of vocal exploration in infancy (Oller et al., 2019, p. 5). Together, the above two stages of pre-canonical (reflexive vocalisations and cooing/laughter) protophones serve as precursors to speech (Jhang and Oller, 2017, Laing and Bergelson, 2020), because they involve exploration of closing and opening the vocal tract to create intentional sounds (as reviewed by Section 2.2.1) rather than purely reflexive ones. Despite their rudimentary, articulatory form, they initiate a foundation necessary for the subsequent, pre-lexical vocal stages.

The next stage is **vocal play**, which emerges between 3-/4- and 8 months. The distinction between (the earlier introduced) cooing and laughter and vocal play is when a difference can be made between the phonetic properties, rather than non-speech functional properties, of vocalisations. This shift is evident prior to 6 months when vocalisations begin to exhibit distinct acoustic differences from each other (Papaeliou, Minadakis, and Cavouras, 2002, p. 311). Such contrasts may illustrate the first instances where infants differentiate speech like elements in their rudimentary, protophone vocalisations, because more minor changes are made to the outputted phonetic contrasts during this stage.

To continue, vocal play is described as when the typical child gains increasing control of their oral and laryngeal articulatory mechanisms (Vihman 2014, p. 86). Also termed the 'expansion stage', this is when speech-like (consonantal and vocalic) elements begin to occur, but do not yet form into syllables akin to adult speech in their durational aspects or particular articulatory features (Nathani, Ertmer, and Stark, 2006). Vihman (2014) proposes that this 'marginal' babbling emerges in the vocal play stage when vocalisations begin to be comprised of consonant-like features, which are produced through a constriction in the mouth or pharynx, and nasal murmurs (Ramsdell-Hudock et al., 2019). As such, it is within this stage, that the acoustic properties of the ambient language begin to emerge. Such consonant-like features in vocal play are identified as immature, quasi-resonant vocalizations, with no clear consonant closure in the oral cavity (Oller, 2000). For example, consonant-like vocalisations include raspberries (or voiced and voiceless bilabial fricatives), which are not part of the English phonemic system) and frication noises, which are more messy and immature (p. 187). Infants will not have been exposed to these phones in the same way, though they are likely to be present during 'play' with a caregiver.

In addition, vocal play is composed of exploratory features, such as extreme variations in loudness (e.g., yells and whispers) and pitch (e.g., squeals and growls) contours, and vowels that are produced using a wide variation in tongue height and tongue position for vowel production (ibid). Vocal play denotes a period of simple articulation emergence. While consonants are not articulated with consistent clarity, and vowels lack full resonance within the oral, nasal, and pharyngeal cavities in this stage, there is an emergence of syllable structures here (Ramsdell-Hudock et al., 2019) in that the transitions between the consonant closure and peak resonance of the vowel are more rapid and audibly speech-like. Despite their irregular timing in the opening and closure of the consonant- and vowel-like segments, this process illustrates a progression in the planning and coordination of consonantal and vocalic elements, prior to the stabilization of syllables, but mark a more speech-like nature that goes beyond grunts and squeals.

Following the more expansive vocal play stage, a more uniform and universal stage of vocal production typically occurs whereby vocalisations become more consistent, stable, and speech-like. **Canonical vocalisations**–frequently known as canonical or reduplicated babble–involve the emergence of simple, duplicated vocal forms. Oller and Eilers (1988, p. 441) describe this phenomenon as the controlled production of repeated sequences, such as /bababa/

and /dadada/, and illustrates a critical milestone in which infants first produce 'mature phonetic sequences' (p. 442). Despite some disparity on the measurability of canonical syllable quantities (Stark, 1980; Roug, Landberg, and Lundberg, 1989), many studies agree that canonical babble typically emerges between 6 and 10 months of age (Elbers, 1982; Ollers and Eilers, 1988; Fagan, 2009) and consists of native consonant and vowel combinations (Nathani, Ertmer, and Stark, 2006). Canonical vocalisations include clearer articulations of constricted consonants, fully resonant vowels, and timely transitions between consonants (Ramsdell-Hudock et al., 2019). As such, it is in this stage that vocalisations begin to consistently have the mature timing of adult speech and sound closer to adult words in the native language.

Canonical babble emerges suddenly and exemplifies a marked change from previous vocalisation stages. It is a better indicator of later speech and language development than chronological age (McGillion et al., 2017) due to the variability of the individual child's vocal timeline (Vihman, 2016). The influence of pre-speech vocalisation on later advances demonstrates the significance of the onset of canonical babble in vocal development. The canonical stage reflects development in vocalisations which are not age dependent, or in other words, vocal progress is considered on an infant-by-infant basis and does not assume progress or 'success' using age. During canonical babble, infants exhibit more purposeful control of their articulators, with productions that have higher stability and rhythmicity. These vocalisations are inherently more 'speech-like' than pre-canonical vocalisations, the characteristics of which are determined by the clarity of consonant-vowel units (distinguishable from placement of articulation and voice onset time).

Another identifier of canonical babble is the idiosyncratic 'preferences' within vocalised consonants, and these manifest in the re-use or repetition of individual-specific vocal structures. This preference is mostly referred to in relation to the VMS measure (established by McCune and Vihman, 2001); it involves the stabilization of an infant's early consonant inventory (its validity as a measure is expanded on later in Section 4.3.2.4). Individuals' preference for repetitive, simple syllable structures is compellingly systematic across infants and is evident from similarities across their first, speech-like syllables, e.g., simple, stop + vowel combinations, such as /ba/ and /de/ are often alike in the visibility (and accessibility) of early-produced consonants, e.g., fronted articulations such as /mi/ rather than /ka/. The purpose of such systematic production is twofold, it is beneficial to solidifying the rehearsal of speech-like units before first words, and resourceful for extending phonetic skills onto early word production/learning, which is expanded on in Section 2.2.3.

The canonical stage is widely understood to be a platform for progressing to more advanced, variegated forms that have wider vowel variation, more consonant complexity, and a more adult, speech-like style when produced. Known as **variegated vocalisations** (or variegated babble), the subsequent stage involves babbled sequences that are composed of a change in vowel and/or place of articulation (PoA) across the vocalisation (Smith, Brown-Sweeny, and Stoel-Gammon, 1989, p. 178), e.g., /badagi/ and /dibaga/. This vocal stage typically emerges around 6-12 months. It is widely documented that this variegated babble emerges with more stability as canonical vocalisations subside, even though some variegated vocalisations do emerge during the canonical stage (Fagan, 2009, Oller, 2000). Productions at this stage consist of a series of segments (consonant-like sounds, and vocalic elements), which start to resemble the syllables in adult speech, particularly in relation to their 'durational aspects' and 'articulatory features' (Ramsdell-Hudock et al., 2019). In this stage of babble, vocalisations are characterised by their structural form: multiple consonant-vowel (CV) syllables occur, whereby each segment is perceived as contrasting to the surrounding ones. As such, it resembles speech more closely in its timing than the vocal behaviours found in any previous stage (Ramsdell-Hudock et al., 2019) and vocalised structures are more complex as a result (Kent, 2021).

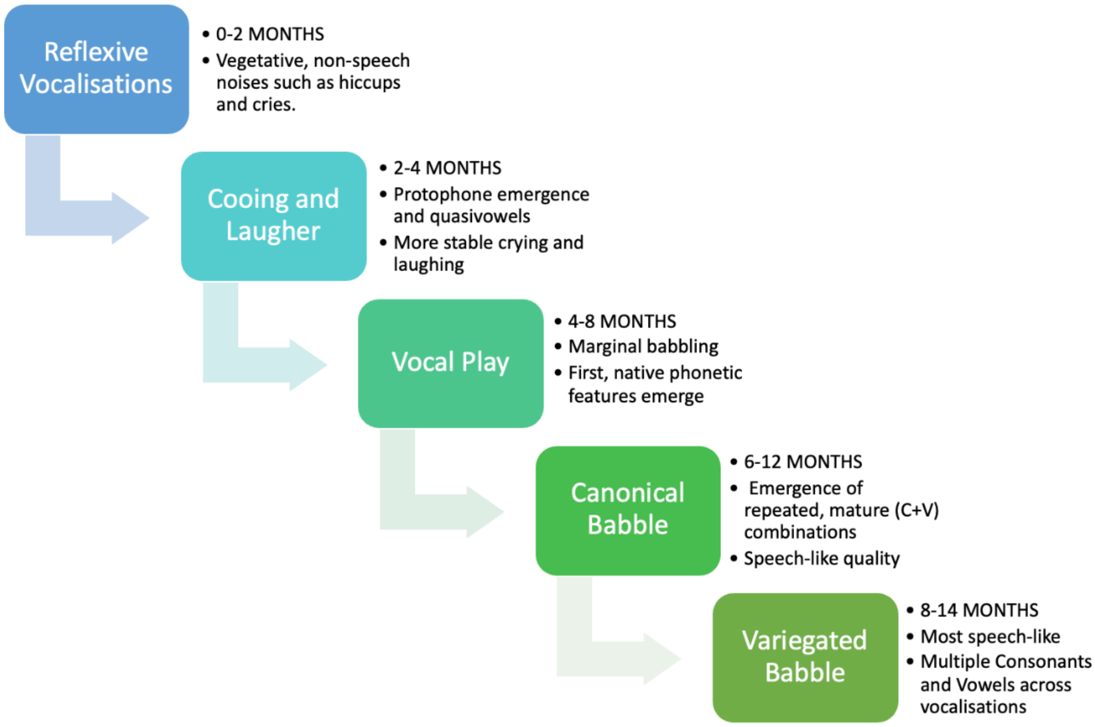



*Figure 2.4: Chart of The Typical Pre-Lexical Vocal Development Stages*

The above five vocal stages (see Figure 2.4) typically occur before first word forms emerge. There is wide agreement on the vocalisation stages as well as the order they appear across infants, and there are cross-linguistic consistencies, too (Oller, 2000). Such universality reflects maturation of what sounds are and are not possible to produce given their physical and cognitive stage. Another universal aspect in which infants appear systematic in their vocal development through infancy, is in infants' perceptual development, which develops through the same timeframes summarised in Figure 2.4. Infants can discriminate phonemic contrasts from a very young age, and experimental studies have demonstrated this (i.e., in head-turn procedures, looking while listening paradigms, and eye tracking experiments). In (and potentially before) the first year of life, infants are sensitive to native and non-native phonetic contrasts (Sawusch and Jusczyk, 1981, and Werker and Tees, 1999). For instance, 4- and 6-month-old infants were able to discriminate subtle phonemic contrasts (Sundara et al, 2018, p. 62). In addition, between 6 and 8 months, infants are attuning to the detailed phonemic contrasts of their native-language phonemes, and these perceptual sensitivities influence and enhance early language development (Kuhl et al., 2006).

Following this phonetic sensitivity, and between the 7-17-month age range, infants transition from a stage of sensitivity to phonetic details in syllables towards a stage of reorganization of phonetic information. In this perceptual stage, infants demonstrate more difficulty discriminating phonetically similar words (Ma et al., 2020., p. 2), which is a process that happens simultaneously across the babble production timeframes summarised in Figure 2.4.

The development of perception emerges alongside pre-linguistic vocal production and both processes exemplify sensitivity to native phonetic contrasts. The systematic likeness of infants' perception and production of vocal structures at and up to the 14-month age also foregrounds how important the rehearsal of repetitive and integrated processes is in this timeframe. Both the perception and the production of sounds are important for coordinating skills involved in the transition from syllable-like sequences (in babble) to set syllable sequences (in first words). Section 2.2.3 expands on the transition from babbling to producing first words. It foregrounds the importance of these production stages and explores theories on how infants progress to first words in case it is in the progression to (or from) canonical syllables where ICPs struggle.

### 2.2.3 The Transition from Babble to First Words

The progression that infants make to the production of early words is now understood to be entirely related to their pre-linguistic, babbled forms. Indeed, Elbers and Ton (1985) present that babbling features are composed of the 'preparatory forms' necessary for the selection and production of accessible first words. Consequently, a foundation on first word characteristics provides a valuable foundation for understanding pre-linguistic vocalisations, as it provides a benchmark of what is needed to progress to the next steps. While research used to view babble as entirely unrelated to first words and early speech (Jakobson, 1968), most recent empirical work overwhelmingly favours the opposite conclusion because the original, Jakobson view does not encompass the dynamic, overlapping nature of the development process (Tchernichovski and Marcus, 2014), nor does it align with the overlapping stages of canonical, variegated and first word vocalisations.

To expand, infants' first words tend to be phonetically and structurally like babbled vocalisations (McCune and Vihman, 2001; Oller et al., 1976), which is a finding that appears to be robust across many languages (Oller, 2000). The resemblances between babble and first words, and, by extension, the transition that infants make from babbling to producing their first words, will be explored in this section by briefly describing the characteristics of first words. Then, by presenting how these characteristics are built from the preceding properties of canonical and variegated babble. Together these factors convey the significance of babble as necessary for word and speech production (and development), but further, they underline the need for analysing prelinguistic vocalisation in the present study.

The phonetic properties of early words can be described at a narrow level to include 'differentiating features' and, as such, help to define the systematic distinctions between early word forms (Elbers and Ton, 1985, p. 559) and variegated babble across infants. These contrastive features include the articulatory gesture (how a sound is produced), the placement parameter (where a sound is produced), the voicing parameter (whether the vocal cords are vibrating, e.g., /b/ or not, e.g., /p/ during production) and were covered in more detail earlier (see Section 2.2.1). First words rarely include more than one place of articulation within the word (Kiparsky and Menn, 1977, p. 58). Furthermore, the features of first words most often involve stop consonants rather than other manners of articulation, such as approximants and fricatives which tend to emerge later, sometimes not even until the third year (McLeod and Crowe, 2018). Consonants in early words also tend to favour fronted places of articulation (Kent, 2021) and are typically bilabials which are closely followed by alveolars (Elbers and Ton, 1985). While contrasts in voicing can appear in early words, this distinction does not appear to be stable across infants until around or well into the second year (Eilers et al., 1984, Macken and Barton, 1978), and this is especially the case at the end of words (Zamuner and Kharlamov, 2016). In fact, many studies in infant speech development do not distinguish between the voicing contrast to cater for this instability. The distributional properties of these differentiating features help to provide a clearer picture of the sorts of words that first emerge, and the speech sound elements that need to be produced by infants during the earlier vocal stages in order to advance to this first word stage.

To continue, research illustrates that early words often involve consonant and vowel harmony. This phenomenon is when a word includes repetition of the same speech sound across the word, either with the consonant placement (as in /beɪpi/) or the broad vowel placement (as in /kitɪ/). This organisation of harmony within multisyllabic forms appears to be a systematic trait across many infants (Vihman 2016, Elbers and Ton, 1985). First words tend to be formed of consonant-initial structures (Namasivayam et al, 2020, p. 11), and avoid complex consonant structures and complex articulatory gestures such as affricates, (Kent, 2021). Above all else, this use of more stable vocal coordination, rather than the complexity of articulatory gestures also signifies the shift of using vocal production to intentionally communicate about the real world (McNeill, 1970, and Vygotsky, 1962). As such, the measure of preferred consonants in babble provides a good indication of which words are likely to emerge within individual infants from the patterns listed above. By extension, there is sufficient evidence that the phonetic and consonantal features of first words mirror the properties used by infants in the canonical and variegated babble stages. This relationship underlines the significance of researching babble, alongside the value of current vocal measures for better understanding production patterns in infancy.

To summarise, this section highlights that infants typically capitalize on their well-rehearsed structures and from sounds in babble when building their early lexicon (Laing and Bergelson, 2020, p. 2). It also reinforces the value of pre-lexical vocalisation stages in the sense that the rehearsal of accessible, preparatory forms during babble seem necessary for the infant to reach first words and with relatively little effort at that. Additionally, this reuse of patterns foregrounds the stages of development in vocal rehearsal to be necessary for an emergent and consolidating early vocabulary; the distinction between differentiating features in similar-sounding novel words is a key skill required for more speech-like vocalisations. These vocal stages illustrate the phonetic and sequential properties of productions that are required for infants to progress from babble to speech.

#### *2.2.3.1 How Infants Transition from Babble to First Words*

The interaction between babbling and early word stages has been evidenced in long-standing work, for instance by McNeill (1970) who analyses the example of a child producing the form

/nana/ for the word *banana* in the kitchen at home (McNeill 1970, p. 23). What is striking about this first word attempt is that its composition is not novel to the characteristics typical of canonical forms. In fact, it is entirely aligned with prelinguistic, pre-word structures and illustrates the reuse of phonetic patterns that are already familiar to infants from their established babbling behaviours (Laing and Bergelson, 2020, Oller, 2000). At the point of infants' first words, there is a substantial overlap between variegated/canonical babbling with first words. This interplay has been termed 'speech-concurrent babbling' by Elbers and Ton (1985) and is in line with Oller et al. (1976); it illustrates a shift between pre-linguistic–or pre-word–productions and the more precise babbling that occurs simultaneously with first word production. Together, these observed patterns encourage explanations as to what drives this progression.

As was presented in Section 2.2.3, first words appear reliant on the previous, speech-like babble stage. Specifically, in the emergent vocalisation stages, infants are not systematic in their vocalisations: they do not exhibit the 'recombinability' of consonants and vowels to generate variety of sound combinations until the canonical and variegated babble milestones (Oller, 2000). However, this phonetic flexibility aligns strikingly well with the demands of simple first words, given the typical consonant-initial and vowel-final structure of babble (Oller, 1980, Boysson-Bardies et al., 1989, Vihman, 2016, Ramsdell et al., 2012). Its suitability is illustrated by the characteristics of first words, which follow and overlap with the phonetic parameters of canonical babble. These consistent patterns (including stop consonant gestures; frontal articulations; words composed of one consonant segment; consonant-initial, open-ended syllable sequences; and simple consonant forms) indicate that typical infants reach a particular point of resourcefulness with existing production abilities when they utter their first words.

Most theories on infants' progression to first words are composed of grammatical, social, cognitive, and perceptual explanations (e.g., McMurray, 2007), and as a result, many disregard the role of production in the process, which has been illustrated as a key part of vocal development (see Section 1.1 and also Section 2.2.2). This section attempts to grasp how infants engage with the transition. It next presents three key theories (sound-referent links, ambient language effects, and the articulatory filter) that are well-integrated with infants' productions to offer explanations for how infants transition from babble to first words. The explanations provide considerations of how the transition may be impacted for ICPs, the concepts of which are returned to later, in light of the clinical influences in the population (see Section 2.4.4.3).

Goldstein et al. (2010) proposed that the reliance on caregiver feedback was similar to infants' object-directed vocalisations. They found that when mothers responded to infant's vocalisations that related to the attended object with similar sounds, word learning was boosted. Their focus offers mechanistic explanations involving word-object associations and elicited labelling, too, however, it does not consider the individual infants' babble stage or its potential impact. To add, Goldstein and colleagues only placed the distinction on whether they did or did not vocalise, rather than making direct comparisons between the phonetic similarities of the production and the object label. There may be some weight to this relationship as a mechanism for reaching first words, for example, their study foregrounds that the way infants produced sounds impacted the stability of their movements. To continue, infants either produced repeated syllable strings (which resembled babbling processes) or nonsensical, novel words (which were attributed to a clear referent), and the latter revealed greater stability in infants' articulatory speech movements (Heisler et al., 2010, Pettinato et al., 2017). This distinction may mark a shift between the function of babble in the transition to first words, whereby more articulatory effort is given to attempted word forms than babbling.

Ambient language effects offer another possible explanation for the transition from babble to first words. Boysson-Bardies and Vihman (1991) provide motivation for this claim in the language frequency effects observed in infants' first 25 words across different languages. Their study revealed that during the transition between babble and first word production, there were clear differences in the frequencies of manners of articulation (ibid, p. 303). For the English infants, stops were most frequent, followed by nasals, then fricatives, then liquids, which were orders that differed to infants acquiring French, Swedish and Japanese. The explanation foregrounds that early words must rely on forms that are 'abundantly modelled' in the input and also 'motorically accessible' (Depoalis, Vihman, and Nakai 2013, p. 647). Together these studies evidence the importance of ambient language influences, suggesting that familiar words (and phonetic patterns) from the auditory environment are attended to and influential to production qualities across these later vocalisation stages, though these elements are outside this research scope.

The impact of infants' own perception of production is another avenue of explanation. Pettinato et al. (2017) present that stressed syllables in the adult vocabulary (Lieberman, 1960, Kochanski et al., 2005) were more likely to feature in early words. The works present that the production emphasis may be particularly salient to infants and that it was a feature mirrored in their own vocalisations. A growing explanation for vocal advances in infancy that is also based on these salience impacts includes the articulatory filter hypothesis. As proposed by Vihman

(2006 and 2014), the theory foregrounds a crucial link between production and perception in early development, whereby a matching behaviour is facilitated by a 'feedback loop' (Vihman et al., 2014, p. 121). This mirroring process is thought to be triggered by an infant's awareness of their own vocalising, which helps them to map the phonetic resemblances between their own sounds with what they perceive in their sound environment. The filtering process encourages continued production of consonants that are established (or establishing) within an infant's own repertoire.

Indeed, these theories could explain which first words are suitable candidates for infants. These influential features may be based on the word-object labels that are modelled in interaction with caregivers; based on sounds that are particularly frequent in the native, ambient language; or based on their phonetic resemblance with the infants' repertoire, with optimal targets being more salient in the language environment. As such, by the articulatory filter hypothesis, infants attend more to forms that resemble their own productions, making individual-specific word forms especially accessible for their production of first words. However, in order to engage with this repetitive, mirroring process, infants must first have established sufficient resemblances to the adult word forms in their babble. The potential divergences to the typical trajectory, including sounds which are later, partial, or absent in the babble of ICPs may impact the phonetic patterns of their first words. While these theoretical explanations offer insight into the mechanisms that could affect ICPs' trajectory, the direct exploration of these theories is outside the scope of this work as they were not directly analysable by the methodological approach.

In summary, it may be that the composition of first words may sound different for ICPs depending on the clinical influences (explored further in Section 2.4.1) they encounter. Deviations to the typical trajectory, for instance omitted onset consonants in targeted words, modified target words, or a different selection of consonants in the target words could all influence the course of production development.

## 2.3 The Clinical Aspects of Cleft and Repair Surgery

This section of the literature review first gives an overview of the clinical aspects affecting ICPs, including the subtypes of CP, the parameters of cleft care, and then the surgical and healing processes involved. This section sets the foundation for understanding how a collection of clinical aspects may impact this population and is crucial to reviewing the production properties of ICPs in the following section.

### 2.3.1 Properties of Cleft Palate

A CP is diagnosed, either prenatally or at birth, when an infant has an opening in the roof of the mouth; it is a congenital abnormality that impacts the hard and/or soft palate (Fell et al., 2022). A CP occurs across a variety of forms (see Figure 2.5) that are broken down into categories, including whether it is present alongside a cleft lip, as well as the sides of the mouth that it affects (e.g., unilateral, bilateral).

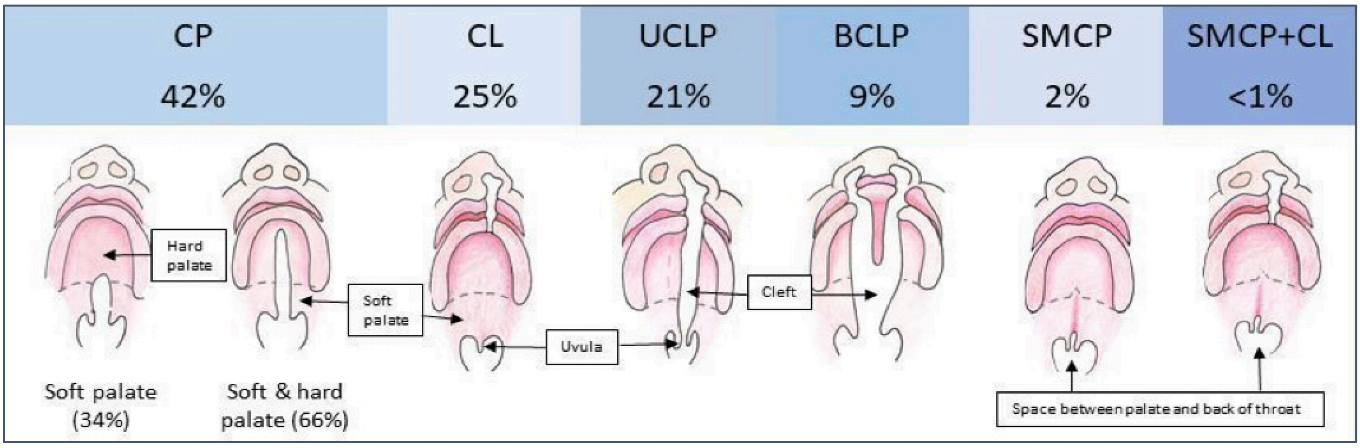



*Figure 2.5: An Illustration of Cleft Types, taken from CRANE Report 2024*

*From left to right, percentages are used to order most to least common: cleft palate only (CP), cleft lip only (CL), unilateral cleft lip and palate (UCLP), bilateral cleft lip and palate (BCLP), submucous cleft palate and lip (SMCP+L)*

Figure 2.5 illustrates some of these varieties, with 'CP' reflecting the participants researched in the present study. The frequency of cleft type was reported recently in national UK statistics and presents consistencies with those from the CRANE Report (2024) and also Fell et al. (2022). The subtypes of cleft include cleft palate, cleft lip, unilateral cleft lip and palate, bilateral cleft lip and palate, and submucous cleft palate and cleft lip. To add, an isolated CP is the most common variety in the UK. Even though CP can impact the soft and/or hard palate, the majority of cases affect both parts of the palate and provide a way of sampling from the cleft subtypes, without grouping all the varieties into one study, which may yield different outcomes. The population of interest in this work is therefore infants born with a CP only, without cleft lip. As such, the subsequent sections will focus exclusively on the clinical care related to children born with CP and will not refer to interventions for cleft lip even though some children born with a CP also have a cleft lip.

### 2.3.2 Parameters of Cleft Care

The nature of cleft care is multidisciplinary and long-term and involves access to a pool of clinical expertise (Sainsbury et al., 2019, Britton et al., 2014). The treatment on offer has improved and centralised more recently, with more consistent surgical procedures adopted, higher use of hearing aids, and overall improved outcomes (Ness et al., 2015, p. 57, Gallagher et al., 2022). Recent research on cleft care also indicates that care procedures are improving in their family-centredness (Pfeifauf et al., 2020), contributing to better outcomes. Cleft care is therefore understood as a collaborative process with guidelines across the UK from standardised disciplines that are agreed to be optimal across countries, too (Frederick et al. 2022, p. 1413).

Care services begin from diagnosis, and are most extensive at the primary, antenatal stage, then at the subsequent stages following the primary surgery. As such, cleft care processes involve monitoring the at-risk aspects of development in this population, primarily concerning psychological wellbeing, speech, and facial growth (Britton et al., 2014, p. 431). Indeed, these medical and surgical needs continue throughout development and care adapts through growth and development in collaborative, comprehensive, and family-oriented ways (Frederick et al. 2022). As such, the versatile nature of cleft care involves services that change depending on what stage of development a child is in (Frederick et al. 2022, p. 1412-1413): feeding difficulties prior to repair; physical growth through infancy; speech through childhood; psychological development through adolescence. To summarise, the parameters of cleft care are involved across the lifespan for those born with clefts, and ICPs rely on a wide selection of clinical services, including specialist nurses, speech and language therapists, psychologists, audiologists, paediatric dentists, restorative dentists, and finally surgeons (Britton et al., 2014, Persson et al., 2015).

### 2.3.3 Surgical Repair

CP repair is clinically termed as *palatoplasty*, which is given to a surgical procedure of repairing the palate and closing the cleft in the mouth (nose and/or lips). The palatoplasty is where the nasal and oral muscles are dissected from the palatal areas and sutured together in the midline of the palate (Doucet et al, 2013, p. 846).

#### *2.3.3.1 Type of Surgery*

While no CP is the same—in size, placement, or shape (Shaw et al., 2019)—the closure of a palatal opening has procedural consistencies across surgeries. Most surgeries use the one-stage method to repair a CP and the most common procedure undertaken in the UK is the *intravelar veloplasty*. In this procedure, the midline of the palate is cut, muscles are moved apart on each side and then pushed back, where the midline is stitched back together into a more transverse direction (Cooper, 2021 and Fell et al., 2022). This type of surgery restores the function of the muscles at the back of the palate, and improves palatal movement (Naidu et al. 2022, p. 3). The intravelar veloplasty is performed in 94% of cases (Fell et al., 2022, p. 8, Davies et al., 2022). The anatomy of CP and surgical characteristics are explored in turn below to evaluate the potential impact that these variables may have on infants' vocal development.

In cleft surgery, there are multiple procedures available to surgeons who carry out CP repair. Studies have illustrated the most common repair procedures and evaluated how effective they are in minimising the impact on speech outcomes. Some of which, notably, found discrepancies in vocal outcomes depending on the procedure, though the outcomes are mixed. One study found that one- or two-stage surgeries do not significantly affect velopharyngeal capacity (Khosla et al., 2008), These studies present that different 'success' rates are likely depending on the procedure adopted as well as the need for any *relieving incisions*. This is a technique using additional procedures on the palate; relieving incisions are carried out during repair surgery to alleviate muscle strain in the tissue which are being moved in surgery and allow space for swelling and healing (Fell et al., 2022).

#### *2.3.3.2 Timing of Surgery*

In the UK, surgical protocols aim to complete entire CP repair by 13 months (Fell et al., 2022), and repair surgery is mostly carried out between 6 and 12 months (Zajac et al., 2021, p. 30). The time of intervention differs slightly across individuals, depending on pre-operative variables, e.g., feeding (Shaw et al., 2019), but the timeframes are by and large the same. As a result, the timeframe of repair surgery is a crucial one in early vocal development, due to the likelihood of the emergence of canonical and variegated babble through these ages. CP surgeries therefore take place at a time in development where many preparatory vocal productions typically emerge, and many factors in the healing and recovery process may also influence the extent of impact on vocalisation behaviour.

The timing of CP repair has potential influences on later outcomes (Willadsen and Albrechtsen, 2006, p. 574). To expand, research from one recent, large-scale study of 558 infants examined whether surgery at 6 or 12 months produced better outcomes at 1, 3, and 5 years (Gamble et al., 2023) in a randomised, controlled trial. The 'ToPS' study focused exclusively on infants with isolated CP who received the same surgical technique, reporting that infants who underwent surgery at 12 months were more likely to have velopharyngeal insufficiency at 5 years than those who had surgery at 6 months (Gamble et al. 2023, p. 799).The study attained longitudinal and cross-linguistic data, from a large sample and comprised a high quality of methods, such as blind analyses, randomised sampling, and 50% of interrater-coded data to explore this relationship between surgical timing and language outcomes.

Despite these strengths, the study provided mixed outcomes. Fell et al., (2024) have questioned the measurements used for velopharyngeal outcomes (p. 2) and pose that the study did not report clear enough evidence for a difference that outweighs potential harm (p. 4). In addition to these concerns, their sampling excluded many variables: the most common UK repair procedure (Davies et al., 2022); wider clefts, clefts which were not operable using the most used techniques; infants with hearing loss; infants with other syndromic diagnoses; all bringing into question generalisability of results to the widest proportion of ICPs in the UK (Fell et al., 2024). Especially given the high potential of such large-scale research, the study lacked transparency in the reporting of variation across exact surgery times, the interference of secondary surgeries, and on the influence of palatal age on outcome measures at 1 year or age, despite a difference on 0 and 6 months between the two groups. While the ToPS research raises these concerns of transparency and generalisability, it does present a large amount of data that points especially to the impact of surgical timing on short term outcomes at 12 months (which are expanded on in Section 2.4.1). Given that earlier surgeries can impact muscle and facial growth, while later ones can impact velopharyngeal function (Abdel-Aziz 2013, Fell et al. 2022.) it is also likely that surgical timing can impact healing and recovery process.

### 2.3.4 Healing and Recovery

The multidisciplinary nature of cleft care following repair illustrates a complex collection of variables that require consideration in research (Mason and Perry, 2016; Naros et al., 2022; Sharp et al., 2017), including surgical differences and success rates. Following surgery, excessive muscular contractions occur, and scar formations take place: this healing process impairs the growth of the bones forming the upper jaw, and the immediate dento-alveolar development (Chitturi et al., 2015). The extent of interference to wound healing was once evidenced as related to the surgeon's skill and abilities (Inman et al., 2005). However, it appears more reliably associated to cleft width and pharyngeal cavity depth pre-op, whereby the time taken to reach full muscle recovery takes longer when the opening is more severe (Skran et al., 2006) and can require relieving incisions (Davies et al., 2022) which may better account for potential individual differences.

Additionally in terms of surgical success rates, Kirschner et al. (2006) reports that up to 60% of CP repairs (that impact the hard palate) have a high degree of complications in the wound healing process. Subsequent to repair, these complications mean that infants acquire a continuous *oronasal fistula*, which is where there is a release of fluid and air through the nasal cavity during speech (Phua and Chalian, 2008). This medical characteristic can appear immediately after surgery or over time as the child grows and the soft palate is no longer able to make complete contact and closure with the pharynx. Although roughly half of post-operative cases of oronasal fistula require additional surgeries and anaesthesia, complete wound healing is reported in 96.5% of those who had the condition (Sakran et al., 2006). This finding is indicative that this complication does not have a long-term impact on most infants, though it does capture interruption to and delay from the optimal post-operative recovery process. Once surgical intervention is complete, the healing process can take place. This involves the contraction of palatal shelf muscles, close of the wound, and restrengthening of the musculature in general (Kirschner et al., 2006).

## 2.4 The Vocal Development of Infants Born with Cleft Palate

The roof of the mouth is an essential component to vocal production and one of the key passive articulators. Given that a CP impacts part of this vocal tract area, research on its impact on prelinguistic articulations is required. First, a review of the way the clinical aspects may impact vocalisation is given is Section 2.4.1. The section is also shaped in light of articulatory phonetics descriptions (in Section 2.2.1) to build predictions about what we would expect to happen for ICPs, based on how sounds are produced anatomically in light of the clinical parameters of CP, including the potential compensatory impacts on their speech sound productions. Third, is a review of the published literature on vocalisations prior to and following repair. As such, Sections 2.4.2, 2.4.3, and 2.4.4 aim to present the existing knowledge on the vocalisation patterns of ICPs, including the predictable vocalisation characteristics in early development. Last, Section 2.4.5 is a presentation of speech therapy, including production impacts in ICPs and therapy goals, to consider the possibilities for treating ICPs' production difficulties sooner. On the whole, this section reviews what is missing in our understanding of ICPs' prelinguistic vocalisations before they reach first words, and whether the composition of babble might help to explain the divergence, atypical redirection of vocal and speech development in this population.

### 2.4.1 Clinical Influence on Vocal Production

From the clinical impacts and articulatory phonetics presented earlier, some relationships and patterns are anticipated in the vocalisations of ICPs. Naturally, the extent of ICPs' speech characteristics relates to where the infant is along the medical timeline (Bearn et al., 2001, Abdel-Aziz, 2013, Fell et al., 2022). Another key association that has been made to speech outcomes in ICPs is the potential for it to occur along with a hearing impairment. Conductive hearing loss is a relatively frequent occurrence in ICPs and further impact production characteristics (Baker et al., 2021). Even though hearing conditions and hearing loss are regularly tested for through infancy, the exact rates of hearing impairment in ICPs are not consistently reported. Hearing status illustrates another avenue that may disrupt these infants' vocal development.

Indeed, Gallagher et al. (2022) report that a majority of infants had comparably typical hearing levels with 14% of 13-month-olds having impaired hearing after surgery. Furthermore, hearing loss may predict lower and later speech levels (Schönweiler et al., 1999, and Hall et al., 2017). To add, hearing impairment can impact canonical babbling at 10 months and may reduce consonant proficiency at 36 months in infants with *and without* CP (Lohmander, 2021). However, hearing conditions are inconsistently reported (Lancaster et al., 2019, Lohmander, 2021). Consequently, the influence of hearing impairment on the current study raises concern for determining the interference it may have on infants who already have one impaired speech faculty to adjust to. As such, the consideration of hearing ability as a sample variable is returned to in Section 4.1.4.2.

Next, in light of the articulatory phonetics descriptions (in Section 2.2.1) and the clinical aspects of CP, we can briefly build some expectations about what we would expect for ICPs, based on how sounds are produced anatomically, keeping in mind the potential impacts to speech sound productions. Many phonemic sounds in English are produced on the palate, with a particular prominence of alveolar and velar articulations realised just before or after the hard palate. Given that a CP most often impacts both the hard and soft palate (see Section 2.3.1), ICPs are expected to have difficulty with alveolar, palatal, and velar articulations due to the impacted palatal area. These infants are therefore predicted to struggle with productions where the articulation involves complete closures using the tip or blade of the tongue, particularly on the alveolar (ridge). Specifically, it is estimated that alveolar (/t/ and /d/) sounds on the alveolar ridge and velar (/g/ and /k/) articulations on the soft palate will have low frequencies or high absences in the data. It is also expected that productions may compensate for the palatal (/j/)

sound near the hard palate, too, due to the production's close proximity to the affected placement of articulation. High pressure sounds, including fricatives and oral stops, are likely to be more challenging due to air and pressure control during articulation. Lastly, vowel placements are not expected to have atypical cooccurrence patterns with consonant articulations because the articulation of vowels relies on tongue placements altering the airflow rather than a forced interruption to it (as is demanded by consonant articulations). As such, many different vowel placements are predicted to occur with all the present consonant articulations in the data. After repair, the potential for creating recognisable realisations of these sounds is newly possible, however, we need to bear in mind that the infants were not familiar with creating the gestures to the same effect pre-repair. To signify whether these predictions hold true for published studies, the impacts documented in ICPs' vocalisations post-surgery are reviewed in relation to these predictions in Section 2.4.4 and then integrated with the established hypotheses (see Section 2.6.1).

Given the predicted delays and weaknesses in the production of certain articulations (for instance, high-pressure, oral articulations and nasals), some sounds are less likely to feature in early words post CP repair. Later (or slower) to emerge sounds are not as dispensable to these infants, and the typical frequency of stops in onset position raises an area that may interfere with the speech concurrent babbling stage. The partial sounds of ICPs were predicted to include palatal articulations and pressure consonants, which may be unstable productions post-repair. Both of these divergences to the typical suggest that these infants could have difficulty producing first word forms with the typical characteristics. An alternative impact could involve compensatory articulations: it might be that when infants intentionally aim for a more complex form, they utilise more basic forms, revealing a typical mechanism in the transition to first words, (Boysson-Bardies and Vihman, 1991) and thus further limiting their options for first words. If oral consonants are much slower to emerge in ICPs, then target first words may be only part of the typical trend, too, or different all together.

The differences between first words and babble in ICPs are therefore highly likely to relate to articulation sequence constraints for producing the target word, as they are already for typically developing infants (Boysson-Bardies and Vihman, 1991, p. 315). However, the impact on the phonetic composition of words will greatly depend on the infants' own production repertoire (including late, partial, absent, and compensatory articulations). The potential impacts of a CP on infants advancing from babble to early words is considered in the discussion, in light of the present study's vocalisation outcomes, even though the direct analysis of first words is outside the scope of this work

### 2.4.2 Emergence of Vocalisation Pre-Repair

ICPs experience vocal challenges observed from birth, and such difficulties are present at least until repair is carried out. For example, 2-month-old ICPs with orofacial anomalies had a significantly higher occurrence of melody breaking (i.e., interrupted pitch and airflow during cries and reflexive vocalisations) when compared to typically developing (TD) age-matched controls (Conrad et al., 2021, p. 86). In the study, this vocal impact is attributed to laryngeal constriction and in fact, reveals potential delay to respiratory-vocal control in CLP infants. One possible influence that this anatomical challenge may have on vocal development is a substantial difference in airflow control and rhythmicity. To continue, atypical respiratory abilities could have an impact on articulation not only prior to surgery, but within the first typical vocal milestone (reflexive vocalisations). Early babble requires control of air flow, breath, voicing and pitch, and the coordination of respiratory and laryngeal systems (Iverson, 2010). These movements facilitate early motoric learning and musculature control, which is known to be important across many months in vocal development (Stoel-Gammon, 2011). If indeed melody breaking is due to laryngeal constriction alone, its anticipated impact on vocal development is expected to change following repair, as it will diminish.

Despite variability across reported early speech abilities of these infants in the early months (e.g., Scherer, 2008, Willadsen, 2012), there is agreement on some patterns pre-repair that deviate from the typical trajectory. For instance, Chapman et al. (2001) and Stout, Hardin-Jones, and Chapman, (2011) showed that 8-10-month-old infants pre-repair have limited articulatory range and produce fewer consonants than TD infants at the onset of canonical babble, e.g., typically alveolar stops are rare. While it is unsurprising that the vocalisations of ICPs were articulatorily restricted (or better, redirected) in this way, the studies reveal no significant difference in the frequency of analysable productions. That is, the vocal rates of CP 9-month-olds were not significantly different to the babbling patterns of typically developing, age-matched controls. As such, the finding highlights how universal infants' desire and/or compulsion to babble is (Nathani, Ertmer, and Stark, 2006), despite having reduced vocal apparatus available and despite the likelihood of having a less stable and less varied vocal repertoire between 8 and 10 months old.

Indeed, it may be that before repair, ICPs are longer in the reduplicated babble stage for production connections and necessary learning to occur without difficult movement. These studies put forward collective evidence that when the anatomy is atypical (prior to repair), infants will still use the articulatory resources available to them to achieve some form of regular, rudimentary vocal behaviour when compared to their TD peers, which is an important, healthy process to keep them developing and interacting. Yet, group differences remain between vocalisations of CP pre-repair and TD infants.

To continue, research foregrounds a difference in the composition and phonetic structure observed in pre-repair vocalisations. First, Willadsen and Albrechtsen (2006) revealed structural differences in the produced concoids (closures in the oral cavity) in the vocal repertoire of ICPs pre-repair and observed that more nasals and fewer alveolars were used by 11-month-olds, along with fewer high, front vowels–or vocoids–than TD infants, which is consistent with Stout, Hardin-Jones, and Chapman, (2011). A smaller frequency of high-pressure consonants, including oral stops were also observed in the prelinguistic stage by Chapman et al. (2001) indicating that the restrictions to sound repertoires are greatly consistent across individuals. While these pre-repair patterns raise the possibility that the vocal features may reflect an earlier stage in the vocal trajectory, both studies also found no crucial difference between TD infants and ICPs in relation to reaching a form of canonical babble. Together, the studies again present that the phonetic composition of ICPs' syllables could be where the contrast to the typical trajectory lies.

In a recent study, Ha and Oller (2022) found that 7- to 9-month-old Korean-speaking ICPs produced significantly fewer true canonical syllables pre-repair than age-matched controls. While we know that crosslinguistic similarities exist across babble (e.g., Peute and Casillas, 2022), the comparability of babble to the typical trajectory is likely to decline between 7-17-month age range due to a decline in the ability to perceptually discriminate non-native phonemic contrasts. This phenomenon is known as perceptual attunement and is marked by increased or maintained sensitivity to native phonetic contrasts and a decrease in sensitivity to non-native contrasts (Polka and Bohn, 2011), consequently, infants exhibit more difficulty discriminating such non-native phonemic contrasts (Ma et al. 2020, p. 2) in this timeframe. Perceptual attunement happens around 4-6 months for vowel categories, and around 10-11 months for consonant categories (Kalashnikova and Carreiras, 2022), therefore this timeline is interrupted in the pre-repair vocalisation process and could have implications on the productions of ICPs.

While Ha and Oller's finding on Korean-acquiring infants raises an immediate question of cross-linguistic generalisability to monolingual, English infants, it foregrounds a striking difference in the syllable composition of the infant vocalisations pre-CP repair. As such, it mirrors Jones et al. (2003) and suggests a pattern that deviates from the dominant CV (i.e., a consonant articulation followed by a vowel articulation) pattern in the typical trajectory (see 1.1

for details on this). It also highlight a need for deeper phonetic consideration (an aspect addressed by the current research). As a result, exploring the complexity of vocalisations requires further research on English speaking infants to extensively document the sequential, phonetic complexity of ICPs' vocalisations at this level. While this finding raises the immediate question of generalisability to English, monolingual infants, it does foreground a striking difference in the syllable compositions produced by ICPs.

While the above differences capture the variety and complexity of vocalisations at the onset of canonical vocalisation, ICPs are delayed entering the phase. There is agreement that ICPs encounter difficulty in early vocalisations in the form of restricted speech sound inventories, but mixed reports of a delay in reaching canonical babble (see Table 2.1). The mixed findings on when ICPs enter the canonical babble stage could be attributed to contrasting data collection methods, with a difference between experimental settings, and naturalistic ones. For instance, most studies used elicitation techniques and play scenes, whereas Ha and Oller (2022) used at-home, naturalistic recordings of spontaneous vocalisations, a method that more closely align to those that are widespread in typical development research practice. The contrasting findings may also reflect different sampling approaches, such as grouping clinical characteristics (outlined in Section 2.2.3.1), pooling wide age ranges, exploring different languages, and combining different cleft and lip subtypes (unilateral, bilateral, CP with and without cleft lip) which are known to influence development (Choa et al., 2014, and Lierde et al., 2004, Shaw et al., 2019). Consequently, these variables complicate the ability to summarise relationships between outcomes in the literature, and future research excluding some of these complicating factors could give a clearer insight to babble milestones of ICP.

Together the pre-repair studies (see Table 2.1) present some variety in the canonical babble timeframes of ICPs, as well as reduced babbling rates and vocal inventories prior to repair.

*Table 2.1: Overview of Main Pre-Repair Patterns in the Literature*

| ***STUDY*** | ***PRE-REPAIR*** | ***Chronological Age*** | ***Cleft Type*** | ***Number of ICPs*** | ***Country*** | ***Language*** |
|---|---|---|---|---|---|---|
| ***Conrad et al. (2021)*** | Higher occurrence of melody breaking. | 1-3 months | Isolated CLP | 8 | USA | English |
| ***Ha and Oller (2022)*** | Higher vocalization rate between 4 and 9 months.<br>No delay to onset of canonical babble, but fewer true canonical syllables. | 4-9 months | Unilateral CLP, Bilateral CLP, and Isolated CLP | 10 | South Korea | Korean |
| ***Chapman et al. (2001)*** | Delay to onset of canonical babble<br>Significantly reduced variety and frequency of high-pressure consonants.<br>No significant difference in the frequency of analysable production. | 8-10 months | Unilateral CLP, Bilateral CLP, and Isolated CP | 30 | USA | English |
| ***Stout, Hardin-Jones, and Chapman. (2011)*** | Significantly reduced variety and frequency of high-pressure consonants. | 9 months | CLP | 16 | USA | English |
| ***Willadsen and Albrechtsen (2006)*** | More frequent nasals and less frequent alveolar productions.<br>Less frequent high, front vowels. | 11 months | Unilateral CLP | 38 | Denmark | Danish |
| ***Ma et al. (2020)*** | Delay to receptive and expressive vocabulary<br>Significantly fewer apical and oral articulations<br>Significantly more nasals and glottals | 9-16 months | CLP | 134 | China | Mandarin |

The extent to which these vocalisation patterns hold through infancy are greatly determined by whether infants undergo repair surgery. Consequently, the next sections will help to illustrate these differences and inform the predictions that can be made about the present study.

### 2.4.3 Vocal Development No Repair

In the UK, only 1% of ICPs do not receive repair (Butterworth et al., 2022). The primary reason cleft repair may not occur in the UK is if the child had a complex presentation and multiple co-occurring conditions which may delay when the surgery takes place.

Due to this small proportion, there are even fewer research reports on ICP when considering those with non-syndromic (i.e., no other diagnosed syndromes or disorders) vocal development. It is of benefit to consider the trajectory of vocal development for infants who have not undergone repair to understand the extremes of production characteristics that may occur if repair is carried out but not fully successful. In this way, it provides a benchmark of the most severely impacted production traits.

Hariharan et al. (2015) researched the productions of unrepaired cleft palates between 9- and 18-months acquiring Tamil. Overall, and separate to the consideration of cross-linguistic differences, they report statistically less vocalisation when compared to controls. This contrast to the findings of pre-repair studies at younger ages may even suggest a critical window for babble production to become established (in its speech likeness) before such rehearsal frequency declines. The outcome could also be attributed to the complex needs of those who do not receive repair, as the majority have additional syndromes and medical needs. A particularly relevant finding was in syllable structure and composition: Hariharan et al. found a significant difference between consonant frequency and vowel frequency between unrepaired ICPs and TD infants. These ICPs had significantly fewer consonants than vowels at all studied ages (11, 14, 15, 16, and 18 months), illustrating the most rudimentary, unrepaired CP patterns to be vowel dominant. Whether this pattern is illustrative of consonant initial deletion or illustrative of a vowel-initial preference, the pattern is inverted to the typical canonical babble form (see Section 2.2.2 for a reminder), which may interfere with the transition these infants make from babble to early words.

Moreover, the higher number of vocalic elements may impact the vocalisation length of produced sequences, due to fewer consonant closures, and hence, fewer options to separate vowel elements rhythmically. Indeed, this finding was indicated by Hariharan et al. (2015) with ICPs producing fewer polysyllables than monosyllables when compared to controls, a difference that declined over the 7-month window but was still evident at 18 months. Such divergence to the typical trajectory cannot solely be attributed to cross-linguistic differences, as the pattern impacts rhythmic elements and not purely phonetic and phonemic elements. In other words, this divergence appears to be independent of the native language, because there are rhythmic differences in the frequency of syllables produced in isolated monosyllables, which reveals a difference that impacts the flow and pace of speech. This finding may also impact ICPs reaching the speech-concurrent babble stage, which is a process which assists the transition from babble to early words (see Section 2.2.3 for details). As such, the reduced usage of polysyllables, consonants, and vocalisation overall maps out the extreme delays and divergences documented when no repair is carried out.

Furthermore, these vocal elements reinforce clinical outcomes for ICPs, too, for instance, their difficulty in breath flow control (Conrad et al., 2021). They also help to understand the impact of unrepaired CP on subsequent babbling behaviours, which we know to be inherently rhythmic (or syllabic) and reliant upon such air flow control. However, Conrad and colleagues do not reflect on the impacts of their finding on continuous babbling patterns, despite observing a structural difference to the typical, CV preference known to impact the progression to words (see Section 2.2.3 for details). While the frequency of consonants and polysyllables increased with age in Hariharan et al.'s study, it was a novel finding that provides evidence of a dominant vowel structure and is in line with Ha and Oller, (2022) who evaluate this as a deviant vocal pattern, even post-repair.

The longer-term impact for infants who do not undergo repair conflates production with expressive language vocabulary: Ma et al. (2020) reveal that children with unrepaired CLP produced fewer oral stops and apical consonants and more nasals and glottal sounds (Ma et al., 2020), which concords with Hariharan et al. (2015). Moreover, it provides a better insight into the long-term impacts on speech development by outlining that these infants have delays in receptive and expressive vocabulary skills between 9 and 16 months (Ma et al., 2020, p. 1) when compared to controls. It is likely that these infants had other complex, clinical reasons for not undergoing repair, but especially relevant to this research, the finding may be due to a range of vocal factors, e.g., the articulatory impact of a reduced phonetic inventory; developmental challenges due to delay or absence in the onset of canonical babble, or even reduced vocabulary size because of a lack of experience vocalising syllables within a sequence, such as inter-vocalic consonants.

Table 2.2 summarises that both prelinguistic and early word production follow an atypical pathway because of the unrepaired CP. These trends provide a baseline for comparison with continuing post-repair patterns, in both the short and long-term, which is required to inform the hypotheses on the potential sound combinations this selection of infants produce.

*Table 2.2: Overview of Central No-Repair Patterns in the Literature*

| STUDY | NO REPAIR | Chronological Age | Cleft Type | Number of ICPs | Country | Language |
|---|---|---|---|---|---|---|
| **Hariharan et al. (2015)** | Lower vocal quantity<br>Fewer consonants than vowels<br>Significantly fewer polysyllables | 11-18 months | CLP and Bilateral CLP | 5 | India | Tamil |
| *Ma et al. (2020)* | Delay to receptive and expressive vocabulary<br>Significantly fewer apical and oral articulations<br>Significantly more nasals and glottals | 9-16 months | CLP | 134 | China | Mandarin |

The no-repair patterns extend the pre-repair patterns to reveal the most severe impacts of CP on vocalisation. The studies point to longer-term delays and impacts to vocal production repertoire. As a reminder, it is very rare that the CP is unrepaired in the UK, and therefore these overviewed patterns only serve as a baseline for predictions for extreme cases within ICPs who do not receive repair. As such, it is most reflective of both the present sample and the UK population of ICPs to next overview the production patterns that occur following repair.

### 2.4.4 Vocalisation Patterns Post Repair

The literature on ICPs' vocal development following surgery overviews the immediate and longer-term patterns across many years of life (e.g., Frey, Kaiser, and Scherer, 2018), but, more relevantly through infancy at 6-25 months post-surgery (Frey, Kaiser, and Scherer, 2018, Scherer et al. 2018; Abdel-Aziz, 2013; Scherer, Boyce, and Martin, 2013, Willadsen, 2012). In this section, the post-repair vocal patterns of ICPs underline what the current study contributes to the published literature. It first covers the vocalisation patterns after CP repair, including the distinction between articulation errors and structural errors. It then covers the emergent and persistent non-target vocalisation patterns to evaluate what is currently understood about production development after repair surgery and what research is still required.

Following cleft surgery there are two broad categories of production difficulties that can affect ICPs' emergent vocalisation patterns. The distinction between these types of production errors depends on whether surgery is successful or not. When repair has been successful, the expectation that infants will develop in the same way as typical infants without a CP is plausible. However, the presence of scaring on the palate area may impact the sensation of the tongue contacting the palate during articulation and could lead to misarticulations due to the place of articulation, which are known as articulatory errors (Southby et al. 2021, Sell et al.

2006). To contrast, where the repair has not been successful, and the child's ability to separate the oral and nasal cavities is weak or absent, then the infant would demonstrate structural problems with their production and would not be able to produce (stop and fricative) pressure consonants and may use more nasal consonants instead.

These structural (or passive) errors can also happen at some point after a successful repair (Britton et al., 2014), for instance if the repair breaks down and an oronasal fistula appears over time, or if the soft palate is no longer able to make complete contact and closure with the pharynx as the child grows. In these situations, the child may also produce speech with hyper nasal resonance as well as making speech sound substitutions and distortions. The traits that are commonly observed in ICPs are referred to as cleft speech characteristics (CSCs). CSCs comprise anterior, posterior, and non-oral articulation errors (active CSCs) or structural errors (passive CSCs); the articulation errors can be addressed through SLT, but structural errors need additional surgery. Figure 2.6 captures the active and passive CSCs with examples of their phonetic features.

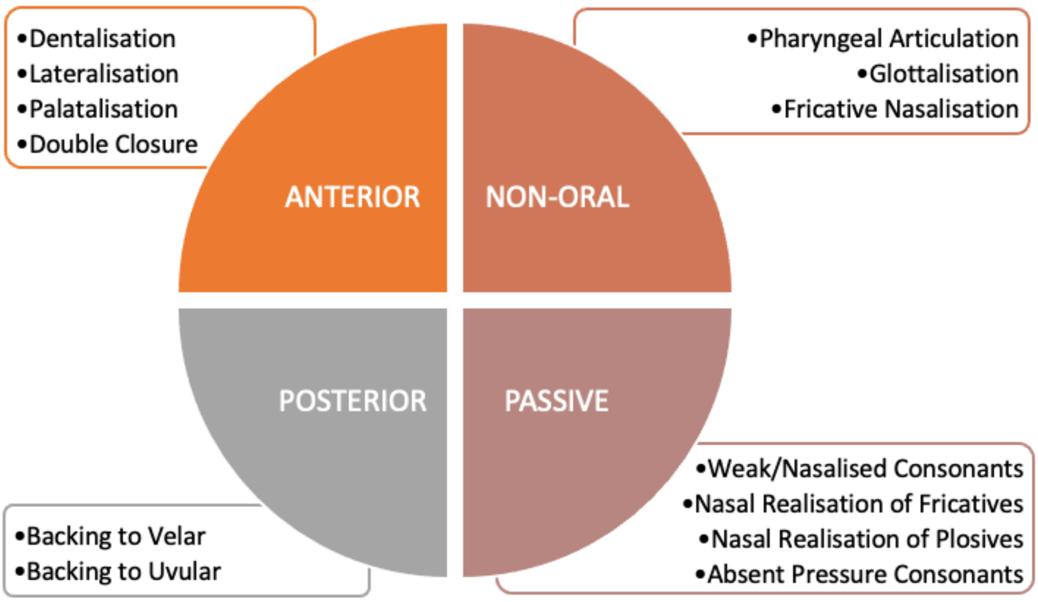



*Figure 2.6: Chart of the Categories of Cleft Palate Speech Characteristics: (condensed from Southby et al. 2021, Britton et al., 2014, Sell et al. 2006)*

Of the reviewed structural and articulatory errors that are possible following cleft repair, ICPs emergent vocalisations after surgery are likely to be different to TD infants. Given that the production difficulties are related to the demands of specific gestures, nasal, glottal, and liquid gestures may be more likely and oral stops and fricatives may be less likely. However, these sounds are not as characteristic of babble at 14 months, which raises the likelihood of production compensations following surgery. In sum, the changes to anatomy during cleft repair (either due to scaring, unsuccessful surgery, or another phonological disorder) impact ICPs' familiarisation, rehearsal, and/or comfort when coordinating movements that involve pressure at the roof of the mouth after surgery. These sounds are typically an integral part of babble formations, and such CSCs may impact the composition of produced syllables. ICPs may also present with phonological or non-cleft related articulation speech errors as part of a developmental speech disorder. This additional outcome complicates the aspects of their post-repair productions further, though, the focus of the present research is limited to phonetic qualities, rather than phonological ones.

The presence of active CSCs presents agreement that these infants experience continued difficulty with oral pressure consonants (Ha and Oller, 2021, Scherer et al., 2018, Wren, 2017, Chapman et al., 2001; and Kaiser et al., 2017). However, the copatterning of different vowel-consonant articulations has been rarely considered. One study which considers ICPs' vocalisations post-repair at this more contextual, phonetic level is Jahanbin et al (2014). In this research, rather than collecting consonant inventories, their work investigates which consonants were produced in combination with which vowels. Consequently, it allowed for the analysis of phonetic sequences, i.e., how consonants affected the following formants. The work investigated three vowel frequencies when they each followed /b/, /p/, /f/, /v/, /k/, and /g/ pre- and post-speech therapy, they only found statistically significant differences in hypernasality for bilabial pairs /b/ and /p/ (Jahanbin et al, 2014, p. 84), which is a finding that reflects a passive error, but also a continuation of consonant preference after repair. The located difference observed post-repair for bilabials highlights a likelihood of the well-established coordination of front, central, and back vowels, and, moreover, a maintained preference for extremes in ICPs' vocalisations. Although these findings show promise for better understanding the vocal patterns of ICPs, there is still very little knowledge on post- and even less about inter-vocalic consonants; these factors have therefore been integrated into the current study. They may shed light on whether it is within the phonetic sequences that some of the differences lie.

#### *2.4.4.1 Clinical Impacts on Vocalisations Post Repair*

The clinical influences in ICPs can have implications on their vocalisations following surgery and may impact the likelihood of structural and articulation errors. For instance, the type of cleft has been shown as highly related to speech and language development (Lierde et al., 2004;

Choa et al. 2014). Additionally, Hardin et al. (2023) found that a smaller percentage (63% versus 89%) of infants with cleft lip and or palate (CLP) entered the canonical babble stage when compared to CP only infants (2003, p. 457). Alongside CP type, the placement of the cleft width can also impact vocal development. An illustration of this is that an atypically positioned posterior palate can result in atypical nasopharyngeal and oropharyngeal volumes (Mason and Perry, 2016) and could result in passive production errors. To continue, clefts which are on both the hard and soft palate have been shown to result in more articulation errors , and greater velopharyngeal incompetence, and subsequently require more speech therapy, than clefts of the soft palate only (Hardin-Jones Chapman, and Schulte, 2003; Lohmander and Persson, 2008; Willadsen et al., 2020).

In addition to positioning, the size of the cleft has been associated with vocal outcomes post-repair, too, with Mulliken and Sullivan (2009) and Mahoney et al. (2013) finding the width of the cleft width to be inherently related to velopharyngeal control. The width of the palate may be particularly relevant as Choa et al. (2014) and Shaw et al. (2019), also documented differences in vocalisation based on this medical characteristic. Furthermore, atypical articulation features were more frequently seen in children with wider and more severe clefts. Different surgeries are required depending on the size of the cleft (Fell et al., 2024, p. 2), and there is some debate around the impact of surgical procedure on speech outcomes. Lierde et al., (2004) concluded that those who received a two stage palatoplasty were statistically less intelligible than those who had a one stage procedure. The research explored vocalisation variables, with intelligibility being measured by the number and dominance of characteristics–phonation, resonance, and articulation–present in speech. Lierde and colleagues reported long-term articulation errors that were still evident at 17-18 years, e.g., nontarget devoicing of fricatives within words '/z/ and /v/' (p.874). Together, the above research illustrates how the formation of CPs can influence development at the structural and articulatory level, and indeed how the certain surgical aspects complicate ICPs' early vocal production. The work reviewed above presents key factors that require consideration and integration for research. Although there are many anatomical variables that differ greatly across ICPs, reducing the potential impact of complex variables may be necessary for sampling decisions in research.

In addition to the cleft properties, timing of surgery is likely to play a role. As was introduced earlier, most research agrees with the long-term opinion that early closure of the palate has the most positive influence on outcomes. This influence also includes the prelinguistic development of children with a CP (Kemp-Fincham et al., 1990, Willadsen and Albrechtsen, 2006, Abdel-Aziz 2013, p. 87, and Fell et al., 2022). Furthermore, when palatal repair is carried out earlier, better post-surgery speech outcomes are more likely; such outcomes include but are not limited to the earlier emergence of oral stops (Chapman et al., 2001), the lower chance of vocabulary delay, and an increased phonetic inventory in babbling repertoire (Jones, Chapman, and Hardin-Jones, 2003).

More recently, Gamble et al. (2023) reported on vocal outcomes from ICPs who had surgery at either 6 or 12 months. The focal point of Gamble and colleagues' work was on the impact of surgical timing on velopharyngeal insufficiency, which has a direct impact on oral-nasal coupling during articulation and can limit the air pressure required for pressure consonants (p. 796). This type of structural error impacts sounds that are a common component of typical babble. The reported relationship between outcomes and surgical timing in Gamble et al.'s findings was mixed in early childhood, with consonant production accuracy; oral and nonoral error frequency; and inventory range being similar at 3 and 5 years (2023, p. 801). However, they did find higher canonical babbling for a greater percentage of infants in the 6-month surgery group than in the 12-month surgery group (p. 799).

The study collated standardised measures of canonical babble ratio, canonical babble and consonant inventory were taken from a minimum of 80 vocalisations, and twenty minutes of each infant's most vocal minutes were taken from structures play with a caregiver (Persson et al. 2015, p. 5). However, it was unclear whether the data was naturalistic or laboratory-based or how consonant inventories were reported. Both of these aspects could yield different results based on naturalistic/elicitation contexts and impact the replicability of consonant inventories. Gamble et al. (2023) did not reflect on the role of production rehearsal on outcomes, despite including contrasting palatal ages of 0 and 6 months in their sample design, and despite their key findings on canonical production at 12 months providing motivation for the impact of palatal age on early vocalisations.

In summary, the clinical differences in cleft properties, surgery type, and repair timing can all influence the potential for structural and articulatory errors through infancy and childhood. Sections 2.4.4.2 and 2.4.4.3 review the emergent and persistent cleft speech characteristics (CSCs) following repair surgery, which, along with the reviewed typical articulatory phonetics, contribute to the predictions formed for ICPs 1-9 months after surgery in the present study. With both articulatory and/or structural errors in mind, the two following sections collates production resemblances across ICPs post-repair.

### *2.4.4.2 Emergent Vocalisation Patterns Post Repair*

It is a long-term possibility that, immediately after surgery, there is a period of vocalisation reduction, after which infants are reported to return to their pre-repair level 2 weeks after surgery (Hattee et al., 2001). This stabilization pattern indicates that infants may often recover their pre-established production repertoire in at least the short term. However, Hattee et al.'s vocal measures did not capture how stable the productions were. As such, the work is missing insight into the consistency or accuracy of productions, which limits its comparability to the typical babble milestones, even though it does provide an estimate for how soon vocal behaviours may re-emerge, post-surgery. Further, it does indicate that infants return to vocalisations that were present pre-surgery, *before* they supposedly remap, redirect, or alter their articulations (Hattee et al., 2001). Such a pattern could reflect the muscle memory of movements or may also serve as the basis from which anatomical differences can be redirected to achieve more typical acoustic productions.

There are ongoing discrepancies about when ICPs start to resemble the typical trajectory. Some work on the emergence of novel consonants post repair point to an increase of approximately three consonants and three true (supraglottal-only) consonants at a palatal age of 5 months (Jones, Chapman, and Hardin-Jones, 2003). Though one study indicates that changes emerge between 5- and 7-months post-surgery (Zajac et al., 2021), many have not homed in on these exact time frames while also ensuring well-balanced samples. To continue, Jones, Chapman, and Hardin-Jones (2003) reported the timeframes in which novel speech sounds (regardless of the mother tongue) may emerge that were not evident pre-surgery. Like Gamble et al (2023), their study reported better short-term outcomes for those who received earlier repair, with these infants having fewer structural errors. Specifically, these results including more the comprehensive acquisition of oral stop consonants, e.g., oral stops were used more frequently as glottals declined until the chronological ages of 18-19 months (p. 20).

Jones, Chapman, and Hardin-Jones (2003) also reported that selection from the following oral stops were acquired /p/, /b/, /t/, /d/, /k/, /g/, /m/, and /n/, and a simultaneous, gradual decline in glottal articulations. Glottal stops are a feature in spontaneous, adult speech, but are a cause for concern among SLTs when they are used to mark absent consonants in babble (p.c. with Lucy Southby, 2023), as they could indicate articulatory errors and potential phonological difficulties. Therefore, the reported glottals reduction by Jones and colleagues reflects a pattern that moves closer to the typical trajectory. While Jones, Chapman, and Hardin-Jones (2003) adopt comparable measures to typical infant research (e.g., babble ratios and true canonical babble), a central limitation of this work was the missing timeframes between the chronological ages of 11 and 14 months, which impacts the certainty of whether these sounds emerged *before* 5 months after surgery, and what potential articulatory errors may have been present prior. Such information is needed in order to deduce whether consonants emerged sooner than 5 months post-surgery, whether redirected sounds might be present due to redirected articulations as a result of scar healing, and how frequently speech sounds were used by these infants in case earlier timeframes should be considered in future work.

To add, a similar study by Zajac et al. (2021) documents that prevocalic stop consonants emerged at palatal ages 9-12 in 80% of infants (p. 30). In their research, oral stop consonants in initial or final position were recorded from elicited vocalisations that were taken in 30-minute sessions with a parent and examiner present. The study measured the emergence of the oral stop category but did not include information on the placements of stops that occurred or their surrounding vowel contexts, which may vary also even in cases of successful repair due to scarring and/or articulation errors. In addition, their methodology classified pre-vocalic stops as acquired when 3 instances were produced, this measure was taken regardless of whether the same consonant was produced three times, or three different consonants were produced once. Consequently, this measure may not be the best indicator of their vocal stage or full vocal repertoire; there could be wide differences in the number of sounds within an infant's repertoire and measures are not comparable with measures undertaken on the typical trajectory in predicting later speech or vocabulary development. More work reporting on the exact frequencies of articulatory gestures (and their place of articulation), is required for understanding post-CP repair production patterns further. These inclusions would add detail to which of the oral stops emerge/are evident at different palatal ages and also how they were used in relation to phonetic combinations with vocalic (or vowel) segments.

While Zajac et al. (2021) did not include intervocalic stops, one study that did consider the syllable contexts (i.e., the phonetic consonant and vowel segments used together) was by Eshghi et al. (2017). The study researched the nasal pressure–i.e., the amount of air escaping the nasal cavity when the velum is lowered–of TD infants and ICPs during the production of CV, VCV and isolated V sequences at the following chronological ages: 12, 14 and 18 months. In this way, the work considers the potential impact of structural errors on the production of difference speech sound sequences. They found that TD 12-month-olds produced 98% of stops and vowels in syllables with VP closure versus 81% for ICPs, with differences that declined between palatal ages of 3 and 4 months. Their work concluded that ICPs did not achieve consistent closures until chronological age of 14 months. Their work indicates these articulation errors to occur within 5 months following surgery, which motivates more research on ICPs in the immediate months post-surgery to consider such potential emergent productions. More work is needed to explore the measures for consonant acquisition, for instance by frequencies of articulatory gestures (and their place of articulation), because these measures are centrally relevant to understanding post-CP repair production patterns. Such inclusions would add more detail to which of the oral stops emerge/are evident at different palatal ages and also how they were used in relation to phonetic combinations with vocalic (vowel) segments.

Additionally, Vilano et al. (2021) also included the data to capture the distinctions between pre- and inter-vocalic position, but they did not present specific results on these patterns in their published analysis, instead these elements were reduced to the collated frequencies of VCV versus CV together and the differences were not discussed. More research on the explicit phonetic frequencies and combinations within ICPs' vocalisations is needed to consider the potential differences based on the structural errors from nasal pressure ability on sequences, or whether articulatory errors are more prevalent. The extent to which palatal age may also play a role on vocalisation patterns is unacknowledged by the above two studies, despite these being potential predictors of later vocal outcomes studies (Fell et al., 2022; Zajac et al., 2021; Abdel-Aziz, 2013; Willadsen and Albrechtsen, 2006; Kemp-Fincham et al., 1990). More work is needed on the impact of palatal age in order to explore how palatal age compares to earlier points along the typical vocal trajectory and whether it may explain absences and deviations in ICPs' vocalisations at 14 months in this study.

#### *2.4.4.3 Persistent Patterns Post Repair*

The longer-term, non-target CSCs are described and understood in relation to their phonetic and/or linguistic segments here. These criteria are sometimes described with specific symbols (or diacritics) that indicate the qualities or characteristics in which the consonants are produced. For instance, some non-target productions may include acoustic or articulatory features which are not typically realised in the production of a consonant, such as nasalisation in consonants which are not nasal–or pre-/pro-ceded by a nasal–(Naros et al., 2022, p. 444). Furthermore, the presence of the passive, persistent speech characteristics: hyper- and hypo-nasality, nasal turbulence or audible nasal air emission that may require additional surgeries. Also, the presence of cross-language CSCs post-repair that mark articulation errors, which are treated with therapy through childhood, such as consonant production error. Some prominent studies have explored the vocal characteristics of these articulation CSCs, including substitution patterns, most predominantly including the fronting and/or backing of consonant realisations, and weaker or omitted pressure consonants (Wills et al., 2017, Scherer et al., 2018). Table 2.3 summarises the most consistently reported CSCs and their documented ages. These collated studies help to inform the thesis' hypotheses on the potential sound combinations that infants in the present study may or may not be able to produce.

*Table 2.3: Overview of Post-Repair Patterns in the Literature*

| ***Study*** | ***Finding*** | ***Chronolo-gical Age*** | ***Cleft Type*** | ***Sample Size*** | ***Country*** | ***Language*** |
|---|---|---|---|---|---|---|
| ***Scherer Boyce, and Martin. (2013)*** | Consonant repertoires are composed of fewer stops, liquids, and velars, and more frequent glottal consonants | 17 - 34 months | Unilateral CLP, Bilateral CLP, and Isolated CLP | 15 | USA | English |
| ***Willadsen, (2012)*** | Consonant repertoires are composed of fewer stops, liquids, and velars, and more frequent glottal consonants | 18 - 36 months | Unilateral CLP | 34 | Denmark | Danish |
| ***Ha and Oller (2022)*** | Higher vocalization rate between 4 and 9 months. No delay to onset of canonical babble, but fewer true canonical syllables. | 11-9 months | Unilateral CLP, Bilateral CLP, and Isolated CLP | 10 | South Korea | Korean |
| ***Kaiser et al. (2017)*** | A smaller frequency of high-pressure consonants, including oral stops | 15 - 36 months | Isolated CP, Unilateral CLP, Bilateral CLP | 19 | USA | English |
| ***Hattee et al. (2001)*** | A stabilization pattern that infants recover to pre-surgery production repertoire in ~14 days. Preference for voiced bilabials, evidence of some alveolars, velars and glottals in some participants An emergence of early fricatives and velar stops at 18 months. | 18-36 | Isolated CP, Unilateral CLP | 9 | England | English |
| ***Jones, Chapman, and Hardin-Jones (2003)*** | An increase of approximately three consonants (including liquids and glottals) and three true consonants (excluding liquids and | 6 - 11 and 15 - 18 months | Unilateral CLP, Bilateral CLP | 14 | USA | English |

| | |
|---|---|
| glottals and including only supraglottal articulations) was documented in the 5-month period post-repair. A selection from following stops were acquired: /p/, /b/, /t/, /d/, /k/, /g/, /m/, and /n/. | |

To collate the post-repair production patterns from Table 2.3 and compare with those from typical articulatory phonetics in Section 2.4.4.2, a few common patterns come to light from the published patterns. Fewer alveolars (/t/ and /d/), fewer velars (/k/ and /g/), and fewer fricatives (/s/ and /z/) tend to be present following CP repair. Indeed, these patterns are reasonable agreed across the literature; they particularly accord between Kaiser et al. (2017) and Scherer et al. (2013). None of the known studies comment in depth on vowel or consonant-vowel articulations, making it difficult to collate an understanding about how close to typical ICPs are. Based on articulatory phonetics and the impacted region of an isolated CP, it might be logical to predict that ICPs would produce vowels close to typical (i.e., mid vowels being most common) due to the lower pressure requirements in vowels, when compared to oral, high-pressure consonants. The documented patterns in vocalisations post-surgery are reviewed together in relation to these predictions in Section 2.6.1 where they are integrated with the established hypotheses.

The categorisation of infants according to palatal age may also provide more insight into the subtle production differences according to such timeframe differences. ICPs post-repair are likely to have a reduced range of sounds—when compared to the typical—that is maintained until chronological ages 36 months/48 months (Lee et al., 2019; and Scherer et al. 2018 respectively). In addition, the post-repair research largely agrees that these infants continue to have smaller consonant inventories than typically developing infants for several months post repair, with at least 40% of infants not reaching the full, typical range (CRANE Report, 2024), and with fewer pressure consonants through their early years. As such, the characteristic repertoires are composed of fewer oral stops, fricatives, and velars, and more frequent glottal consonants after repair even when compared to age-matched controls (Scherer, Boyce, and Martin, 2013, Willadsen, 2012). In cases where these types of non-target articulation CSCs occur, speech therapy is required. The scope of these stages is therefore given in the next section.

### 2.4.5 Speech Therapy for Infants with Cleft Palate

This section examines the current parameters of speech and language therapy (SLT) for ICPs following repair. It explores the central targets of intervention to underline the focus of the present research aims in order to situate therapy targets among the most persistent post-repair production characteristics. Section 2.4.5.1 reviews the production impacts on ICPs following repair at the centre of SLT targets. Then, Section 2.4.5.2 outlines the most common ways that therapy sessions aim to improve these production impacts in early years to foreground the need for the present research on prelinguistic research studies from naturalistic data. Lastly, Section 2.4.5.3 illustrates the traditional ways that therapists record measures of sounds within children's production repertoire from SLT phonetic reports. It reviews the function of phonetic inventories and critiques them in relation to the purpose of analysing production patterns in naturalistic, babble contexts. The section, on the whole, motivates the need for research on the current data set and allows for later reflection on whether the results in the current study amplify the possibility for treating production differences sooner.

#### *2.4.5.1 Production Impacts*

As was reviewed above (in Section 2.3.1), the anatomy of the speech faculty (e.g., the size and shape of the cleft width) and the timing of repair in this population of infants all contribute to the impacts on speech development for ICPs (Scherer, Boyce, and Martin, 2013, and Shaw et al., 2019). These structural outcomes are often assessed by speech therapists in terms of their medical criteria: palatal fistula (which is an abnormal communication between the oral and nasal layers of the palate) and velopharyngeal insufficiency (which is the inability to make a functional seal between the nose and mouth, Sainsbury et al., 2019, p. 5). These anatomical features are often a cause of lasting CP speech characteristics, such as hyper-nasal speech (ibid), where repair has been unsuccessful or where the cleft has broken down over time.

The impacts of nasal-oral interaction and velopharyngeal insufficiency are both highly relevant to the coordination of articulators, particularly for sounds produced in these two areas because they impact consonants that often appear in pre-word vocalisations (see Section 2.2.2). To continue, these production difficulties either stem from medical limitations, (e.g., velopharyngeal insufficiency) or from the subsequent outcome (e.g., level of speech at 5 years). The primary level causes predict the secondary level outcomes that SLT approaches attempt to reduce (Shaw et al., 2019, Bunton and Hoit, 2018, and Sainsbury et al., 2019). The second level factors include compensatory articulations, which directly impact speech intelligibility (Lierde et al., 2004, p. 874) and can persist in long term development (Sell et al., 2015).

Some persistent characteristics are more minor and relate to articulation errors, such as small-scale sound substitutions like lateralisation and palatalisation: they operate ‘within the range of normal non-cleft speech’ and do not require intervention (Sell Harding, and Grunwell, 1999). Whereas the more major patterns include the following: pharyngeal and glottal misarticulations, backing to uvular, backing to velar, nasal fricatives, absent pressure consonants, nasal realizations, and weak nasalized consonants. These examples are more prominent and require therapy, further surgery, or both (Chapman et al., 2001; Kaiser et al., 2017, Nikhila and Prasad, 2017). They mark a diversion in the execution (or release phase) of articulations that could impact phonemic contrasts in English and the overall clarity (and intelligibility) of consonant productions. As such, these impacted production qualities could be evident in many of the pre- and proto-linguistic stages before first words, as well as up to age 3, around the age that therapy sometimes starts.

Such persistent patterns could impact progression through the trajectory to first words, however the therapy studies centrally report on older ages (3 years) and do not shed light on how (or when these patterns develop). Therefore, it is unclear how early along the recovery and vocalisation timeline that production impacts would be evident in the babble of ICPs. While the medical awareness helps to understand the anatomical criteria (and predictions) about which production difficulties are likely to manifest in ICPs’ vocalisations, their impact on the Babble of ICP is still under question, especially in relation to the therapy aims within infancy.

#### *2.4.5.2 Speech Therapy Goals*

The work on therapy aims and interventions for ICPs has focused largely on young children, predominantly at and above 3 years (e.g., Lane, Harding, and Wren, 2022). Much of this research is weighted towards the persistent speech sound errors that occur through childhood, rather than those that occur in the earliest window of vocal development post-repair (e.g., vocal play and canonical babble), which is at the heart of the present thesis. In fact, only a small number of studies document the therapy interventions at or prior to the age of 3 (Scherer, 1999; Hardin-Jones and Chapman, 2008; Scherer et al., 2008; Bessell et al., 2013; Ha, 2015; Kaiser et al., 2017; Williams, Harding, and Wren; 2021; Southby et al., 2022), meaning that therapy interventions within the more immediate timeframes post-surgery remain less explored by the literature. As was outlined in Section 2.1, the prelinguistic vocal stages for progressing to first words form the building blocks for speech because this is when and how infants explore, acquire, and stabilise the motor movements required for speech. The lack of earlier-aged research may be due to clinical populations constituting a smaller proportion of the population, or because this group is more complex to explore when compared to typically developing infants. It could also be because of the variability at these ages or due to over-generous healing timeframes, though this is challenging to determine.

It is common practice that SLTs adopt a combination of approaches in their therapy sessions; these can comprise direct (explicit, task orientated) and indirect (implicit, contextualised) approaches (Williams, Harding, and Wren., 2021). However, Bessell et al. (2013) express that more research is required on whether the combinations of SLT approaches could be valuable to implement at earlier, pre-school ages, which includes the age ranges considered in the present study and is when infants are typically producing speech sound combinations and first words. This earlier implementation is needed in order to better support the confidence for gaining more understanding of how sequences of sounds are formed in ICPs' vocalisations is required, and a central aim of the present research, but with a younger population.

Indeed, the few studies that *do* explore therapeutic intervention for ICPs *before* 3 years old uphold a dominant focus on vocal rehearsal and elicitation of the sounds which are absent, non-target, and/or weak across the most common approaches. These treatment plans post-repair usually comprise direct therapy sessions with an SLT that includes follow-up tasks and activities to be carried out by parents at home (Bessell et al., 2013; Southby et al., 2022). As such, most of these approaches are not implemented in the stages immediately after repair, even though the approaches are not invasive and would be accessible to young infants (at 15 + months) in relaxed settings. However, the range of production skills that SLTs would encounter within this younger window is not extensively detailed in relation to babble ability, as ICPs remain under explored in relation to how soon after repair such targeted speech sounds emerge. Indeed, if the current study reveals that diverse, speech-like units are produced by infants 1-9 months post repair it could motivate more therapeutic input earlier (see Section 6.1.1 for the integration of therapeutic aims).

The speech therapy ICPs receive post-repair often adopts naturalistic approaches to target infants' compensatory articulations and involves attempting to change the placements of articulation from what has been acquired pre-repair (details on these vocalisation characteristics were reviewed in 2.4.2). Naturalistic interventions in the UK aim to embed targeted speech goals within speech and interaction activities (Southby et al., 2022, p. 454) and are used before

3 years of age. The two main kinds include the Milieu approach (which has a structured focus on the production of target sounds in different skills of language) and Focused Stimulation (which has a less structured focus, but targets speech sounds by stimulating listening opportunities for the infant to select the target form, Lane, Harding, and Wren, 2022). These approaches foreground the prominence of naturalistic methods in the earlier ages of intervention. Even though these approaches are carried out in a clinical, elicited environment, they emphasise the importance of vocal rehearsal in relation to the production of targeted speech sounds, a behaviour carried out in a wide range of environments. Such consideration of pre-existing rehearsal behaviours is valuable, particularly including those inherently involved in babble. However, intervention processes fall short by mostly considering infants closer to 3 years old, because it is well before this stage that ICPs indicate production rehearsal mechanisms (see Section 2.4.4).

To continue, the more common, naturalistic techniques that enforce goals are strikingly relevant to prelinguistic vocal processes. These include the following: to consistently increase use of true consonants, to reduce compensatory misarticulations (Ha, 2015), to increase the size of sound inventories (Scherer, 2008), and to add new sounds and existing sounds in new positions (Scherer, 1999, and Lane, Harding, and Wren, 2022). The focal points here are highly relevant to the composition of babble and involve the flexibility and recombinability of different speech sound formations. Despite this close connection with the processes involved in typical vocal development, the understanding of how these processes manifest in the actual productions of ICPs is far less evident. While the interventions help to expand the knowledge on which CP production patterns are persistent around 3 years old, there is still limited understanding of the actual production rehearsal by infants in naturalistic, every-day vocalisations. In order to assess whether more should be made of these consonant-expansive approaches, the present thesis determines the composition of 14-month-olds in comparably naturalistic data.

The literature above provides the CP characteristics that hold through infancy and are often the focus of therapy, which are essential to understanding infants' production tendencies post repair. What is missing in vocal development research is whether phonetic absences, delays, and divergences occur in the earlier age of 14-month-olds after repair. The present work therefore aims to shed light on how babbling behaviours resemble and reflect the patterns in the typical trajectory, and whether any of the persistent difficulties can also be located in the sequences of produced syllables at a much earlier stage than research currently acknowledges.

If there are differences in the absences of productions and order of sound sequences, it may have a knock-on impact on the transition ICPs make from babble to words.

#### *2.4.5.3 Speech and Language Therapy Reports*

Speech and language reports provide insight into the phonetic content of vocalisations within and across infant productions. They compile phonetic inventories (including the number of different consonants within an infant's repertoire) to provide a list of elicited phonetic features (the properties of consonant-like features). Ultimately, these measures are not able to examine pre-linguistic consonant frequencies and preferences, or whether the sounds produced are stable across palatal groups. Isolated consonants are the focal point of phonetic inventories, and most studies explore how the major substitution patterns relate to phonological targets, rather than infants' phonetic abilities prior to these stages. Additionally, the contextual characteristics (i.e., the ordering of phonetic sounds) of syllables are overlooked by the measure, with vowel productions ignored despite them playing a large role in determining the maturity of vocalisations (2.2.2) and consonants are not always considered in relation to their naturally produced form (e.g., babble categories as are also given in Section 2.2.2). These pre-word features were earlier established to be a tangible stepping stone in development, and more understanding of patterns prior to 3 years of age would benefit clinical understanding. Therefore, production inventory measures should help pinpoint the compositional and organisational components vocalisations (i.e., the phonetic and sequential properties of babbled 'consonants' *and* 'vowels' in vocalisations) and, centrally, the extent to which they resemble the typical (or CP) production patterns at and before 14 months.

## 2.5 Research Context

The purpose of this work is to extend existing explorations of cleft repair characteristics onto an analysis of consonant-vowel combinations, and babble formations evident in 14-month-old infant vocalisations, with different palatal ages, from hour-long, naturalistic recordings. Of the work reviewed on the infants' consonant repertoire following CP repair, most measures are reduced to isolated lists of phonetic production abilities; are from elicited contexts; taken after the point of first words; and do not sufficiently consider and organise sample characteristics. Research on the production of syllables in the babble (and pre-babble) context in typically developing infants is a growing field of research (e.g., Oller et al., 2021 and Kalashnikova and

Carreiras, 2022), however, research on the development of babble remains very limited in atypical populations, including ICPs.

In fact, only one study analyses them in phonetic detail whilst making a distinction between the vocalic positioning of consonants (Zajac et al., 2021). They found that ICPs were 3.5 months delayed in their acquisition of pre-vocalic stops when compared to TD infants, however the approach only included assessment data from SLTs, and fixated on stop articulations. Therefore, the current study will contribute novel insight into a wider range of phonetic and sequential properties of infant vocalisations post CP repair. Plus, this exploration will elucidate whether more naturalistic data and more contextual, phonetic vocalisation measures (e.g., MBL, vocal count, VMS) may give any novel understanding on emergent vocalisations post repair. It will also shed light on vocalisation patterns in a context with more strictly considered variables (namely palatal age, cleft type, and canonicity) and could explain variation in vocal development in relation to the use of speech sounds and sequential combinations. To follow is the presentation of the influences and motivation from the reviewed literature on the current study; on the research questions; and on the collated hypotheses. The predictions will be examined by three analyses which each hold sub questions throughout; the hypotheses help to explore the cohort sample of infants' vocalisations after CP repair.

## 2.6 Integration and Influence of The Literature on The Present Study

This chapter has reviewed the stages of vocal development in typical populations and based on that foundation, it has established the common differences to the typical trajectory in ICPs' development before and after repair. It has highlighted the common CSCs depending on structural errors (e.g., hyper-nasality) and articulation errors, (e.g., substitutions, absences, emergent sounds post-repair, and persistent difficulties). It has also revealed some key weaknesses in published work (different cleft type impacts, sample grouping, collected data, and vocalisation categorisation) that the present study rectifies in its design. Such choices are evident within the selected exclusion and inclusion criteria (see details in Section 4.2.3) and the classifications of vocalisation variables (see below in Section 4.2.1). A clear challenge of the sample in question (taken from the sections in 2.2.3.1) is how different each case is, which emphasises some anticipated challenges for the present study. Below is a summary of the central ways that the present study responds to the reviewed challenges in its sampling, design, and measures.

First, the literature suggests different vocal outcomes depending on certain clinical properties: eft type, surgical procedure, timing of surgery and additional diagnoses. The proposed sample from the cleft collective corpus for the current study attempts to reflect the most common CP type. Given that cleft type may play a role in development, this was the only type included in the study. The justification for considering CP, rather than cleft lip (CL), is that is a CL likely to mainly impact labial articulations, whereas CP is likely to impact more contrastive sounds at the roof of the mouth. The impact of including CP only was to reduce the possibility of different CP subtypes impacting outcomes, in light of Section 2.4.1. The implementation of grouping and selecting the sample in this way is critiqued in Section 7.1.

Additionally, there were different vocal outcomes depending on the surgical procedure carried out. The proposed sample from the cleft collective corpus for the current study attempts to reflect this most common procedure in the UK. The intravelar veloplasty procedure was used for all but 3 of the infants in the current study, reasonably reflecting the most common routine surgery process in the UK. Another of the clinical influences is the potential impact of additional complications and diagnoses (such as syndromes, hearing difficulties). Infants with oronasal fistula and Otis Media were excluded from the current study in order to avoid confounding explanations for delayed outcomes and to reduce the potential anatomical impacts of surgeries on vocalisation behaviours. Given this challenge of discerning articulatory impacts over auditory-perceptual impacts on vocalisation, instances of hearing impairment were excluded in the present study, though the decisions surrounding the validity and the impact of excluded participant variables is returned to in the Reflections (see 7.1).

Additionally, in many of the studies on ICPs, CP size and severity is not reported, nor is a consistent distinction made between cleft types. The lack of separation between these clinical factors may be due to sampling and infant availability or based on purposeful decisions to represent the whole population. Given that both factors, along with timing of surgery, may have an influence on vocal development (see Section 2.3.3.2). Consideration of these variables would improve the outcome measures on post-repair vocalisation patterns and may help to explain some of the variability unveiled in persistent CSCs post repair. Further, there are additional inconsistencies in relation to unavoidable data collection methods across studies, with some comprising reviews, cohort studies, and longitudinal data, but most not reporting on smaller timeframes post-repair (at a month-by-month level) which may miss valuable leaps in development.

Second, the review revealed that there may be differences depending on different palatal ages, which are often disregarded in research designs of published work. The present sample was grouped in relation to palatal age throughout all analysis chapters, but Analysis I also overviews the interaction of chronological age at repair. By organising the sample by palatal age and including a pre-analysis of the relationship between cleft size and consonant inventories at 24 and 36 months, these decisions helped select statistical tests that considered these factors prior to analysis. The categorisation of three groups was also motivated by the likelihood of different outcomes depending on repair surgery timing and data collection timing, which meant that the sample eligibility was informed by the potential differences revealed by literature regarding outcomes and age (see Section 2.2.3.1 for a reminder). To continue, the variability of healing timeframes post-op was extended by the possibility of different numbers of procedures. This challenge meant that during sampling, infants in the sample who had had fewer surgical procedures were prioritised (only 1 of 28 infants underwent relieving incisions, and none of their vocal data were included in the extreme or outlier values in the results).

The current study will contribute to the literature's missing window of 3 months post-surgery in its sampling focus and will add detail to the consonant repertoires by contextualising repertoire measures in relation to the consistency and complexity of produced syllables. It will therefore provide insight into whether the lower likelihood sounds that Jones, Chapman, and Hardin-Jones (2003) report to emerge first were also present in smaller timescales (from 2 to 9 months) post-surgery. This will update our knowledge of syllable productions post-surgery and contribute new insight into whether vocalisations included later-to-emerge consonants (or vocal closures) and in what combinations (patterning with vowels in either reduplicated strings or isolated contexts).

Third, the literature also suggests that there may be differences between timings of canonical babble onset, therefore methodological analyses need to be compared to the vocal stages rather than chronological (or actual) ages. These stages (given in Section 2.2) can be identified or aligned with the vocal measures reviewed next in Section 2.5 to give an indication of how phonetically mature (or speech-like) vocal abilities are for each infant as well as for each palatal group. There may also be differences between age at surgery and, as such, the sampling process ruled out the youngest and oldest ages at surgery from the sample to reduce the potential impact of this variable. As such, the participants' surgical ages are close together with a range of 5 months and mean of 9.36 months because there may be differences between those who have had more time in between surgery and the time of data collection recording across the across 28 infants. Consequently, the sample is grouped according to months since full repair (or palatal age, as termed by Zajac et al., 2021): 1-3 months (n = 9), 4-5 months (n = 10), 6-9 months (n = 9). Grouping participants in this way helps to explore the complex sample in relation to palatal age and (along with the exclusion of multiple cleft types) reduces some of the potential impacts of the individual, clinical differences. To add, there may be an interaction between the two (chronological and palatal) ages and will be tested for in Analysis I, to identify any complex relationships between fixed variables that may impact the results.

Lastly, the literature suggests that there is a potential impact of SLT input on outcomes. Therefore, in present study the participants are unlikely to have had individual therapy, though they may have had babble therapy (Williams, Harding, and Wren, 2021), and therefore we do not know how therapy will change potential deviations to the typical in production beyond the ages considered in the analysis. However, the current line of enquiry could indicate which (and whether) certain differences in early vocal forms are illustrative of typical processes or long-lasting cleft speech characteristics (which therapy could be further tailored to), and how they align with the later CP trajectory from 2 + years. The present work will therefore build on this missing link through an exploration and analysis of patterns in pre-speech vocalisations (e.g., frequency, phonetic structure, VMS, MBL, and phonetic sequences) that may even indicate the need for earlier or contrasting intervention.

Together, these additions above will provide reliable data from a more valid sample of ICPs and will help gain an understanding of vocal patterns at a deeper sequential level than currently exists. It provides a level of depth that is required to understand babbling abilities of this population to establish whether this is an area where infants deviate from the typical trajectory.

### 2.6.1 Research Questions and Hypotheses

Having reviewed the literature on the vocal development of ICPs, this chapter has laid out the clinical and academic context of the present work. This thesis will address one central research question and 3 subsidiary questions to investigate the vocalisation patterns of ICPs. It will present some new insight into the similarities/differences to the persistent, non-target vocal characteristics documented in nearly half of ICPs. The research questions will extend the established approaches and measures from typical vocal development research onto clinical data and will be considered in relation to ICPs' trajectory. In addition, three central predictions were collated in response to the reviewed literature (see Sections 2.2.3.1-2.4). The following hypotheses address each of the study's subsidiary research questions in turn, with the aim of each contributing towards the central research question. The research questions and predictions are outlined and motivated below.

Central research question:

*RQ1: To what extent do the phonetic and sequential properties of vocalisations produced by 14-month-olds with a repaired CP resemble the typical path of development?*

Subsidiary research questions:

*RQ2: How do the vocalisation measures of vocal, count, vocalisation length and canonicity vary with palatal age, and does the inclusion of these measures reveal new insights into the typical/CP trajectory of known vocalisation patterns?*

In relation to RQ2*, Hypothesis One* (H1) predicts that vocal count, vocalisation lengths, and MBLs will be lower than typical amounts at 14 months, but also lower than measures that typically occur at 7 months. This prediction expects that palatal age and chronological age will relate to these three vocalisation measures (Fell et al., 2022, Zajac et al., 2021). Given that the rates and onset of canonical babble are delayed in ICPs (Ha and Oller, 2021, and Scherer et al., 2008), it is likely that vocal count and MBL will also be lower, and likely too that these measures will depend on palatal age, due to differences in opportunities for rehearsal.

Furthermore, it is predicted that the range of consonants produced by ICPs will depend on the stage of vocal development they have reached but will be smaller than typical regardless. This prediction is based on concurrent research which found that 12-month-old ICPs had smaller consonant inventories that were composed of fewer stops, liquids, and velars (Zajac et al. 2021), potentially resulting in fewer canonical options in their babble, which would impact vocalisation length and MBL measures. By H1, if the infant has reached variegated babble, for instance, they are predicted to have a wider consonant repertoire than one who was at the vocal play stage, where more rudimentary consonant forms are expected.

*RQ3: What are the compositional and organisational components of syllables produced by ICPs (i.e., the phonetic properties of babbled 'consonants' and 'vowels') following repair?*

In relation to RQ3, by *Hypothesis Two* (H2) it is expected that most common organisational properties of the vocalisations will be glottal-, liquid-, and vowel-initial syllables (with fewer oral stops, fricatives, and velars). This prediction is in line with outcomes from clinical reports on phonetic repertoire and misarticulations (Kaiser et al., 2017, Scherer, Boyce, and Martin, 2013, Willadsen, 2012). The literature also revealed that, for the majority of ICPs, prevocalic oral stops may not emerge until at least 9 months after repair (Zajac et al. 2021, p. 30) and that

ICPs exhibited a preference for vowel-initial structures (Ha and Oller 2021, p. 10), indicating their compositional patterns to be inverted to the most common babble properties in typical development. Together with the reviewed literature, these studies motivate H2's expectations of more glottal-, liquid-, and vowel-initial vocalisations. It is also expected that there will be fewer oral stops and fricatives overall, motivated by the well-reported absence of high-pressure consonants in ICPs. It may be that nasal stops are more present than these oral stops and fricatives because they are low pressure and also do not require the oral cavity to be closed off.

These predictions are based on the phonetic inventory studies from ICPs, and such vocalisation properties could exemplify properties from earlier stages in typical vocal development than the chronological ages of ICPs. Unsurprisingly, this prediction implies that the infant is delayed and, as such, will not have reached variegated babble, which would be well expected for a typically developing infant at 14 months. However, the prediction of vowel-initial structures is one that extends to the prediction of a structural preference for vowel-initial vocalisations (due to predictable error patterns, Namasivayam et al, 2020, p. 11, and a typical default to CV structures). This outcome might illustrate a vocalisation pattern that deviates from the typical stages of vocal development as outlined in Section 2.1.

Lastly, by H2, central vowels are predicted to be more common than front and back vowels across the sample. The typical development studies illustrate the central vowels are most prominent in 7-10-month-olds' pre-linguistic syllables, and this hypothesis predicts deviation (documented by Ha and Oller, 2022) in the range of vowel production (documented by Chen and Kent, 2004) in this population. This question may provide novel insight on CP syllables, and the C + V combinations in pre-word vocalisations.

*RQ4: To what extent do the vocal measures and their sequential features show consistencies with published CP patterns? Does the visualisation of transitional probabilities– a method for visualising phonetic and sequential details from vocalisation transcriptions – benefit analysis of and reveal new insights into production patterns of ICPs post-repair?*

In relation to RQ4, *Hypothesis Three* (H3) makes the prediction that palatal age will relate to the vocalisation measures of harmony, MBL, and VMS count at 14 months. This prediction is motivated by Fell et al. (2022) and Zajac et al. (2021) who found palatal age to be a significant predictor of later vocal measures. By extension, the relationship between palatal age and these 3 vocal measures are predicted to be evident in earlier palatal ages (which is representative of earlier in the vocal trajectory, too) and existing research has not yet determined this matter.

This prediction is also encouraged by the awareness that babble in TD is also a predictor of early vocabulary and later speech outcomes (McGillon et al., 2017, and Wu and Gros-Louis, 2014).

Moreover, H3 also expects that vocal count and MBL will be a better predictor of VMS count and sequence inventories than palatal age (Bruderer et al., 2015; Davis and Redford, 2019; McAllister Byun and Tessier, 2016; Menn and Vihman 2011; Zamuner et al., 2018; Cychosz, Munsonc, and Edwards, 2021). As such, H3 predicts that vocal rehearsal (from vocal count) and canonicity (from MBL) may be more influential than palatal age in determining stable consonant production, and the range of sound sequences produced post-surgery. These elements may be influential on later advances along the vocal trajectory.

# 3 Pilot Research

This chapter sets out the research design and outcomes from two pilot studies that were undertaken to refine a robust approach to exploring the data from ICPs. The two piloted approaches included transcribing a range of phonetic and sequential features to analyse typical and vocal data from ICPs. As such, these data had many potential avenues for analyses, depending on the outcomes and vocal measure decisions. In coding for such a range of variables, the pilots helped to gain an understanding of which qualitative and quantitative measures would be most valid and reliable for using with a greater sample of infants. As such, this section describes the steps taken in the two pilots and the features that encouraged the adjustments made to the finalised transcription, coding, and analysis stages. This section also motivates the finalised sample (see Section 4.4) because the pilot research helped me to gauge the amount of speech data that could realistically be transcribed and analysed and, crucially, which of the infants could be explored at the required level of detail within the scope of this thesis. Moreover, the pilot was considered in parallel to the outcomes from the reviewed clinical literature, which also influenced the final sample size and inclusion criteria. The two pilot studies therefore revealed the most valid and relevant vocalisation variables and methodological factors for my research questions (see Section 2.6.1 for the main study's research context).

The first pilot involved the transcription approach of using parametric phonetics (a method for transcribing speech sounds on a continuum, Tench, 1978). It included experimenting with a very narrow transcription method from publicly available (otherwise termed 'open source') audio files from a typically developing infant. The second pilot included an initial transcription approach on the first test file from one infant in the Cleft Collective Speech and Language Corpus (CC-SLC). Both processes are described below in relation to why elements were rejected and/or integrated into the design.

The two main software programmes used for the pilot research were PRAAT (Boersma and Weenink, 2019) and ELAN (Version 6.0). PRAAT is an acoustic analysis software, which allows users to isolate a word, speech sound, or utterance and zoom in on it to view it as a wave form while simultaneously hearing the sound. As such, the interface shows spectrographs of speech as well as integrating formant analysis (which is how the frequency and type of vowels can be measured quantitatively). ELAN is a coding software used to transcribe and code audio and/or video data alongside the recording in as many categories as are needed. The codes are timestamped to the segments of the recording they correspond with, and files can be exported straight into Microsoft Excel. It also integrates PRAAT into its interface system, which allows quick access to using both tools interchangeably on the concerned selections of audio. PRAAT was used primarily as a reference point in Pilot One and ELAN was particularly beneficial to Pilot Two.

### 3.1.1 Pilot One

Pilot one assessed the depth needed for analysing and capturing the infant vocalisations. The approach piloted a narrow transcription approach called parametric phonetics which is outlined below and contributed to understanding the scope of the full study.

#### *3.1.1.1 Parametric Phonetics*

Parametric phonetics is a transcription approach which considers phones as the output of finely sequenced muscular movements (Tench 1978, p. 34). When working with auditory data only (i.e., no visual or articulatory data from videos or ultrasound), as is the case for the data in this thesis, data are approached using the kinaesthetic sense (as applied by Kelly and Local, 1989). This is an approach to transcription whereby—with the accompaniment of spectral observation, but no articulatory data—transcriptions are made auditorily. It is a process that can be achieved through retracing movements by mental or internal mimicry of how adult speech sounds are produced and allows for insight into configuration of the vocal tract when sounds are produced in connected speech. This is the method that was piloted and was applied to the infant speech below, however, first is an exploration of the particular details in the method.

The level of phonetic and articulatory detail that is captured in this transcription method offers a very fine-grain approach to transcribing speech and narrow transcription details which can be used in tandem with the mapped-out movements in the oral, nasal, and pharyngeal cavities (Tench, 1978, also Tench, 2011), as is exemplified in Figure 3.1.

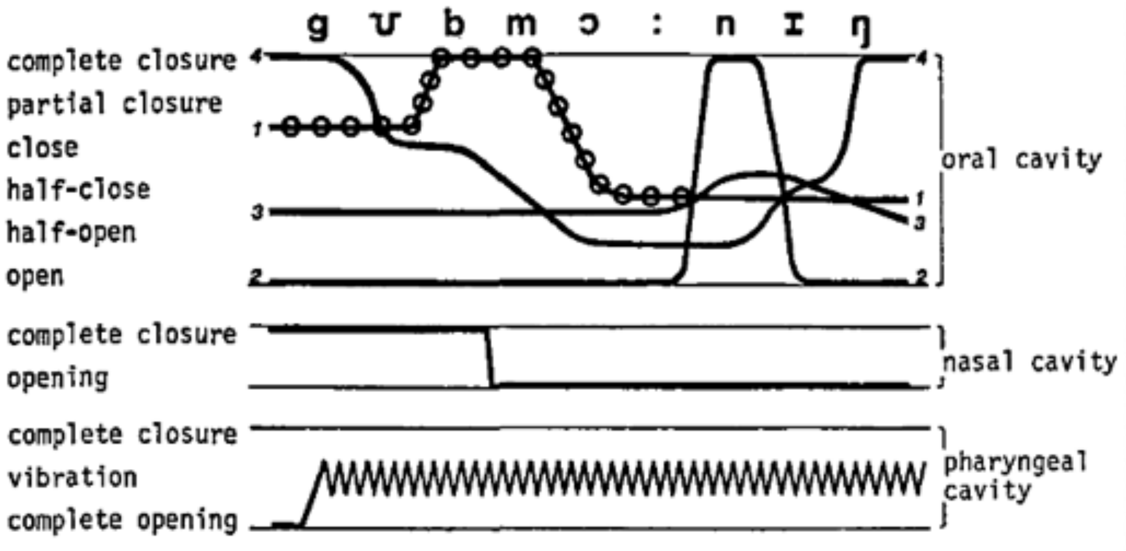



FIG. 8. A parametric diagram showing six parameters in the phrase *good morning.*

*Figure 3.1: Extract from Tench (1978, p. 41) of a Parametric Diagram*

As is visualised, the parametric diagram captures dynamic information for describing the articulatory process, including the simultaneous articulatory overlaps and sequences in the speech organs. Given its phonetic versatility, it allows for the impact of co-articulation effects on how speech sounds are released, and it captures the independent and collaborative functions of the organs of speech (Rahilly and Lowly, in Ball, 2021, p. 3). This is the method that was piloted first for phonetically transcribing audio data, it is considered in relation to the necessary details to include for the purpose of (a)typical, infant vocalisations.

#### *3.1.1.2 Parametric Phonetics and Infant Vocalisations*

Infant productions are often highly variable and messy (Nathani, Ertmer, and Stark, 2006; Laing and Bergelson, 2020; Ha et al., 2021). In order to address this variability, the transcription system selected for analysing infant vocalisations at 14 months needed to be robust enough to capture a wide range of vocal qualities that can reliably describe the CP speech characteristics reviewed in Section 2.2.3.1. While previous transcription practices aimed to capture children's unique sound systems, and some consider them close to, but not the same as, that of the adult (Waterson and Vihman, 2006, p. 62) vocalisations. Phonetic transcription approaches, like Waterson and Vihman's, achieve a level of detailed transcription that incorporates the following features in the transcription system: articulation features (nasality, sibilance, glottalisation, plosion, continuance, frontedness, backedness, voicing, rounding); the grade of vowel opening, the syllabic structure of words, and syllable prominence. Such fine-grain phonetic and phonological details are crucial to reliably capture prelinguistic vocalisations in typical language development (Goldstein et al., 2010, p. 636) and the level of detail used to record the features of atypical, infant speech is expanding in clinical phonetics (Ball, 2021). As a result of these transcription needs, parametric phonetics was piloted for this research. Unlike some of the more discrete transcription systems, parametric phonetics takes a dynamic and multidimensional approach to describing speech details in a way that may benefit infant production studies.

To continue, parametric diagrams include the kinetics of speech to capture the aspects that are hard to replicate or psychologically imagine. This approach is especially beneficial to use with CP speech data because these recreated aspects are unique to everyone on the microlevel. The auditory parameters captured in this approach serve to categorise the acoustic output and are inclusive of a range of vocal qualities, i.e., friction, voicing, and plosion. Consequently, parametric phonetics incorporates the specific CSCs (see Section 2.4 for a reminder), such as nasal, glottal, and velopharyngeal vocal quality.

#### *3.1.1.3 Pilot One: Parametric Transcriptions of Infant Vocalisations*

The initial stages of the pilot transcription involved familiarisation and practice using parametric diagrams (as first approached by Tench, 1978), and this stage helped to train and gain skills using the method. The pilot transcriptions included nine parametric diagrams of speech from typically developing infant productions. This data were selected because the transcription method to date has only been used to model typical, adult speech. As such, in order to pilot the plausibility of capturing vocalisations from ICPs, typical infant speech was used because it was closer to existing work on typical adult speech than atypical infant sounds.

The typical speech data were located and downloaded from CHILDES, in the Davis (1995) corpus, which is publicly available online. Three vocalisation strings (or segments) were selected at three different ages, a decision that was based on typical vocal development timeframes: the first extract was at 6 months (vocal play and expansion: 3-6 months), the second at 9 months (canonical babble onset: 6-10 months) and the third at 12 months (variegated babble onset: 10-14 months). The pilot data specifically consisted of the following ages: 6 (00;06;10), 9 (00;09:02), 12 (01;02:24), which were chosen as they were likely to reflect the three stages of typical babble development. They therefore exemplify a good measure to test the transcription method on infant vocalisations.

The process of the pilot transcription took the following stages. Firstly, infant productions were located using browsable transcripts on CHILDES. Although there is potential for inaccuracies, or missed valid productions here, this was less essential to prioritise in the pilot than for the main study. The next step was selecting which sequences of sounds—or babble strings—to transcribe. To determine which vocalisations were piloted, the following criteria were used: vocal strings had to have at least 1-2 seconds of silence preceding and proceeding the vocalisation, and vocalisations that were the most variable (i.e., they had the most phonetic contrast and diversity in sound combinations) across the recording were selected. The selections were therefore, not in favour of reduplications, but instead had a higher likelihood of capturing varied consonant sequences of sounds within the child's repertoire. Next, after listening to the vocalisations 4 times, the nine strings were broadly transcribed first, and then diacritic information was added to detail the transcription to a narrower level (e.g., including aspiration and glottal reinforcement). After this, the parametric diagrams were structured around the articulatory, auditory, and kinaesthetic approach. Lastly, the parametric diagrams were filled in, by using Tench (1978) as a guide for the appropriate cavities and lines and these transcriptions were checked to the creator's standard (Tench, 2022, pc).

Due to transcription challenges, the exclusion criteria encountered using this approach included the following: high pitch squeals, overlapping speech, fussing/cries, unintelligible productions after 4 attempts (as in Majorano et al., 2020, p. 4) because a narrower transcription could not be completed on these categories confidently or consistently. There were two alterations made to the parametric model following the pilot, which were required to be able to cater for vocalisations from ICPs. Firstly, the thickness of the line needed to cater for fortis/lenis contrasts (i.e., the strength or pressure with which a consonant is released), and the pharyngeal cavity should distinguish between vibration and friction to capture fricative productions. The new addition of fortis/lenis distinction might be of importance to ICPs whose productions can have differing air pressure (Naros et al., 2022, p. 444) and inclusion of the friction versus vibration distinction will afford for the increased likelihood of ICPs using comparatively more glottal and nasal friction in productions than TD infants (Scherer et al., 2018).

To build on this, the information captured on a spectrograph (e.g., the acoustic wave extracted from a moment in the speech stream), shows the acoustic waveform and articulatory aspects of production, such as amplitude, stricture, air pressure, and friction. Some of these finer acoustic details are also particularly relevant to CP speech characteristics that were earlier overviewed (see Section 2.4); for instance, nasal turbulence would be seen in the form of lower amplitude on a spectrograph. Subsequently, PRAAT may be a useful support for parametric phonetics in the cases where the degree of CP vocal characteristics needs to be clarified or even. Furthermore, the acoustic descriptions of atypical speech can provide ‘a valuable tool for the assessment and remediation of a number of different speech disorders’, including craniofacial anomalies like CP (Papakyritsis, in Ball 2020, p. 18). As such, this approach is also a valuable tool for analysing the phonological details in CP speech at 14 months.

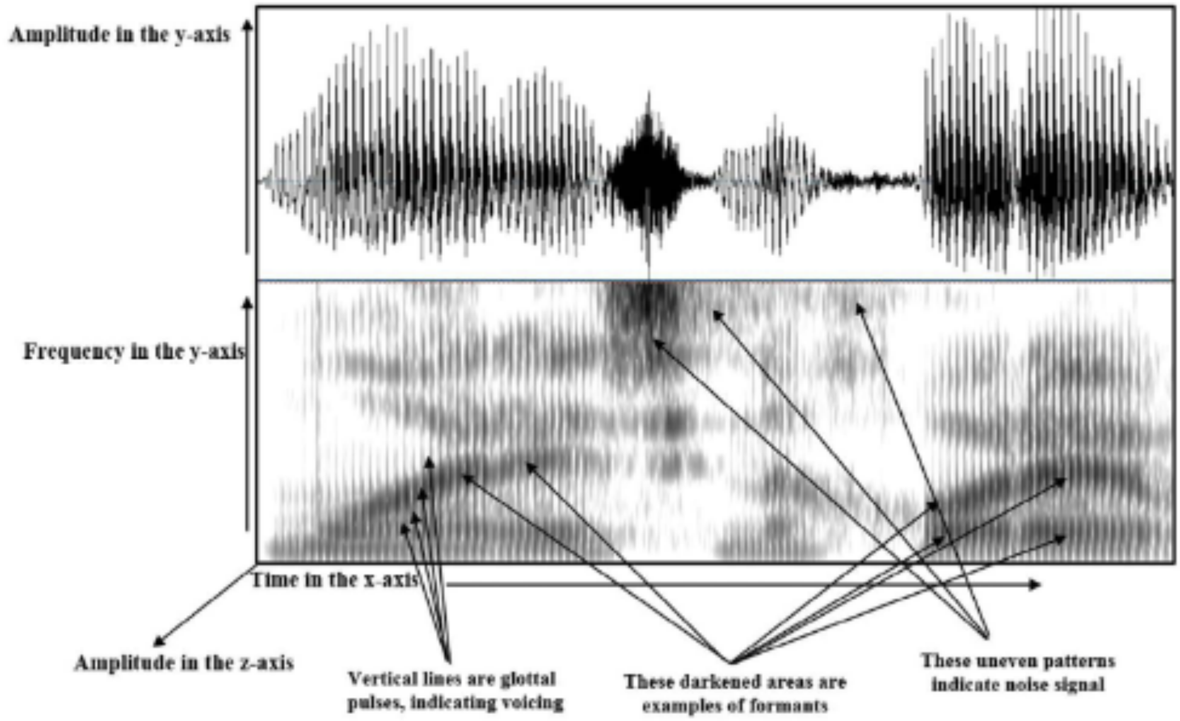



*Figure 3.2: Extract from Papakyritsis, in Ball (2020, p. 18) of Annotated Spectrograph*

Figure 3.2 illustrates an example of what information is provided in a spectrograph. For instance, the lines noting glottal pulses could be one way to categorise CP glottalization and glottal reinforcement (which is when the onset of a vocalisation is supported by pressure from the glottis). Although, there was difficulty in identifying whether formants are glottalized in PRAAT with complete accuracy, how glottals were determined in the final study was considered and integrated into the methodology (see Section 4.2.2.1) as a result of this pilot process.

PRAAT may also be useful for locating and measuring other vocal factors. Richards et al. (2017) capture the challenges of analysing vocalisations made by individuals and reflect that ‘speech sounds are not fixed objects’ (p. 2058), but are instead dynamic and have extensive, acoustic variation as a result of individual circumstances—voice quality, rate of speech etc—as well as the phonetic context. One aspect that is yet to be determined, is how beneficial PRAAT is for notating a sequence of movements from atypical speech, particularly in relation to mapping out more variable productions. Vowels are highly variable in infants' early vocalisations, and as such, the grouping and categorisation of them is an important consideration to have. One option considered during Pilot One was to group the classifications of them by approximating vowel spaces in relation to what formants come up on a PRAAT analysis.

A study that makes a distinction between syllable-like vowels and melodically complex vowels was in Hsu et al., (2000), where the first is identified when the vocalisation contains 'a fully resonant vowel sound with normal phonation' and the second, when 'a quasi-vowel sound is characterized by a nasal anti-resonance with low pitch' (p. 2). Whether vowels are more similar to those used in more adult-like syllables, could be assessed through the acoustic analysis of formant values. This approach to viewing infants' production of syllable categorises them in relation to their vowel resonance, and also categorises them in relation to the vowel spaces within infant's own vocal repertoire.

Two limitations of this method are that vowels are associated with formants rather than discrete measurements, so only approximate measurements can be taken. The method was relatively feasible across all three ages, though closures were more challenging to discretely capture in vocalic elements. Testing on typical children meant that exploring the CP data in 3.2.3 with a detailed transcription method was more informed. It meant that the level of detail did not need to be as fine, but that capturing sounds in their sequential contexts was possible with pre-speech vocalisation data. The aspects of this research that were integrated into the final study are presented in Section 3.1.1.4, because they were used in conjunction with the outcomes from Pilot Two to inform the method process.

#### *3.1.1.4 Pilot One Outcomes*

An evaluation of the parametric approach indicated some strengths of the method, the first of which being that there is a similarity between more complex sequences in variable infant productions and the coarticulation of sequences in adult speech. Given that Tench's examples were carried out on connected speech, the approach considers naturalistic features of speech that allow for movement across sequences of consonant productions. A benefit of parametric phonetics is its versatility for the complexity and variability in infant productions. By carrying out the pilots on three typically developing infants, the approach can be shown to cover two extensions to the original transcription method in order to cater for the potential details in child speech, however, the comparability of these vocalisations with those from the sample of ICPs was yet to be determined at this stage in the process.

Furthermore, one aspect that emerged from using this method, was how to categorise the degree of nasal emission (or nasal turbulence) on the diagrams. There were two options which addressed this, the first was that nasalisation could be captured in the IPA part of the transcription with a /˜/ symbol. The second, was that the nasal cavity section could have an additional friction setting, alternatively we could analyse the degree of nasality on the waveform in PRAAT, and further consideration to this analytic approach is given below. To summarise, the parametric phonetics approach does benefit atypical characteristics because it can capture narrow details, including nasalisation, however, classifying and quantifying the degree of these characteristics is less clear cut.

While capturing the vowel details with this approach would report on individuals' vowel space and give a more robust, quantitative set of results on the vocalisations, gaining the acoustic information from so many spectrograms is extremely time consuming to annotate and there could result in discrepancies across phoneticians during the segmentation process. However, an acoustic analysis of vowels in PRAAT would allow the approach to capture approximate vowel patterns across ICPs' vocalisations. This approach allows for the comparison of vowel space across the Vocalisations of ICPs and will also characterise (or detail) the vowels used in relation to phonological structures.

In summary, the detail achieved by Pilot One had many benefits, particularly the extent of phonetic and transitional detail which it captures, however, it was a time-consuming process even when carrying out the transcription on typical and older children than were part of the present study. To add, to achieve a robust parametric phonetic transcription, the process required very clean audio data. As such, after initial listens to the CP sample, there were at times background sounds (e.g., movement of the infant or background voices) which meant that this type of audio data were outside the scope of this transcription approach. The approach confirmed the value of detailed sound symbols (including the IPA transcription system), it also helped prepare for the consideration phonetic qualities that would be captured by parametric phonetics (e.g., nasalisation, glottalisation, and frication). In light of Pilot One, the awareness of coarticulation impacts (how sounds occur together rather than in isolation) also influenced the transcription needs. As a result, transitional probabilities were considered for the final procedure to boost the validity of the considerations (see below).

### 3.1.2 Pilot Two

For Pilot Two, an audio transcription was carried out on a case study infant from the CC-SLC. The participant was suited to the variables required in the full sample (as outlined in Section 4.4) and the initial transcription process involved coding of an hour of speech data selected from when the infant was most vocal across the day-long recording. Data were coded for various phonetic and prelinguistic information. These details contributed to a tier template with transcription categories, the final versions of which are set out in detail in Section 4. The main software programme used for the pilot research was ELAN (Version 6.0). ELAN is a coding software used to transcribe and code audio and/or video data alongside the recording in as many categories as needed. The codes are timestamped to the segments of the recording they correspond with, and files can be exported straight into Microsoft Excel.

For this second pilot study, a phonetic transcription was carried out on a 60-minute audio clip from the cleft collective corpus. The available data for this infant included the variables listed below and given later in Table 3.1 where the entire dataset is provided. This infant was selected at random based on the criteria of the project submitted to the Cleft Collective Team at Bristol University in order to reduce selection biases.

*Table 3.1: Overview of Case Study Variables*

| **Demographic Details** | |
|---|---|
| Biological sex | Female |
| Age at surgery | 7 months |
| Ethnicity | White |
| Socio-economic status | |
| **Cleft Details** | |
| Intertuberosity Size (Pre-op width of the palate at the tuberosity): | 15mm |
| Soft Edge Width (Pre-op soft edge width of the palatal cleft at the hard/soft palate junction): | 11mm |
| **Age Details** | |
| LENA Age (when recording was taken) | 14 months |
| Palatal Age | 7 months |
| Exact Age at 24 Month SLT Assessment Report | 24 months |
| Exact Age at 36 Month SLT Assessment Report | 37 months |

Table 3.1 outlines the timeline that the infant experienced and is illustrative of the clinical timeline in the UK. The phonetic transcriptions were exported from ELAN (as tab-lineated text) and into an Excel document. Each of the coded segments in ELAN were organised by their timepoints along the audio file, this meant that the transcriptions could be exported into Excel, with each of these timings forming a row in Excel. From here, each of the IPA transcriptions were ordered by ascending time points. The resulting data were a list of several transcriptions, each with its corresponding tiers (number of syllables, speakers) and the time within the recording in which it occurred. From here, the xlsl file was compatible with R-Studio for the analysis. These export processes were used for the full study and are also given in Section 4.2.1.1. The pilot collated data on the range of consonant types and how frequent they were in the audio file, (see Figure 3.4) and also the range and frequencies of most common vocal structures too (see Figure 3.5 in Section 3.2.3.1).

#### *3.1.2.1 Pilot Two Results*

The relevant results from Pilot Two that shaped the main study are given here to reflect on the format and impact of data captured by the pilot study, in order to inform the final study. In the second pilot, the frequencies of consonant and vowel formants were explored. As a reminder, vowels are highly variable in infants' early vocalisations, and as such, the grouping and categorisation of them was an important aspect to consider. For the pilot study, three instances of each corner vowel /i/, /u/, and /a/ were captured in PRAAT on a spectrograph and then analysed and grouped on formant 1 and 2 values (see Section 2.2.1 for a reminder of these categories), to test what this might look like in relation to typical trends. Therefore, these acoustic measures were grouped by approximated vowel spaces in PRAAT, and categorised by their vowel resonance, which generated ratio values that were averaged and then mapped out into a vowel space within the infant's vocal repertoire. The vowel space results from the case study followed Kalashnikova and Carreiras (2022, p. 34) by extracting the clear corner vowels and plotting these for their first and second formant valued (F1 and F2) to usefully divide the vowel space. Table 3.2 presents the frequencies from the vowels across the case study of vocalisations.

*Table 3.2: Pilot Two Mean Corner Vowel Formants*

| Vowel | F1 (mean) | F2 (mean) |
|---|---|---|
| /i/ | 439.99 | 1780 |
| /a/ | 1075.68 | 1474.55 |

| | | |
|---|---|---|
| **/u/** | 519.33 | 1049.89 |

The formant values are also visualised in relation to the vowel space in Figure 3.3 for reference.

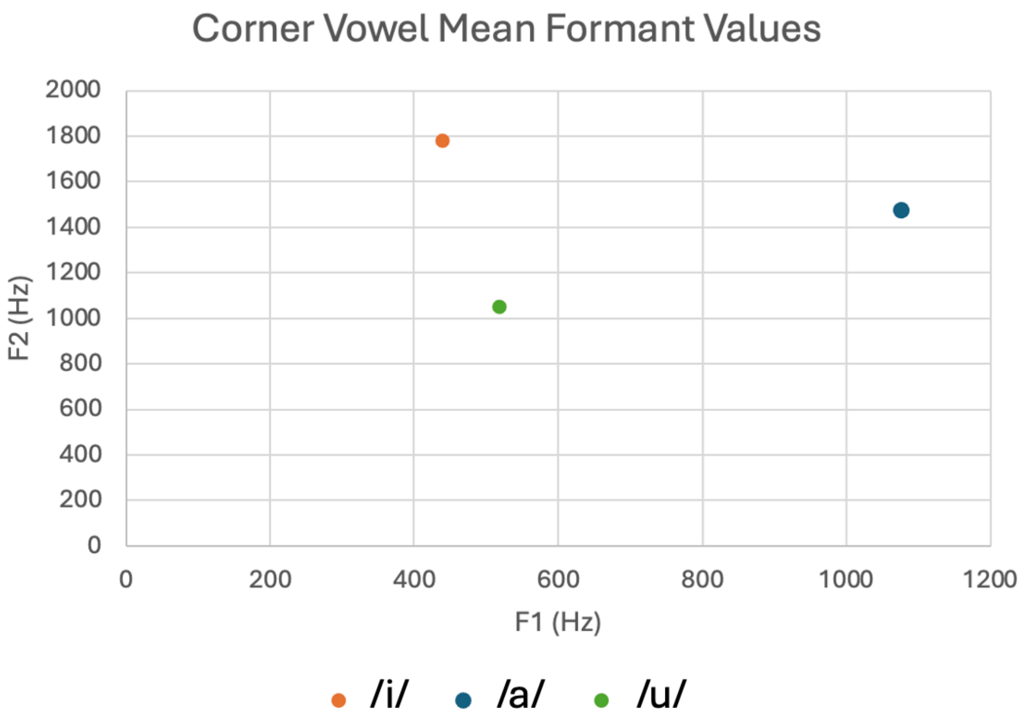



*Figure 3.3: Pilot Two Mean Corner Vowel Formants*

Overall, the pilot case study only captured ~100 vocalisations, but indicated some phonetic diversity, nonetheless, it brought some considerations to the surface for how to best illustrate the vocalisation characteristics. This diversity was first present in the selection of consonant productions. Figure 3.4 presents the pilot findings at a brief level; it illustrates the range and frequencies of consonants.

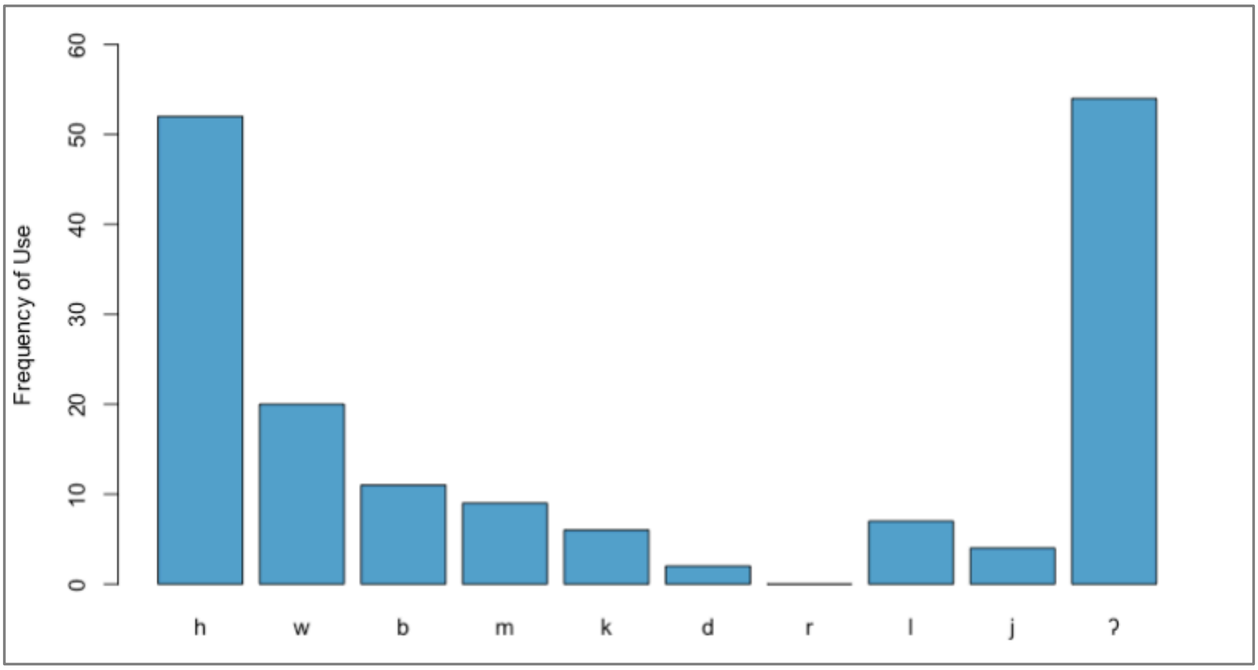



*Figure 3.4: Raw Frequency of Consonant Types in Pilot Two*

These outputs from the pilot indicated highest tendency in the glottal fricative, glottal stop, and labial velar liquid, marking acquisition of these, and lower use—or emergence—of oral stops and nasals overall. While these oral and nasal sounds were less common in this infant, a range of consonant gestures and placement were evident. As such, Pilot Two's less frequent sounds were not deemed to be because there was not the opportunity for them to occur in the sample time (i.e., the absent sounds were not a result of sampling opportunities). Plus, the findings indicated that the inclusion of glottals was necessary and formed a contribution to the decisions around vocal motor scheme criteria (see Section 4.3.2.4). When compared to Pilot 1, these findings indicated (as was expected by the literature) that the types of sounds were more challenging to discern than in typical child vocalisations (including frequent glottals and liquids). They also presented that this transcription approach should cater for vowel distinctions. While the parametric phonetic details were not all necessary to investigate the vocalisations at the sequential level, some clarity on vowels was needed based on the first pilot. The distinctions between vowels was integrated into the final procedure (see Section 3.1.2.2).

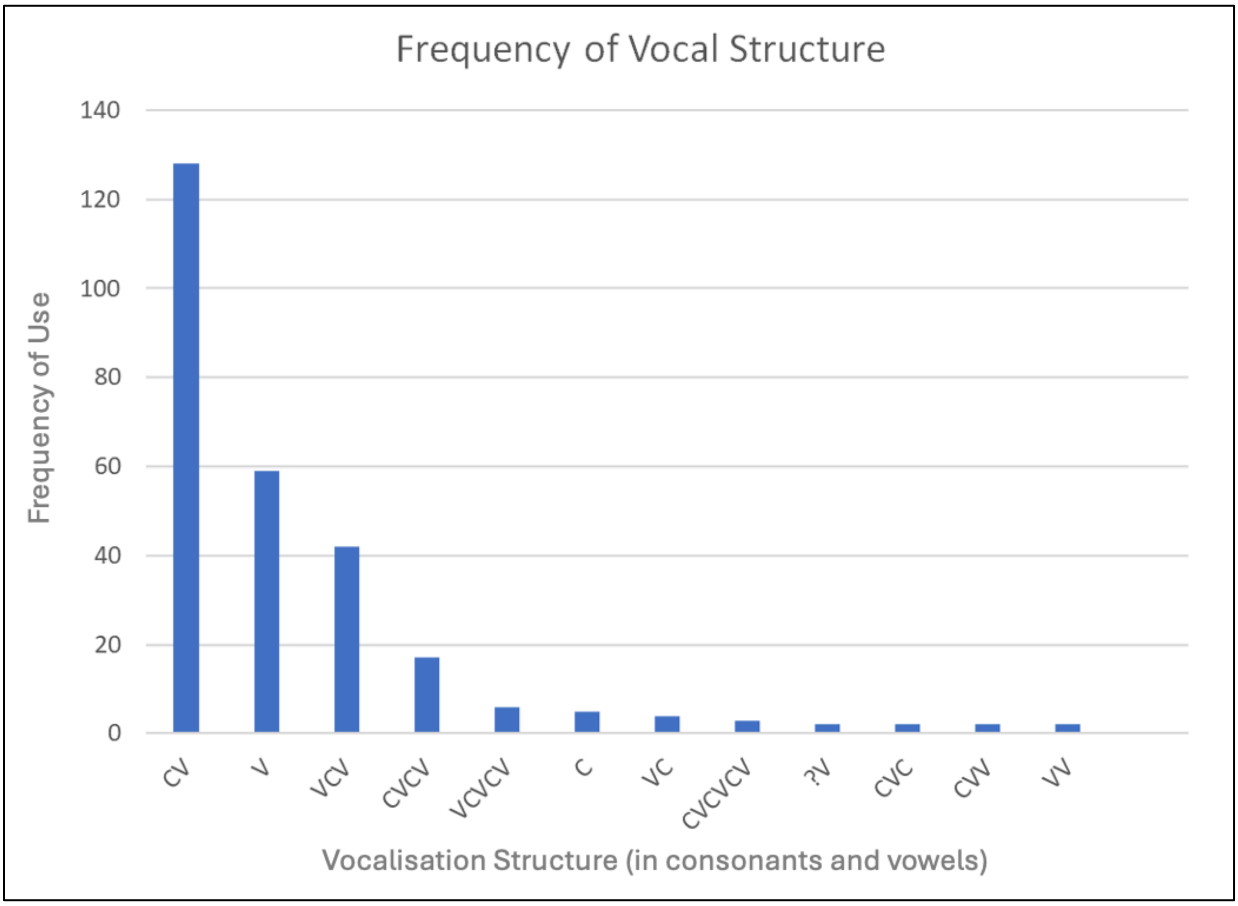



*Figure 3.5: Frequency Bar Plot of Vocalisation Structures in Pilot Two*

The sequences in Figure 3.5 showed that CV was the mode structure, with vowel-initial structures next most common. This was a preliminary finding that pointed to consistencies with H2, which expected that vocalisations would often be vowel-initial (see Section 2.6.1 for a reminder) and, in fact, illustrated some contrast to the typical, consonant-initial sequence. This trend provided motivation for the subsidiary research questions (see 5.1.1.2).

#### *3.1.2.2 Pilot Two Outcomes*

This section outlines some of the preliminary findings from Pilot Two, and then brings together the impact that both pilots had on the final procedure. The process of generating outcomes and graphs throughout Pilot Two outputted isolated and unorganised data, a limitation of the pilot that was addressed by the final analyses design (particularly by Section 4.3). This aspect was also not workable with the much greater collection of transcriptions from the full sample, and consequently more consideration was given to the collation of data and template used for coding the vocalisations. Furthermore, it encouraged a more streamlined approach to subsetting, categorising, and columnising the phonetic transcriptions, and specifically the vocalisation structures in the main study. The benefit of this pilot case study was to boost the organisation and workability of the data from an additional 27 participants in the full study.

More specifically, the case study only considered phonetic repertoire in relation to very broad categories (consonant types and vowels), and as a result, was not sufficiently detailed for understanding the production of sequences. The changes regarding phonetic structures that were integrated into the main study included the following four choices. First was the categorisation of vowels into front, mid, and back categories (see Section 4.2.2.2), which involved the IPA tier transcriptions being grouped in a new column for exploration in Analyses II and III. Second was the expansion of vocalisation structures into more phonetic categories, rather than just consonants. These categories were expanded to include details for consonant gestures in order to give more understanding of the fine-grained patterns that were present or absent within the articulations. Third was the inclusion of transitional probabilities to gauge the transitions between sounds occurring together in connected speech/contextual vocalisations. Furthermore, this measure would capture details of the cooccurrences of consonant and vocalic segments, given the range of frequencies and combinations of exact C + V formations (as are highlighted by Section 4.3.2.5). Last of the changes to expressing phonetic structures was the exclusion of strings longer than 3 + syllables for the full analyses, due to their relative rarity across the preliminary pilot findings. As such, the pilots motivated the inclusion of the most common syllable inventories across the sample (in Analysis II) and compiled more detail than Pilot Two, and less phonetic detail than for the finalised transcription system.

While Pilot Two included some key measures that were carried through into the main study (namely vocal count, vocalisation length and MBL), some new variables were also introduced in order to capture vocal characteristics in an analysable way (these were integrated in the conversion phase, see Script 2 in the processing scripts). These new variables included harmony, VMS, and transitional probabilities which were instated to capture the systematicity, the maturity of vocalisations, and the variety of sequences, respectively, which the pilot studies did not cover.

#### *3.1.2.3 Collective Pilot Impacts on Full Methodology*

The limitations and benefits from both pilot studies encouraged a more detailed and robust approach to considering the vocalisations sequences in the full study, and as such contributed several outcomes to solidifying the final research design. As a response to the pilots, the following elements were implemented in the final procedure of the main study:

- The final transcription procedure was confirmed (see Section 4) for maintaining consistent inclusion standards for a diverse number of vocalisation possibilities.
- The syllables were categorised in more detail (see Section 4.2.1.5) based on the challenges from both pilots in ensuring the replicability of coder decisions and the validity of categories considered by the analyses.
- The inclusion criteria, decision-making guidance, and exclusion criteria were solidified (see Sections 4.2.1 to 4.2.3) for capturing valid detail of vocalisations, which was also in line with published research.
- The scripts in R-Studio were created and tested to maintain consistency of data collation, cleaning, and conversion (see Section 4.3) ahead of the analysis.
- The vocalisation measures were consolidated (see Section 4.3.2) for ensuring that the relevance, workability, and the level of transcription depth was appropriate for the scale of data.
- The number of infants in the final sample (see Section 4.4) was re-evaluated for the prioritised eligibility criteria and for ensuring time limits.

In summary, the two pilot studies were used to determine what data variables to include and to add, as well as the transcription choices in the main study (including the depth of phonetic detail captured, and the specific variables taken). As a result, both pilot studies informed the main study's transcription procedure in Section 4, the coding and conversion processes in Section 4.3, and the finalised sample in Section 4.4.

# 4 Methodology

This chapter provides a comprehensive outline of the practical stages leading up to the analyses, illustrating its rigor and replicability. It overviews the dataset used for the investigation of vocalisation patterns of infants following CP repair. It also details the methodological procedure adopted, beginning with two pilot studies, which were imperative for the composition and consolidation of the main research design. In addition, given the heterogeneous nature of ICPs (earlier outlined in Section 2.3.1), the design for the sample variables and focal points in the methodology were essential to maintain validity. For instance, the sample participants were eligible for the study based on various anatomical and medical variables (e.g., age and syndromic status), resulting in the infants being characterised into 3 groups in relation to their palatal age (number of months after surgery at the point of data collection) rather than other characteristics such as gender or birth position, a limitation that is discussed in Section 7.1.

Section 4.1 overviews the corpus, including the corpus' primary data collection and preparation stages along with the ethical procedures undertaken prior to data access. Section 4.4.3 provides a detailed description of the selected sample, specifically including details on the exclusion criteria and relevant decisions surrounding the considered variables. The impacted research stages and the influences of the pilot studies on them include the transcription procedure (4.2), the coding and conversion process (4.3), as well as the finalised sample characteristics (4.4). This final section contains a detailed description of the main sample of twenty-eight infants, including the spread of clinical variables ahead of the analysis in Chapter 4. Therefore, this chapter addresses how the dataset and methodology both facilitate the exploration of the phonetic and structural properties of vocalisations produced by ICPs post repair at 14 months of age.

## 4.1 Data

The present research investigates data from the CC-SLC, which is a large dataset from a UK-wide, cohort study and includes data from hundreds of English-speaking infants who have undergone full CP repair (Wren et al., 2017). The CC-SLC was built by a team at Bristol University to learn more about what factors help ICPs to develop speech, which includes finding out which sounds are most recognisably produced, and which are most accessible to them while they grow up (Bristol.ac.uk, 2022). An additional aim of the Bristol research team was to capture babbling patterns, by including data on how children acquire speech and language over time. The data collection for CC-SLC began in 2014, and it continues to collect information and SLT reports; the details of information collected are laid out in Section 4.1.1.

### 4.1.1 Cleft Collective Speech and Language Corpus

The CC-SLC contains a cohort of over 600 children studied from birth to 5 years of age. It is composed of assessment report data, infant-adult naturalistic speech recordings, and clinical data from surgical questionnaires reported by surgeons. The therapist reported data also contains additional variables on demographic, surgical, hearing, and speech/language information, which were considered in relation to the sampling and research methods. The recruited CC-SLC participants from across the UK were contacted through cleft centres and medical institutions whereby parents volunteered their infants' vocalisations to be part of the databank. Participant eligibility required parents to enter the study when their baby was younger than twelve months, from this point, speech recordings were taken at ~14 months, plus reported and medical data were collected longitudinally at 24, 36, and 60 months.

The corpus contains assessment reports (as detailed in 2.4) taken by Speech and Language Therapists (SLTs) at 24 and 36-months; the details captured for these forms are available online.[2] The SLT reports give information on the infants' speech and language development from parents and professionals. In addition to the assessment reports, the data includes naturalistic day-long speech recordings to provide a richer opportunity for babbling analysis than assessment reports do. As a result, this section of the corpus was most suited to the central aim of the current research because it allows for the investigation of the infants' phonetic and vocalisation characteristics from audio recordings taken at home.

### 4.1.2 Ethical Procedure

The study involved the research of human data from a young and clinically vulnerable population. As such, it required full ethical approval from ENCAP's Ethics Committee ahead of gaining access to the corpus (see appendix A for a blank form in Section 9.1), as well as evidence of the ethics obtained for the primary research undertaken by the Cleft Collective Team (CCT). The approved ethical regulations from Cardiff University required the researcher taking research integrity training to ensure that ethical standards were understood and maintained throughout the project. It also required a full research proposal, outlining what data were required and for what aims. Along with these two documents, in order to gain approval,

[2] See http://www.bristol.ac.uk/dental/cleft-collective/families/information/speech/

the ethics committee required evidence that the primary research was conducted in compliance with the necessary Standard Operating Procedures and full ethical regulations as are dictated by the postgraduate research guidelines.[3] These documents were then reviewed by the ENCAP ethics committee at Cardiff and approved ahead of data access and transcription. In addition to Cardiff's procedure, the required ethics documents from the CCT ahead of their data collection process included consent forms, participant information sheets, and application forms (see Appendix A in Section 8.1), which were approved by the primary data collection team and the NHS ethics board well before the primary research was carried out.

Participant anonymity was a central consideration prior to conducting this research, consequently, ethics were addressed consistently throughout the research period, particularly in relation to the maintenance of pseudonyms and the retention timeframes. No shared documents included participant names, however the audio recordings had identifiable names, therefore the coding process adopted here has maintained anonymity throughout by not notating any names. Another potential ethical matter was the identifiability of individual's voices from the audio recordings; however, given that the Cleft Collective recordings were taken many years ago and the infants will have undergone many voice changes since data collection at ~14 months, it was determined that the children in the recordings would all sound very different today and would have low identifiability from the recordings. Given that all these checks were undertaken, as are documented in Appendices A and B (in sections 9.1-9.1), this research was signed off in full compliance of the ethical guidelines.

### 4.1.3 Dataset Selection

The infant data was collected by the CCT using language environment analysis—or LENA—technology (LENA Research Foundation, 2018). The LENA recording device captures productions in naturalistic settings and carries out automatic data analysis. It provides additional information on how participants' vocal output is distributed throughout the day. The automated analysis captures a range of information on infant vocalisations (child vocal count, and vocalisation rates, i.e., the distribution of vocalisations across the timeframe recorded); as well as the potential for analysis of adult word count (which was not implemented in the current study). Although some of the recordings from the corpus have been analysed by others for vocalisations (e.g., ratio of canonical to non-canonical babble and consonant inventories),

[3] See https://www.cardiff.ac.uk/research/our-research-environment/integrity-and-ethics/research-ethics

there was (and remains) much coding of these samples still to be undertaken for many infants in the corpus, which is a contribution of my research.

LENA technology has been used to research both typically (Sacks et al., 2013, Suskind, 2015) and atypically developing infants (Dykstra et al., 2013, and VanDam et al., 2015), which, by extension, adds weight to the suitability of the data collection method for researching ICPs. While the quality of LENA audio can sometimes be reduced by background noise, the recordings have many rich benefits for capturing naturalistic speech and vocalisation data. Furthermore, LENA recordings allow low-impact, flexible, large-scale data sampling and 'an automated analysis framework that is reliable and valid', whilst also reducing research impacts (of an environmental and parental nature) on children vocalizing because the device is unobtrusively worn all day (Richards et al., 2017, p. 2047).

A review of many research studies by Cristia et al. (2020, p. 483) reported that LENA can underestimate the number of child vocalizations and child-adult turns. However, they do speculate that this finding could be a result of their methodological design and the 1/2-minute windows they analysed. As such, the error rates from the automated LENA analysis over longer recordings are likely to be smaller (ibid). To add, more recent research has illustrated that LENA recording and analysis accuracy was not statistically different to that of speech coded by researchers who received extensive transcription training on identifying syllable boundaries and infant vocalisations (Ha et al., 2021, p. 10). Further, a comprehensive systematic review of LENA technology used for infant research found it to be a strongly reliable method for measuring English utterances (Wang et al. 2017., p. 307). This finding gives methodological value to the use of LENA for the exploration of the CC-SLC data whilst also confirming the speech tracking to be a useful and reliable tool for guiding and choosing which parts of the speech data to transcribe (see Section 4.3.2 for more details).

Lastly, CC-SLC assessment reports include information on participants' demographic information as well as a range of medical and development information (e.g., feeding behaviours, socio-economic status, surgical data, which includes size of palate opening, speech and language, number of siblings). Some of these variables, as were highlighted by the reviewed literature in Section 4.1.4, informed eligibility criteria in the sample design.

### 4.1.4 Sample Eligibility Criteria

The eligibility criteria for the sample in this research were selected due to specific reasons and processes that are laid out in this section. A total potential sample of 40 ICPs was acquired from the CCT, but, because of the inclusion and exclusion criteria presented in this section, and time constraints for transcription, the size of the final sample was reduced. Section 4.4 later describes the participant sample(s) in detail and clarifies how the total potential sample of 40 participants was reduced to 28 given the time required by the transcription. The next two sections detail the inclusion and exclusion criteria and the process of participant selection for the sample to report how the sample of 40 were selected. More detail is provided on the exact participants' (surgical, chronological, and palatal) ages in the sample overview (see Section 4.4.1, specifically see Section 2.2.3.1) but also informed the final sample of 28 participants prior to analysis.

#### *4.1.4.1 Inclusion Criteria*

The list of inclusion criteria for the sample of the CC-SLC is given here:

- A sample size of 40 participants.
- Participants had CP only.
- Recorded LENA ages (in months) and surgical repair ages (in months).
- Participants following cleft repair.
- Participants from the CC birth corpus.
- Data from the most vocal hour, extracted from naturalistic, LENA recordings.
- English as the only language spoken at home.

Firstly, the size of the sample was selected to yield data from comparable CP work. It was selected to be greater than those used in recent CP research (e.g., Ha and Oller, 2021: N = 10, and Bonanthaya, 2020, N = 17), in attempt to view patterns with more statistical power, whilst also being viable for the duration of the research scope of this research study.

In addition, and in line with Section 2.3, infants with a CP only was a priority of this research because this area of the palate affects high pressure, oral consonants, which are a common/typical feature of canonical babble and prelinguistic vocalisations. This work also focused on infants following repair, with a particular focus on variation depending on the number of months participants were post-surgery at the time of data collection. The choice of the 14-month age range in the study was based on the typical bench post for first words, in combination with the known and likely delays in ICPs. It is within and around this timeframe that infants are likely to produce sounds and sound combinations that impact their progression to early words.

Next, the inclusion of LENA age and surgical repair age was required in order to calculate palatal age, which was a central contribution and design feature of the present study. To continue, the automated analysis from LENA data can allow for comparison of speech variables across the sample—particularly the distribution and rate of infant vocalisations throughout the whole day; number of conversational turns; and adult word count (Ha and Oller, 2021). The measures can indicate the variation across hour-long recordings and indicate the infants' babble behaviour overall as well as how often caregivers interact with infants. The recordings are therefore a useful guide for identifying the segments of highest infant production rate (i.e., the sections in the recording when the infant vocalised the most) across the day-long recordings.

Hour-long samples were extracted from the day-long recordings (12-16 hours in length) to select a manageable amount of speech data to transcribe. Vocal rate was the selected criteria to guide which part of the sample was extracted because it captures the most amount of data from each infant and therefore potentially the widest range of sounds that they are rehearsing. The decision regarding which sections of the day-long recordings to analyse, was also based on similar studies in infant language research (Ha and Oller, 2021 and Scherer et al., 2018) that select timepoints where infants produce the most sounds throughout the day of audio. The criteria also reduced the chance of other activities, such as sleep and changing, interfering with the audio as much, where the audio would be of no use. The limitations of vocal rate (or count) is acknowledged in the Limitations (see Section 7.1), but overall, this process was consistent across infants and boosts the chances of capturing infants at their best in the day. Additionally, the selection criteria for the audio data allowed for vocal motor schemes (VMS) to be captured (this measure is used to assess the stability of consonant productions). The duration of the sixty-minute segments were sufficient criteria for assessing whether a child has any VMS (Vihman et al., 2014 and see Section 2.2.2) meaning that the data were applicable for standardised vocal measures.

A final criterion was for English to be the only language spoken in the home, given that bilingual infants produce sounds that are different to those of monolinguals (Fabiano-Smith and Goldstein, 2010, Kehoe, 2015), and that bilinguals have a production repertoire that is dependent on the unique properties of the languages they are acquiring, (Montanari, Mayr, and Subrahmanyam, 2018, p. 2468). Consequently, the decision to use a monolingual sample in which only English was spoken in the home, was made to maintain consistency across the sample regarding the native-language features of their vocalisations.

#### *4.1.4.2 Exclusion criteria*

Given the complexities involved in atypical populations (see Section 2.3 for a reminder), a selection of participant criteria was excluded from the sample, too. These are given below:

- Participants with any additional craniofacial anomalies (e.g., submucous CP).
- Participants with other known syndromes or hearing difficulties

When narrowing down the pool of infants, the possibilities were motivated by Choa et al. (2014) and Fell et al. (2022) who made distinctions for type and size of the cleft. This decision was made to eliminate any other anatomical factors that may impact vocalisations; for instance, cleft lip (CL) could influence the release of bilabials, as well as palatal/supraglottal articulations. Additionally, the exclusion of additional syndromes or disorders (e.g., hearing impairment, neurological disorders, and less known disorders like Robin Sequence) aimed to reduce the potential medical and/or cognitive influences on productions that were not a direct result of CP and repair surgery. While some dental details were available, these are less acknowledged by literature in their impact on infant vocalisations.

In addition, as Section 2.1 presented, each CP is unique, which raises difficulties for generalising patterns in academic research. Given this challenge, the selected data in the present study had particular exclusion criteria (see Section 4.2.3), and within the sample, infants were grouped to minimise the major differences we would expect to observe, especially within the type and size of cleft, timing of surgery, and grouping of participants by palatal age. The aim of which, was to make the study more balanced in terms of the known variability and the likely influences we can expect to see in data analysis from the clinical literature on ICPs.

Additionally, the CC-SLC contains a range of influential variables—such as cleft width and parental qualifications—that show up the complexity of extraneous factors influencing larger sample sizes. The reviewed literature highlights several key factors that inform the present research and although there are clinical variables that may impact development, some could not be addressed in this sampling process, particularly including those which may impact recovery time. For instance, Kaye and Che (2019) report on the potential impact of dietary intake on weight changes. Moreover, postoperative weight loss has been associated with a higher likelihood of complications in palatal healing (Cooper-Brown et al., 2008; Goyal et al., 2012), reaffirming that reduced and/or interrupted feeding is a predictor of recovery speed and quality because non-thriving infants are known to have language delays. The extent of these individual impacts is returned to in the Section 7.1.

### 4.1.5 Evaluation of the Dataset

This section evaluates the sample in relation to its empirical limitations and benefits. First, there is variation in quality across the audio samples, which thus limits their complete comparability with each other. Arguably, this could be the case in naturalistic, lab environments (e.g., baby labs), however the extent of variability is increased by the diversity of different home environments reached in a national cohort study. Also, the current study extracted the hour in which the infant was most vocal, however there were not set activity types or number of speakers, which again could impact on generalisability and infant comparability, however, the approach offered consistent sampling of data across all 28 infants. A further limitation of the LENA device is its limited ability to distinguish multiple speakers' voices (Cristia et al., 2020). As a result, a higher number of speakers and potential interference from siblings may affect the accuracy of automated participant identification and the accuracy in detecting different children's vocal count. The qualitative transcription approach reduces the potential interference of this limitation because the human transcriber is more attuned to the individual infant's voice tone than the LENA device.

While there are limitations with any data collection method (see Section 7.1 for an expansion of these), using the CC-SLC data is very valuable for babble studies. The value of this dataset is fourfold: the timeframe the infants are in post-repair; the data are novel and hard to come by; the LENA recordings are reflective of the infant's everyday interactions and represent naturalistic data; the sample includes data on medical factors. To expand, the speech recordings attained from the CC-SLC were underexplored, offering a rich and vast selection of data. Next, the use of a LENA benefitted this research by capturing the infant's own vocalisations in a naturalistic setting, which may be crucial for valid research. Whilst the approach was less structured than experimental methods, the technology provides an ecologically-sound and contextually rich representation of infants' experiences (Tamis-LeMonda et al., 2017). Lastly, as was explored in 3.1.3, the interference of syndromic status, cleft type and so forth, can drastically impact results. This sample of 28 infants addressed these factors and therefore represents a higher proportion of medically selective variables across the infants than most CP research has yet offered.

### 4.1.6 Data Preparation

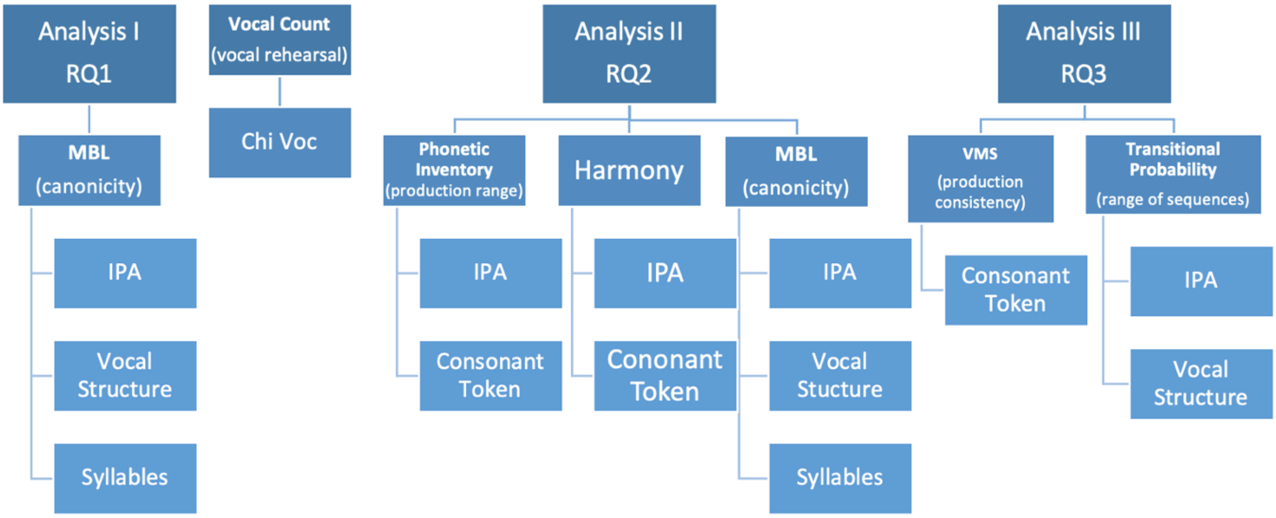
This section overviews the tasks carried out by the Cleft Collective research team prior to them extracting a sample of forty infants from the collection of 600 + that was tailored to this research's sample criteria. Their process involved compiling information from the questionnaire data and professional Speech and Language Therapist (SLT) reports on infant's consonant inventories to organise and prepare the dataset for the speech recordings.

The first stage in the data preparation included selecting the sample based on the eligibility criteria (which are set out in Section 4.1.4) and downloading these data for each participant from when the LENA device detected the highest child vocal count. After the selection stage, an initial quality check was carried out by a research assistant at Bristol University to ensure that what was detected on the scanning software was consistent with the content of the raw data file. Following this, the whole dataset was cleaned, which involved organising participants to ensure that the variables were available in an analysable format. Some additional steps also aimed to address cross-infant variation: quality checks for outliers in relation to the inputted participants' biological information (i.e., birth weight values and age); and checks to ensure no participant had any identifiable data within the dataset. Lastly, before the data were shared for my study, the participant names were swapped with an ID code to maintain anonymity and a collaborator ID was assigned to the dataset on my behalf.

## 4.2 Transcription Procedure of the Main Study

The first stage of the audio transcription involved listening through a 10-minute sample from each of the hour-long audio recordings, because this amount was a shorter, more manageable chunk of time to become familiar with the sounds and noises in the recordings for each of the 28 infants. The initial phase also included recording notes on variables, such as how many speakers were present, vocalisation exclusion considerations, the quality of audio recording, and potential tier categories for coding. Following the initial listening stage, the recording was listened to a second time, this time notating infant vocalisations, and all the other tier categories on the productions. The third stage involved breaking down the productions into more detail—including which consonants and estimated vowels were produced, the number of syllables, harmonic status of the vocalisation and the syllable structure of child productions (i.e., CV, VCV). Together, these findings motivated consideration of syllables and syllable structures in infant vocalisations. The categories were notated using a tier template that is detailed below using a transcription system appropriate for atypical, pre-speech sounds capturing both consonantal and vocalic details to reliably investigate the central research question.

Figure 4.1 provides an initial summary of the coding tiers, vocalisation measures and the corresponding concept being investigated, and the designated analysis section. Each Analysis links with its relevant research question, as was outlined in the Introduction.




| | | | | | | |
|---|---|---|---|---|---|---|
| **LEVEL 1** | Analysis I | Analysis II | Analysis III | | | |
| **LEVEL 2** | MBL | Vocal Count | Phonetic Inventory | Harmony | VMS | Transitional Probability |
| **LEVEL 3** | IPA | Vocal Structure | Syllables | Consonant Token | Chi Voc | |

*Figure 4.1: A Tree Diagram of Analysis Variables*

The Analysis stage and relevant RQ are in level 1, the concerned measures on level 2 (with concept being measured in brackets), and the coded ELAN tiers are on the level 3. The figure therefore provides context to the following vocalisation criteria, and its relevance to the larger aims of the present research.

### 4.2.1 Vocalisation Inclusion Criteria

This section describes which elements of the transcriptions were included in the analysis. For the data coding, a template was created which included a range of tiers and variables (see Appendix C, Section 9.3). The tier system used for audio files in the main study was categorised into a range of criteria to capture the following phonetic and sequential speech characteristics across the naturalistic interactions. To describe the system, the tiers either fell into the caregiver or infant code categories, and these are presented below.

#### *4.2.1.1 Vocalisation*

The *CHI VOC* (child vocalisation) tier served to mark the timepoint when the infant vocalised. The purpose of this tier was to keep track of child vocal count (which can later be compared and verified against the automated LENA data), and to enable sub tiers that related only to the infant's production, i.e., the codes were separate to those in the caregiver Speech.

The *IPA* tier was allocated for more detailed transcriptions of the infant vocalisations. These codes were transcribed using IPA transcription conventions. In cases where vocalisations were unclear, they were coded with ‘XXX’ and these unintelligible vocalisations were later excluded. For certainty, those that were too unclear to discern after four listening attempts (consistent with Majorano et al., 2020, p. 4) were not transcribed in the IPA tier. In deciding whether a consonant was voiced or voiceless, an auditory decision was made, whilst viewing the voice onset time on the waveform visible in ELAN. The depth of the finalised transcription method was informed and guided by two expert phoneticians (Tench and O’Grady), ensuring that the phonetic decisions made were consistent and in line with auditory and phonetic distinctions.

#### *4.2.1.2 Harmony*

Consonant Harmony (CHARM) and Vowel Harmony (VHARM) were used to code speech sounds which reduplicated across the vocalisation. Consonant or vowel harmony is when the same consonant is used in syllable-initial position across the vocalisation, or when a vowel is repeated across a vocalisation. For example, /**b**e**b**a/ has consonant harmony because /b/ is reduplicated but the vowel is not versus /g**u**t**u**/, which has vowel harmony but no consonant harmony. The CHARM or VHARM tier was coded as either yes or no. Including this category helped to capture the degree of phonological similarity across babbled forms/vocalisation and may point to what stage of vocal development the infants are in, i.e., whether productions are mostly reduplicated, whether they are reduplicated for some consonants/vowels more than others, which features (if any) are more variable etc.

The coding of harmony category was only applied to front loaded syllables, meaning the maximum number of consonants were considered together at the beginning of syllables (e.g., ‘dainty’ would be split into ‘dain’ and ‘ty’ rather than ‘daint’ and ‘y’). This decision for syllable-initial positions ensured consistency across the measurement and therefore was only relevant to code when vocalisations had 2 or more syllables. In other words, vocalisations were not applicable to consonant harmony when consonant clusters were adjacent to each other across a syllable boundary, for instance a VCCV structure like /ibdi/ was not applicable to consonant harmony, only vowel harmony. The reason these consonant clusters were not applied to the CHARM tier as either the coda or onset of a final vowel was because they are instances of double closure (as explored in Section 2.2.1) and as such they do not exemplify the reuse of harmonic segments because they are produced in the same gesture.

The analyses of harmony did not make a distinction between voiced consonants (e.g., /b/, /d/, /g/) and voiceless consonants (e.g., /p/, /t/, /k/). The advantage of capturing this information was to provide a measure for articulatory skill and to control contrastive pairs. While voiced tokens are considered to be salient to infants and acquired before voiceless ones, the acquisition patterns do not appear to be stable across infants until around 2;0 in typically developing infants (Eilers et al., 1984), which could explain why so many studies in infant speech development do not distinguish between the voicing contrast (Barton, 1980; Eilers et al., 1984). For the main study, this distinction was considered an unnecessary feature to analyse, especially given how time consuming it is to run acoustic analyses on rudimentary consonants.

In cases where the vocalisation contains more than 3 consonants and 3 vowels, vowel harmony was disregarded due to the high variability within these clusters. For instance, in the vocalisation /ewaituju/, there were many competing sounds to categorise harmony, with four vowel types and three consonants. In this way, some constraints were placed on the harmony tier to ensure that its inclusion was discrete, consistent, and not overly generous. To continue, in cases of diphthongs, vowel harmony was not applicable unless a second diphthong followed an earlier one. This approach was only relevant where there were two or more closures within the vocalisation. Consonant harmony was not applicable when two consonants are used next to each other, but only when they are separated by a vowel (e.g., in /nju/ where there is a simultaneous, or double closure in the consonantal segments versus /jun/, where the vowel clearly separates the consonantal elements.

#### *4.2.1.3 Vocalisation Structure*

Phonetic Structure (PS) was used to detail the vocalisation structure and capture the sequences in consonant-vowel combinations within infants' vocalisations. The syllable structure was included to test whether the infants' rudimentary speech sounds follow the typical consonant-vowel (CV) structure, before they progress to their first words (McCune and Vihman, 2001). Given the reviewed literature on Korean-acquiring ICPs and their preference for VCV sequences (i.e., di-syllabic structures, Ha and Oller, 2021), when the infant produced /idu/ it would be noted as VCV, whereas baba would be CVCV. Their finding therefore indicated a difference in the combinations of sounds in pre-word vocalisations. The consonant vocalisations were challenging to analyse in the audio files in Pilot Two (3.1.2) and running an acoustic analysis on systematic sections from the vocalisations revealed some areas for concern. More specifically, consonants lacking clarity and air pressure releases were difficult to measure, as were those limited inconsistency across the productions. As a response to Pilot Two, to keep track of whether consonants that were unreleased or contrastingly quiet (i.e., with noticeably less supraglottal pressure during articulation), these instances were transcribed with a lowercase symbol, such as 'cV' for /hi/ with a quiet /h/. Quieter vocalisations were identified by their lower amplitude in the acoustic waveform displayed in ELAN. If the amplitude was more than half of the other sounds (as measured by distance on the wave form in the ELAN window), it was coded with a lower-case letter. In addition, where vocalisations were unclear for one unit in the production, a question mark was coded after the C or V that was uncertain within the PS tier.

The phonetic structure (PS) was generated from the IPA transcriptions and is detailed in R-Studio (see Langner, 2024, Data Processing Script 2) during the converting phase. This process was time efficient, but also consistent when handling large sized data. There was flexibility in the level of phonetic detail captured, including the generation of columns with vowel contrasts, as well as manner of articulation contrast. For instance, at the broadest level, /ba/ was transcribed as CV, but at the gesture level, SB (for stop and back vowel) meaning that these columns offered flexibility for analyses.

#### *4.2.1.4 Consonant Token*

The *Token* tier was used to track how many tokens of each consonant were present in the infant's vocalisations throughout the recording. Therefore, each consonant was denoted with a number (e.g., b3) to code the third instance that the child produced a voiced bilabial stop. This row therefore gave a view of consonant token frequencies chronologically for each infant. The tokens serve as a reliable indicator of which consonants are more stable in the child's repertoire and may map onto production theory measures such as Vocal Motor Schemes (or VMS, Vihman, 2016), which is used to define the stability of productions by assessing how frequent a consonant is in a child's production at a given point in development. For instance, DePaolis, Vihman, and Keren-Portnoy et al. (2010) define consonants as stable and consistent when they are produced 50 + times in one 30-minute session, however there is questionable comparability of using the same measure on atypical populations. A review and justification for using the VMS measure is given in Section 4.3.2.4, but in relation to the procedure, the study analysed a measure for consonants acquired (with 2 or more uses of each sound) as well as VMS sounds (with 50 + used of each sound) across the whole hour.

These measures give a more comprehensive consonant repertoire than most studies on CP consonants (which have focused on stops, but also grouped gesture categories together to measure acquisition, meaning that many details on the actual usage patterns were overlooked (e.g., Zajac et al., 2021). Moreover, the measure of whether ICPs have VMS within their production repertoire could indicate how regular and stable their consonant productions are in relation to typically developing infants, and in relation to one another.

#### *4.2.1.5 Syllables*

The *Syl* tier was used to code how many (broad) syllables there were across the vocalisation. This was mostly rhythmically discerned as termed by Oller (2000, pp. 91-98). Syllables can be defined by their resonance and formant patterns, which were determined by their phonetic composition, along with the rapidity of transitions, which was auditorily discerned according to Oller's criteria below. Given that cross-linguistic syllables are rhythmically similar in structure (ibid, p. 91) and that syllables can be audibly determined by whether the vocal tract is open and whether there is vocal fold vibration (ibid, p. 96), the Syl tier followed Oller's four criteria to count the number of syllables in each vocalisation:

- The syllable contains 'a single centre nucleus with normal phonation' that is a vocalic element with comparable voicing to that of everyday speech (e.g., not infant cries, squeals, or screams).
- The syllable contains 'full resonance of the nucleus' that is, the vowel is articulated with an active vowel position, and not a resting posture.
- The syllable contains 'at least one margin', that is, a movement by the articulator(s) to produce one consonant-like element along with a vowel (i.e., the basic criteria for a canonical syllable).
- The syllable is realised with a 'rapid, uninterrupted full transition from margin to nucleus', meaning that there is a quick movement between the consonant-like closure and vowel element.

There are four exceptions to the canonical instances, and each of these were allocated four different MBLs accordingly (see Section 4.3.2.3 for a reminder of the categories): isolated vowels or syllabic consonants; reduced syllables with low stress and/or resonance or syllables with glottal and a vowel, a liquid and a vowel, or a liquid only. These instances did not reflect the necessary transition between the silence (or valley) during the consonant closure and the formant energy (peak) during the vowel articulation. As they did not include these two states next to each other, they did not fit the canonical criteria (captured by MBL3 and MBL4) and/or listeners would not be 'able to identify the consonant and vocalic segments' (p. 96). Due to the identifiability of syllables in nasalised articulations, nasal only productions were including in the tier, but fell into the MBL1 category, in line with the criteria in Section 4.3.2.3. Lastly, in places where it was unclear after 4 listening attempts, the vocalisation was coded accordingly in the notes tier (see below in Section 4.2.1.6). Consonant productions with no vocalic element were not coded in the Syl tier as they were not applicable to the definitions given here.

#### *4.2.1.6 Notes*

Lastly, the *Notes* tier was where details were annotated for further consideration, and for reference in qualitative analyses in the finalised procedure. For instance, this tier located notes on whether certain categories were considered for exclusion (as given in Section 4.2.3) in initial listening stage or in the transcription process, e.g., overlapping, or latching speech. Additional considerations coded in the notes tier during the pilot research included whether to include laughter and /h/ initial vocalisations. The disadvantage of including laughter is that there is a blurred line between breathing and/or laughter with intentional production, which is especially complicated by the likelihood of glottal friction being common in this population. On the other hand, the advantage of including laughter is that /h/ has phonemic value in English and still illustrates articulatory coordination, which is at the heart of this research. Moreover, given that there is no visual data to identify valence within the social context of laughter, the distinction between a glottal fricative vocalisation and a laugh is very challenging, if not impossible, to reliably separate. To exclude glottal fricatives would mean having no data on a consonant that is phonemic in English, therefore even though /h/ has more than one function in production, it was valuable to include. Based on these considerations, laughter was included in the full study.

Two other considerations were added to the Notes tier, but these were not incorporated into the analysis: the notation of infant directed speech to signal when adults are speaking directly to the infant, and the inclusion of turn taking to map out the distribution of interactional characteristics, given that it is an instinctive behaviour (Oller, 2000, p. 254). In addition, the record of reflections in Pilot Two's Notes tier informed the decision to add a category for ranking rudimentary forms that did not fall into the true canonical babble criteria in the finalised procedure. The below criteria exemplify how this variable was implemented due to the variable non-supraglottal closures across infants in the listening stage and initial listening processes ahead of transcription. The Notes tier assigned rudimentary forms based on the following criteria:

1: liquid and vowel combination lasting 3 + syllables

2: the criteria from 1 but with 2 different placements of liquid

3: vowel-like vocalisation with a range of pitch and duration

4: the criteria from 3 with nasalised quality (mild closure)

These noted numbers also captured elongated vocal sounds and more 'sung' vocalisations, which would otherwise have been excluded. It is a system that resulted in a standardised, numerical value which can be attributed to each vocalisation that could not be confidently coded in the syllable and IPA tier.

### 4.2.2 Discerning Vocalisation Categories

Part of the inclusion process was determining which vocalisations were necessary to include in the analysis, therefore this section provides detail to guide such decisions. In light of the initial 10-minute transcriptions, decisions were made to optimise and clarify the transcription process. Guidance on this decision making was also informed by Pilot Two (in Section 3.1.2) and is given here in relation to three main criteria: glottalisation guidance; vocalic determination; and the separation of vocalisations and these are presented and justified in sections 4.2.2.1, 4.2.2.2, and 4.2.2.3 respectively.

#### *4.2.2.1 Glottalisation Guidance*

Much linguistic research discounts glottals from transcriptions, perhaps because of their difficulty to discern or because they are not considered to be a common phonemic in the English language. However, they are used in naturalistic, connective speech, and are also an included sound in many SLT assessments. To continue, there are challenges in determining them during the onset of vowels, or from laughter. To address the difficulties in transcribing glottals, a series of steps were followed because in the pilot research (see Section 3.1.2.3) there was difficulty in discerning heavy breathing from glottal fricatives at times, and also in determining glottal friction at the onset of vowel-initial structures. In cases where very heavy breathing blocked the audio quality of the vocalisation, vocalisations were not included. The key contrast to laughter with this instance is in whether a vocalic element was clearly present. In cases where glottals were used as grunts (i.e., where the vowel was not resonant, and easy to categorise as front mid or back) the utterance was not coded. Similarly, breathy glottals were only transcribed where there was an audible quasi resonant or fully resonant vowel because glottal friction interferes with the formant values on a spectrogram. This interference challenges the consistency of including these sounds as they vary in acoustic clarity and/or resonance. In cases where the infants had glottalisation throughout their vocalisations, these were not coded as individual glottal gestures, but a note was added about the quality of the articulatory sound. Whisper voice was not coded, often the resonance of whisper vocalisation was low, plus whispered sounds in the audio made it harder to determine different speaker voices from fricative-only articulations.

#### *4.2.2.2 Vocalic Determination*

In determining the vowel elements in the recordings, the focus was on resonance rather than articulatory restriction, e.g., vocal fries that have a lower frequency of vocalic vibration were excluded. As given earlier in 3.3, vowel productions can be messy, therefore the exactness of vowels was approached with consideration to vowels that were nearest in placement to the three broad vowel categories (front, mid, or back). These three vowel types were selected because most English vowels fall into these three categories, whereas the four open to close parameters (open, open-mid, close-mid, and close) are less clear cut. In addition, having only three categories, rather than four, allows for greater distinction between each vowel type. The categorisation of vowels was sometimes blurrier to decide, the most prominent interference here was the rudimentary liquids in babble strings (e.g., as in /jɔɹjɔɹjɔɹjɔɹ/) which were frequent in the pilot data (see Section 3.1.2.1) and often occurred in much longer segments (or in vocalisations with more syllables). These instances had a reasonable amount of vowel resonance across the vocalisation but had less timing and rhythmic coordination than in fully canonical syllables. While this example is generally a signal of less-advanced production, according to the vocal stages laid out in Section 2.2, it was still coded in case such usage of more liquids was a prominent characteristic in CP productions. More information was given in Section 3.3.1.6 to detail how these instances were notated.

#### *4.2.2.3 Separating Vocalisations*

To consistently separate vocalisations, audible breaths were used. These were the most frequent markers of vocalisation boundaries, while there was more disparity between pauses within multiple vocalisations that were audibly produced in one breath. To distinguish this gap, a space was transcribed in the IPA tier to point to the brief pause to ensure consistent transcription of vocalisations that are close together. A distinction was made auditorily to segment units based on bursts (shorter articulations with a quick breath in between them) verses those released over longer, sustained vocalisations. This decision was still in line with using breaths as a guide (in accordance with Lee et al., 2018 and also et al., 1995) and helps to distinguish vocalisation boundaries from syllable boundaries in a consistent way. The advantage of this approach to separating vocalisations was that it was more discrete than using pauses, which differed greatly in length, and in many cases would be evidenced on the wave form in ELAN to back up decisions. On the other hand, breaths did sometimes vary in volume and identifiability, and therefore the final approach relied on a mixture of brief pauses and breath groups to determine where vocalisations began and ended.

### 4.2.3 Vocalisation Exclusion Criteria

It was decided at this point that caregiver speech would not be integrated in the full study. This exclusion was determined by the time constraints indicated by both the second pilot study (see Section 3.1.2.2) and by the initial approach, which used 6 10-minute samples from the data. In addition, capturing caregiver input as well as infant vocalisations had the danger of including too broad a focus to capture the phonetic detail needed to fulfil the research questions. There were some more specific exclusion criteria in the main transcription process detailed here, including the classifications of when vocalisations were too rudimentary and unclear to transcribe, along with other criteria adopted in infant research. The excluded vocalisations were only coded between 30-40 mins across each session, in this way they were able to provide an indication of what proportion of vocalisations were analysable per infant, without taking too much time from the focus of the transcription process. In the full transcriptions therefore only included vocalisations that were coded for inclusion criteria in order to ensure the process was maintainable and consistent.

#### *4.2.3.1 Rudimentary and Unclear Vocalisations*

In cases where closures were not produced in a combination with a vocalic component, they were excluded; this choice was made because such instances did not conform with the defined syllable criteria (given earlier in Section 4.2.1.5) and also due to the difficulty in discerning which placement of articulation was used (due to the quality of the recording). In cases where a vocalisation is excluded due to infant fussing and environmental noise that makes the vocalisation muffled and unanalysable the code ‘EXF’ was used. This clarification was to capture a distinction between this methodological, recording obstacle with unclear or unanalysable vocalisations. Furthermore, an exclusion category specific to this characteristic included coughs, sneezes, big breaths which did not contain a fully resonant vowel element, nor any analysable supraglottal consonant closures (EXCO). Consequently, a distinction was made between EXCO and the third code 'EXS', because EXS included cries, squeals, and yawns, which do include vowel resonance and may contribute later to analysis of the vowel range, usage, and potential ability. These elements are given here for replicability purposes but were not presented in the analyses and equated to 32% of the vocalisations across the first stage of the procedure (see earlier in Section 4).

#### *4.2.3.2 Other Exclusions*

All feeding sounds and eating sounds were excluded; a discrete approach ensured consistency across the transcriptions. These sounds did not capture the relevant sounds within the aim of the study. Overlapping or latching speech was also excluded, as these instances did not have clarity on who was producing each vocalisation as there was no visual evidence to back up these decisions.

Additionally, any other sounds that were too challenging to transcribe were excluded, along with sounds that were not phonemic to English, (e.g., bilabial fricatives), for the same logistical reason. For instance, sounds that were muffled, such as fussing near the microphone or sounds from objects in the environment (or at least sounds that may have been vocal but were covered by sounds in the environments) were also excluded as they were not relevant to the aims of the thesis and could not be checked later if acoustic analyses were required. Such external noise prevented speech sounds being confidently identifiable and these exclusions are in line with conventional infant research practice (Goldstein and Schwade, 2008, p. 517; Laing and Bergelson, 2020, p. 5; Majorano et al., 2020, p. 4). The only exception to this exclusion was the glottal stop, which was included based on the clinical literature, which suggested that ICPs use more glottals in replacement for oral pressure consonants (see Section 2.4.4.2).

## 4.3 Coding and Conversion Procedure of the Main Study

This section details the process following transcription including formatting and processing the data in RStudio, which were organised in light of Pilot Two (see Section 3.1.2 for a reminder). It then outlines and motivates the vocal measures taken from the phonetic transcriptions collected from the procedure in Section 4 and expands on how they were generated in the statistical software. Section 4.3.1 covers the pre-analyses data processing and then Section 4.3.2 expands on the introduced vocalisation measures in more detail and the procedure for generating results for vocal count, mean babble level (MBL), phonetic inventories, VMS, and transitional probabilities.

Figure 4.2 summarises the processes presented in the following sections. It lays out the steps in their chronological order to ease interpretation of the followed methodology stages.

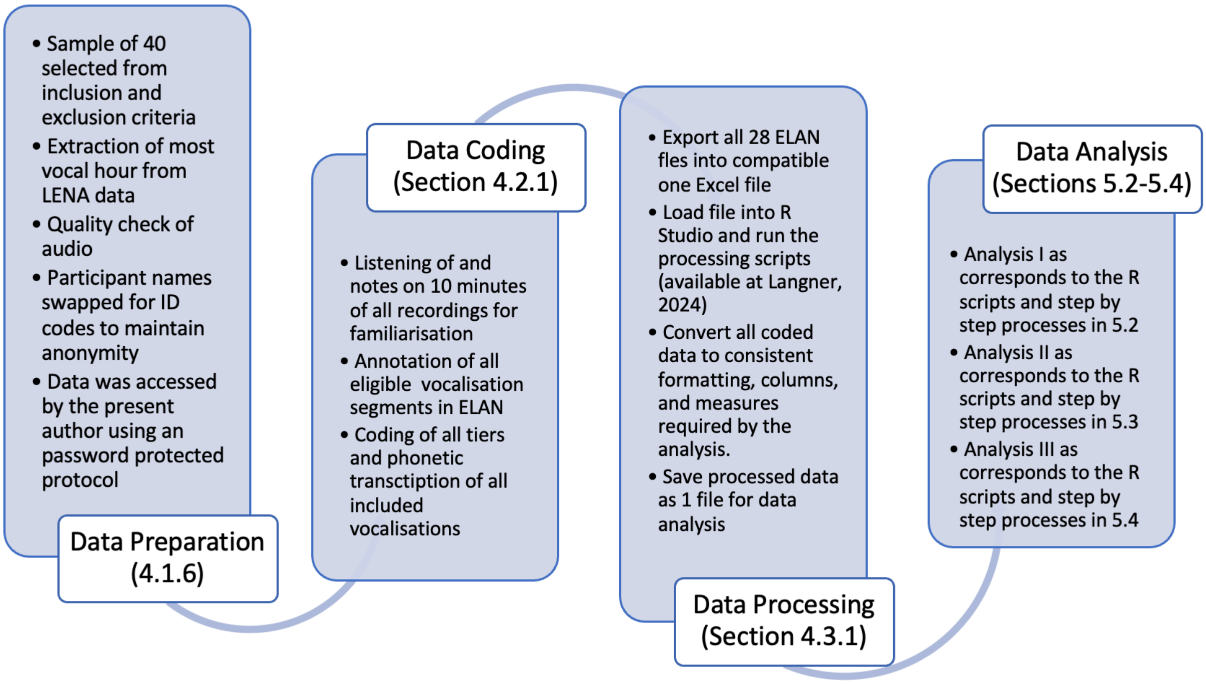



*Figure 4.2: Flowchart of the Data Processes*

### 4.3.1 Data Preparation

The data preparation involved three stages. Exporting and converting the data, formatting the files and then conversions into the vocalisation measures. These three stages are summarised in this section.

#### *4.3.1.1 Data Exportation Process*

The scripts for processing the data are openly available online in an OSF repository.[4] These were used for the extraction, importation, and cleaning of data, all of which were necessary ahead of the analyses. The coded data were exported from ELAN as a tab-limited text file and then inputted into Microsoft Excel. Following this stage, the data were cleaned in R-Studio using a script (see Langner, 2024), which is a series of commands used to organise and

[4] See https://osf.io/vah5d/?view_only = e8d31f0c1ad647469761be4233e3c570.

structure data visualisation and statistical analyses in R. This process was undertaken to ensure that all the coded data were consistent across participants. The cleaning script was necessary to maintain consistent accuracy, spelling, and formatting of the data entries, and will clean any human errors and highlight typos at the same stage of the procedure. Consequently, any remaining exclusions and errors from the transcribed data entries were removed at this stage, ahead of the full analysis. The dataset was next sorted, organised, and further categorised/coded to provide impressionistic information on the distribution of the dependent variables across all the individuals in the dataset. Columns were added to divide the participant pseudonyms and assigned numbers, and then columns were filtered into a randomised participant order ahead of the main analysis stage.

#### *4.3.1.2 The Data Cleaning Process*

The cleaning process involved running the data through a formatting script in R-Studio which ensured that the columns were consistent in terms of case and punctuation, symbols, empty cells, etc. This script also created new columns where necessary to keep the raw data available at a later date, but also to streamline the variables to be more useful for producing replicable visualisations and running statistical tests.

### 4.3.2 Vocalisation Measures

From the reviewed literature in Section 2.2-2.4, inconsistent approaches in analysing vocalisations were challenged. Such approaches to studying ICPs' vocalisations are not yet aligned with TD research measures but new studies would benefit from consistent measures which could assess how well ICPs mirror the typical trajectory. The selected measures are critiqued and justified here to foreground why they were used, why they are valuable, how they are beneficial to a naturalistic selection of data, and how, novel data visualisation could aid the analyses of phonetic sequences. There are key measures such as phonetic inventory and VMS that are widely adopted in typical development research that are lacking in the study of atypical populations. To address this issue, the following measures are reviewed in their reliability and validity, and justified in turn: vocal count, phonetic inventories, MBL, VMS, and lastly transitional probabilities. Each of these measures were processed from the exported and processed spreadsheet using R Studio (the scripts for which are available at Langner, 2024).

#### *4.3.2.1 Vocal Count*

Vocal count is the measure used to assess how much infants vocalised–and how much production rehearsal occurred–across a set timeframe. This review illustrates that there are minimal differences in the vocal count across CP and TD infants. As such, vocal count (or count) provides the first point for comparison against palatal age ahead of examining the phonetic content of vocalisations and it may also indicate cases that have gone awry in the sample of 28 infants. Studying vocal count is of clinical value as it marks critical chances for infants to practice speech sound production and attach their sounds with their surrounding language (Scherer et al., 2008). Moreover, if there are differences in vocal count across palatal age (a measure overlooked by most existing research) the results in the current study will indicate whether this differentiation is more important than published work gives credit to.

One consideration when selecting vocal count as a measure, is consistency of the variable across different infant social and real-world settings. There is similarity in the number of analysable vocalisations of infants with and without CP that holds across contrasting data collection methods, with recent work from Long, et al. (2022) finding that vocalisations analysed from the first 100 utterances in a laboratory versus the highest vocal rate in a naturalistic environment were not statistically different. The versatility of this measure motivates the validity of sampled Language Environment Analysis (LENA) recordings taken in naturalistic homes alone. Vocal count is therefore calculated from the most vocal hour in the day-long audio data to align with this consistent measure, and as such, it strengthens the validity of the present sampling approach (more detail on this is provided in Section 4.1.3).

The present measure will provide an overview of how much infants vocalised, how this varied across palatal age, and how variable vocal count was across infants to indicate whether vocal count mirrors the typical trajectory and/or tells us more about the CP trajectory. However, the amount of production alone is not insightful enough for considering the phonetic characteristics of CP speech. Consequently, vocal count will be presented and analysed alongside measures of the other vocalisation characteristics (e.g., phonetic structure, and syllable composition) and the complexity of prelinguistic, and reduplicated forms, such as phonetic inventories and mean babble level.

#### *4.3.2.2 Phonetic Inventories*

Phonetic inventory is a compiled list of sounds used to measure an individual's production repertoire. In most of the clinical studies presented in Section 2.4.4 it is used as a measure of assessment, taken from elicited vocalisations with a speech and language therapist. It therefore provides two measures, the size of inventory (e.g., the number of sounds produced by a given infant), and the variety and phonetic details of the sounds within their repertoire. In the 14-month data, all the phones perceived in the speech recordings were transcribed to gain a clear picture of actual vocalisations. These data are useful in providing an initial insight into infants' emergent consonants (alongside repeated ones) within their repertoire and will provide a measure on inventory in spontaneous vocalisations, which is missing from much of the clinical literature. Later, when we look at the phonetic detail of these sounds, we can use this data to assess which stage of the vocal trajectory infants are in. For instance, if they are exploring fewer sounds, and producing more rudimentary consonants, this may be a signal that they will be delayed later in development. However, if they are exploring fewer sounds, but are producing oral pressure stops, this may signal that they exhibit the properties of typical canonical babble. Inventory size also sets the foundation for exploring and analysing phonetic repertoire in Section 5.3.2 and indicates how many of the ICPs are producing a range of different sounds at 14-months.

A consistent benefit of the phonetic inventories is that they report on IPA detail (i.e., the classification of sound gestures and places of articulation), by which patterns can be analysed. To recap, some studies agree that ICPs did not have significantly different consonant inventory sizes from typically developing children, (Scherer, 2000 and Hardin-Jones, Chapman, and Schulte, 2003), however the types of sounds within inventories are often different to the typical (see 2.2 for a reminder). Such contrasting phonetic inventories consist predominately of vowels, nasals, liquids, and glottals produced with labial, velar, or glottal place of articulation (Scherer et al., 2008, p. 828), but many of these clinical studies do not distinguish between CP and CLP, which problematises the generalisability of findings. The present study excludes multiple cleft conditions to address this limitation but makes the literature challenging to interpret.

In addition, the clinical uses of phonetic inventories do not provide the best reflection of naturalistic vocalisation behaviour and should include more ecologically valid samples to reflect unelicited vocal behaviour. The current study will achieve this and will also contextualise the phonetic repertoire studied by including pre-vocalic, inter-vocalic, and post-vocalic positions alongside the categorisation of front, back, and central vowels, in order to relate sound inventories to how they are used within vocalisations. My work will extend this line of enquiry onto the frequency, consistency, and variety of stops (among other gestures) to ascertain whether the usage of phonetic inventories outlined in the above studies appears to be reflected in naturalistic, unelicited vocalisations of ICPs.

Additionally, many SLT phonetic reports do not capture the usage of this repertoire in naturalistic, at-home environments. While this approach makes the measurement more robust in a clinical manner, its clear limitation is that it is an unnatural, isolated judgement, versus a realistic reflection of what an infant is likely to produce on an average day. Consequently, the present research extends the phonetic inventory to be taken from naturalistic data to offer flexibility with the analysis of how consonants are used in connection to vowel categories and syllables. Such an approach collates a list of phonetic segments from produced vocalisations, rather than in a clinically prompted assessment. This inclusion involves a big contribution to data in this population and offers insight into a new approach to studying syllables from day long naturalistic data, using a standardised system of symbols, which in turn can capture longer vocalisation units, such as babble strings, to assess a greater scope of patterns.

#### *4.3.2.3 Mean Babble Level*

MBL is the numeric measure that corresponds to the level of canonicity (or speech-likeness) of a vocalisation (Scherer et al., 2018). For this measure, MBLs were each allocated to each vocalisation to distinguish a range of phonetic elements (e.g., voicing, gesture types, the sequencing of consonants within vocalisation). As such, it is a consistent, replicable way to rank the pre-linguistic vocalisations for analysis.

By the measure, a 4-point system was used. This extended Scherer et al 2008's 3-point system to include an additional, lower MBL to capture non-canonical sounds alongside the three different types of canonical ones in the original criteria. This decision was made to capture as much data as possible in the measure and to work out canonicity across all ICPs' vocalisations, even those that were most delayed to the typical timeline. Each vocalisation therefore was allocated an integer between 1 and 4, and consisted of the following categories: 1 contains a syllabic or vocalic unit (i.e., the most rudimentary category of production with no oral consonant closures, e.g., /i/ or /w/); 2 contains at least one glottal or liquid gesture in addition to a vocalic element; 3 contains at least one supraglottal sound in attrition to a vocalic element; and 4 contains more than one supraglottal consonant with a vocalic element (i.e., most speech-like production that is concurrent with typical variegated babble, e.g., /badi/ or /gifi/). For each infant, all MBLs were totalled and divided by their vocal count, providing a mean MBL score for each infant.

While the measure does not standardise how coders/researchers navigate sounds that are challenging to discern, the measure provides a numeric value to vocalisations and involve categories that can logically be compared to typical vocal milestones, such as variegated babble (which is composed of syllables with two or more different consonant types, disregarding voicing differences). After each vocalisation is assigned a babble level, a mean is computed to provide an average level for a collection of vocalisations from infants and groups (Scherer et al., 2008, p. 830). To compare the MBL values in this measure with the babble levels of Scherer et al. (2008), subtract 1 from all values and means. The outcome of which generates scores between 1 and 3 that are relative to the original definitions from her 3-point system. A key benefit of this measure is that it allows for standardised values, regardless of vocal count or palatal age. It is useful in gauging a baseline of vocalisation content, and of the phonetic composition of the babble, whilst capturing vocalisations that are non-canonical (e.g., reflexive, protophone noises) and speech-concurrent (e.g., variegated babble) vocalisation.

It was established by the literature (in Section 2.5) that there is differentiation across the onset of canonical babbling depending on cleft type (Scherer et al., 2018). Plus, as mentioned, many studies that include babble measures do not make the sampling distinction between CL and CL + P. The current study addresses the limitations of babble studies that group cleft type, by focusing on CP, which adds a higher degree of reliability to the sample. Moreover, this study integrates measuring whether an infant has reached the onset of canonical babble and exploring the composition of babble units by using the MBL measure. MBL breaks down vocalisations into these stages and allocates each vocalisation to a numeric value that corresponds to its level of speech-likeness, or vocal maturity. MBLs are able to distinguish a range of phonetic elements (e.g., voicing, gesture types, and the sequencing of consonants within vocalisation) comprising a consistent and robust way of ranking pre-linguistic vocalisations (more detail is provided in Section 4.2.1).

#### *4.3.2.4 Vocal Motor Schemes (VMS)*

Vocal motor schemes are a standardised measure used regularly to assess the consistency of an infant's production. Typically, infants produce preferred, consistent consonants, often at the onset of canonical babble (Vihman 2011, p. 591). Preferred consonants are a within-child characteristic, whereby an infant favours (and therefore more frequently produces) certain consonant productions over others. An infant is considered to have a preferred consonant—or VMS—when they produce it with consistency across numerous occasions, or 50 + times in an hour of data. How the consistency of consonants compares with the typical milestones in ICPs remains unclear. There is some evidence to suggest that post-repair, they continue to show a preference for productions at extremes in the vocal tract, e.g., velars, labials, glottals, (Scherer et al., 2018, p. 828), however, these conclusions were not made using a standardised measure, nor were they taken for this reason. As such, the VMS category used in the present thesis integrates glottals into the measurement (while the original implementation from Vihman and McCune, 2001, did not). Through the integration of stable glottal productions as well as the integration of a well-balanced sample as the current study offers, this thesis builds on Scherer's study who reported outcomes that were not concluded by a standardised measure.

It is likely that ICPs have some consistent consonants in their repertoire across one hour of vocalisation data, however, whether the stage and number of VMS consonants are equal to typical VMSs is a challenge to predict because no work to date has considered this. We know that infants with CLP may have sound preferences and sensitivities: Scherer et al. (2018) found that infants learned words with sounds that were within their consonant inventories faster than words with sounds that were outside their inventories. The behaviour reinforces that smaller phonetic inventories restrict options for first words. This is a result that amplifies the importance of stable consonant production for later speech advances and foregrounds its value as an included measure in the present study. A limitation of the VMS measure is that the threshold for having a VMS may be too high in application to atypically developing groups, however, it remains a consistent, transferable measure across infants and can benefit the comparison across studies assessing phonetic ability. The current research quantifies consistent consonants in vocalisation data, by attaching the same VMS categories as Vihman (2016) to assess how infants mirror the typical trajectory, but the appropriateness of these affordances will be reflected on in the Discussion (see Section 6).

#### *4.3.2.5 Transitional Probabilities*

Transitional probability (as first documented by Aslin et al., 1998) is the statistical measure used to quantify sequences or boundaries between words' and/or syllables' segments, conceptually representing how versatile an individual's use of sound sequences are. It is a measure that helps to predict the probability of the next occurring segment (Dal Ben, Souza, and Hay, 2021, see also Hay et al., 2011). The strengths of this approach include visualising large amounts of detailed data at once, to find out the patterns and connectivity of phonetic elements. The approach also lends itself well to flexible visual settings, whereby data can be subset for zooming in on focal aspects of research, for instance, different MBL levels. Transitional probabilities are not however useful to look at the exact phonetic details all at once, as this would be too complex in one diagram and provide too many elements for researchers/readers to glean from the graph.

The value of transitional probabilities in the present research is to connect findings on the phonetic elements to the sequential characteristics of vocalisations; whereby the sequences of phonetic elements are presented using transition matrices. A transition matrix is a graph which presents the probabilities of one sound following another. By visualising probabilities in this way, this analysis measure quantifies the likelihood of transitions from one sound to another: an effective, novel way to view vocalisations within sample variables together.

Transitional probabilities to date have mostly been used to research perceptual development (e.g., statistical learning by 8-month-olds, Pelucchi, Hay, and Saffran, 2009), or for vocabulary acquisition (e.g., word learning by 24-month-olds, Lany, Karaman, and Hay, 2024), but not yet to visualise vocalisation patterns. To continue, while there are standardised measures to detail infants' production of consonants and the phonetic, IPA detail of babble, a way to visualise the trends across big collections of data are limited. Transitional probabilities provide an efficient method for visualising coded vocalisation data and variation across different groups, e.g., participant variables, and babble levels.

Figure 4.3 and Figure 4.4 illustrate how transitional probabilities were captured in the measure (and how they are later presented in Analysis III). The oval shapes (known as nodes) represent a different phonetic segment, and the symbols in yellow—/>/ and /#/—mark the beginning and end of a vocalisation respectively. The connectivity (or regularity) of transition occurrences in the data will be reflected by the thickness of lines between each node, where thicker lines indicate higher probabilities. In Analysis III, numbers will also be given next to each line to numerate the frequencies.

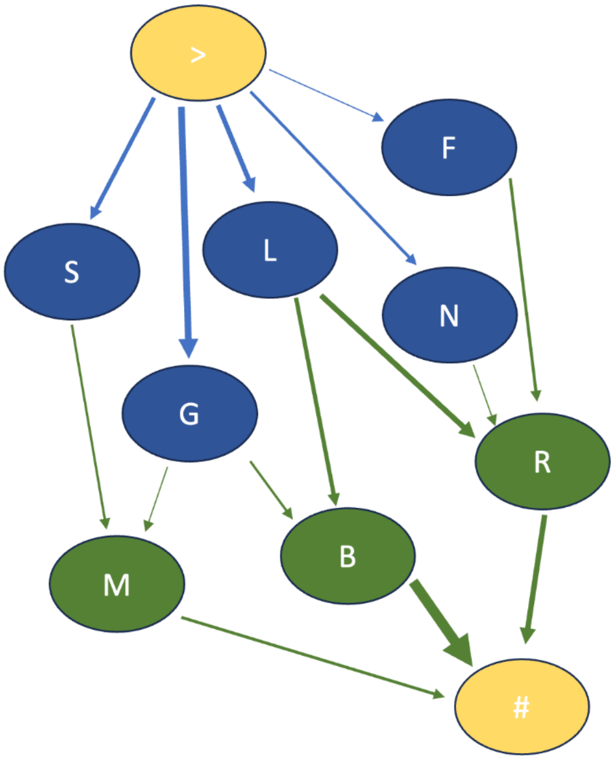



*Figure 4.3: Transitional Probability Illustration Example 1*

Figure 4.4 also contextualises this data visualisation approach. Yellow captures the beginning and end of a vocalisation, blue marks the consonant types, green denotes the vowels. The letters correspond with the following groups: S: stops /b/, /p/, /t/, /d/, /k/, /g/; F: fricatives /f/, /v/, /s/, /z/, /ʃ/; G;glottals /h/, /ʔ/; L:liquids /ɹ /, /l/, /w/, /j/; N:nasals /m/, /n/, /ŋ/; B for the back vowels /ɔ/, /ɒ/, /ʊ/, /ʌ/, /u/, /ɑ/; M for the mid vowels /ɜ/, /ə/; and R for the front vowels /i/, /e/, /a/, /æ/, /ɛ/.

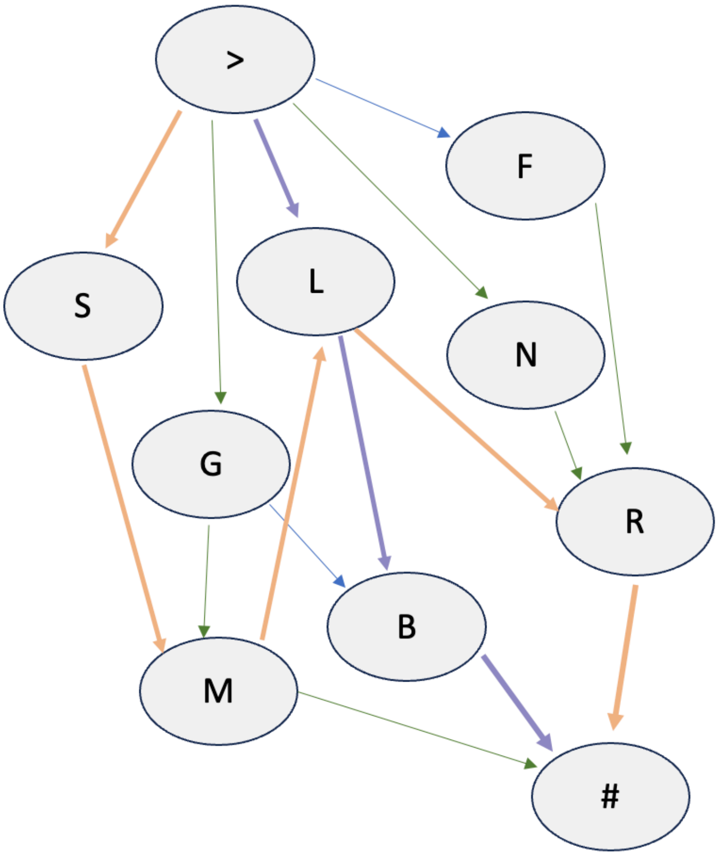



*Figure 4.4: Transitional Probability Illustration Example 2*

For instance, the vocalisation /wɒ/ (as in the purple lines) has a liquid at start, then it transitions to a back vowel before it ends. The method also captures vocalisations with multiple syllables, as in /bəwi/, which has a stop at the start, transitions to a mid-vowel, then to liquid, then to front vowel before it ends. The transitional probability graphs present data that visually illustrates a great amount of data in one place. As such, it captures the absent or deviant vocalisation patterns from collated transcription data, which contributes to the overarching aim of examining how well ICPs mirror the typical trajectory.

The conversion process followed the transcription of the vocalisation measures and was undertaken once all coding was complete. This stage included formatting text into consistent symbols and columns across the data. It also involved collating all 28 excel documents into one file with 28 tabs and ensuring that human coding errors were cleaned and that all columns of data entries were consistent across all columns and rows. A detailed account of these processes is given in a stepwise manner in the processing scripts (Langner, 2024).

Once cleaned, the IPA transcriptions were converted into ‘Phonetic Structures’ to numerate the productions and allocate each vocalisation to a MBL mean score. These structures were in accordance with the 4-point MBL criteria (presented earlier in Section 4.3.2.3) and were therefore allocated into levels 1, 2, 3, and 4. These categories were used to provide a measure of comparable babbling tendencies in ICPs and were categorised as follows:

◊ MBL1: The utterance is non-canonical and composed of only a vowel or a consonant gesture with no surrounding vowel (e.g., a bilabial fricative). MBL1s also capture all rudimentary productions that are not eligible to MBLs 2-4 vocalisations.

◊ MBL2: The utterance is composed of a vowel, voiced syllabic consonant (/m/), or CV syllable in which the consonant is a glottal stop (/ʔo/) or a glide (/wi/). MBL2 structures mirror combinations of emergent sounds that are evident in the vocal play stage, with glottal and glide gestures present.

◊ MBL3: The utterance is composed of a VC (/up/) or CVC with a single consonant type (/kek/), or any CV syllable that does not fit the criteria for Level 1. Voicing differences are disregarded. Level 3 structures are consistent with canonical babbling that includes syllables comprised of repeated consonants and vowels that appear speech-like.

◊ MBL4: The utterance is composed of syllables with two or more different consonant types, disregarding voicing differences. This level is characterized as representing variegated babbling in which consonants and vowels are varied within the syllable string.

The last stage following this babble measure was to calculate a mean babbling level ('MBL') value which served to provide a mean score for each participant by totalling the BL scores and dividing them by their frequency. Frequencies were calculated and compared with the VMS characteristics. Additional columns were generated in R to capture different patterns at a time, for instance 'Vowels' which included V for all vowel categories, and F, M, B for each broad vowel category (e.g., front, mid, back), and also 'Consonants' which alternatively focused on the details of consonant gesture categories, with certain columns containing only broad vowels. These columns allowed for easy viewing of large sets of data and for visualising different phonetic patterns at a time. After all conversions were complete, the data were saved in a final version named '28 PS MBL Processed', which was ready for the three analyses given later in Chapter 4.

#### *4.3.2.6 Summary of Vocalisation Measures*

My study contributes to the field by exploring vocalisation stages *and* characteristics in a more balanced sample (that is, organised in relation to palatal age and cleft type) than the existing academic literature offers. Additionally, the selected measures for vocalisations and babble level more closely align to those from typical development practices that are often carried out in a naturalistic environment. The study reflects what infants produce regularly when they are most vocal in a day, rather than what infants produce in contexts that are isolated from their common reality (e.g., therapeutic assessments, elicited vocal production), which remains an underexplored area of published work.

Additionally, given that the typical vocal literature has outlined canonical vocalisation and babble maturity as influential to later production advances in infancy (see Section 1.1.2 for a recap), a connection between consonant repertoire and context of consonant-vowel sequences is necessary for exploring this naturalistic set of data with more depth and novelty than existing work. This study has the potential to relate vocalisation patterns to the trends documented typically, particularly in relation to the contexts of phonetic inventories, babble maturity, and consistent consonants, of which there is limited understanding on Vocalisations of ICPs currently. Further, the exploration of these values will indicate possible areas that therapeutic aims may benefit addressing.

## 4.4 Final Sample Characteristics of the Main Study

This section presents the final number of infants in the sample, which was reduced from the available selection of 40 infants to 28 infants (in Section 4.4.1). The second pilot study boosted the need for prioritising participant eligibility and ensuring time limits (see Section 3.1.2.3). In this section, the participant characteristics provide an overview of the initial statistics. They set the foundation and parameters for the subsequent three analyses that follow in Chapter 5 (see sections 5.2 to 5.4). Next, Section 4.4.1 presents the process used to refine and confirm the final sample of participants. Here, a description of how the potential sample of 40 was reduced to 28 participants, using criteria described earlier in this chapter; it includes detailed information such as ID numbers, cleft subtypes, and age at surgery. Section 4.4.1 then summarises the final sample's features, e.g., central tendencies of different age measures to overview the distribution of ages and medical variables across the sample to introduce and familiarise the data that is later presented in Chapter 5.

### 4.4.1 Sample Reduction Stages

In the proposal stages, this research aimed to research a selection of 40 infants. Table 4.1 provides full information on the original sample of infants.

*Table 4.1: Full Table of Participant Details*

| PP | Order | Sex | Surg. Age | Intertub | LENA .age | Pal. Age | Cleft Type | Ethnicity | Maternal Education | Eng. 1st lang | Partner Education | 24m Data | 36m Data |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9 | M | 7 | | 14 | 7 | CP | | First degree | Yes | Other | Yes | Yes |
| 2 | 5 | F | 7 | 15 | 14 | 7 | CP | | Other qual | Yes | Don't know | Yes | Yes |
| 3 | 18 | F | 7 | 12 | 14 | 7 | CP | White | Higher degree | Yes | Higher degree | Yes | Yes |
| 4 | 23 | F | 7 | | 13 | 6 | CP | White | First degree | Yes | First degree | Yes | Yes |
| 5 | 14 | F | 7 | | 13 | 6 | CP | | | | | Yes | Yes |
| 6 | 16 | F | 8 | 35 | 13 | 5 | CP | White | Higher degree | Yes | First degree | Yes | Yes |
| 7 | 27 | M | 8 | | 14 | 6 | CP | White | NVQ Level 45/HNC/HND | Yes | 1+ GCSE | Yes | Yes |
| 8 | 24 | M | 8 | 35 | 13 | 5 | CP | | 1+ A/AS Level | Yes | Don't know | Yes | Yes |
| 9 | 2 | F | 9 | | 16 | 7 | CP | | 2+ A Levels | Yes | Other qualification | Yes | Yes |
| 10 | 22 | F | 9 | | 13 | 4 | CP | White | NVQ Level 2/Int. GNVQ | Yes | 1+ A/AS Level | Yes | Yes |
| 11 | 13 | F | 9 | | 14 | 5 | CP | | First degree | Yes | First degree | Yes | Yes |
| 12 | 17 | F | 9 | 26 | 14 | 5 | CP | White | NVQ Level 3/Adv. GNVQ | Yes | 5+ GCSEs | Yes | Yes |
| 13 | 9 | M | 9 | 39 | 14 | 4 | CP | | First degree | Yes | First degree | Yes | Yes |
| 14 | 15 | M | 10 | 36 | 14 | 4 | CP | White | Higher degree | Yes | First degree | Yes | Yes |
| 15 | 21 | F | 10 | 33 | 15 | 5 | CP | | | | | Yes | Yes |
| 16 | 10 | M | 11 | 36 | 14 | 3 | CP | White | 2+ A Levels | Yes | Higher degree | Yes | Yes |
| 17 | 28 | F | 11 | 5 | 15 | 4 | CP | White | First degree | Yes | Higher degree | Yes | Yes |
| 18 | 19 | M | 11 | | 13 | 2 | CP | Mixed | First degree | Yes | First degree | Yes | Yes |
| 19 | 3 | F | 11 | 39 | 14 | 3 | CP | White | First degree | Yes | First degree | Yes | Yes |
| 20 | 12 | F | 11 | 38 | 14 | 3 | CP | White | Higher degree | Yes | Higher degree | Yes | Yes |
| 21 | 1 | M | 12 | 36 | 13 | 2 | CP | | 1+ GCSE | Yes | 1+ GCSE | Yes | Yes |
| 22 | 6 | F | 13 | 36 | 14 | 1 | CP | | Higher degree | Yes | 5+ GCSEs | Yes | Yes |
| 23 | 7 | M | 8 | 36 | 14 | 6 | CP | White | NVQ Level 2/Int. GNVQ | Yes | NVQ Level 2/Int. GNVQ | Yes | No |
| 24 | 25 | M | 8 | 28 | 19 | 11 | CP | White | 5+ GCSEs | Yes | NVQ Level 3/Adv. GNVQ | Yes | No |
| 25 | 20 | F | 10 | N/A | 19 | 9 | CP | | Other qual | Yes | NVQ Level 2/Int. GNVQ | Yes | No |
| 26 | 26 | F | 13 | 33 | 15 | 2 | CP | White | 1+ GCSE | Yes | 1+ GCSE | Yes | No |
| 27 | 4 | F | 8 | 34 | 14 | 6 | CP | White | Higher degree | Yes | Higher degree | No | No, |
| 28 | 11 | F | 10 | 6 | 13 | 3 | CP | White | First degree | Yes | NVQ Level 3/Adv. GNVQ | No | No |
| 29 | 29 | F | 7 | 4 | 15 | 8 | CP | | | | | Yes | Yes |
| 30 | 30 | M | 12 | 28 | 17 | 5 | CP | White | NVQ Level 3/Adv. GNVQ | Yes | NVQ Level 3/Adv. GNVQ | Yes | No |
| 32 | | F | 10 | N/A | 20 | | Submucous CP | White | First degree | Yes | Other qual | Yes | Yes |
| 31 | | F | 15 | 13 | 13 | 3 | CP | White | First degree | Yes | First degree | Yes | Yes |
| 33 | | F | | | 14 | | CP | White | First degree | Yes | Higher degree | Yes | Yes |
| 34 | | F | | | 14 | | CP | White | First degree | Yes | Higher degree | Yes | Yes |
| 35 | | M | | | 15 | | CP | | | | | Yes | Yes |
| 36 | | F | | | 14 | | CP | White | Other qual | Yes | | Yes | Yes |
| 37 | | M | | | 14 | | CP | White | Higher degree | Yes | First degree | Yes | Yes |
| 38 | | M | | | 14 | | CP | White | First degree | Yes | 2+ A Levels | Yes | Yes |
| 39 | | F | | | 19 | | CP | White | First degree | Yes | First degree | Yes | Yes |
| 40 | | M | | | 13 | | CP | | White | Yes | NVQ Level 3/Adv GNVQ | Yes | Yes |

*Yellow: coding time restrictions, pink: cleft type, pale orange: pre-op participant, orange: no surgical age data. For a table of abbreviations used, see Appendix C, List of Abbreviations*

For the final study, the sample size reduced to 28 based on the following steps. The variables that guided the reduction of infants for the final sample were based on two central matters: the likely influences of surgical timing and cleft type, and the time constraints of the transcription process. Given the potential impact surgical timing may have on early vocal outcomes revealed in the literature, incorporating data from the measure of palatal age was central to the method and analyses in this research. Therefore, any infants from the received dataset of 40 infants that did not have data on the age at surgery, and therefore palatal age, were not eligible for the final study. The shared dataset from the CC-SLC included 8 participants without a reported age at surgery, reducing the potential sample from 40 to 32 participants (infants 33-40 were therefore removed from the sample, Table 4.1). Similarly, one participant in the available sample had an age at surgery of 15 months, but a chronological age of 13 months (infant 31), meaning that this infant's speech sample was collected 2 months pre-repair, meaning it did not meet the inclusion criteria of the study. Based on these criteria, the sample reduced from 32 to 31 infants.

Next, given the potential significance of cleft type on a multitude of outcomes, infants with any other cleft type to CP only were also excluded. With this in mind, one participant from the original 40-participant sample with submucous CP (infant 32) was not eligible to be in the final sample, reducing the pool of 31 to 30 infants. A spreadsheet of all 30 remaining infants was then generated following the exclusions based on surgical age data and cleft type. It was filtered first for cleft palate type, second for surgical age, and next for age at LENA recording, which also gave confirmation of the excluded infants by this stage. Following the exclusion of these 10 infants from the potential sample of 40, the remaining 30 infants were assigned a participant number (when sorted in ascending age at repair). Once each infant had a participant number between 1 and 30, the order for coding the samples was systematically randomised (by palatal age, to ensure a balance within this variable's range). These participant numbers dictated the order followed through the coding process, meaning than individuals' information was not accessible during the transcription and coding process. Due to the ordering of these numbers, the transcriber was unable to recall and identify which infants were which until the transcription process was complete. Due to time constraints, the coding only managed to incorporate 28/30 infants in the final study, meaning that the two infants last in the order for coding were not included. The full process for the sample reduction is provided in Figure 4.5.

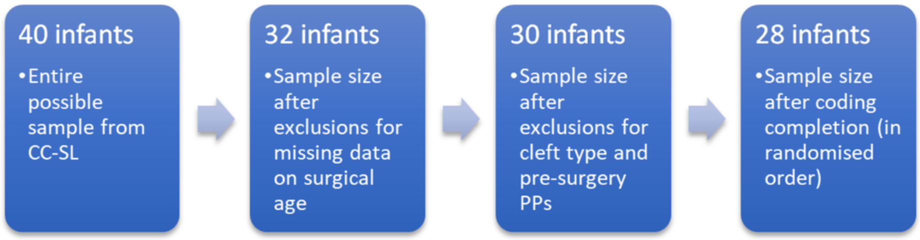



*Figure 4.5: Flowchart of Sample Reduction Process*

The flow chart captures the prioritised variables to reduce the original sample of 40 to the final sample of 28. It presents how a portion of the infants available were not eligible for the final sample, and how those not completed due to time constraints were (randomly) excluded to reduce bias and boost transparency and replicability.

#### *4.4.1.1 Chronological and Palatal Age Justification*

The proposed sample aimed to include only infants aged 13 to 14 months, aligning with a specific time frame in typical vocal development. The targeted age range of 14 months is beneficial age to analyse because it is within the timeframe when most typically developing infants reach variegated babble and their early words (McCune and Vihman, 2001; Ramsdell-Hudock et al., 2019; McCune and Vihman, 2001, see Section 2.2). This (st)age can therefore accommodate for potential vocalisation delays in ICPs because canonical babble typically emerges earlier than this point (e.g., from 6 months, see 2.2.2). As a result, around this chronological age, infant data are likely to illustrate some of the most (or least) advanced stages of vocal development and may relate to whichever stage of vocal development the ICPs resemble most. As such, the work aimed for this age range.

However, due to data availability and the secondary nature of the dataset, in practise, there was a trade-off between chronological age and palatal age when prioritising the participants in the final sample of 28 infants. As such, when prioritising infants for the sample, some variables were favoured before the exact chronological age range in the sample, in light of the literature.

The sample was categorised based on two key criteria to facilitate comparisons among similar groups of infants with cleft palates (ICPs). First, infants were selected based on their age at repair (7 to 13 months) and the number of months post-surgery (1 to 11). Given the significance of these age ranges in vocal development, palatal age was taken as the primary consideration for sample ages, offering novelty but also consistency in how the sample was organised. By prioritising surgical age with LENA age (and therefore palatal age) this approach ensured that a range of evenly distributed production experience following repair was captured across different ICPs, making the subgroups more comparable than chronological age alone (see Section 4.4.1).

### 4.4.2 Grouping of Palatal Ages

Palatal age was a central variable in the study that served to make sense of the patterns in a vast amount of phonetic data. The process and justification for grouping palatal age into three subgroups was made following the transcription and confirmation of the final sample; it took place a priori of any data analysis. The reasons for grouping the palatal ages into three subgroups was threefold: to explore the variation across palatal age in detailed phonetic depth; to cater for the wide, 9-month range of palatal ages in the results and analysis; to investigate the findings in conjunction with palatal age as a continuous variable. The nature and size of the data meant that considering the production patterns with any individual detail was most straightforward within the focus of three palatal groups. It allowed for a more detailed exploration of the data. For example, viewing the entirety of the transitional probability data in one graph would not give sufficient insight into the impact palatal age on vocal sequences because of the measure's complexity.

The ages were split evenly into three across the sample, to ensure that each group was balanced (with numbers per group as a primary consideration). The justification for choosing three groups over any other number was to produce balanced sets of participants and by splitting them in this way (see Table 4.2 for detail), the distribution of palatal ages was reasonably even, without having too many groups to become unwieldy. Consequently, breaking down the data visualisations in this way helps to shed light on the outcomes for this variable. It also meant that this variable could be considered in more depth by grouping the variable evenly.

Palatal age is explored both as a continuous variable and as an ordinal variable (within the three groups) through the analysis. This way of analysing the variable is particularly valuable for the statistical tests carried out, because it boosts the statistical power, which a valuable priority with a small sample. In all, exploring palatal age as a discrete and continuous variable, the analysis maximises the understanding of the findings.

### 4.4.3 Final Sample Features

The finalised sample of twenty-eight infants is detailed in Table 4.2, which gives the means, ranges, and standard deviation values of participant ages along the clinical timeline. It shows the spread of clinically related ages across the whole sample (N = 28). Palatal age refers to the number of months post-surgery, whereas chronological age refers to the number of months since birth.

*Table 4.2: Final Sample Ages and Average Characteristics*

| Variable | Surgical Ages (months) | Chronological Ages (months) | Palatal Ages (months) |
|---|---|---|---|
| Range | 7-15 | 13-19 | 1.77-9.03 |
| Mean | 9.36 | 14 | 4.97 |
| Median | 9 | 14 | 4.86 |
| SD | 2.02 | 1.53 | 2.28 |

There was a range of 8 months across age at surgery, with a mean of 9.4 months, median of 9 months, and a standard deviation (SD) of 2 months. Additionally, the range of chronological ages (6 months) in the sample was close to that of the surgery ages with a mean and median of 14 months, and SD of 1.5 months. Lastly, the palatal age (number of months since surgery at the time of data collection) range was between 1.8 and 9 months, with a mean of 5, a median of 4.87, and a standard deviation of 2.3 months. Given this 7-month difference across the sample, this range encouraged the decision to categorise palatal ages into 3 groups by 2-3-month differences. These three age measures were close to a normal distribution, because the mean and median values were either equal to or close to each other (as in 9.26 and 9; 14 and 14; and 4.97 and 4.86 respectively). However, SD values highlight that the distribution of chronological ages was less spread than for palatal ages in the sample, which reveals more variability regarding palatal age which was addressed by the allocated groups in Table 4.3.

*Table 4.3: Distribution of Palatal Ages and Sex Across Groups*

| Group | 1 | 2 | 3 |
|---|---|---|---|
| **Palatal Ages (months)** | 1-3 | 4-5 | 6-9 |
| **Count** | 9 | 10 | 9 |
| **Female** | 6 | 6 | 6 |
| **Male** | 3 | 4 | 3 |

While this grouping process attempted to balance the numbers of age and time factors in the sample, of course, it did not match infants on individual differences and experiences in the same way, as these are independent differences that cannot be addressed in this study.

To add, the ratio of females to males was 9:5, and is given purely for reference, as biological sex differences are not considered and is outside the scope of this thesis. For reference, the table here also briefly outlines the distribution of sex across the palatal groups, and how they were balanced across the three groups. Additionally, Figure 4.6 indicates the frequencies of surgical ages (months) across the sample.

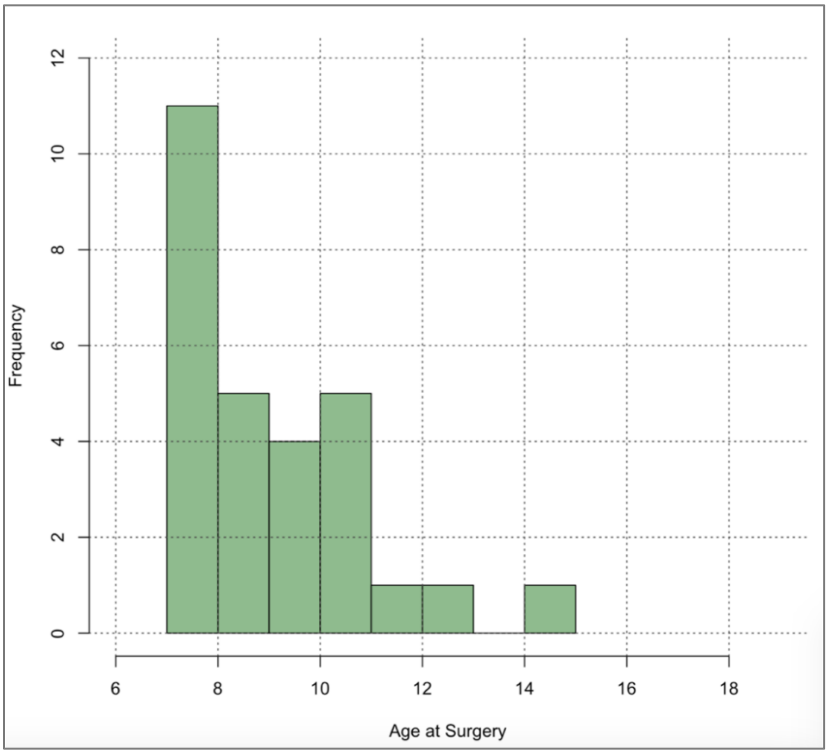



*Figure 4.6: A Histogram of Surgical Ages (in months) Across the Sample*

It illustrates that most surgeries were carried out before 11 months, with the most frequent surgical age being 7 months. This timeframe is in line with the UK aim for surgery to be completed by 12 months (Fell, 2022) because medical guidelines report better healing and anatomical development progress before this time point. The distribution was skewed towards earlier ages, which was reinforced by it being significantly different to a normal[5] distribution (W = .91, p = .02). The distribution of palatal ages paints a different picture, perhaps due to the wider ranges of ages at surgery and individual medical timelines.

[5] A distribution is sufficiently normally distributed when the p value is >0.05, and the W-value indicates distribution of the data, it is most like normal when it is closer to 1, and very unlike a normal distribution when it is close to zero.

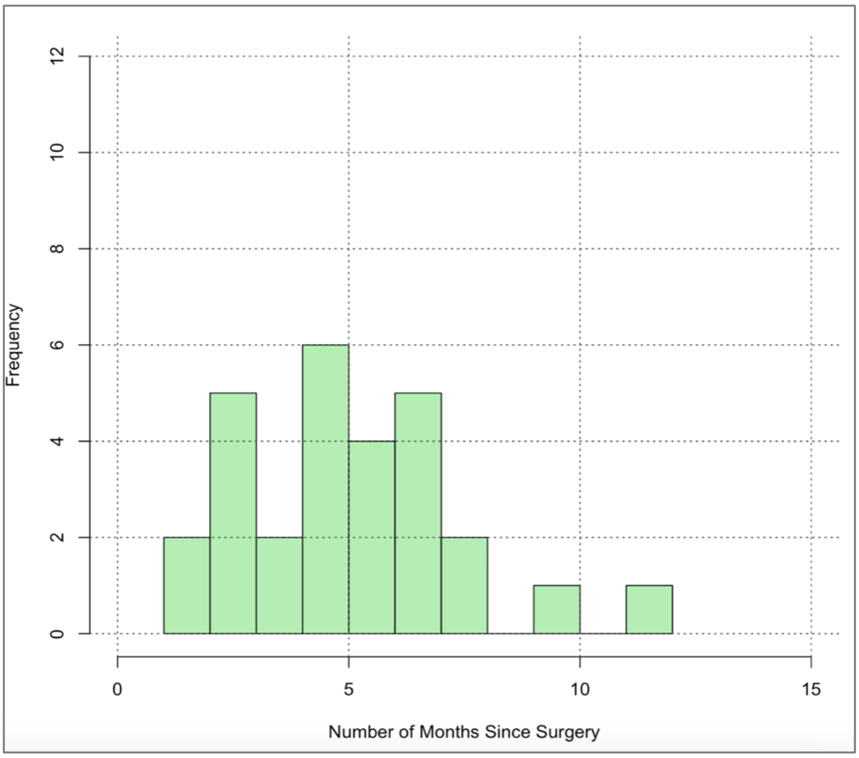



*Figure 4.7: A Histogram of Palatal Ages Across the Sample*

As Figure 4.7 illustrates, the palatal ages were visually closer to a normal distribution—supported by a normality test ($W = .96$, $p = .30$)—and therefore a higher proportion of infants had a palatal age between 4 and 7 months. This was important to test because it gives an indication of how balanced, or symmetrical, the sample data were, and when a variable is normally distributed, it has more statistical power.

Given the variation across the entire sample in relation to the available clinical ages, before diving into the analysis more closely, the sample was balanced into 3 groups. Due to the wide age range and the variation in surgery and chronological ages (both of which are known to impact speech outcomes, see Section 2.2.3.1 for a reminder of these details), such grouping was beneficial to the analysis. From the literature, we anticipate that palatal age may impact vocalisation patterns, therefore, modifying the analysis approach to incorporate palatal groups provided a more focused research approach. Group selection was guided by the availability of clinical data for each infant, with the age at surgery and cleft type being the central priorities. From the final 28 infants (as justified in Section 4.4.1), selecting the palatal groups was chosen to ensure a balanced number of infants were in each group. Furthermore, the groupings reflected an even range of months post-surgery. Consequently, palatal age was used to create 3 subgroups: Group 1 (1-3 months, N = 9), Group 2 (4-5 months, N = 10), Group 3 (6-9 months, N = 9); Table 4.3 provides these details. These groups were prioritised to each have 1/3 of the sample in each group, except for Group 2, which had 10 infants rather than 9. This group reflected the mean and median palatal age, therefore this exception seemed appropriate to include.

# 5 Analyses

This chapter investigates cleft characteristics through three analyses of the infants' vocalisations: the features (e.g., vocal count and vocalisation length), the overall speech-like nature (e.g., MBL), and the consonant and vowel combinations within vocalisations. The analyses examine the transcribed and human-coded data, given in the previous Chapter, which captures fine grain phonetic and sequential details. In this way, the range of coded variables in the tier system (e.g., harmony and VMS count) are explored in relation to palatal and chronological ages to explore their influence on the vocalisations of ICPs. The vocalisations are also analysed and compared within and across ICPs in this study to explore the within-participant, within-group, and sample-wide differences. Together, the sections below help to investigate the properties and canonicity of productions at 14 months (1-9 months post CP repair).

The data analysis will address the research questions by using a combination of quantitative and qualitative approaches that were carried out using R Studio (R Studio Team, 2020) to examine the within- and between-participant differences. In addition, this chapter draws from reflections on graphs and data visualisations to support or contradict the research hypotheses. As such, this chapter contributes to our understanding of the properties of ICPs' vocalisations, to elucidate whether they reflected the emergence of vocalisations in the typical trajectory and whether they revealed unexpected results given the literature on patterns post-repair. If the results indeed show speech sounds were used in different sequential combinations, they could indicate the extent to which vocalisations resemble the typical prelinguistic trajectory. Moreover, the vocal measures are considered in relation to the vocal stages from the typical vocal development milestones. As such, the analyses explore how far along the typical trajectory the ICPs were at 14-months in relation to the typical timeline, and whether palatal ages influenced these outcomes. The analytic responses to the findings will also motivate comparisons that can be drawn from the typical vocalisation literature later in the thesis.

## 5.1 Overview

To follow are three separate analysis sections, each addressing one subsidiary question, (as allocated in Section 5.1.1.2) in turn, and will then contribute to the main research question (RQ1, see Section 2.6.1), which is explored in the following Discussion. To begin with, Analysis I quantitatively reviews the transcribed vocal measures in line with the research criteria outlined in 4.2.1 and is followed by a mixed methods analysis of the sample, which will be explored in relation to the phonetic repertoire within vocalisations (see Analysis II) and then to sequential features of vocalisations (see Analysis III). Some correlation and linear regression tests and data visualisations (boxplots, multiple bar plots and transition matrices) were conducted using R Studio (R Studio Team, 2020) to illustrate the basic distributions and frequencies of the dataset and to highlight the initial trends.

After a recap of the research questions and the analysis goals (see Section 5.1.1), Section 5.1.2 introduces and overviews the collection of vocalisation measures, including the central tendencies of vocal count, vocalisation length, and mean babble levels. To follow are the analyses of the ICPs' vocalisations, displayed in a collection of graphs, tables, and data visualisations to explore the research questions. The chapter also integrates hypothesis testing with a combination of statistical tests alongside qualitative analysis. The phonetic transcriptions captured the following infant production features: vocal count and vocalisation length (explored in Section 5.2); harmony, consonant, VMS repertoire, and fine grain phonetic details (explored in Section 5.3); and lastly the phonetic and sequential structures across palatal groups (explored in Section 5.4). Thus, the data analyses address the subsidiary research questions in turn by considering the relevant vocalisation variables from the coded data. The outcomes of all three analyses will contribute to the discussion (in Chapter 6).

### 5.1.1 Research Questions and Analysis Goals

This section lays out the research questions and describes how each analysis section will address the aims. As presented first in the literature review (see Chapter 2), there is one main research question and three subsidiary questions.

#### *5.1.1.1 Main Question*

***RQ1: To what extent do the phonetic and sequential properties of syllables produced by ICPs across palatal ages post-repair resemble the typical path of vocal development?***

To investigate the cleft characteristics in the sample, the analyses chapters will examine infants' vocalisations within consonant-like and vowel-like combinations and the overall speech-like nature of them. It examines the extent of phonetic and sequential similarity between syllables produced by ICPs and typically developing infants at 14 months. The analyses will explore the variables transcribed and coded above (see sections 4.2.1 and 4.2.3). First, the infant vocalisations and consonant repertoires will be qualitatively analysed, second, they will be quantitively analysed with a statistical analysis carried out using R Studio to examine within participant and across participant differences.

The likelihood of sound and syllable sequences will be presented, analysed, and considered in relation to the typical milestones (in relation early vocal development) as well as evident harmony patterns, transitional patterns and MBL values within and across ICPs. The distribution of vowels and consonants across the recordings can also be considered in relation to the typical combinations and are addressed closely by Analysis III.

#### *5.1.1.2 Subsidiary Research Questions*

***RQ2: How do the vocalisation measures of vocal count, vocalisation length, and canonicity vary with palatal age, and does the inclusion of these measures reveal new insights into the typical/CP trajectory of known vocalisation patterns?***

Analysis I provides an overview of the vocal measures; it investigates babbling level, vocalisation length, palatal age, vocal count, and extreme points in the data. The first analysis, which addresses RQ2, tests H1 that vocal count and MBLs will be lower than typical infants' levels at 14 months, but also lower than measures that typically occur at 7 months. Moreover, it will test whether palatal age correlated more than chronological age for these two vocalisation measures. It also tests the prediction that the range of consonants in the productions of ICPs will depend on the stage of vocal development reached but will be smaller than typical regardless, which will be elucidated by comparisons to Scherer (2008) who reported MBL measures on typically developing infants.

***RQ3: What are the compositional and organisational components of syllables produced by ICPs (i.e., the phonetic properties of babbled 'consonants' and 'vowels' following repair)?***

To consider the sequential features of syllables produced, this question will analyse the similarity and systematicity across sequential characteristics. It will also explore the distribution of vowels and consonants, emergent and acquired sounds, as well as the combinations of sounds used most and least frequently across groups to test the hypotheses. For instance, H2 predicts that the most common formations of vocalisations will be composed of fricative-, liquid-, and vowel-initial syllables (with fewer stops and fewer velars). These measures will also help to determine whether mid vowels were more common than front and back vowels across the sample as predicted by the literature on the production of sounds and vocalisation patterns post-repair.

Next, H2 predicts that the structural and phonetic components of vocalisations will exemplify properties from earlier stages in typical vocal development rather than the properties relevant to the chronological age. It will be tested by transitional likelihoods of sounds occurring together depending on group characteristics (palatal age, babbling level) as well as the measure of VMS, which captures the regularity, stability, and frequency of consonant productions.

***RQ4: To what extent do the vocal measures and their sequential features show consistencies with published CP patterns? Does the visualisation of transitional probabilities—a method for visualising phonetic and sequential details from vocalisation transcriptions—benefit analysis of and reveal new insights into the production patterns of ICPs post-repair?***

Analysis III will assess whether the role of rehearsal in prelinguistic vocalisation appears more influential than palatal age for predicting stable articulations following CP repair. It examines the sequential elements of the 14-month-olds' syllables by exploring the transcribed data. The last analysis also investigates the phonetic patterning of vocalisations by examining sound combinations, including vowel harmony, consonant harmony, and transitional probabilities (e.g., how likely certain types of consonants and broad—front, mid, back—vowel categories were to occur next to each other). As such, it tests H3, which predicts that the infants with a higher babble level (e.g., variegated vocalisations) will have a wider range of emergent consonants and VMS consonants, by exploring the distribution of VMS across vocalisations and across groups to discern whether palatal age had any significant effect on VMS count, as was also predicted by H3.

This final analysis will also investigate the phonetic sequences against MBL and palatal age to examine whether the relationship between palatal age and the vocal measures could be evident earlier in the vocal trajectory than clinical measures indicate. Moreover, it will examine whether these vocal measures are a better predictor of consonant inventories and MBL scores than palatal age itself.

### 5.1.2 Overview of Vocalisation Measures

To provide an overview of the data, this section provides the central outputs of the results. It presents the simple vocalisation measures, which will be used to address the research questions from Section 5.2. Table 5.1 summarises how vocalisation measures were distributed across the whole sample of 28 infants. The total row refers to the complete dataset of vocalisations, when grouped together by the vocalisation, syllable, and MBL measures (are as defined by the inclusion and exclusion criteria laid out in Section 4).

*Table 5.1: Overview of Vocalisation Values*

| Variable | Vocalizations | Syllables | MBL |
|---|---|---|---|
| Total | 8640 | 16069 | N/A |
| Range | 107-588 | 1-32 | 1.95-3.01 |
| Mean | 308.57 | 1.94 | 2.51 |
| Median | 299 | 1.16 | 2.5 |
| SD | 122.24 | .5 | .26 |

Table 5.1 indicates a wide range of variation between vocal count across the sample (107-588 vocalizations, per infant), but overall median and mean values that were close together (308.6 and 299 respectively). The longest vocalisation was 32 syllables and the shortest was 1, the more telling values here were the mean (1.94), median (1.16), and mode (1), which illustrated that disyllables and monosyllables were most common across the whole dataset. As a reminder, if an infant produced an independent glottal or supraglottal (without a vocalic element) it was not counted because the vocalisation must contain a vowel. The variability of these measures was highlighted by the standard deviation, which was approximately half a syllable, indicating more evidence that the variation was within mono, di- and tri- syllables and that longer vocalisation strings (consisting of more than 3 syllables) were less common. The canonicity of vocalisations was informed by the mean babble level measure and was expanded on in more detail in Section 4.3.2.3.

To continue, the distribution of MBL was also normally distributed (mean = 2.51 and median = 2.5). This means that the central tendencies in the data were midway between canonical syllables containing a supraglottal sound with a syllabic, resonant vowel and non-canonical syllables including a liquid or glottal release next to a syllabic, resonant vowel. The (.26) SD indicates the variation across the sample and confirms that most MBL means were situated between babble level 2 and 3, which highlights some fluctuation across the sample.

## 5.2 Analysis I

The central variables that are investigated in Analysis I include the properties of the infant vocalisations produced at 14 months. This exploration addresses H1, which predicted that vocal counts and MBLs would be lower than typical amounts at 14 months, but also lower than measures that typically occur at 7 months. H1 also expected palatal age to serve as a better indicator than chronological age for these three vocalisation measures (see Section 2.6.1). The measures explored here include vocal count, vocalisation lengths, MBL, and extreme points in the data. Section 5.2 presents the data and also establishes some of the statistical relationships between the vocalisation measures and the participant variables at a broad level. These analytic measures are presented first at a group level (in sections 5.2.1 to 5.2.5) considering vocal count and vocalisation length across age in the sample, but will be analysed on a closer, infant-by-infant basis in Section 5.2.6.

### 5.2.1 Vocal Count

This section presents vocalisations from the infants when at their most vocal point in the day. It is considered across the whole sample of 28 infants and then considered across palatal age to examine how these trends look in relation to the variables at both the variable level and the group level. The number of analysable vocalisations were based on the exclusion criteria (given in 4.2.3) and represents 28 hours of vocalisation data. Figure 5.1 overviews the distribution of vocal count across the whole sample, the horizontal black lines marking the lower and upper range, and the rectangle indicating the majority spread of values.

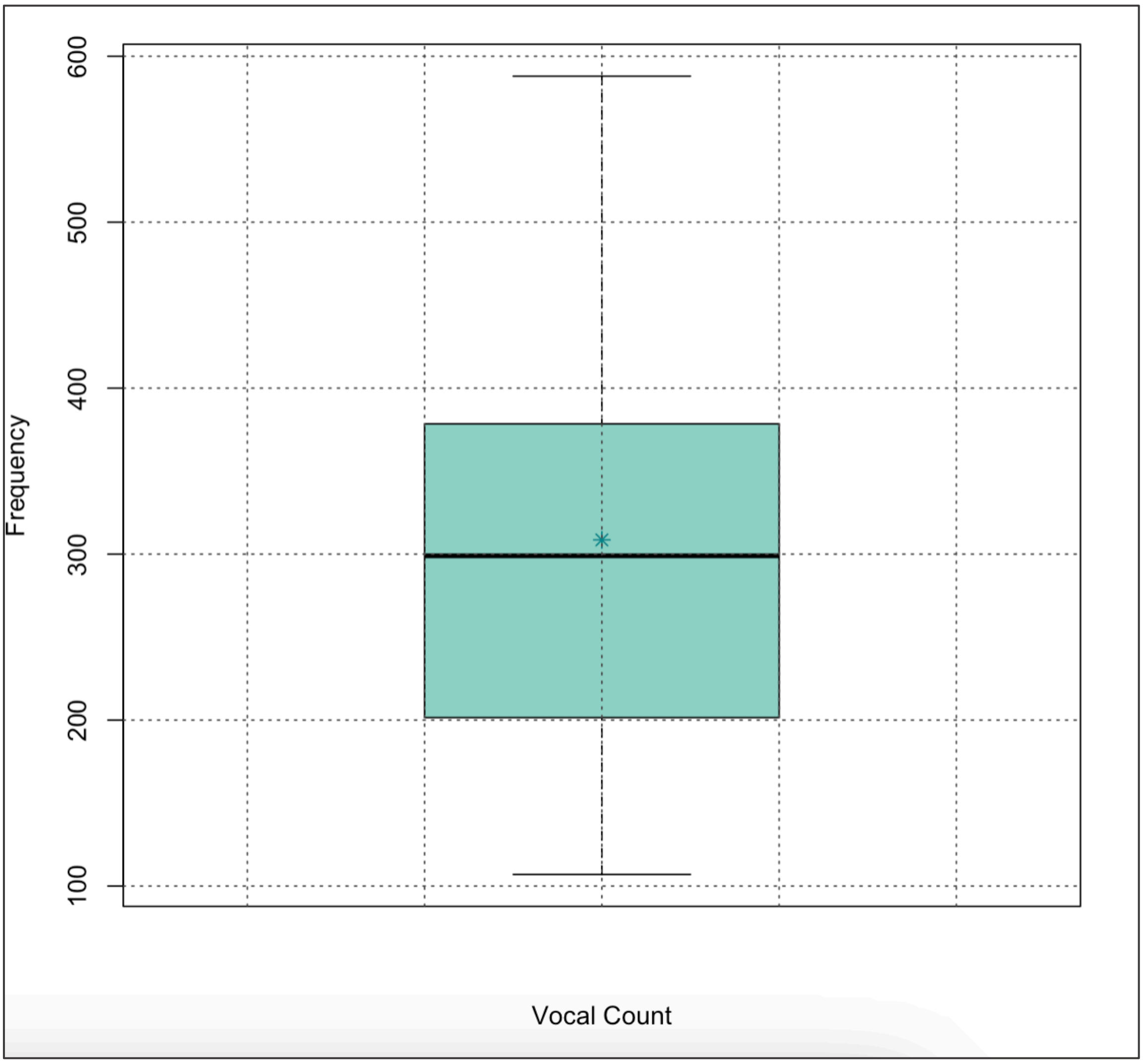



*Figure 5.1: A Boxplot of Vocal Count Across the Whole Sample*

Figure 5.1 has the vocal count from each infant in the sample on the x-axis, with the vocal count frequency on the y-axis; it indicates the median with the thick black line within the turquoise region and the star illustrates the mean. The figure highlights that the median (299) and mean (308.57) were very close together, indicating a normal distribution, which was confirmed by a Shapiro Wilk test (W = .94, p = .12). The distance between the most and least vocal infant was nearly four times the standard deviation, indicating these to be outliers to the overall trend. In fact, the standard deviation showed that vocal count across infants varied by 122.24, providing an indication about how much variability there was in vocal count across the whole sample of 28 infants. It indicates that, while the upper and lower quartile were reasonably far apart, the standard deviation signifies that this difference was not outside the spread across the whole sample. It also reveals that the most variability was within the upper and lower quartiles at approximately 180 vocalisations, but outliers (visible from the black, horizontal range lines) were responsible for bringing the mean value marginally above the median.

To get an insight into how these values might be differentiated by the number of months since surgery, vocal count was plotted in relation to the palatal group (as in Table 4.3, p. 117) and is visualised in Figure 5.2. Similar to the previous figure, the multiple boxplots capture the spread of the data, but this time is categorised by the palatal groups on the x-axis.

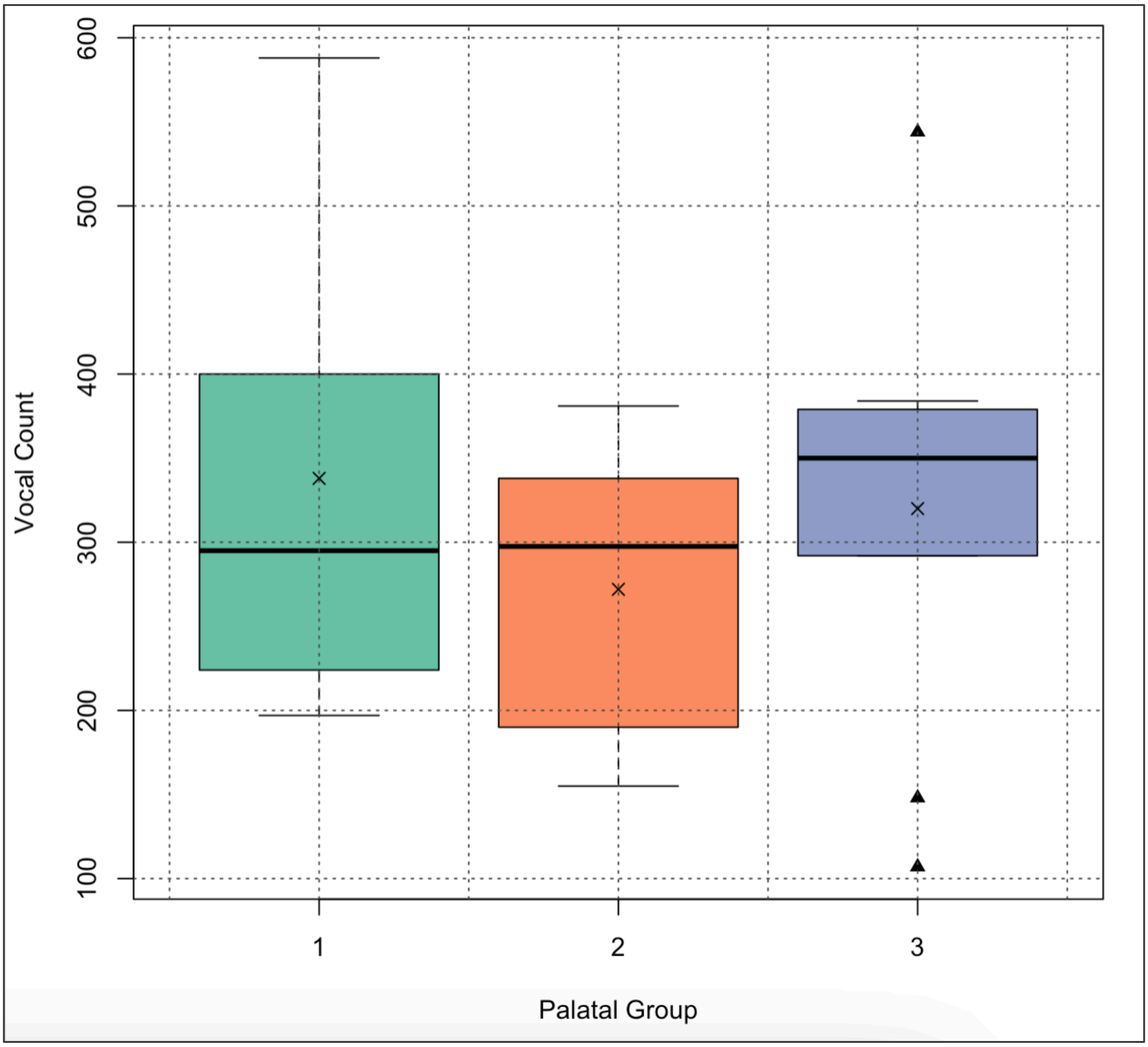



*Figure 5.2: A Boxplot of Vocal Count Across Palatal Group*

The initial impression of vocal count across the three palatal groups is that there appears to be variation across different groups. It indicates that the palatal age may influence the variation across the whole sample, which shows some support for H1. Black crosses in Figure 5.2 denote the means. They signal that vocal count was centring around the 300 mark, but that there was a slightly lower distribution in the middle group. It is also necessary to comment on the outliers in Group 3. The 2 infants who vocalised less in this group could be an example of less stable, or less speech like vocal patterns, however it might be that they were vocalising less, yet with more phonetic accuracy or diversity. This outcome required a closer, qualitative analysis and is explored further in Section 5.3.1.

Figure 5.2 also reveals that Group 1 had a higher ceiling, and this is because of two infants, rather than one lone outlier. Indeed, the largest interquartile range was most apparent in Group 1 and smallest in Group 3, which presents the least variation in the older palatal ages, signalling lower variability here. The median for Group 3 was also higher than in groups 1 and 2, which—perhaps unsurprisingly—indicates that there was the most variability closer to surgery, but this variability reduced as palatal age increased, a difference which was especially evident >5 months post-surgery. This is a trajectory that matches typical development and is a reflection which will be explored in detail in Section 6.2.

### 5.2.2 Vocal Count Across Age

The distribution of vocal count across both chronological and palatal age is explored here to determine how much the analyses should consider age throughout, and to confirm whether palatal age was related, as was anticipated by the hypotheses. Figure 5.3 shows the distribution of vocal count across chronological age, with individual boxplots allocated to the five age categories and the number of infants both presented on the x-axis.

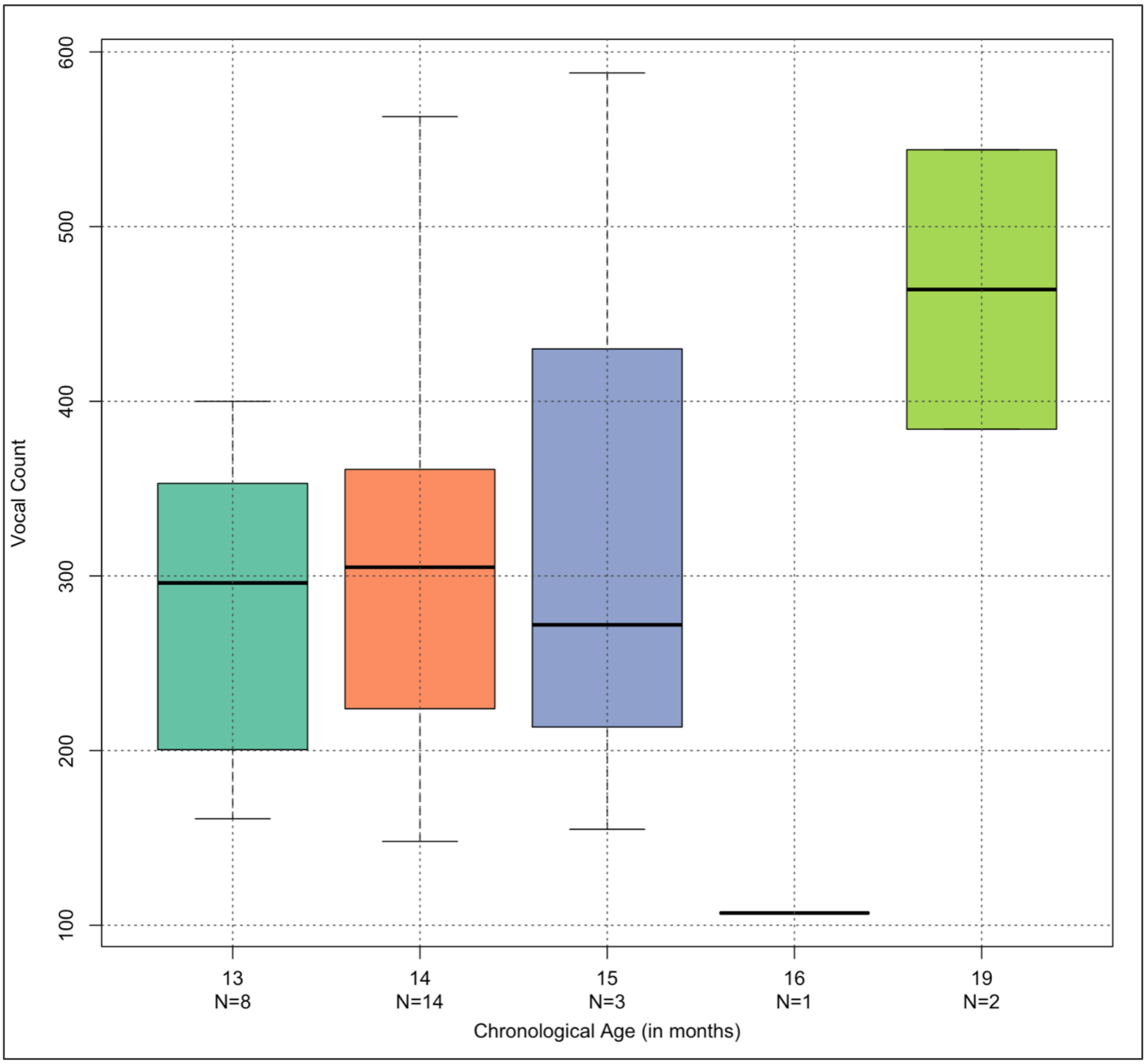



*Figure 5.3: A Multiple Boxplot of Vocal Count Across Chronological Age*

It illustrates an overall trend, in that vocal count increased with chronological age. This was most evident from the incremental increasing range lines and upper quartile values; however, the median bars indicate some variation here, mainly at 15 months where there was a dip. Most noteworthy though was the outlier of one infant at 16 months, where their vocal count was lower than all other groups and ranges. The individual may be demonstrative of having a less vocal/healthy day during data collection, or this infant may have been consistently less vocal than the others in the sample, they were treated as an outlier for these reasons. The impacts of individual differences here and the time available for rehearsal are relevant to all three analyses and will be considered further in the Discussion.

Figure 5.4 presents vocal count against chronological and palatal age (as a continuous variable) to compare the distribution of count across the ICPs' ages. The coloured lines reflect the best fitting linear relationship between the different age types and vocal count, and each infant is therefore assigned to both an orange and blue triangle.

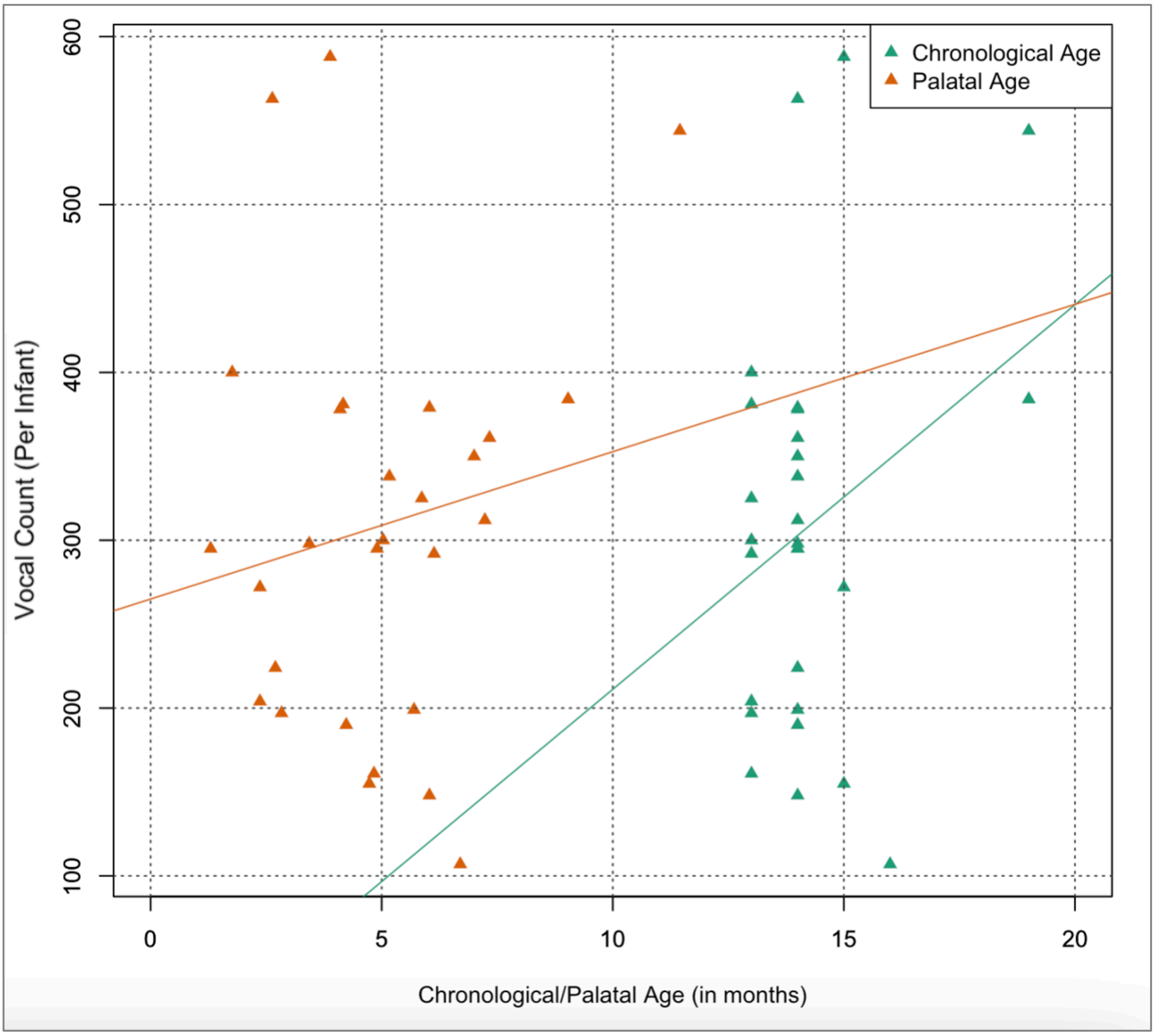



*Figure 5.4: A Scatterplot of Vocal Count Across Palatal and Chronological Age*

The chronological ages were more closely clustered in their distribution, but palatal ages were slightly wider spread overall, which is visible from the orange ab line in Figure 5.4. Table 5.2 provides the results of three normality tests on the ages and vocal count.

*Table 5.2: Shapiro-Wilk Normality Test Outcomes*

| | | |
|---|---|---|
| Chronological Age | W = .67 | p- value < .001 |
| Palatal Age | W = .96, | p = .3013 |
| Vocal Count | W = .94, p = .12 | p = .12 |

The Shapiro-wilk tests illustrated that vocal count and palatal ages were both normally distributed, but chronological age was not, therefore Spearman's Rho (Fang and Yang, 2019) was used to test the correlation between vocal count and chronological age[6]. The correlation coefficient revealed a strong, positive relationship between chronological age and vocal count values (*R*(26) = .79, *p* = .053) that was marginally significant.

It was also hypothesised that palatal age would relate to vocal count; the null hypothesis was that palatal age would have no effect on vocal count. To test the relationship between count and palatal age for H1, Persson's correlation test was used for palatal age as a continuous variable vocal count[7]; the coefficient indicated a moderate positive relationship (*R(*26) =.41, *p* =.16) but it was not significant. As such, chronological age appeared to have a stronger relationship with vocal count than palatal age, but both appear to copattern with vocal count, providing evidence in favour of H1. The outcomes here together indicate clear relationships between age and vocal count, which was expected by the hypotheses. However, other aspects of these relationships require expansion such as vocalisation length, MBL, discussed shortly in sections 5.2.3 and 5.2.5 to fully examine H1.

### 5.2.3 Vocalisation Length

The second measure of importance for the analysis is vocalisation length; that is, the total number of syllables in each vocalisation. This section considers the mean vocalisation lengths across all infants and within groups to discern whether vocalisation length related to any of the sample characteristics, or vocal output in the data.

Figure 5.5 illustrates how vocalisation lengths were distributed across the whole sample.

[6] Line of code: cor.test(PInv$COUNT,PInv$CAGE, method="spearman")
[7] Line of code: cor.test(PInv$COUNT, PInv$PAGE)

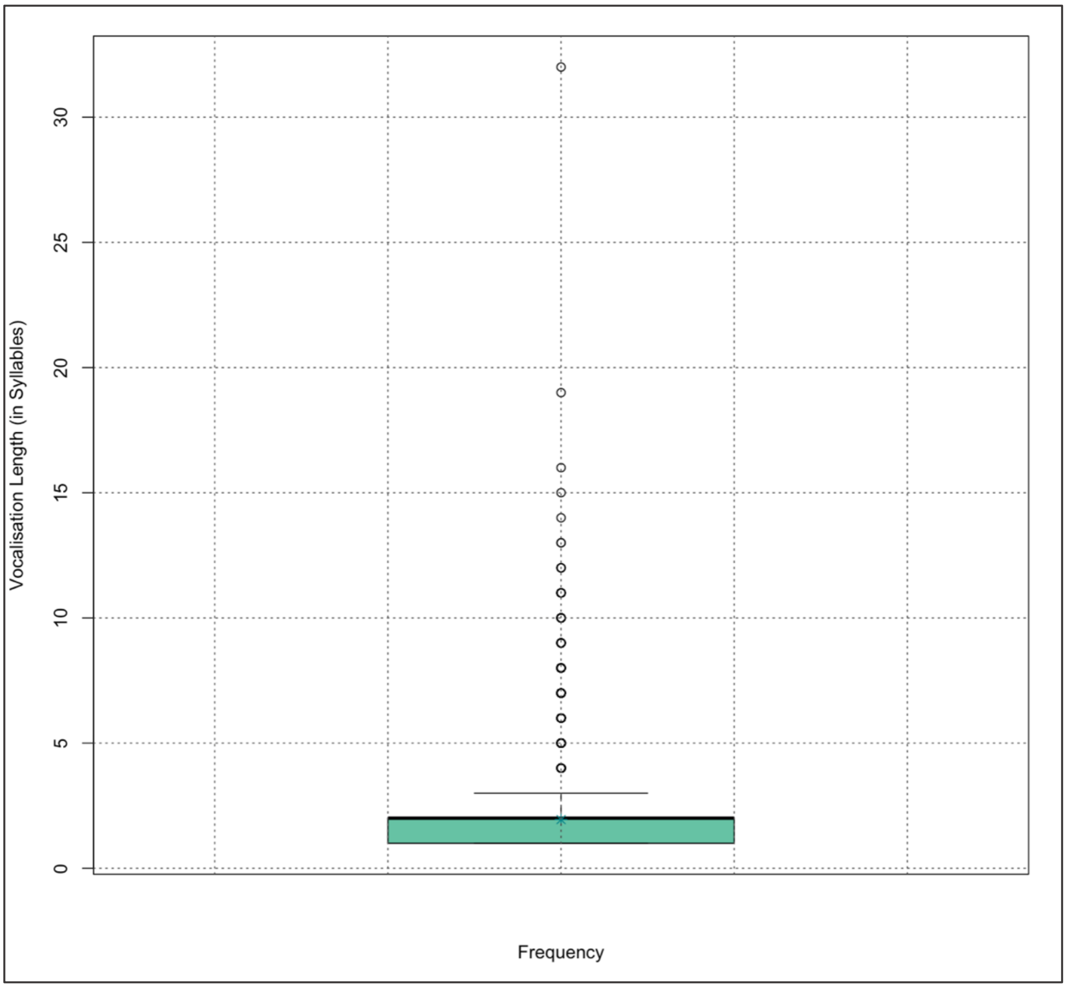



*Figure 5.5: A Boxplot of Vocalisation Lengths in the Whole Sample*

It presents that mono, di, and tri-syllables (e.g., /bʌ/, /ʔælæ/, /gʊwænʊ/) were most common (respectively), and that any strings longer than 4 syllables were considered outliers. Of the extreme outliers here, the longest vocalisation was 32 syllables. While the outliers appear to raise the mean, longer vocalisations were actually very rare by comparison to the mono- to tri-syllables, therefore this was not an issue for interpreting the results.

### 5.2.4 Vocalisation Length Across Age

The differences in vocalisation length are next visualised and examined against palatal group which has just been shown to relate positively to vocal count. Figure 5.6 illustrates the spread of vocalisation length (number of syllables per vocalisation) across the three palatal groups. The multiple histograms present the frequencies of occurrence on the y-axis and the number of syllables per vocalisation on the x-axis.

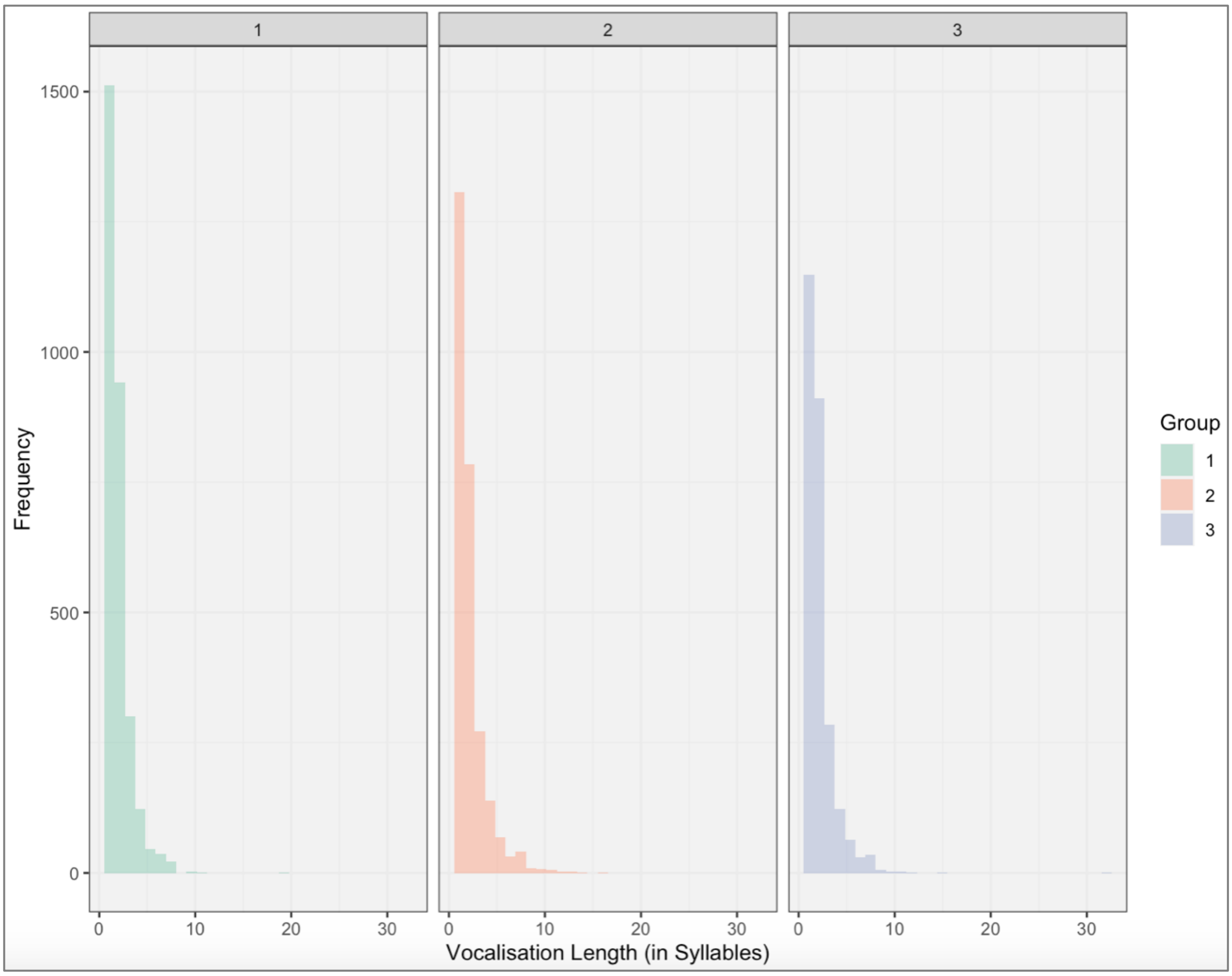



*Figure 5.6: A Multiple Histogram of Vocalisation Length Across Palatal Group*

It reveals that the most frequent vocalisation length in all groups was the monosyllable, which was expected by H1. The distribution of monosyllables and disyllables was most balanced in Group 3. In addition, most tri-syllables had a similar frequency across all three groups, which was a more surprising outcome to Section 2.2.1's prediction that vocalisation would tend to be shorter due to control of the articulators and airstream. Typically, at 14 months, infants are producing their first words, (see Section 2.2.3.1), therefore these tri-syllables suggest that they are not targeting short, first word forms yet. What was also apparent from the multiple plots was that while the distribution of vocalisation length was similar across all three groups, longer vocal strings were more frequent in Group 3. Furthermore, with Group 2 and 3 presenting a rise in 6 + syllable strings; this pattern confirms that as palatal age increased, so did the frequency of longer vocalisation lengths.

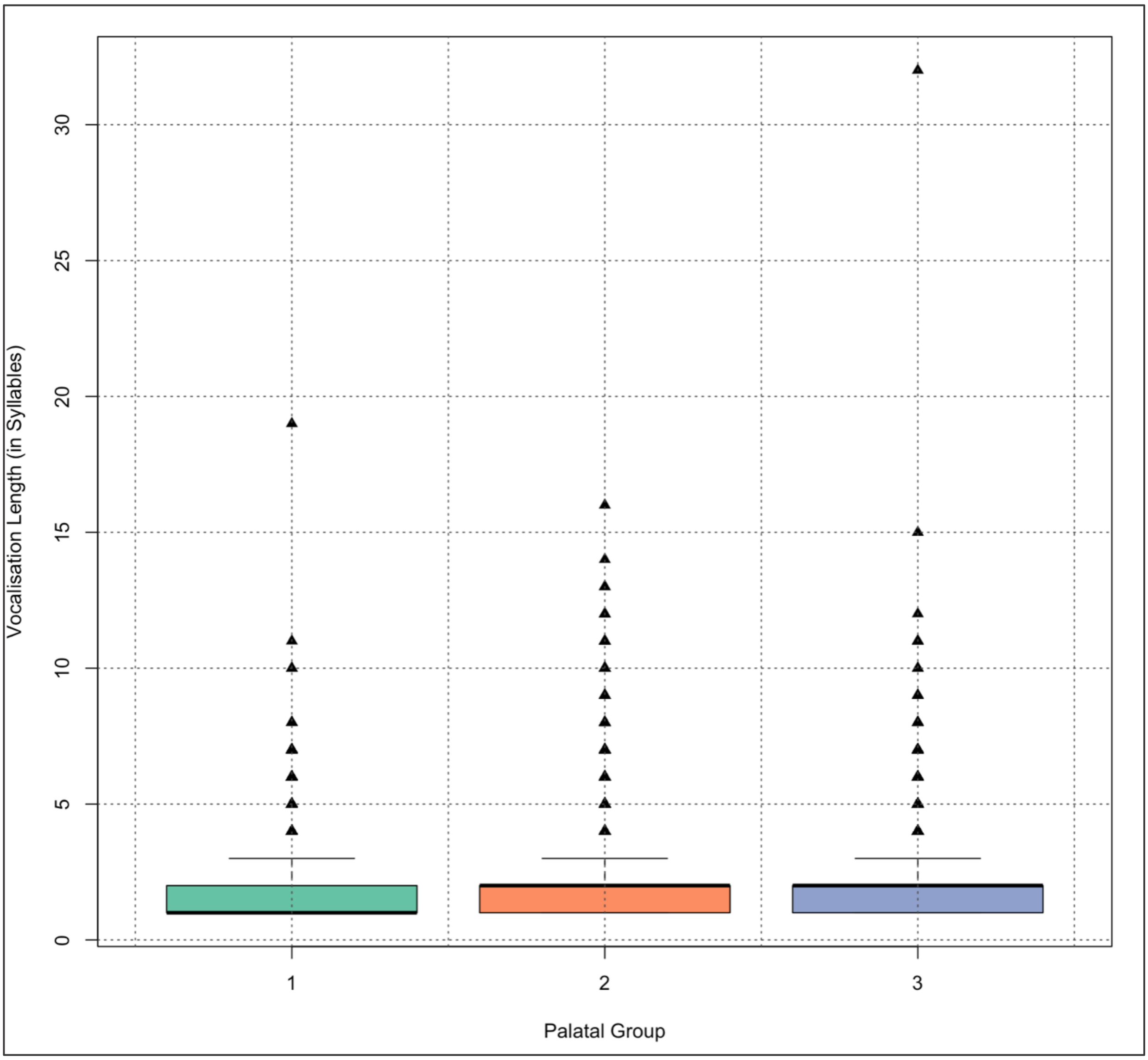



*Figure 5.7: A Multiple Boxplot of Vocalisation Lengths Across Palatal Group*

Figure 5.7 provides evidence in favour of this observation. It reveals the distribution of vocalisation length across palatal groups and shows their similar distribution in terms of the interquartile range, range bars, and plotted mean values. However, it also illustrates that medians were higher in palatal ages 2 and 3 (1.89, and 1.8 respectively) than 1(2.12). Therefore, together with the data described in Section 5.2.3, there was evidence that in older palatal ages infants vocalised more, and in longer vocal strings. This interaction with palatal age may indicate that during infants' healing timeframe post repair, they were more likely to produce shorter vocalisations, as these require less coordination (lower breath control and fewer gesture repetitions). The content of these vocalisations is compared with vocalisation length later to explore this possibility in more detail (see Section 5.2.4).

To give a more robust idea of the spread of vocalisation lengths across the groups, the mean vocalisation lengths (according to syllable count) across individuals is presented. Figure 5.8 illustrates the pattern within-participants, not only within palatal groups, but also to analyse the variability of vocalisation length further. It displays the mean vocalisation length per infant in violin plots (a visualisation method used to view data density and dispersion). The coloured bands provide a shape that best reflects the distribution of the data in each group, with wider plots showing the interquartile range, and longer shapes indicating a wider interquartile range. The wideness of the coloured section indicates the density of data, and the shape illustrates the spread of data, providing more detail than a box plot.

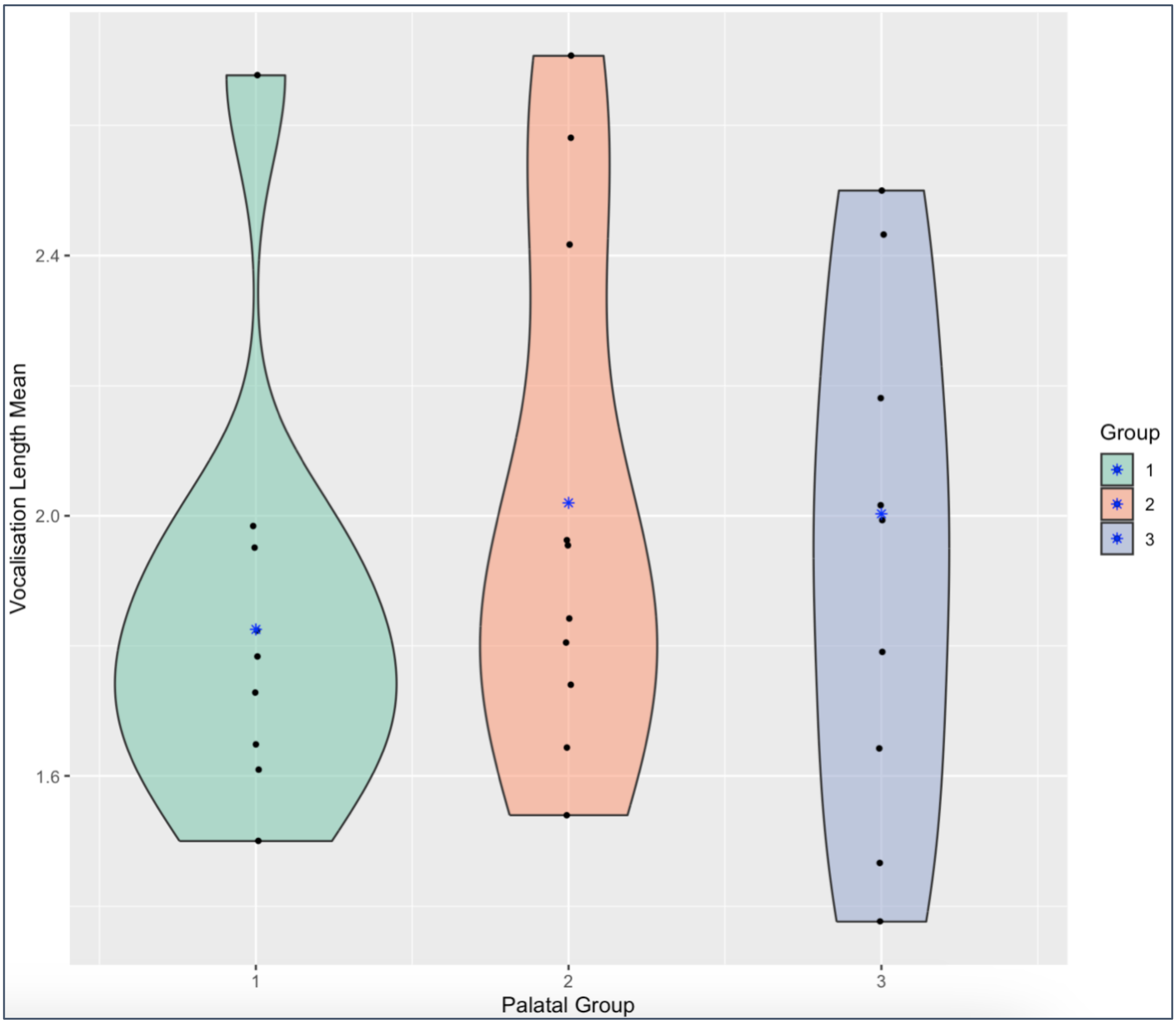



*Figure 5.8: A Multiple Violin Plot of Mean Vocalisation Lengths Across Palatal Group*

These distributions reveal some similarities to Figure 5.6 because the means indicate Group 3 to be more balanced, overall, whereas groups 1 and 2 were most concentrated between 1.6 and 2.0 syllables, but there were still some means above 2.4. Figure 5.8 also provides a more standardised insight into syllable counts across vocal repertoire as the means appear individual specific, rather than a collated sample of all vocalisations. This relationship was considered further in relation to variability in each palatal group.

*Table 5.3: Standard Deviations and Syllable Means Across Palatal Group*

| Palatal Group | Vocalisation Length Mean | Vocalisation Length SD |
|---|---|---|
| **1** | 1.83 | 1.20 |
| **2** | 2.02 | 1.59 |
| **3** | 2.00 | 1.49 |

The variability was consistent across the palatal groups. The SD values were slightly greater for the two older palatal groups given by standard deviation values in Table 5.3, and lowest in Group 1, indicating slightly more variation as vocalisation length and palatal age increased. To explore the relationship in more depth, palatal age was considered as a continuous variable to assess whether there was a relationship with syllable means.

Syllable means were not normally distributed ($W = .92$, $p = .04$). As such, a spearman correlation tested the relationship between palatal age (as a continuous variable) and vocalisation length means for each infant: with the correlation coefficient revealing a moderate, positive relationship ($R(26) = .48$, $p = .14$), but was statistically non-significant. Together, the result indicates that palatal age may explain some of the variability in vocal count and vocalisation length (in syllables) across the sample. Figure 5.9 illustrates the vocalisation length distributions across each infant, with palatal age presented as a continuous variable. The separate boxes represent each infant's exact palatal age with the spread of all vocalisation lengths (y-axis) and the triangles representing outliers.

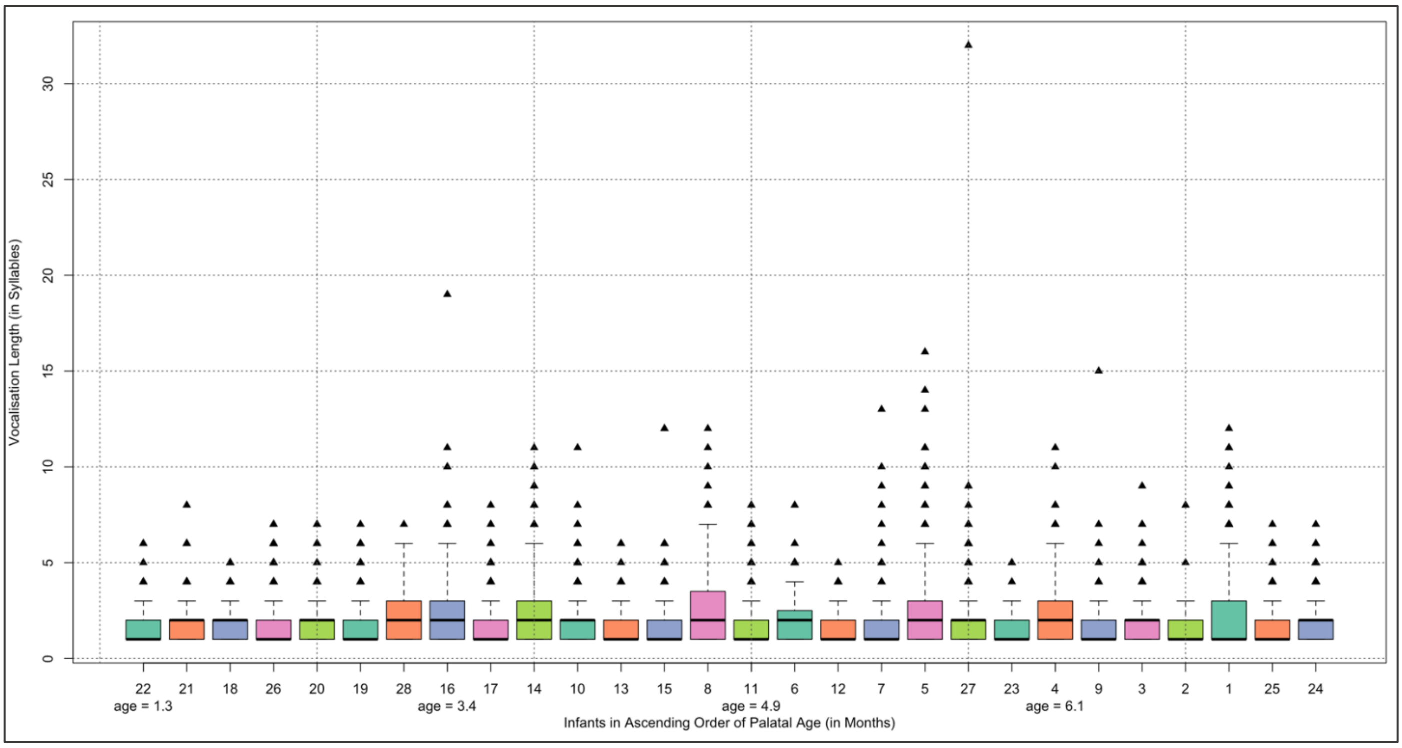



*Figure 5.9: A Multiple Boxplot of Vocalisation Lengths Across Palatal Age (in Months)*

The distribution of vocalisation lengths shows medians in a similar range to the chronological ages, which indicated that in both chronological and palatal ages, the outliers were akin to each other. There was some cross-individual variation in the interquartile ranges, but this trend did not appear to be clearly changing with palatal age per se. The only trend of note in Figure 5.9, was that outliers with longer vocalisation lengths increased with palatal age, with the exceptions of infants 12 and 23, whose outliers were lower.

To determine whether vocalisation length was a production feature worth considering further, the distribution of vocalisation lengths was also analysed across chronological age, because it may also illustrate a relationship with vocalisation length. In Figure 5.10, the black triangles mark outliers, whereby the values were outside the range bars by more than or equal to double the SD.

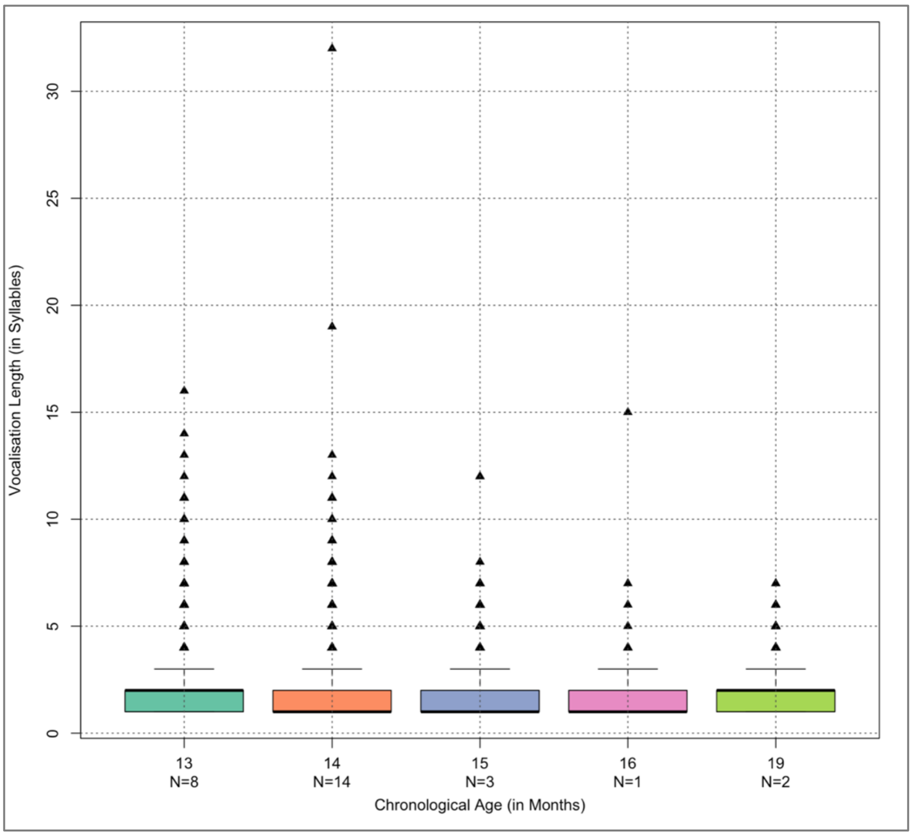



*Figure 5.10: A Multiple Boxplot of Vocalisation Length Across Chronological Age*

Figure 5.10 illustrates that there was not much variation across chronological age, other than the median differences between mono and disyllables. The range bars and interquartile ranges were similar across all 5 chronological ages (see each boxplot above). The only minor fluctuation across the groups was with the median, which only contrasted (by 1 syllable) in the 13- and 19-month-olds. In these groups the median vocalisation was 2 syllables long rather than 1. When looking at the outliers, there is a steady decrease in vocalisation length over chronological age, which suggests some contrast to the increase in palatal age. As has been analysed above, it may be that palatal age and chronological age are also worth considering together. Looking at the medians between both age variables there was consistency between palatal age and chronological age because they only fluctuated between mono-, di-, and trisyllables. The lack of clear trend in relation to vocalisation length, indicates that it may not be the best measure for analysis and assessing vocal development, and therefore only mono-, di-, and tri-syllables are considered in the third and final analysis section (see Section 5.4).

### 5.2.5 Mean Babble Level

Canonicity was measured using the MBL values for each infant. The overall mean for MBLs was 2.51, with a SD of .26. Overall, 16/28 of the ICPs had an MBL of 2.5 or over, meaning that their vocalisations were closer to canonical babble than variegated babble or non-canonical vocalisations. Figure 5.11 provides the distribution of MBL mean scores across palatal group where a dot represents each infant's mean MBL value.

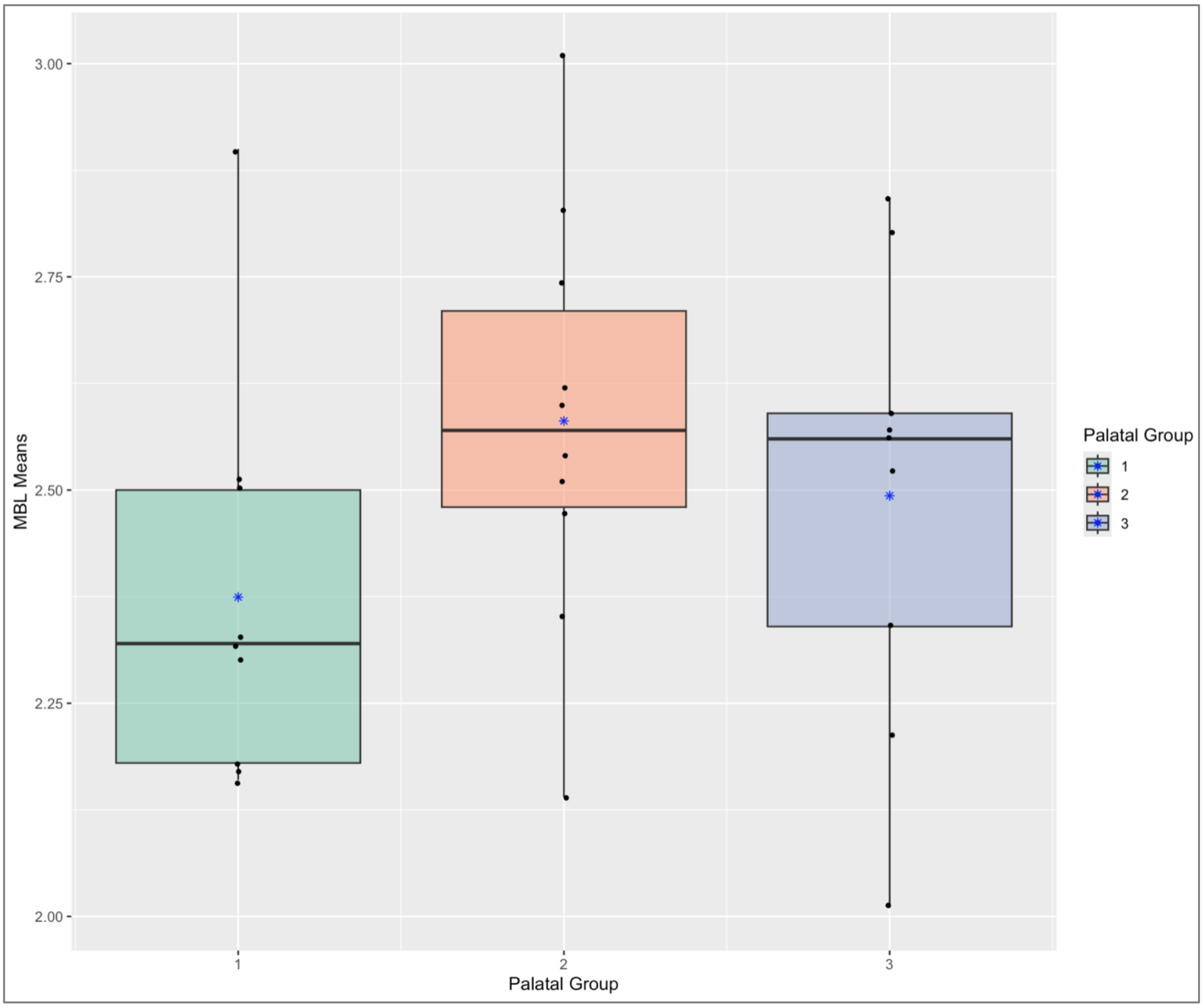



*Figure 5.11: A Multiple Boxplot of MBL Across Palatal Group with Means*

In the middle palatal age, median values were below but very close to the mean values, indicating more evenly distributed data within Group 2 than within the other two groups, where the mean was nearing the upper quartile.

It was expected that most variation would be evident in Group 1 (especially given that this group demonstrated the most variability in vocal count) and least in Group 3. However, this was not the case as Group 1 had lower MBL scores than the other two groups. The highest

MBL values were in Group 2, therefore the overall data were mixed but mainly in line with an increase in scores with palatal age.

To test whether the data were normally distributed, a Shapiro Wilk normality test was conducted, which revealed MBL to be normally distributed (W = .97, p = .67). What is immediately evident from the multiple boxplots, is that the distribution of MBLs varied most between Group 1 and groups 2 and 3. To evaluate whether this difference held in relation to the normality of the data, three Shapiro-wilk tests were carried out on each palatal group.

*Table 5.4: Shapiro-Wilk Normality Values for MBL Scores Across Palatal Group*

| Palatal Group | W Value | P Value | MBL mean | MBL sd |
|---|---|---|---|---|
| 1 | .84 | .0568 | 2.37 | .24 |
| 2 | .99 | .9953 | 2.58 | .25 |
| 3 | .94 | .6077 | 2.49 | .27 |

The results in Table 5.4 reinforce Figure 5.11 that Group 1 MBL means were differently distributed as they were the only group to not be normally distributed. While overall these Group 1 had the lowest mean scores, they also exemplified the lowest variability despite these data not being of a normal distribution. This finding in itself was surprising because it indicates more within group consistency for infants with the fewest months between data collection and cleft surgery.

Given that MBL and palatal age were normally distributed, to test the overall relationship between palatal age and MBL across the whole dataset, a Pearson's correlation test was used[8]. The significance threshold was set at .05. The result indicated a marginally significant relationship: R(26) =.33, p =.089), suggesting that as palatal age increased, so did MBLs. Although the correlation coefficient was weak, the direction of the trend provides some evidence in favour of H1, indicating a relationship between babble level and palatal age. It could be that the relationship result reflects more systematicity in the composition of vocalisations during the healing process. There was the most variability reported in Group 1 for vocal count and vocalisation length, in contrast to the lowest variability in MBL, which suggests a slight distinction between how vocal an infant is and their MBL, in other words, there appears to be a trade-off between quality and quantity. Although the mean MBL for Group 1 appeared to be driven up by an outlier, this group pattern was compelling. As a

[8] Line of code: cor.test(PInv$PAGE, PInv$MBL)

contrast, Groups 2 and 3 did have higher MBL values, but more variability (SD values were .25 and .27 respectively), including an extremely obvious outlier, with the lowest mean of all infants at 2.01. Such outliers are explored in more detail next in 5.2.6 to evaluate what they could indicate about the findings.

### 5.2.6 Extreme Data Points

Despite the steps taken to reduce the impacts on outcomes in the sample, this final section gives attention to the outliers within the findings. It considers which of the considered variables (or individual differences) might have driven the extremes of the vocalisation data yielded, and to indicate whether any clinical variables may explain such instances. All the considerations given relate back to the values highlighted in red (Table 5.5 through Table 5.9) to follow.

Table 5.5 provides an overview of the vocalisation variables in relation to individual infants in the dataset. The acronyms expand in the following ways: ID (infant), TF (24-month inventory size), TS (36-month inventory size), Chronological Age (number of months since birth), MBL (mean babble level score), palatal age (number of months since surgery), count (number of vocalisations from the hour of audio), Gender (sex of infant). The values presented in red from Table 5.5 to Table 5.9 underline the extremities in the dataset and are now discussed in turn. The categorisation of outliers in this way helps to address and make sense of the variation across the large set of results. This section later zooms in on 2 infants at a time to assess whether there were clear participant variables that drove the variation or whether it is more complex than this alone. First is a summary table of all the data, then an analysis of the following extreme points: most and least vocal infants, highest and lowest MBL mean scores, and actual and palatal ages. The blank cells indicate emissions from the CC-SLC data where reports were unavailable or empty.

*Table 5.5: Table of Sample Features with Vocal Count and MBL*

| ID | 26M Inventory | 36M Inventory | ACTUAL AGE (in months) | MBL | PALATAL AGE | VOCAL COUNT | GROUP | GENDER |
|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 12 | 14 | 2.56 | 7.33 | 361 | 3 | M |
| 2 | 3 | | 14 | 2.01 | 7.23 | 312 | 3 | F |
| 3 | 1 | 10 | 14 | 2.59 | 7 | 350 | 3 | F |
| 4 | 8 | 9 | 13 | 2.8 | 6.13 | 292 | 3 | F |
| 5 | 5 | 13 | 13 | 2.83 | 5.87 | 325 | 2 | F |
| 6 | 4 | 12 | 13 | 3.01 | 5.03 | 300 | 2 | F |
| 7 | | 16 | 14 | 2.35 | 5.7 | 199 | 2 | M |
| 8 | 6 | 16 | 13 | 2.51 | 4.83 | 161 | 2 | M |
| 9 | 11 | 15 | 16 | 2.34 | 6.7 | 107 | 3 | F |
| 10 | 8 | 17 | 13 | 2.62 | 4.17 | 381 | 2 | F |
| 11 | 5 | 17 | 14 | 2.47 | 4.9 | 295 | 2 | F |
| 12 | | 4 | 14 | 2.6 | 5.17 | 338 | 2 | F |
| 13 | 7 | 10 | 14 | 2.14 | 4.23 | 190 | 2 | M |
| 14 | 10 | 16 | 14 | 2.74 | 4.1 | 378 | 2 | M |
| 15 | 6 | 9 | 15 | 2.54 | 4.73 | 155 | 2 | F |
| 16 | 8 | 14 | 14 | 2.9 | 3.43 | 298 | 1 | M |
| 17 | 4 | 15 | 15 | 2.5 | 3.86 | 588 | 1 | F |
| 18 | 4 | 14 | 13 | 2.16 | 2.37 | 204 | 1 | M |
| 19 | 18 | 9 | 14 | 2.18 | 2.7 | 224 | 1 | F |
| 20 | 7 | 13 | 14 | 2.51 | 2.63 | 563 | 1 | F |
| 21 | 3 | | 13 | 2.17 | 1.77 | 400 | 1 | M |
| 22 | 4 | 11 | 14 | 2.3 | 1.3 | 295 | 1 | F |
| 23 | | | 14 | 2.21 | 6.03 | 148 | 3 | M |
| 24 | 12 | 7 | 19 | 2.84 | 11.45 | 544 | 3 | M |
| 25 | 9 | | 19 | 2.52 | 9.03 | 384 | 3 | F |
| 26 | 4 | | 15 | 2.32 | 2.37 | 272 | 1 | F |
| 27 | | | 14 | 2.57 | 6.03 | 379 | 3 | F |
| 28 | | | 13 | 2.33 | 2.83 | 197 | 1 | F |

Table 5.5 gives the full set of vocalisation characteristics across the whole sample. In particular, the extreme (actual) ages across the sample are considered here to observe whether any general trends were visible in the output data. The youngest age at the time of data collection was 13 months (N = 8), and the oldest was 19 months (N = 2). It was noted that vocal count varies by age, and perhaps as expected, older infants vocalised more than younger infants. In addition, Table 5.5 reconfirms that the canonicity of vocalisations did not closely relate to chronological age, however an outlier to the expected outcome was infant 9 who had the lowest score but was one of the older infants at 16 months.

Finally, the least vocal (infant 9) and most vocal (infant 17) participants are compared. Given there was a range of 481 vocalisations, it is valuable to consider whether these parameters reveal any immediate differences in the participant details.

*Table 5.6: Table of Most and Least Vocal Infants*

| ID | SEX | TF | TS | AGE | MEAN MBL | PALATAL AGE | VOCAL COUNT | GROUP | SURGERY AGE |
|---|---|---|---|---|---|---|---|---|---|
| 9 | F | 11 | 15 | 16 | 2.34 | 6.7 | 107 | 3 | 8 |
| 17 | F | 4 | 15 | 15 | 2.5 | 3.86 | 588 | 1 | 10 |

Interestingly, infant 9 underwent palatal surgery 2 months earlier than infant 17 and they had a greater palatal age (6.69 months), too, therefore the least vocal infant had 3 more months of recovery and rehearsal time with their articulatory capacities than the most vocal one. Consequently, and relevant to the earlier point on the significance of palatal age, this contrast in vocal count was opposite to what might be expected, given the reviewed literature in Section 2.3.3.2 showing that earlier surgery was a predictor of language development. This outcome brings the matter of individual differences to the fore. Given that there was contrast in vocal count alone (shown in Table 5.6) the outliers could not be directly explained by age. While the relationship between the two variables in question was evident, as was expected from academic and clinical research, individual variation may also be at play.

To add, there was only a difference of .16 in mean MBL scores between infant 9 and 17. A pattern which was reflected in the standard deviation values of all MBLs from infant 9 (.68) who had more variation across vocalisation MBL scores when compared to infant 17 (.56) who had slightly less variation. The comparison here indicated that the lower vocal count and MBL mean for infant 9 also had more variable vocalisation maturity, but overall, the differences (aside from vocal count) were slight. Therefore, these data are indicative that these infants may have been at similar points along the vocal development trajectory in terms of how advanced—or 'speech-like'—their vocalisations were. However, this pattern was mirrored later into their development and was illustrated by their equal scores for inventory sizes at thirty-six months (noted in the '36M' column). As infants 9 and 17 produced the same number of sounds in their SLT assessment at three years of age, despite variation at the twenty-four-month stage (see column '24M'), the trends appeared to be consistent between infants. While the speech reports at 24 and 36 months from the CC-SLC had potential for considering outcomes more longitudinally, however, they may not be a completely robust measure because of some missing data values. The next analysis therefore reports on the natural inventory of sounds collected in the current thesis. As such, Section 5.3.1 illustrates that the number of sounds made at this earlier timeframe was the same for infants 9 and 17, presenting further consistency between the infants in relation to the composition of their vocalisations, even though the number of vocalisations was so different.

Next, the extremes and/or outliers of MBL scores are analysed to assess whether the transcribed and coded vocal data presented any trends akin to those that have been presented above regarding age. In relation to vocal count, to continue, the impact of age did not seem to have a direct relationship on the outliers' results, even though, as expected, older infants overall tended to vocalise more. By comparison with Table 5.5, Table 5.7 reveals that the extreme MBL values and the extreme vocal count values did not correspond to the extreme chronological or palatal ages, indicating that the ages here are not at the extremes of age or vocal count.

*Table 5.7: MBL Outliers and Sample Features*

| ID | TF | TS | ACTUAL AGE | MBL | PALATAL AGE | VOCAL COUNT | GROUP | GENDER |
|---|---|---|---|---|---|---|---|---|
| 6 | 4 | 12 | 13 | 3.01 | 5.03333283 | 300 | 2 | F |
| 2 | 3 | N/A | 14 | 2.01 | 7.23333311 | 312 | 3 | F |

Table 5.7 displays that infants 6 and 2 were only a month apart, and their palatal ages only 2 months apart, however they had the highest and lowest MBLs in the dataset. These outliers point to the impact of individual differences on results, which are addressed in Section 6.1.1.

In addition, Table 5.8 reveals that MBL did not have as clear a trend, across chronological age in relation to how speech-like vocalisations were or how vocal infants were.

*Table 5.8: Overview of Chronological Age (from Youngest to Oldest) and Mean Vocal Count*

| **Age (MONTHS)** | **13** | **14** | **15** | **16** | **19** |
|---|---|---|---|---|---|
| VOCAL COUNT (MEAN) | 284 | 309 | 338 | 107 | 464 |
| MBL (MEAN) | 2.56 | 2.45 | 2.74 | 2.34 | 2.5 |

Table 5.8 illustrates this trend and reveals a clear outlier at 16 months (this age consisted only of infant 9) given in red. Infant 10 deviated from the trend in both vocal count and MBL and, as

such, highlights outliers and possible variability in the dataset; they represent a small proportion of the sample that deviates from the group trend. To continue, the youngest age at surgery in the sample was 7 months (N = 6), and the oldest age was 15 (N = 1), both of which were only marginally behind the NHS timeline for CP repair. Surgical age did not appear to reveal any trend in relation to vocal count, or MBL.

Lastly, given that there was a wide range of palatal ages, Table 5.9 provides context to the MBL scores and other variables connected with the palatal age extremes.

*Table 5.9: Palatal Age Extremes with Vocal Outputs*

| ID | TF | TS | CHRONOLOGICAL AGE | MBL | PALATAL AGE | COUNT | GROUP | GENDER |
|---|---|---|---|---|---|---|---|---|
| 22 | 4 | 11 | 14 | 2.3 | 1.30000019 | 295 | 1 | F |
| 24 | 12 | 7 | 19 | 2.87 | 11.4511294 | 544 | 3 | M |

Table 5.9 illustrates a clear trend for infant 27, who was the second most vocal across all infants and also the oldest in chronological and palatal age, with nearly a year between surgery and data collection, whereas infant 24 had just 1.3 months between these two stages. Despite this wide difference in palatal age, the MBL measures did not coincide with the lowest or highest in the data (although there was a difference of .57 between both infants). There did seem to be a clear contrast in the vocal count, though, indicating that infant 27 was roughly 2 times as vocal; this pattern suggests that palatal age may drive vocal count, though MBL may be more influential on the former measures, however, drawing any interpretations based on data from two extremities in the data are very limited.

### 5.2.7 Conclusion

To bring together what has been discussed above, the sample was complex and involved a wide range of clinical ages that required consideration regarding the three centrally relevant vocal measures (vocal count, vocalisation length, and MBL). A summary of the main findings is given in Table 5.10 in relation to RQ2.

*Table 5.10: Summary of Findings in Relation to RQ2*

| ID | **Palatal Age (in months)** | **Palatal Group** | **Vocal Count** | **Vocalisation Length (mean syllable count)** | **MBL** |
|---|---|---|---|---|---|
| *1* | 7.33 | 3 | 361 | 2.43 | 2.54 |

| | | | | | |
|---|---|---|---|---|---|
| *2* | 7.23 | 3 | 312 | 1.38 | 1.95 |
| *3* | 7 | 3 | 350 | 2.02 | 2.72 |
| *4* | 6.13 | 3 | 292 | 2.5 | 2.77 |
| *5* | 5.87 | 2 | 325 | 2.58 | 2.89 |
| *6* | 5.03 | 2 | 300 | 1.97 | 3.01 |
| *7* | 5.67 | 2 | 199 | 1.75 | 2.4 |
| *8* | 4.83 | 2 | 161 | 2.71 | 2.31 |
| *9* | 6.7 | 3 | 107 | 1.79 | 2.39 |
| *10* | 4.17 | 2 | 381 | 1.84 | 2.66 |
| *11* | 4.90 | 2 | 295 | 1.81 | 2.49 |
| *12* | 5.17 | 2 | 338 | 1.64 | 2.59 |
| *13* | 4.23 | 2 | 190 | 1.54 | 2.14 |
| *14* | 4.10 | 2 | 378 | 2.42 | 2.74 |
| *15* | 4.73 | 2 | 155 | 1.95 | 2.8 |
| *16* | 3.43 | 1 | 298 | 2.68 | 2.92 |
| *17* | 3.89 | 1 | 588 | 1.65 | 2.51 |
| *18* | 2.37 | 1 | 204 | 1.82 | 2.22 |
| *19* | 2.7 | 1 | 224 | 1.61 | 2.17 |
| *20* | 2.63 | 1 | 563 | 1.73 | 2.43 |
| *21* | 1.77 | 1 | 400 | 1.78 | 2.29 |
| *22* | 1.30 | 1 | 295 | 1.5 | 2.3 |
| *23* | 6.03 | 3 | 148 | 1.47 | 2.33 |
| *24* | 11.45 | 3 | 463 | 1.99 | |
| *25* | 9.03 | 3 | 384 | 1.64 | 2.52 |
| *26* | 2.37 | 1 | 272 | 1.95 | 2.33 |
| *27* | 6.03 | 3 | 379 | 2.18 | 2.64 |
| *28* | 2.83 | 1 | 197 | 1.98 | 2.4 |

The summary of outcomes is synthesised in relation to the analyses below:

- There was a moderate, positive correlation between palatal age and vocal count that was especially evident >5 months post-surgery, illustrating a trajectory that matches typical development when compared with the number of months since birth.
- Palatal age and mean vocalisation length were not significantly related to each other, given the distribution differences across palatal groups. The Spearman correlation indicated that palatal age may explain some of the vocalisation length variation ($R(26) = .48$, $p = .14$). Other than the median differences between mono- and di-syllables, vocalisation length trends were unclear, indicating that longer syllable sequences were not a valuable focus for Analysis II and III.

- There was a marginally significant relationship ($R(26) = .33$, $p = .089$) between MBL and palatal age, suggesting that as palatal age increased, so did MBLs.
- 16/28 of infants had an overall MBL of 2.5 or over, reflecting the cohort to be between canonical babble and non-canonical vocalisations. The youngest palatal ages had the lowest mean score, but also the lowest variability ($SD = .24$), which is at sharp contrast to the high variability reported in Group 1 for vocal count. It suggested that there was a distinction between how vocal an infant was and their MBL and there was a trade-off between quality and quantity.
- The extreme data points in the participant features did not clearly relate to outlier results. The most notable interaction was in infants 6 and 2 (1 month apart in chronological age, 2 months apart in palatal age), who had the highest and lowest MBL in the dataset. The high and low extremes of MBL scores did not coincide with other participant features, capturing that the outliers reflect the role of individual differences on results.

In conclusion, the implementation of palatal groups is motivated and solidified by the positive relationships between palatal age with vocal count and MBL, but not by vocalisation length, although a slight increase in vocalisation length occurred with palatal age. Within palatal groups, there was undoubtedly the most variability in Group 1 (1-3 months post-repair) for all three vocal measures analysed here, but the variability seemed to stabilise by palatal ages of 4 months and over. In sum, the three vocal measures have been found to vary based on chronological age in previous research, but these relationships were not as clear, they were more apparent for palatal age, however it is unclear whether other elements were also playing a role. Thus, Analysis II and Analysis III continue this line of enquiry in relation to phonetic patterns, sequential patterns, and palatal age.

## 5.3 Analysis II

Analysis II explores articulatory range, frequency, and regularity of syllables produced in the infant vocalisations overviewed earlier (see sections 5.1.2-5.2). Ultimately, it provides insight into the phonetic content of vocalisations within and across the sample of infants' data. This analysis also examines how the vocalisation variables in question relate to palatal age and MBL as a continuation of the analysis explored in Section 5.2. Its overarching goal was therefore to establish how well vocal characteristics in ICPs reflect patterns that emerge along the typical trajectory.

First is an overview and analysis of phonetic inventories (including the number of different consonants that were within the infants' repertoire) and how these were spread across palatal age. Second is an analysis of phonetic features (the properties of consonant-like features and vowel-like, or vocalic, elements); last is an investigation of how syllable patterns (the combination of vocalic and consonant-like elements) relate to MBL and later, the phonetic inventory data. Ultimately, these measures examine pre-linguistic (or even proto-linguistic) consonant frequencies and preferences in the sample and determine whether they were stable across palatal groups. The measures will also help pinpoint what the compositional and organisational components produced by ICPs (i.e., the phonetic and sequential properties of babbled 'consonants' and 'vowels' in vocalisations) were, and, centrally, whether they reflect typical syllable production patterns at and before 14 months.

### 5.3.1 Phonetic Inventory Size at 14 Months

Phonetic inventory is the number of consonants within an infant's production output. It therefore provides two main measures, the size of the inventory (e.g., the number of sounds produced by a given infant), and the variety and phonetic details of the sounds within their repertoire. In the 14-month data, all the phones captured in the hour-long speech recordings were transcribed to capture actual vocalisations (see Section 4 for a reminder of these details). Such data are useful in providing initial insight into the emergent consonants and vowels (alongside the consistent ones, as are captured by vocal motor schemes, or VMS) within an infant's repertoire. The phonetic inventories therefore provide a measure on articulatory inventories in spontaneous vocalisations, which is missing from much of the clinical literature.

Later, when the phonetic detail of the acquired and consistent sounds is considered (see Section 2.2.2 for the definition of VMS consonants), this analysis will also assess which stage of the typical vocal trajectory the ICPs resemble. For instance, if the infants produce fewer sounds, more rudimentary forms (e.g., glottals and liquid consonants), and combinations that are not typical, it may signal that they deviated from the typical orders of acquisition. However, if they explore fewer combinations but produce oral pressure stops, this may signal that they do exhibit the properties of typical canonical babble, just at a delayed time frame respective to their existing physical constraints. The composition of these sequences and the absence of certain vocal gestures may be the result of incomplete healing (which is reflected on in Section 6.1.1), but it may also be influenced by a preference for different sequences. Therefore, Analysis II focuses on the number of sounds and the range of emergent sounds in the data. Inventory size also sets the foundation for exploring and analysing phonetic repertoire in

Section 5.3.2 and indicates how many of the ICPs repair are vocalising a range of different sounds at 14 months.

Table 5.11 provides an initial view of the emergent phonetic repertoire at 14 months.

*Table 5.11: Overview of Phonetic Inventory Statistics*

| VARIABLE | PHONETIC INVENTORY (14 MONTHS) |
|---|---|
| **NO. OF INFANTS INCLUDED** | 28 |
| **RANGE OF INVENTORY SIZE** | 8-16 |
| **MEAN** | 11.68 |
| **MEDIAN** | 11 |
| **SD** | 2.11 |

The table illustrates the descriptive statistics of the phonetic inventory data, and also the variation across the sample. To explore the variability in different inventory sizes further, the spread across palatal age was considered.

Figure 5.12 contains a multiple violin plot of the number of sounds within each infant's naturalistic repertoire (y-axis) against their palatal group. The black dots outside of the coloured region mark outliers and the blue asterisk notates the mean value.

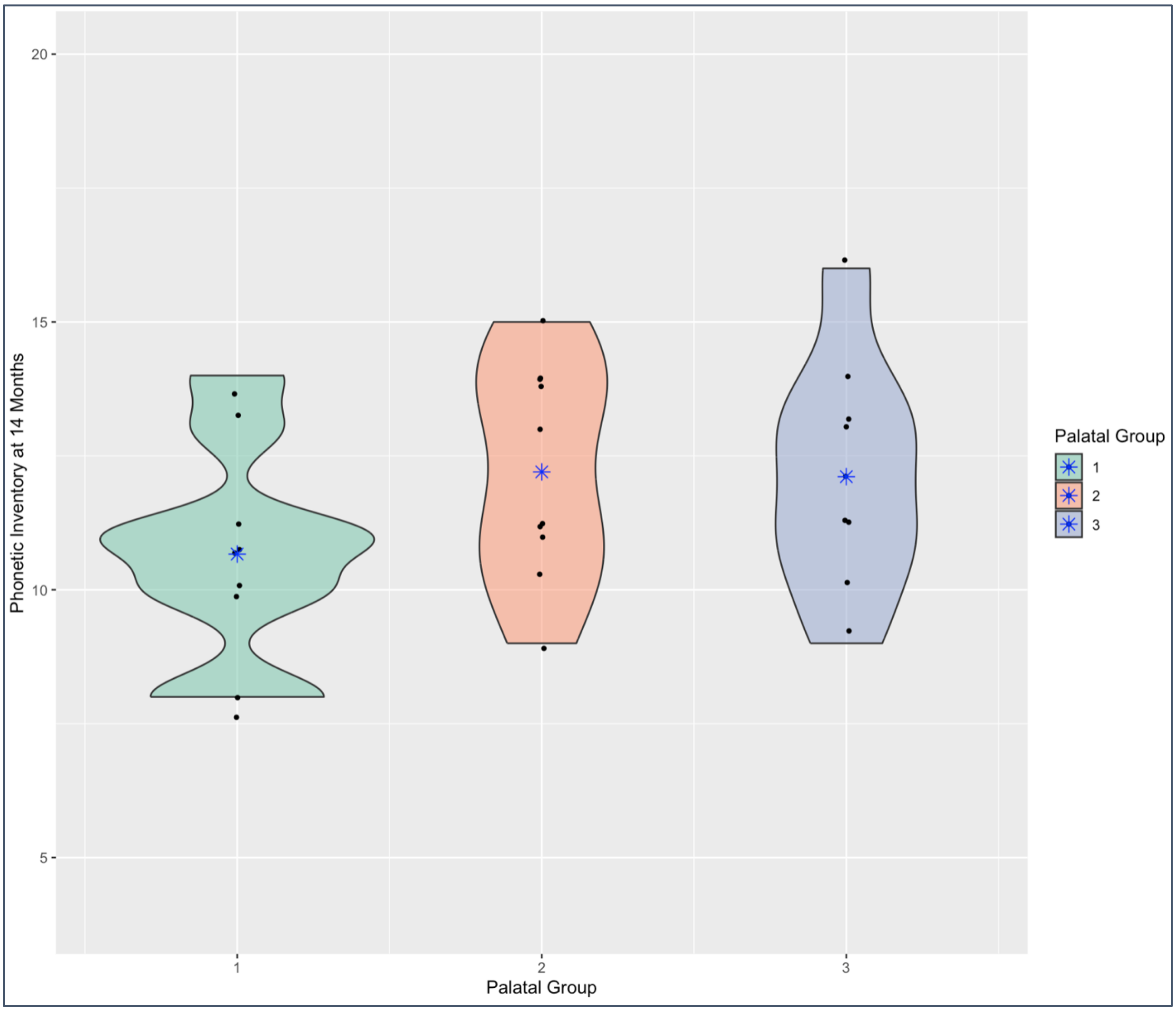



*Figure 5.12: A Multiple Violin Plot of Phonetic Inventories Across Groups at 14 Months.*

Figure 5.12 illustrates the distribution of inventory size across the different palatal age groups. A clear trend was apparent in the phonetic inventory size across palatal ages in the 14-month-olds in which groups 2 and 3 had greater inventory sizes. To test the effect of palatal age on consonant inventory size, a simple linear regression model[9] was used with inventory size as the dependent variable, and chronological age or palatal age as the continuous, independent. The significance threshold was set at .05. While inventory size did not significantly increase with chronological age (coefficient = -0.091, $R^2$ = .004, F(1, 26) = .11, p =74), it did significantly increase with palatal age[10] (coefficient = 0.389, $R^2$ = .18, F(1, 26) = 5.54, p < .03). The regression suggests that palatal age and inventory size were strongly related, therefore, the data presented within palatal groups were in line with this trend. To expand, Group 1 had the lowest mean (and smaller mean and standard deviation values: m = 10.9, sd = 1.9), with a more

[9] Line of code: summary(lm(PInv$FO ~ PInv$CAGE))
[10] Line of code: summary(lm(PInv$FO ~ PInv$CAGE))

balanced collection of values from 4 + months after surgery (shown in groups 2 and 3). Group 1 also had the most variation in inventory size, because the spread of the violin plot was driven up by the smaller and greater extreme values.

To explore whether there was any influence of palatal age on the consistency of consonant production, VMS consonants are explored next. In order to improve interpretability, palatal groups are provided here, too. Table 5.12 presents the number of VMS consonants and the size of emergent consonant inventories documented across the sample of infants to assess whether the maturity of production (or range of stable consonants) patterned with phonetic inventory size.

*Table 5.12: Total Phonetic Inventory Sizes and Number of VMS Consonants at 14 Months*

| Variable/ Infant | Palatal Group | VMS Consonants (Used 50 + Times Per Infant) | Phonetic Inventory (14 months) |
|---|---|---|---|
| 1 | 3 | 6 | 12 |
| 2 | 3 | 2 | 11 |
| 3 | 3 | 4 | 14 |
| 4 | 3 | 8 | 13 |
| 5 | 2 | 6 | 14 |
| 6 | 2 | 5 | 14 |
| 7 | 2 | 3 | 11 |
| 8 | 2 | 1 | 13 |
| 9 | 3 | 1 | 10 |
| 10 | 2 | 5 | 11 |
| 11 | 2 | 4 | 11 |
| 12 | 2 | 2 | 14 |
| 13 | 2 | 2 | 9 |
| 14 | 2 | 5 | 10 |
| 15 | 2 | 1 | 15 |
| 16 | 1 | 5 | 14 |
| 17 | 1 | 7 | 11 |
| 18 | 1 | 2 | 8 |
| 19 | 1 | 3 | 10 |
| 20 | 1 | 6 | 13 |
| 21 | 1 | 3 | 8 |
| 22 | 1 | 3 | 10 |
| 23 | 3 | 1 | 11 |
| 24 | 3 | 7 | 16 |
| 25 | 3 | 3 | 9 |
| 26 | 1 | 2 | 11 |
| 27 | 3 | 7 | 13 |
| 28 | 1 | 2 | 11 |

From an initial view it shows that the infants with only 2 or 3 VMS consonants in their repertoire tended to also have smaller inventory sizes, however infants 8 and 15 show a reversed pattern, which was a more surprising outcome, because they had only one stable consonant but some of the highest number of emergent ones in their inventory (8 and 15 respectively). This pattern was illustrative of a more exploratory process, whereby before sounds are stable in the infants' production output, the range of sounds to emerge was wider, and perhaps therefore less systematic, too. These mixed results require further exploration to understand whether there is a connection between emergent consonant inventory and the number of stable consonants; this is explored in relation to the types of sounds produced later in Section 5.3.4 to indicate whether the VMS measure is beneficial to consider in this population.

### 5.3.2 Phonetic Inventory at 14 Months

Inventory size gave some insight into the number of sounds the ICPs were producing. This section explores the vocalisation data at a narrower level. The phonetic inventory measure gives an indication of the range of sounds an infant can make articulatorily, which would point to greater coordination of their articulators, like tuning an instrument. This section explores phonetic inventories in the sample; it includes an exploration of frequency and regularity of usage in vocalisations. It also gives a detailed picture of how these measures hold across infants, and relate to inventory size, palatal age, and MBL to reveal the consistent phonetic and sequential properties of syllables from ICPs.

Figure 5.13 presents the phonetic distribution from the entire dataset of vocalisations at 14 months in a frequency table, a visualisation method which illustrates frequencies in relation to the size of each quadrilateral. The bar width represents the amount in which a speech sound was produced, the bar height represents the amount of data respective to the given infant and provides ranked frequencies of the whole group trends. The consonant ratios were ordered by the frequency of sounds across the whole sample of vocalisations and were ranked from most common (on the left) to the least common (on the right). To evaluate whether any noticeable trends were clearer due to palatal age, the above data were subsetted by palatal group.

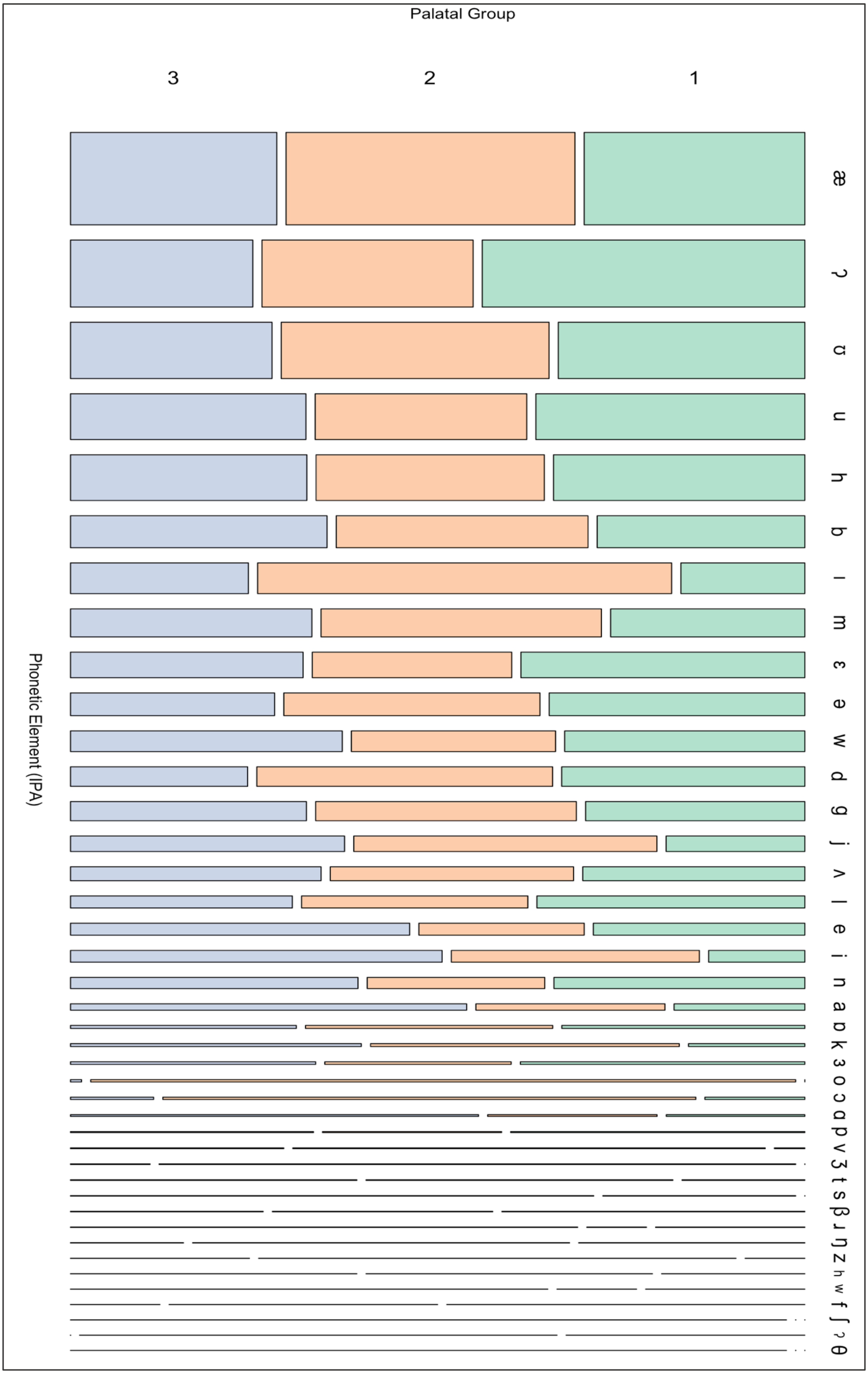

Palatal Group
3
2
1
Phonetic Element (IPA)

*Figure 5.13: A Stacked Frequency Plot of All Phonetic Elements Across Palatal Group*

There were some common sounds across all 28 infants, glottals were most frequently used and voiced supraglottals were second. Alongside consonants, the most frequent vowels were close, back, and open, front categories, proving to be far more common than central vowels. This reveals that the mode vowels had a higher degree of contrast to each other. The finding also reveals more contrast to the most common consonant-like elements because glottals are articulated furthest away from the vowel space than any other of the consonants in English, and glottals were most common across the groups and in all infant data.

Figure 5.13 also illustrates some differences between palatal groups, though they were relatively balanced. The first difference was that there were fewer glottal stops produced by the oldest palatal ages, while these were dominant in Group 1. There was a mostly balanced use of vowels across all three palatal groups, the only exceptions to this pattern were /ɪ/, which was more dominant in Group 2, and /e/ and /æ/ which was more dominant in Group 3. Overall, no striking discrepancies in phonetic repertoire were evident from Figure 5.13, p. 152, therefore the analysis below is broken down further into consonantal and vocalic elements; this is expanded on in Section 5.3.3.

#### *5.3.2.1 14 Month Phonetic Repertoire: Vocalic Elements*

All vocalic segments produced in the data were also subdivided into palatal groups to assess whether vowel use varied in line with palatal age. Figure 5.14 provides stacked bars (where each vowel category is visualised in separate bars for each palatal group) to compare the frequencies in one place. Each colour represents the respective group (see the legend).

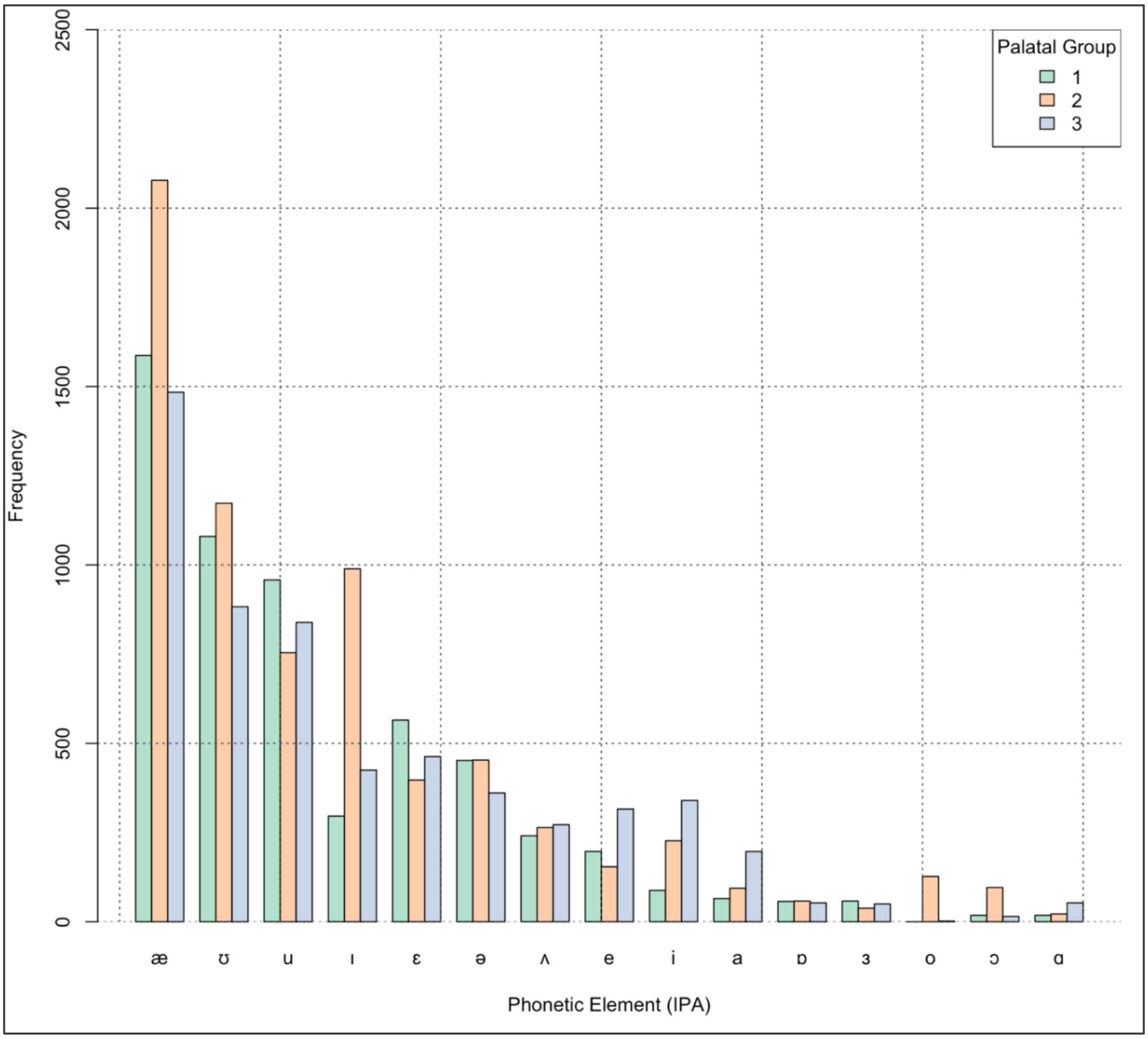



*Figure 5.14: A Bar Plot of Vowel Frequency Across Palatal Groups*

As such, Figure 5.14 again shows that the most common vowels had a high contrast in placement to each other (open, front /æ/ was most common, back, close vowels /ʊ/ and /u/ being second and third, then close, front vowel /ɪ/ and open-mid, front /ɛ/), all of which were more common than the mid-central vowel, or more centralised vowels generally. This finding opposed the hypothesised frequencies as mid vowels were less common and instead indicated that vowels tended to be at the extremes in the oral cavity (i.e., at the corners of the vowel chart). To add, the three low frequency vowels (/e/, /i/, /a/) were mainly produced by Group 3, and while the differences were not striking, according to Figure 5.14 the presence of these vowels was spread across infants from the two older palatal groups.

There was a similar trend for two of the rarest vowels, which was dominated by Group 2 (these were back close-mid /o/ and back open mid /ɔ/). It could be that both of the vocalic realisations had the same target, but a difference in the execution of the production. However, this pattern was attributed to one individual's vocal repertoire, rather than a group trend, and was therefore more reflective of individual variation, whereby infants favoured different vowels over others. The two combinations in question concern the mid vowel placement, which was relatively rare in comparison to the hypothesised outcomes. It might be that the coordination of mid vowels is more challenging for the ICPs, given its location in the mouth.

For now, the individual variation across all the vocalic elements will be considered in relation to the transcribed symbol (e.g., without being assigned broad categories) to assess the discrepancies of vowel production within individuals rather than within the palatal groups. Figure 5.15 visualises the spread of frequencies across each of the infants (as marked by different colours) and provides an indication of the individual variation across the data. The vocalic elements are given along the x-axis and the cumulative frequency is marked on the y-axis.

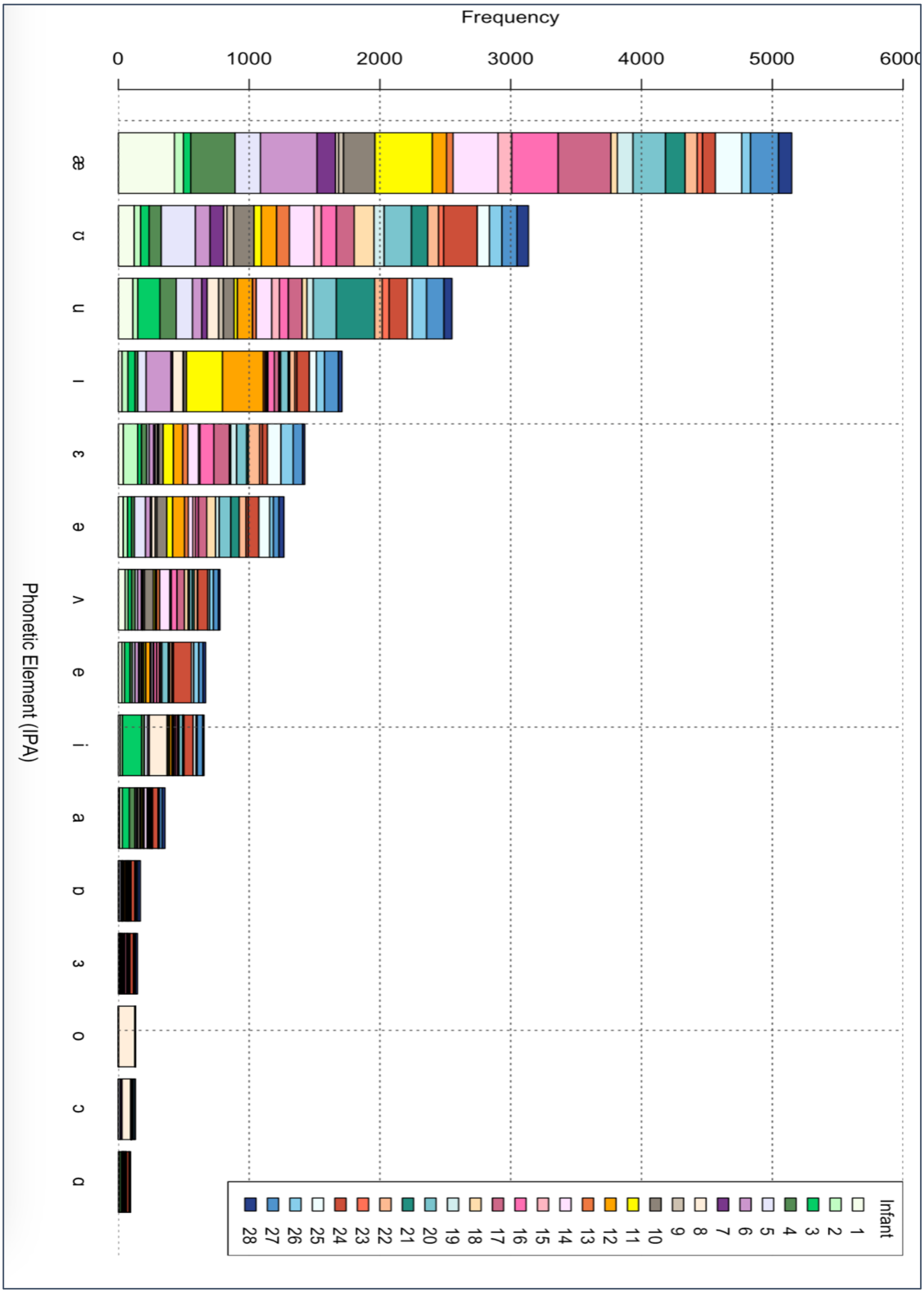



*Figure 5.15: A Bar Plot of Vowel Frequencies Across Infants*

Immediately, Figure 5.15 illustrates some individual variation in the frequency of vowels usage, highlighting infants 1, 4, 6, 11, 12, 14, 17, 21, 24, and 27 to dominate the production frequencies. From these infants' data, there appears to be 1 or 2 mode vowels per individual, most of these were in favour of the sample-wide mode vowel (that is /ae/), but infants 4 and 24 also had /ʊ/; infant 21 had /u/; and infants 11 and 12 had /ɪ/. These modal vowels point to some more individually grounded preference patterns, as they were not securely dictated by palatal group.

Overall, the figure's modal vowels across the sample were /ae/, /ʊ/, and /u/, compared to those illustrated by Figure 5.12 and Figure 5.14 above, but are presented more clearly on an infant-by-infant basis here. These vowels illustrate a consistent preference across all infants, particularly for the first 3 columns, though it is unclear whether /ʊ/ and /u/ (and indeed /e/ and /ɛ/ above) were being used interchangeably or whether infants were already discriminating between the acoustic contrast here. What is undeniable though, is that /ae/ and /ʊ/ or /u/ both contrast in height and backness from each other, which highlights a trend in acoustic and articulatory contrast in the most frequent vocalic uses, perhaps because these features may be more perceptually and motorically salient to the infants. Figure 5.15 also illustrates that /ɑ/, /ɔ/, /o/, /ɜ/, and /ɒ/ were the rarest vowels, and 4/5 of these were (close-mid to open) back vowels, which illustrates an absence of these vowels across the entire sample of infants. These patterns go against the expectations from Hypothesis 2 because the mid vowels were much less frequent than the other mode vowels. This contrast is considered at the end of Section 6.1.2.

#### *5.3.2.2 14 Month Phonetic Repertoire: Consonantal Elements*

The phonetic repertoire is also analysed in relation to consonant-like components first in the frequency across the sample, then across groups. Figure 5.12 visualised the results earlier, highlighting that, overall, glottal (stops and fricative) articulations were most frequent across the whole sample. Second to these were bilabial stops, nasal stops, and then the labial-velar approximant, indicating a pattern for frontal articulations with more visual cues (i.e., one can see the sound being produced during articulation, for example through lip movements) being next most common across the sample. The frequency of consonant usage was more mixed across individuals than with vowels; /b/ and /m/ were the only non-glottal sounds that all infants in the sample produced. The frequency of these two supraglottal stops after the two most frequent glottals was evident and more reflective of typical emergent babble consonants, as these tend to be early acquired articulations in typically developing populations (Menn and Vihman, 2011).

Next, these production characteristics will be considered against palatal age, to examine whether this variable influenced the data. In Figure 5.16, the consonant frequencies (y-axis) are illustrated across the coloured palatal groups (x-axis). The smaller values are given in an additional window, with a much smaller range of frequencies to ensure that the smaller values are legible.

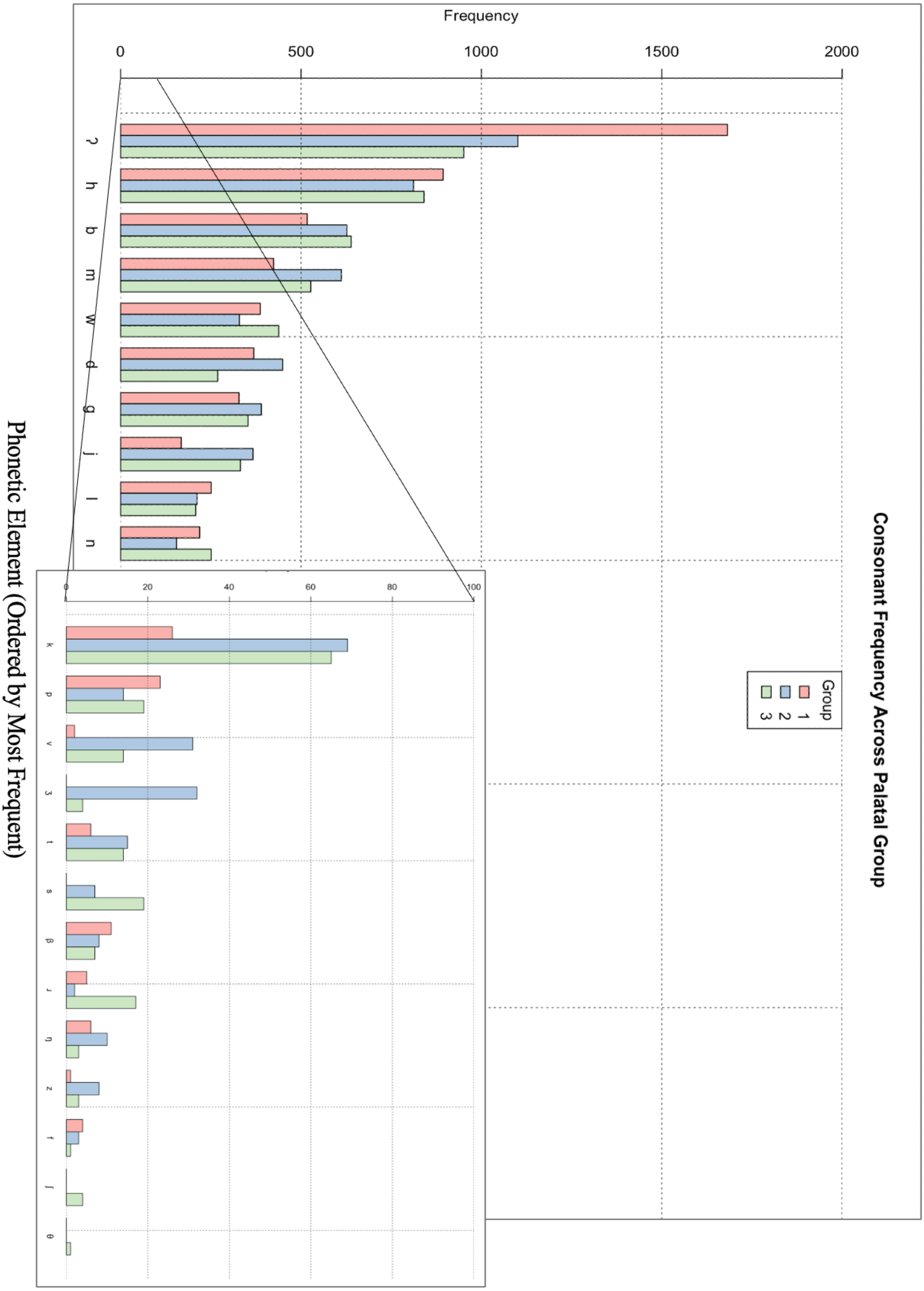



*Figure 5.16: A Stacked Bar Plot of Consonant Frequencies Across Palatal Group*

Figure 5.16 shows that the most common consonant elements (up to /v/ where colours are still likely to be visible in the bars) were composed of supraglottal stops followed by approximants, nasals, and finally fricatives; meaning that across each of the palatal groups, stops were visibly dominant over other manners of articulation, a pattern which is also reflective of typically developing infants at this stage. As is also visible in Figure 5.16, the most use of glottal stops was in earlier palatal ages, but glottal fricative frequencies were much more balanced across groups. It also illustrates /d/, /l/, /n/ (tip of the tongue articulations) are all amongst the 8 most frequent supra-glottal consonants, which illustrates that productions requiring the coordination of other parts of the tongue were rarer, and rarer consistently across palatal groups. This in itself did not stand out from the typical patterns of sounds in canonical babble or vocal play (McLeod and Crowe, 2018); however, some coronal sounds appear to be more rare, perhaps indicative of a delay to the typical timeline in the gestures that emerge soonest.

When the consonant frequencies are compared to those that naturally occur, the first three most common CP sounds do not align with any of the most common consonants (Wells, 2000). The closest resemblance is in the frequency of /m/ which is the second most common consonant in English. The next includes /l/ and then later /d/, indicating the most frequent consonants (similarly to the most frequent vowels) do not directly reflect the most common English sounds.

Together, the consonant patterns reflect a mix of expectations. The placement of sounds alone cannot explain the differences in high and low frequency sounds given that palatal sounds, including alveolar /d/ and approximants /j/ and /l/, were relatively common, and there was particularly high presence of the palatal sound /j/. The presence of stops was lower than in typical babble composition (see 2.2.2), and therefore, by contrast, the gesture and part of the tongue used for sounds seemed to play more of a role. Fricatives and approximants tend to emerge in older palatal ages, which reflects the typical orders of acquisition, however the absence of high-pressure fricatives (or continuants), appears to be a more evident feature in relation to CP vocal characteristics.

To continue, the bilabial stop /b/ and the nasal, bilabial stop /m/ also were evenly spread across groups 2 and 3 with a contrast to lower occurrences by Group 1 in /j/ and /k/. The two minor exceptions to this trend were for /w/ and /n/, where articulations across the groups was more mixed. To assess the impact of individual variation on consonant production, Figure 5.17 illustrates the data patterns across each infant.

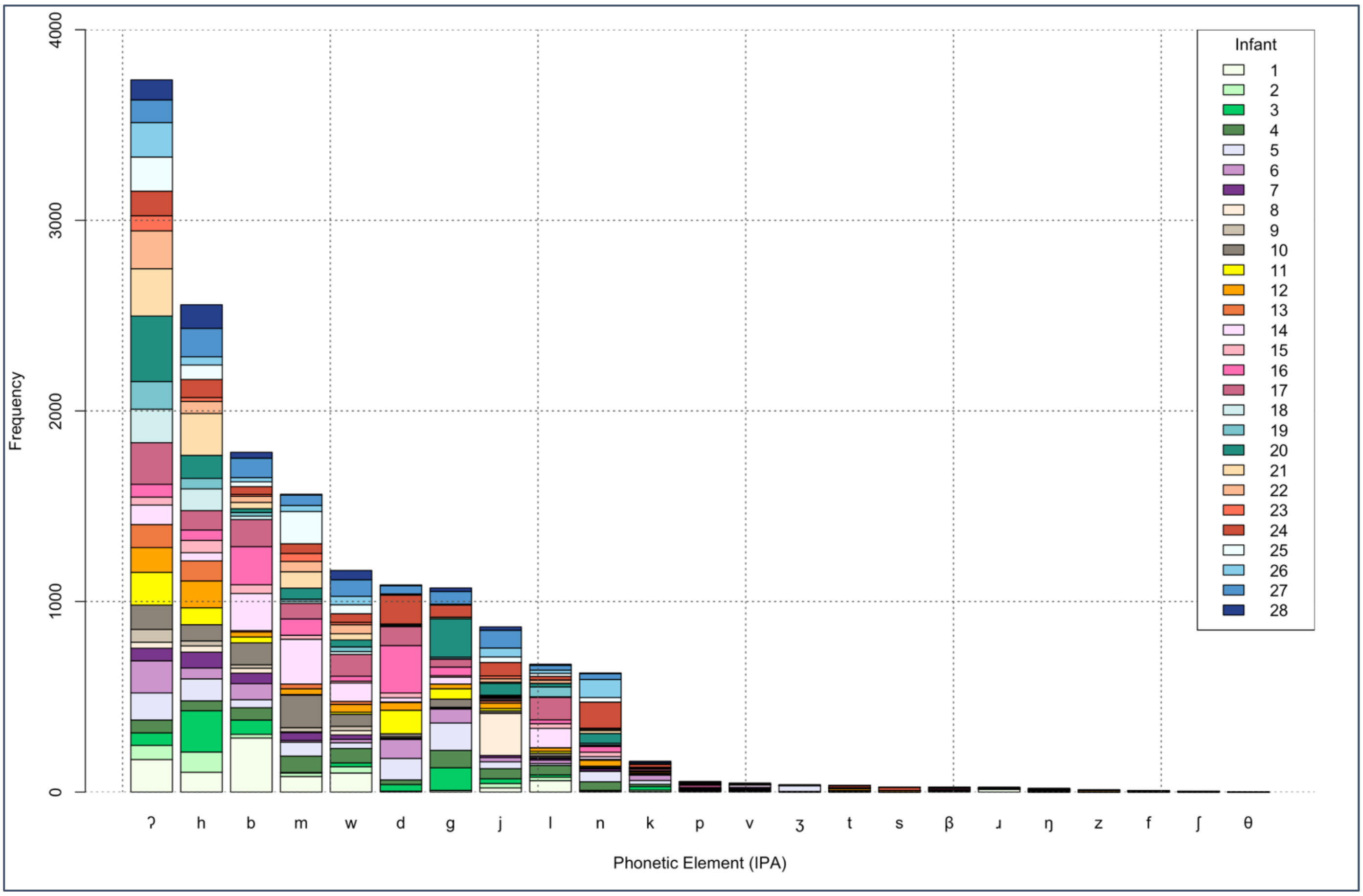



*Figure 5.17: A Stacked Bar Plot of Consonant Frequencies Across Infants*

It illustrates that instances of individual variation were a norm, such as /b/, which was more frequent than glottals for infants 2, 15, 18, and 19, and /m/, which was more frequent than glottals for infants 11, 15, and 28. Therefore Figure 5.17 captures the spread of data across the individual infants, revealing within-participant patterns that palatal group alone did not capture. It did also confirm some cross-group trends, the first clear—and unsurprising—pattern being that voiceless tokens were rarer or absent in many infants' repertoire, as they are later acquired along the typical trajectory (Eilers et al., 1984; Vihman et al., 1985). Another less frequent consonant pattern (excluding /h/) was across fricatives, which contrasts to the hypothesised outcome that infants would have fewer stops, but more liquids and glottals. In fact, while the expectations from H2 were partially met by the presence of liquids /w/, /j/, and /l/, oral fricatives were absent from the main group trend.

### *5.3.2.3 Consonant Acquisition and Vocal Motor Schemes*

This section analyses the consonants acquired, as defined by Hardin-Jones et al. (2023) as 2 + different uses in naturalistic production data and by the vocal motor schemes acquired, as defined by Vihman, 2016. It will present the ICPs' consonant frequencies among a series of tables and figures to present how the findings varied across the groups and the infants and also how the data compared to Hardin-Jones et al. (2023)' on CLP children post-repair.

The next two tables contain the percentage of participants who produced each sound twice or more in the data, with the speech sound (or gesture type) on the left and the corresponding percentage of infants that acquired it on the right. Table 5.13 illustrates the collection of supra-glottal consonants acquired and it shows that only 4 sounds were produced twice or more by all 28 infants: /j/, /m/, /w/, and /b/.

*Table 5.13: Percentage of Acquired Consonants Across Infants*

| *Consonant* | **Percentage of Sample** | **Number of Infants** |
|---|---|---|
| *j* | 100% | 28 |
| *m* | 100% | 28 |
| *w* | 100% | 28 |
| *b* | 100% | 28 |
| *l* | 96% | 27 |
| *n* | 93% | 26 |
| *d* | 86% | 24 |
| *g* | 82.1% | 23 |
| *k* | 53.6% | 15 |
| *p* | 53.6% | 15 |
| *v* | 32.1% | 9 |
| *t* | 21.4% | 6 |
| *ŋ* | 21.4% | 6 |
| *ɹ* | 14.3% | 4 |
| *ʒ* | 10.7% | 3 |
| *β* | 7.1% | 2 |
| *f* | 7.1% | 2 |
| *s* | 7.1% | 2 |
| *z* | 7.1% | 2 |
| *ʃ* | 3.6% | 1 |

Hypothesis Two (H2) expected that the most common consonants would be glottals and liquids, with potentially more nasals, too. While two of the mode consonants acquired were liquid gestures, two of them were stops, together presenting a mixed response to the hypothesis. The shared phonetic element across the 8 most acquired sounds was voicing, and 82.1% or more of the sample acquired these voiced sounds.

More stops were present than was anticipated by H2; even though stops are typically earliest to emerge and common in first words, the literature showed ICPs to lack pressure consonants post repair. The details of these occurrences are therefore explored next. When reflecting on the infants' stop repertoire, it is important to consider the percentage of the 6 oral stops acquired too, rather than only the exact consonant frequencies from all gestures, because they are a focus in typical babble research and also because coordinating the pressure to produce oral stops may be less challenging for ICPs than alveolar ones. Furthermore, the vocal data can be viewed in a more standardised way, that categorises the stops (/p/, /b/, /t/, /d/, /k/, /g/) relative to individual infants, in this way the results were focused on the gesture category, rather than exact IPA symbols, all at once.

*Table 5.14: Total Number of Different Oral Stops in Consonant Inventories*

| | **% of participants** | **Number of Infants** |
|---|---|---|
| 0 stops | 0% | 0 |
| 1 stop | 3.6% | 1 |
| 2 stops | 7.1% | 2 |
| 3 stops | 28.6% | 8 |
| 4 stops | 25% | 7 |
| 5 stops | 21.4% | 6 |
| 6 stops | 14.3% | 4 |
| **Total** | 100% | 28 |

Table 5.14 gives these figures and illustrates that most infants had 3 stops within their *acquired* repertoire (i.e., 2 + uses across the hour), followed by 4, and then 5, meaning that most infants were producing these amounts of stops. It might be that place of articulation plays a role in these results, and, as such, the stop placements were considered. Table 5.15 provides the data from all 28 ICPs in the current study, the percentages for oral stop acquisition were combined for voicing types because no voicing distinction is made in the measures of harmony or babble level. It also contains comparable data from Hardin-Jones et al. (2023), which will be revisited in the Discussion.

*Table 5.15: Total Stops Acquired with No Voicing Contrast*

| | % in Current Sample | **% in Hardin-Jones et al. 2023** |
|---|---|---|
| b | 76.8 | 70 |
| g | 67.8 | 64 |
| d | 53.7 | 70 |

Therefore, the percentages represent /b/ and /p/ collated into a mean percentage. It may be that these patterns signify off-target attempts, though this interpretation is challenging. The unsurprising lower presence of alveolars also contrasts to the emergent sounds of typical canonical babble, and most often before velars (Elbers and Ton, 1985, Eilers et al., 1984, Macken and Barton 1978, 1980). Overall, there were similarities across CP and CLP acquisition of these sounds, enforcing reliability in different data methodologies, however, as was reviewed in Section 2, the impact of these acquired consonants was not sufficient alone to understand vocal development for ICPs.

Therefore, to explore consonant repertoire in further detail, the established measure of VMS that is used in typical research next assesses the stability of productions. As a reminder, the ICPs are described to have VMS when they produce a consonant 50 + times in one hour, as defined in Section 4.3.2.4. Figure 5.18 first presents the frequency of consonant productions across all palatal groups, and this spread can then be compared against the distribution of stable, VMS consonant frequency in Figure 5.19.

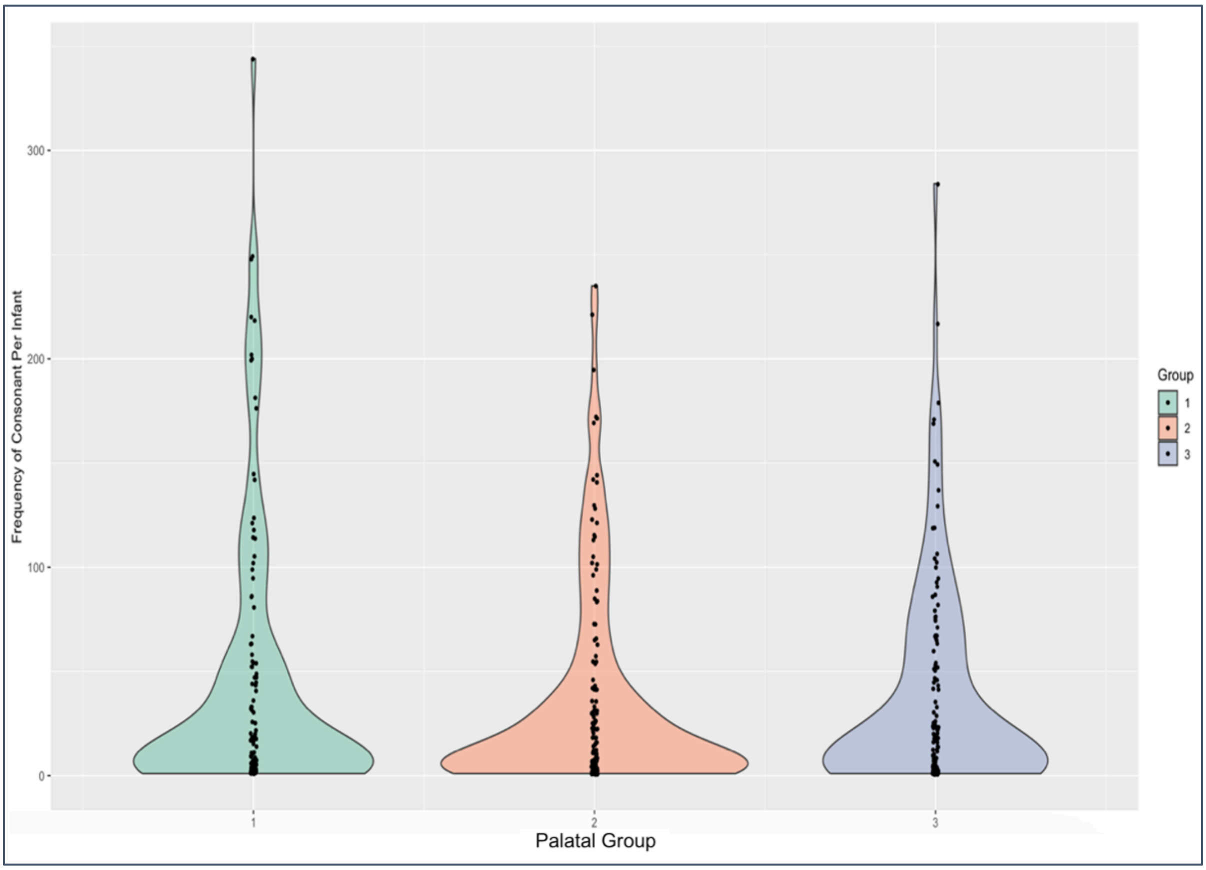



*Figure 5.18: A Multiple Violin Plot of Consonant Frequencies for Each Infant*

The violin plots in Figure 5.18 illustrate how frequent each consonant was, with a dot representing each sound's frequency per infant. The highest number of different consonant types was in Group 2 because the width of the orange plot was widest, however it also shows that in Group 1, consonant types that were produced, had higher frequencies. Group 3 appears somewhere between these two distributions, however this pattern changes when the data are only presented for stable, repeated consonant productions below.

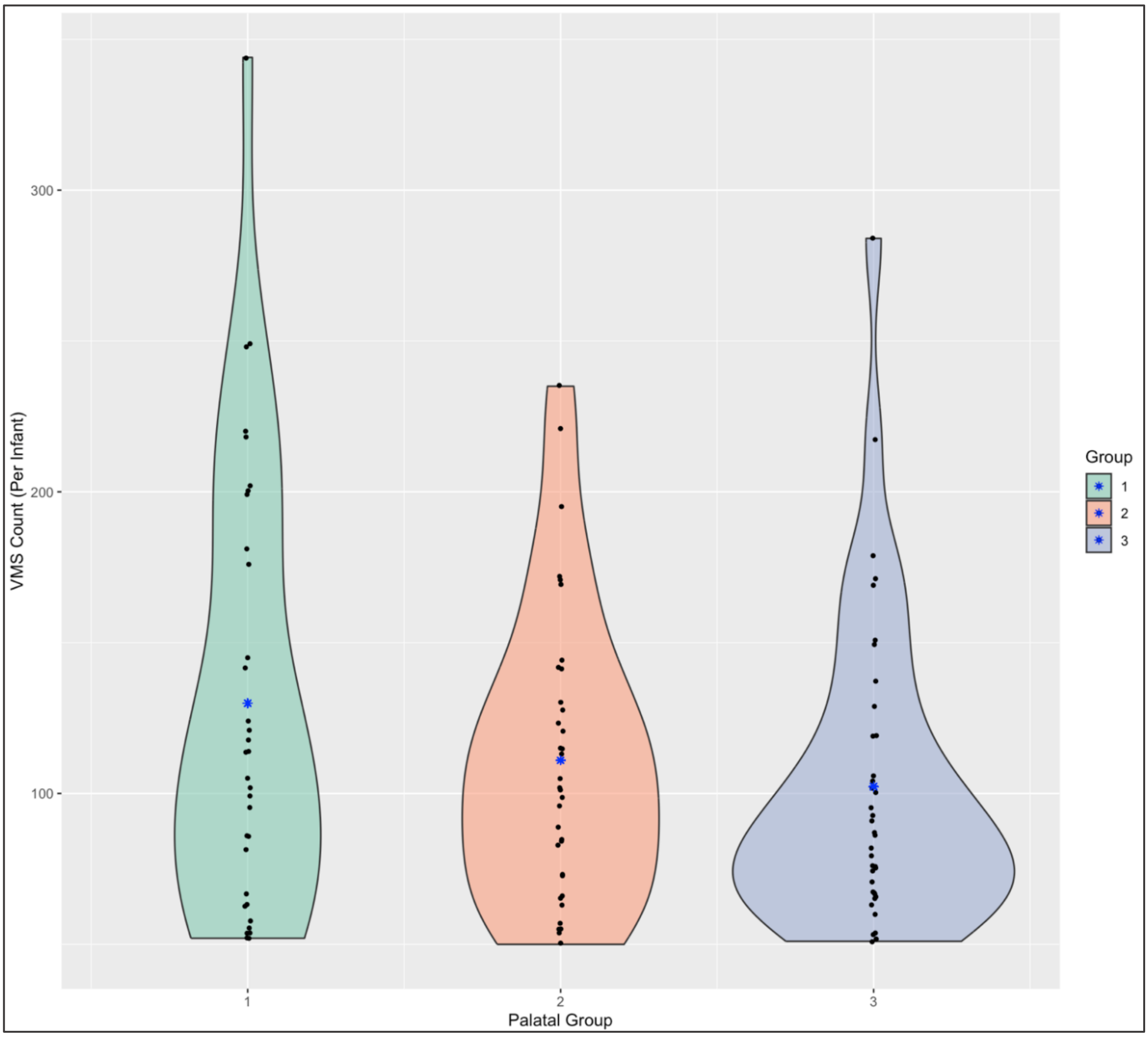



*Figure 5.19: A Multiple Violin Plot of VMS Count Across Palatal Group*

Figure 5.19 shows that the highest frequency of VMS consonants was present in the youngest palatal group, even though every group had VMS. That is, no one group used any 1 VMS consonant exclusively. These data exemplify more stable use of more consonant types in older palatal ages, while this contrast was only slight, the trend across each palatal age was clear. Figure 5.20 expands on the findings by including the VMS consonant types produced by infants across palatal group.

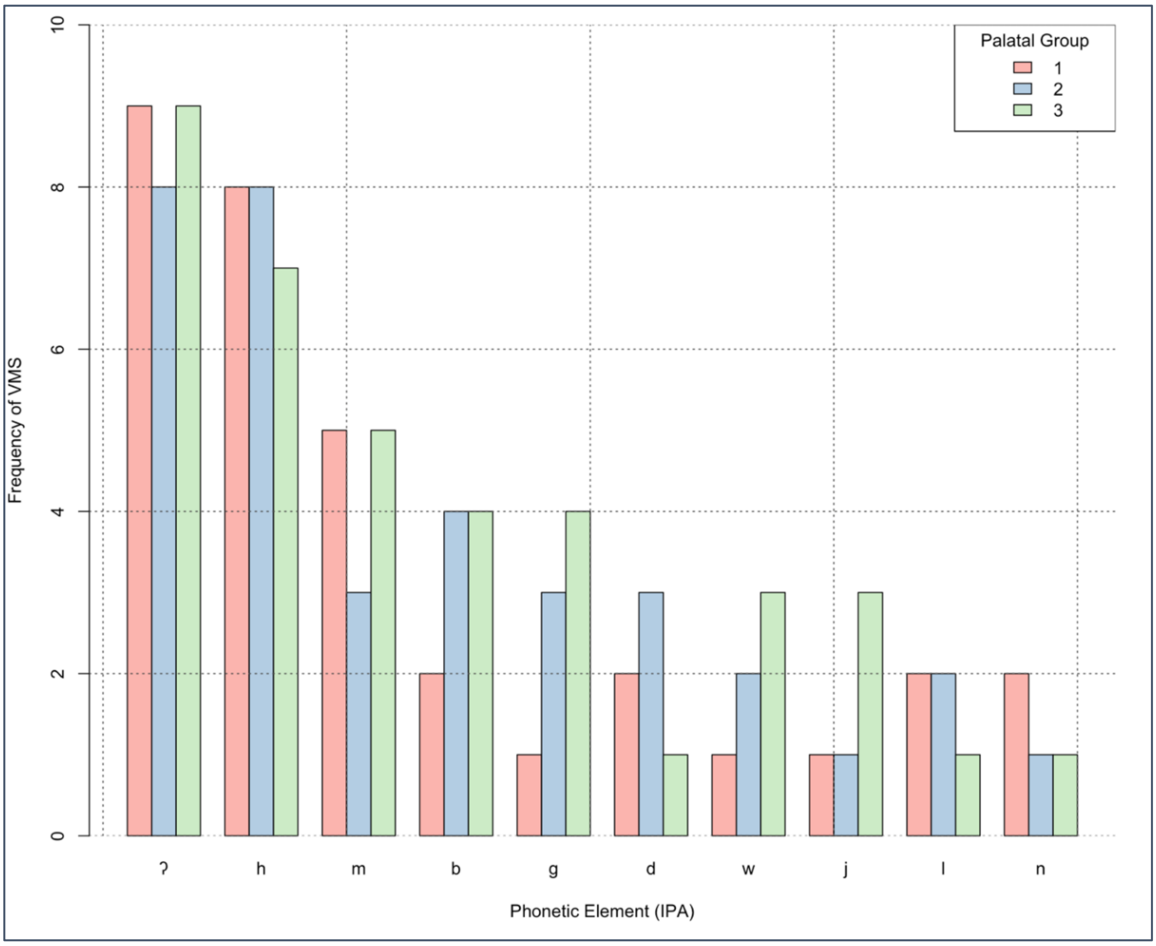



*Figure 5.20: A Stacked Bar Plot of VMS Types and Frequencies Across Palatal Group*

It immediately highlights that, with the exception of glottals, all VMS consonants were voiced, and of the supraglottal (true consonant) articulations, /m/ was the mode production. This outcome was followed by the bilabial stop, indicating the most common supraglottal articulations to be voiced bilabials, which are both visible gestures during production. Following this, oral stops were the most frequent manner of articulation, followed by approximants and then nasal stops. No fricatives were present in VMS consonants and other than glottals, no voiceless articulations were produced frequently enough to meet the VMS criteria.

There were a few minor differences within palatal groups. For example, Group 3, has the same frequency as Group 1 for /m/ and the same as Group 2 for /b/. Group 3 had more use of /g/ than the other two groups, but a lower frequency of /d/ whereas Group 2 used more /d/ articulations than other groups. Given that this VMS consonant is an alveolar articulation, it was expected to be rarer across vocalisations, and as such it marks a clear difference to the typical vocal trajectory. To add, /d/ was produced at least 600 times across the whole dataset, equating to 50 + times for 6 infants (which equates to 20% of the sample). Lastly, Group 1 had more /n/ and /m/ VMS consonants, both of which were proportionate to Group 3, but they had fewer supraglottal stops (/g/ and /d/) and liquids (/w/ and /j/) in their VMS, indicating a lower range of VMS consonant types in the youngest palatal ages. In summary, there was a relatively balanced distribution across groups in the use of glottals, but more contrast across the other consonant types that could be categorised as VMSs. Overall, following glottals, the mode manners of articulation were nasal stops, followed by voiced (bilabial, velar, and alveolar) stops, then liquids.

Figure 5.21 presents how the range of VMS was distributed across individuals and addresses any preference patterns. It contains the cumulative frequency of VMS sounds on the y-axis and the phonetic segment on the x-axis, with each colour representing each infant.

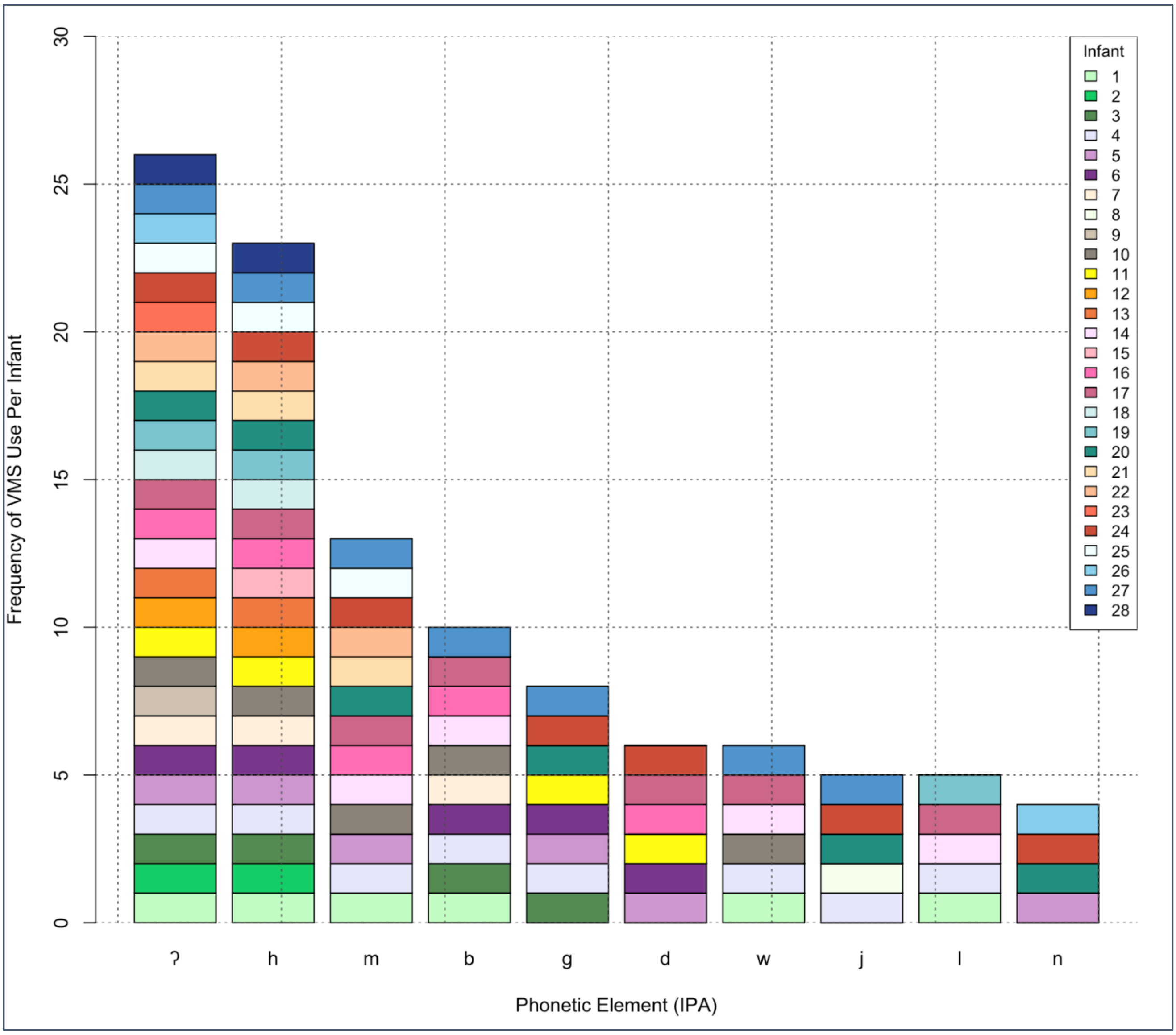



*Figure 5.21: A Stacked Bar Plot of VMS Consonants Across Infants*

The figure shows that some infants (2, 10, 12, 13, 15, 18, and 28) only had glottals in their VMS repertoire illustrating consistency with earlier data visualisations and the known substitution patterns of ICPs (p.c. with Lucy Southby, 2023). Furthermore, the glottal stop was the mode VMS across all infants (N = 26), meaning that all but 2 of the sample had glottal VMSs. To relate to the earlier findings (in Figure 5.17), it is important to note that glottals were also present in the vocalisations of the other two infants but not quite as frequently. This pattern may reflect such glottals being used in substitution of the sounds that typically emerge earlier (e.g., oral stops), a concept expanded on in the Discussion. It might be that a different sound is being targeted in these instances, though it is challenging to interpret this reason. Additionally, it could even be that vowel-initial vocalisations were supported by glottal friction at the onset (glottal reinforcement), which would illustrate a pattern of epenthesis or substitution using glottals over sounds which rely on oral pressure. 22 out of the 28 infants in the sample had at least one supraglottal consonant that was consistently produced in a naturalistic context. The sequencing of phonetic sounds—that is, where in the vocalisation/across syllable boundaries sounds were used—is explored in Analysis III and will expand on this pattern with examples.

Of the supraglottal sounds, 13 infants had /m/ in their stable production repertoire, revealing the bilabial nasal to be the most frequent, non-glottal sound, as was hinted earlier by Figure 5.20. This mode VMS was followed by /b/, which 10 infants produced consistently. However, the velar stop /g/ was third most frequent, which, unlike /m/ and /b/, did not have as much visual information available, because it is a more backed placement when compared to the bilabial articulations.

Following /g/ there was a more balanced spread in VMS frequency across /d/, /w/, for /j/, /l/, and /n/. The only outlier in VMS repertoire was infant 9, who had the lowest acquisition/emergence of supraglottal and glottal consonants. Lastly, the low frequency sounds (see Figure 5.20 for a recap) were voiceless consonants and all fricatives, and the least frequent fricative was /ʒ/, which was produced by infants 6 and 30 and is reflective of a sound that is not common in infant speech or adult production (Stark, 1980) or the natural and ambient language frequencies and it would not be a target sound at this age.

Figure 5.22 helps the reader assess whether the number of VMS within the infants' repertoire was related to their palatal group. This figure (along with the following ones) illustrates a scatterplot with a linear regression line (given in blue), which was plotted to represent the statistical relationship between the frequency of most consistent consonants (y-axis) across palatal groups (x-axis). The grey region indicates the 95% confidence intervals around the mean values.

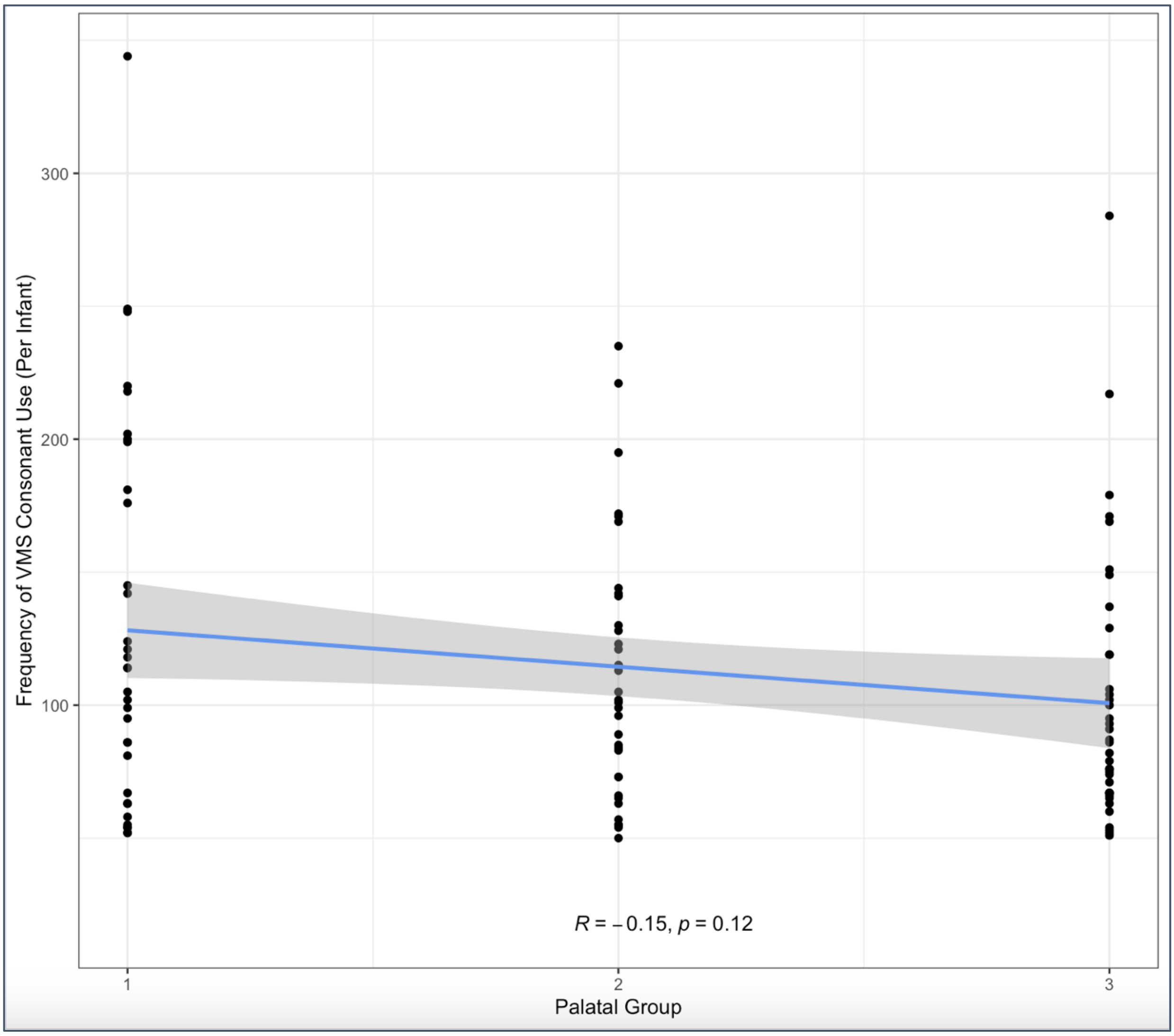



*Figure 5.22: A Smooth Scatterplot of VMS Consonant Frequency Across Group*

Given that palatal groups were ordinal data, a spearman correlation test was used to test the relationship between palatal group and VMS count. With the significance threshold set at .05, the test gave a low, but non-significant result (R(26) = -0.15, $p$ = .12). The graph clearly illustrates that palatal age and frequency of VMS consonants were related, in that as palatal age increased, the overall frequency of VMS use decreased. Such a result means that the older palatal groups were producing more consonants with lower frequencies than Group 1.

VMS use appeared stable across the group, therefore the frequency of true VMS consonants within the phonetic repertoire across the palatal age as a continuous variable may be even more enlightening. It could illustrate any diversions from the palatal group trends

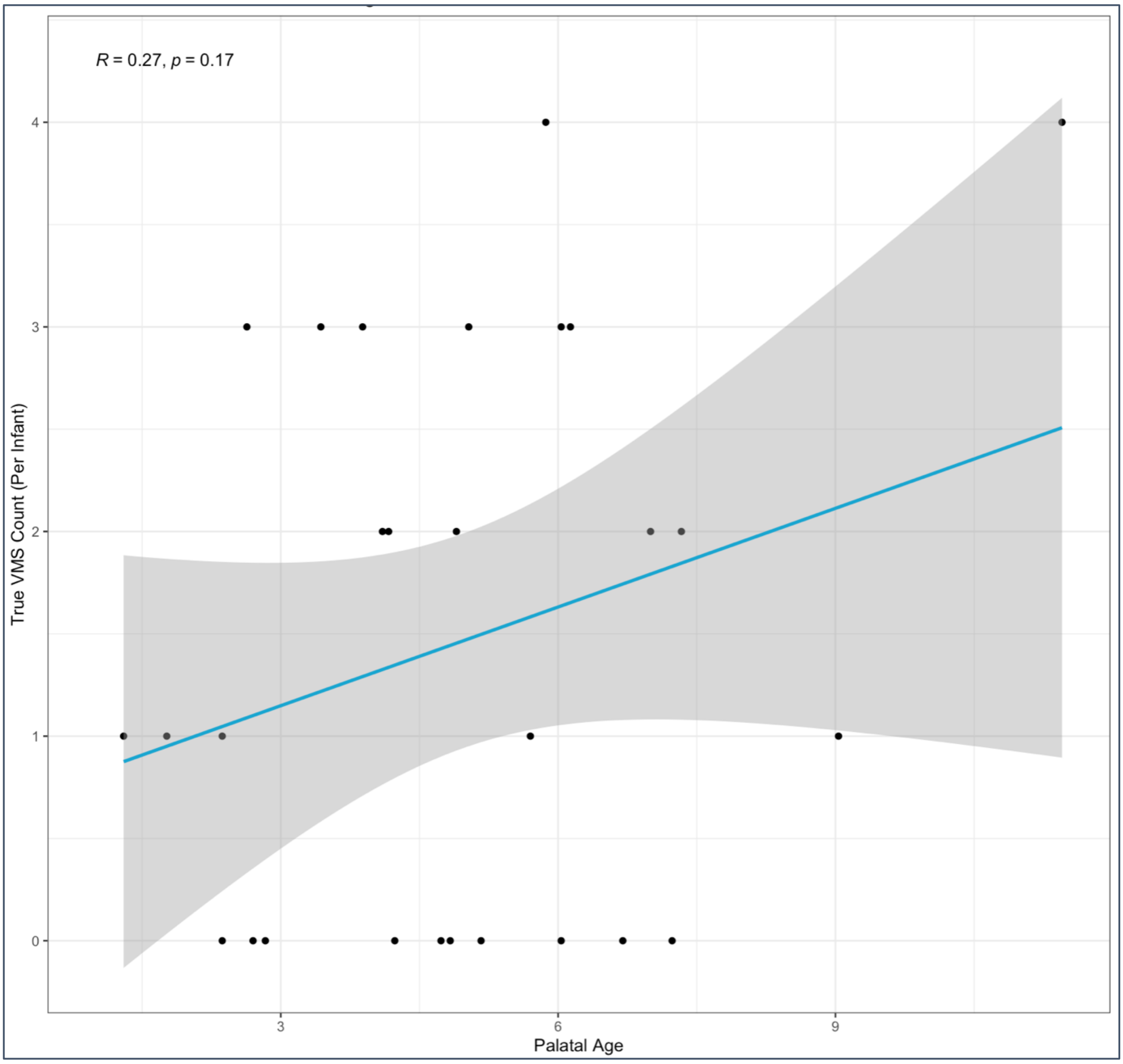



*Figure 5.23: A Smooth Scatterplot of True VMS Across Palatal Age*

Figure 5.23 illustrates the relationship between palatal age and true VMS frequency. While the correlation coefficient result did not reveal a close relationship and was not significant (R(26) = .27, *p* = .17), it did show a positive trend between exact palatal age and true VMS acquisition at 14 months, as is illustrative from the blue regression line. It also revealed reasonable variation in the results across palatal age, but still points to a relationship between the two variables in question. The results indicate that the relationship between vocal rehearsal opportunities and the production of high pressure, oral sounds may be more crucial to practise in infancy than has been addressed by most research. This point is also responded to in Section 6.1.1.

### 5.3.3 Mean Babble Level and Phonetic Segments

MBL was discussed in some detail earlier (see Section 4.2.5), but here it is considered directly in relation to the vocal count and phonetic inventory size along with the VMS results, to assess H1. H1 predicted that the range of consonants in productions would depend on the stage of vocal development they were in but will be smaller than typical regardless.

#### *5.3.3.1 Mean Babble Level and Inventory Size at 14 Months*

To test the relationship between the stage of vocalisation (MBL) and the number of consonants in the infants' repertoire (inventory size) at 14 months, a correlation and linear regression test was run. As above, vocal count and MBL were both normally distributed, therefore Pearson's correlation was used. Figure 5.24 illustrates that while there was a positive trend between the two variables, it was marginally significant (R = .36, p = 0.058).

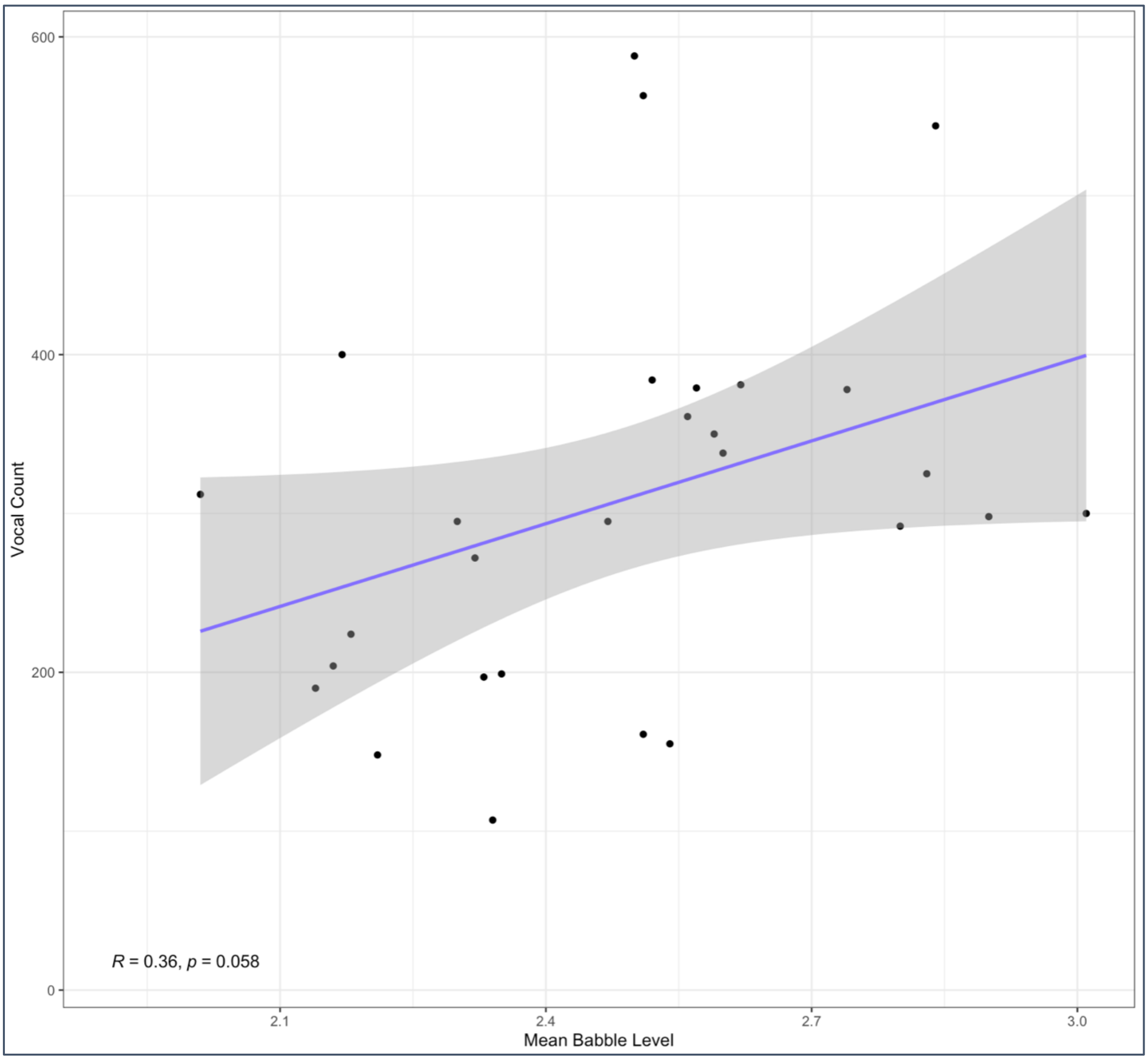



*Figure 5.24: A Smooth Scatterplot of Mean Babble Level and Vocal Count*

The results here highlight that vocal count closely relates to babbling proficiency, but the relationship was not completely robust as it was slightly over the significance threshold ($R(26) = .36$, $p = .058$), even with the small sample size. What is clear from these findings, is that the more vocal infants also had higher MBL scores, suggesting that vocal count could be a valuable measure for vocalisation assessment. While we know from the literature review that ICPs do not vocalise significantly less than their typical peers, this is a finding which could be of value to parents and therapists of infants who were exhibiting moderate to extreme patterns of delay. This relationship between vocal count and mean speech-likeness of productions could serve as a source of consideration for speech and language therapists, given that the more an infant vocalised, the more likely it was to represent typical babble.

#### *5.3.3.2 Mean Babble Level and Consonant Inventories*

Next, the relationship between MBL is explored against the number of emergent consonants within the infants' repertoire. If these two dependent variables were significantly related, it would indicate results in favour of research H1. The 14-month consonant inventory measures captured *emergent* consonants in the data (i.e., consonants that occurred once or more per infant), however the majority of production instances occurred 3 or more times. There were a total of 395 uses of different consonants and 303 of them included (acquired) consonants that were produced 3 + times per infant, meaning that the 14-month inventories were more illustrative of emergent gestures than acquired ones. This result indicated that most of the produced sounds were more established than exploratory ones.

A normality test showed that the 14-month inventories ($W = .94$, $p = .12$) had a sufficient normal distribution (along with MBL means as given in Section 5.3.3), making the two variables suitable for Pearson's R correlation to quantify the nature of the relationship.

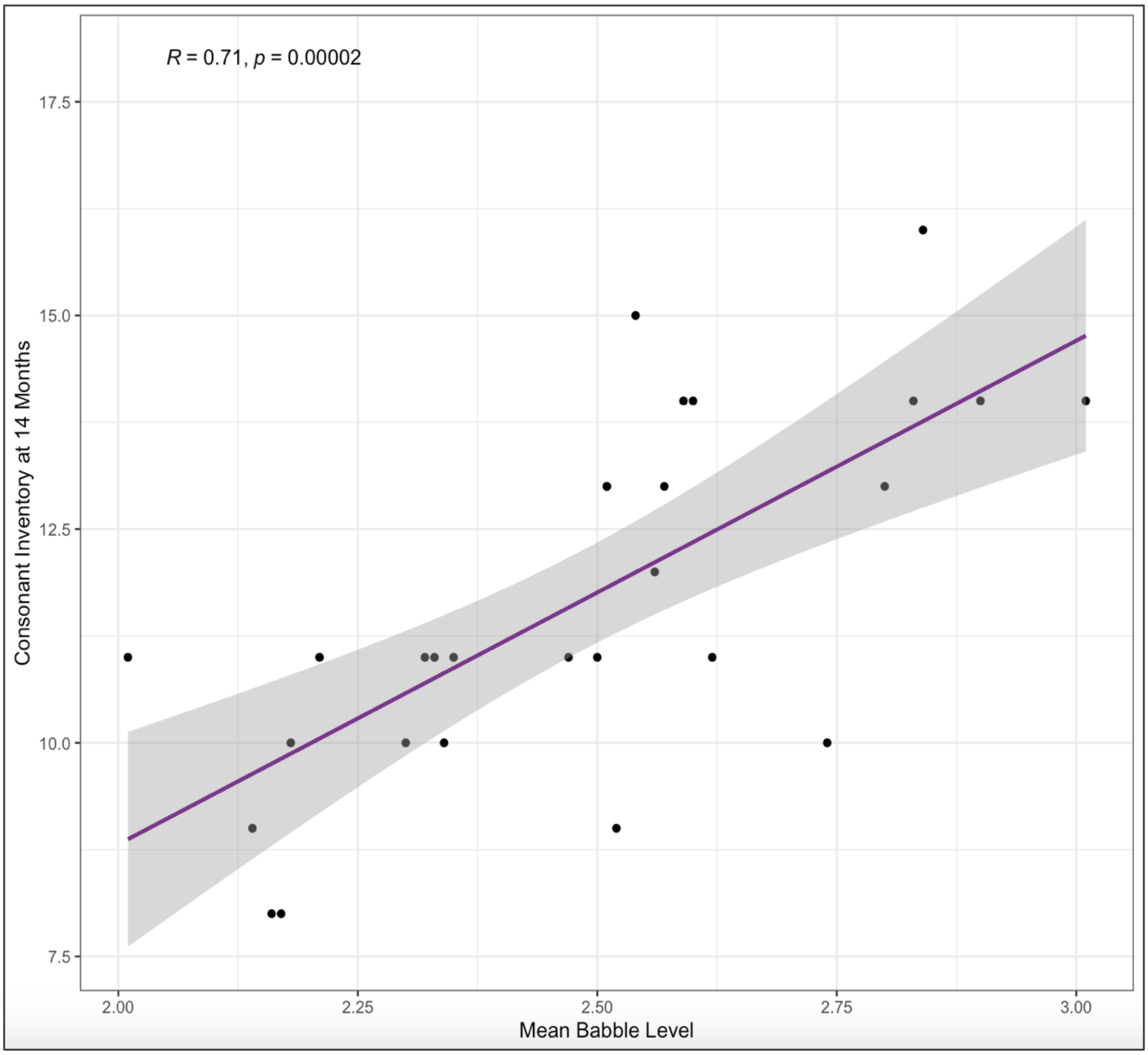



*Figure 5.25: A Smooth Scatterplot of Mean Babble Level and Consonant Inventory at 14 Months*

Figure 5.25 shows a moderate, positive correlation (R(26) = .71, p = .001) between MBL and consonant inventory at 14-months, and it foregrounds that MBL and consonant repertoire were significantly related. Therefore, the results indicate that as MBL increased, so did the number of consonant types in the infants' emergent consonant repertoire. This relationship reveals that the vocalisations do not only consist of a small range of repeated sounds (which would not influence the MBL measure), but that a higher variety of consonant types were significantly predicted by higher MBL scores. This relationship is next explored in relation to palatal age because Analysis I illustrated it to be a key variable to consider.

In relation to palatal group, the results for individual groups reinforce the importance of this significant relationship between 14-month inventories and MBL, because when broken into each group, the effect values remained within or close to the significance threshold:

*Table 5.16: Correlation Between MBL and Consonant Inventory Across Palatal Group*

| ***Palatal Group*** | ***R Value*** | ***P Value*** |
|---|---|---|
| ***1*** | .89, | .0012 |
| ***2*** | .56 | .095 |
| ***3*** | .64 | . 061 |

There was an absence of interaction between palatal group and MBL in predicting consonant inventory. While the p-value is only below 0.05 for palatal group 1, all coefficients are positive and moderate to strong, and the p-values for groups 2 and 3 are marginal. These results suggest that if the significance threshold was set higher (e.g., at .1 instead of .05) to allow for the clinical variation, the conclusion would be more clear cut. Despite this, consideration of the p values around the significance value can still shed light on the trends here. These results suggest that the relationship was present across participants, regardless of how many months post-surgery they were at when the data were collected. As such, they support H1 because the range of consonants produced by ICPs relates to the mean speech-likeness score, which is an indicative measure for the stage of vocal development. Further, they boost validity for the impact of palatal age on inventory size and MBL, because the relationship was visible across groups, suggesting some generalisability within the clinical population.

#### *5.3.3.3 Mean Babble Level and Vocal Motor Schemes (VMS)*

Next, as explored earlier (in Section 5.3.5) VMS were beneficial to exploring H1, because they offer a more reliable indication of vocalisation patterns; they quantify and categorise stable articulatory coordination more definitively than emergent consonants. To continue, the VMS measure was broken down into *VMS* (where all consonant-like closures, including glottals and liquids, were included) and *True VMS* (whereby glottals and liquids were excluded), to assess how MBL scores related to consistent consonants that did and did not make the supraglottal distinction.

The total number of all VMS consonants within the sample were normally distributed (W = .95, $p$ = .16) and to test whether there was a relationship between the consistent consonants also related to the stage of development (as indicated by MBL), the two were plotted together in a scatterplot with a Pearson's correlation result generated. Figure 5.26 visualises a significant relationship between the two measures.

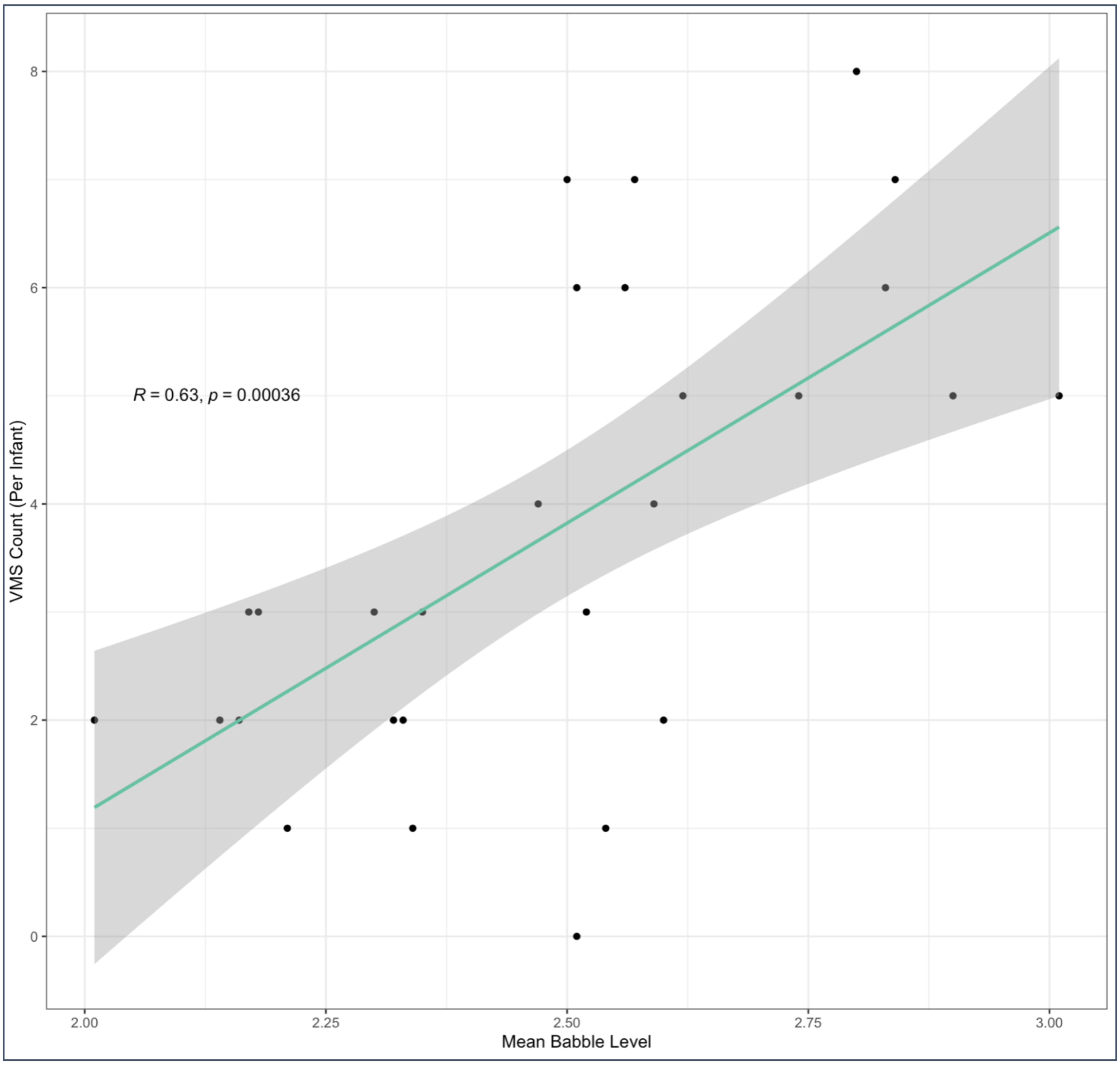



*Figure 5.26: A Smooth Scatterplot of Number of VMS and MBL*

It shows that infants with a higher MBL (or speech likeness) had a higher number of stable, consistent consonants within their repertoire. To expand, this outcome not only mirrors the relationship revealed between MBL and consonant inventory but surpasses it in its statistical significance. When this outcome is broken down into palatal groups, the relationship holds.

*Table 5.17: Correlation Between MBL and VMS Across Palatal Group*

| ***Palatal Group*** | ***R Value*** | ***P Value*** |
|---|---|---|
| ***1*** | .64 | .06 |
| ***2*** | .59 | .07 |
| ***3*** | .83 | .005 |

even though the latter were both nearing the significance threshold. This pattern mirrors the within-group variation that was overviewed in Group 2 for vocal count and MBL scores in Analysis I, but also confirms how the overall group trend was robust to palatal group variation.

The last measure explored to test H1 is true VMS against MBL; that is, whether an infant's number of supraglottal VMS was also related to their MBL scores.

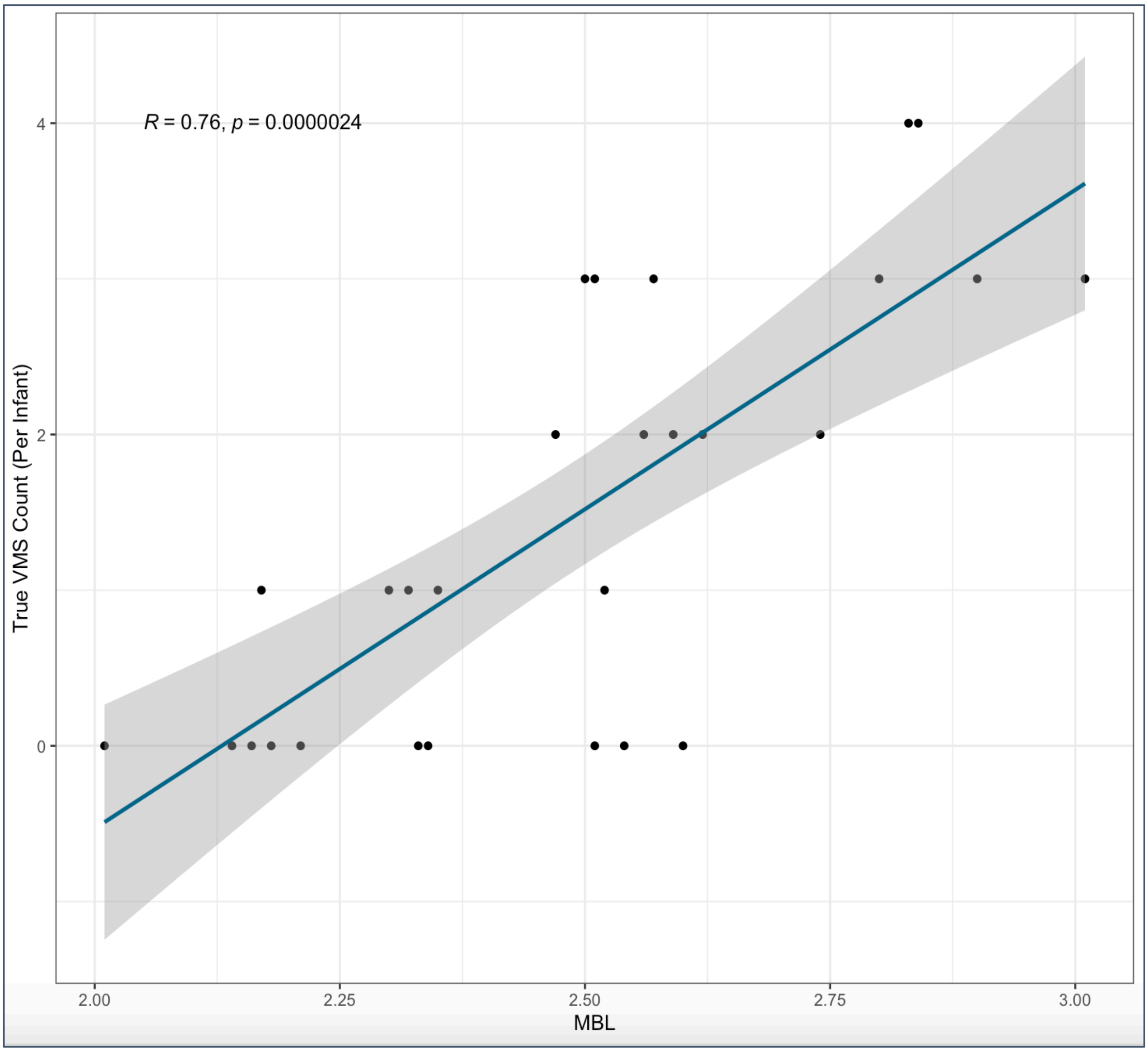



*Figure 5.27: A Smooth Scatterplot of True VMS Count and MBL*

Figure 5.27 illustrates a stronger trend here than in Figure 5.26 meaning that the number of true VMS consonants in the infants' repertoire was significantly related to MBL. However, here this significant relationship was robust across all three palatal groups unlike for all VMS previously, as shown by Table 5.18.

*Table 5.18: Correlation Between MBL and True VMS Across Palatal Group*

| ***Palatal Group*** | ***R Value*** | ***P Value*** |
|---|---|---|
| ***1*** | .81 | .008 |
| ***2*** | .71 | .02 |
| ***3*** | .9 | .001 |

This positive relationship was significant and presents a compelling result that was much more magnified than shown in Figure 5.26. Furthermore, the bidirectional relationship showed MBL to be significantly related to true VMS itself, meaning that it could be a beneficial measure for assessing vocal milestones. It also revealed that an even proportion of infants across each palatal group had 0 true VMS consonants at 14 months, while some had 4, reflecting variability that is regularly present in typical development. Collectively, the three measures of vocal count, inventory size and VMS count all related to MBL, meaning that we can reject the null hypothesis because the range of consonants produced by ICPs related to the stage of vocal development. By extension, we accept H1 that the stage of development has an impact on the range of consonants in the sample.

### 5.3.4 Syllable Inventories

The ordering of vocalic and consonant-like segments across vocalisations, including the number of syllables, is examined here to address H2. It proposed that most syllables in question would be composed of fricative-, liquid-, and vowel-initial syllables (with fewer stops and fewer velars) and that central vowels would be more common than front and back vowels. This section explores the most frequent syllable sequences and gives more phonetic detail than the earlier analysis in order to explore and find out what the compositional and organisational components of syllables produced by ICPs were. It presents the most used syllables across the sample, and how these patterns vary across palatal ages and MBLs to explore H2.

#### *5.3.4.1 Syllable Inventories: Most Common Phonetic Sequences*

This section presents the mode vocalisation sequences. Table 5.19 presents the phonetic structures that occurred 10 or more times. This number was reflective of their relative frequency, because these instances included the majority of structures (N = 7461) verses those only produced up to ten times (N = 1179), which were least representative of vocalisation patterns because they were not repeated and less reflective of stable patterns within a single infant or across multiple infants' repertoires.

This section of analysis focuses on the first most frequent 50 sequences, ordered by most frequently vocalised.

*Table 5.19: Vocalisation Composition and Frequency*

| Number (by most frequent) | Phonetic Pattern | f | Number (by most frequent) | Phonetic Pattern | f |
|---|---|---|---|---|---|
| **1** | GV | 1995 | **26** | GVN | 33 |
| **2** | SV | 582 | **27** | SLV | 32 |
| **3** | GVGV | 444 | **28** | SVS | 30 |
| **4** | GVV | 304 | **29** | GVLVV | 28 |
| **5** | NV | 223 | **30** | GVVLV | 27 |
| **6** | LV | 206 | **31** | SVNV | 25 |
| **7** | GVLV | 198 | **32** | GVLVLV | 24 |
| **8** | SVSV | 168 | **33** | LVGV | 22 |
| **9** | VLV | 162 | **34** | SVSVV | 21 |
| **10** | GVSV | 136 | **35** | GVGVV | 20 |
| **11** | V | 116 | **36** | LVSV | 20 |
| **12** | GVNV | 115 | **37** | NVN | 20 |
| **13** | GVGVGV | 110 | **38** | VSVSV | 20 |
| **14** | VNV | 109 | **39** | VLVV | 19 |
| **15** | VSV | 97 | **40** | NVLV | 18 |
| **16** | SVV | 94 | **41** | VLVLV | 18 |
| **17** | SVGV | 83 | **42** | GVNVNV | 17 |
| **18** | VGV | 78 | **43** | NSV | 17 |
| **19** | NVNV | 71 | **44** | SVVSVV | 17 |
| **20** | SVLV | 54 | **45** | VNVV | 17 |
| **21** | SVSVSV | 51 | **46** | VV | 17 |
| **22** | LVLV | 50 | **47** | NVSV | 16 |
| **23** | LVV | 43 | **48** | VNVNV | 16 |
| **24** | N | 42 | **49** | VGVGV | 15 |
| **25** | NVV | 39 | **50** | VVLV | 15 |

*Glottals: G, vowels: V, stops: S, nasals: N, supraglottal liquids: L.*

Table 5.19 shows that glottal initial monosyllables were most common, which is a finding that directly supports H2. However, the next two most common sequences were stop-initial and nasal-initial monosyllables, which contradict H2. The predicted frequency of fricative initial syllables was not at all evident in the 50 most frequent structures, but liquids did appear in the top six most common sounds, 5/6 of which were single syllables formations, which is in line with the typical babble form (Nathani, Ertmer, and Stark, 2006). Of the other structures, the patterns were more mixed across the consonant gestures in initial position, but glottal and vowel initial structures were persistent trends across the rows at the onset of vocalisations.

### *5.3.4.2 Vocalisation Sequences and Palatal Age*

The distinctions between vocalisation structures across palatal group are explored next. The mean vocal counts across each palatal group were relatively balanced but note that Group 2 had slightly fewer vocalisations overall (G1 = 333, G2 = 272, G3 = 320).

*Table 5.20: Most Frequent Phonetic Gestures Across Palatal Group*

| **Number (by Most Frequent)** | **GROUP1** | | **GROUP2** | | **GROUP3** | |
|---|---|---|---|---|---|---|
| | Patterns | Frequency | Patterns | Frequency | Patterns | Frequency |
| **1** | GV | 916 | GV | 547 | GV | 532 |
| **2** | GVGV | 243 | GVV | 190 | SV | 175 |
| **3** | SV | 218 | SV | 189 | GVGV | 118 |
| **4** | GVLV | 109 | GVGV | 83 | NV | 101 |
| **5** | LV | 102 | SVV | 66 | SVSV | 82 |
| **6** | NV | 67 | NV | 55 | VLV | 74 |
| **7** | GVNV | 57 | LV | 46 | GVLV | 68 |
| **8** | GVSV | 57 | VLV | 45 | V | 61 |
| **9** | GVV | 54 | GVSV | 37 | GVV | 60 |
| **10** | GVGVGV | 52 | SVSV | 35 | LV | 58 |
| **11** | SVSV | 51 | NVNV | 30 | VNV | 45 |
| **12** | VLV | 43 | V | 28 | VSV | 43 |
| **13** | SVGV | 38 | GVGVGV | 27 | GVSV | 42 |
| **14** | VNV | 37 | VNV | 27 | GVNV | 37 |
| **15** | VSV | 33 | SVGV | 22 | VGV | 32 |
| **16** | SVSVSV | 29 | GVLV | 21 | GVGVGV | 31 |
| **17** | VGV | 28 | GVNV | 21 | NVNV | 26 |
| **18** | V | 27 | VSV | 21 | SVLV | 26 |
| **19** | LVLV | 22 | NVV | 19 | SVGV | 23 |
| **20** | N | 21 | VGV | 18 | LVLV | 21 |
| **21** | SLV | 16 | LVV | 16 | SVV | 20 |
| **22** | SVLV | 16 | SVVSVV | 14 | LVV | 17 |
| **23** | GVLVLV | 15 | LVSV | 13 | N | 17 |
| **24** | NVNV | 15 | GVVLVV | 34 | SVSVV | 17 |
| **25** | VSVSV | 14 | SVLV | 12 | GVN | 16 |

Table 5.20 illustrates, as foregrounded by Table 5.19, that the glottal + vowel structure was the mode across all three groups, with the monosyllable being most frequent, with 300 + more uses than the second most common sound. A difference in glottal initial structures only is evident

from higher frequencies overall in Group 1, with stop- and nasal-initial structure having higher frequencies in groups 2 and 3 respectively. Another cross-group trend is that 72 of 75 vocalisations were vowel final, conforming to the open syllable structure, however 2 of the exceptions included the syllabic, nasal monosyllable, and the only other closed syllable was in Group 3, which was only produced 16 times and was closed by a nasal. The preference, therefore, was overwhelmingly for vowel-final syllables and vocalisations.

A more subtle trend that was not clear across the majority but was clear across a reasonable portion of the infants, was that nearly half of the structures contained only 1 consonant in the vocalisation (32/75 of the most common phonetic sequences), which is a typical feature of babble and even of first words (see Section 2.2.3.1). This pattern indicates that a large portion of vocalisations contain one consonant gesture, which involves less articulatory coordination than consonant clusters or structures with more consonants. In addition, nearly a third of the vocalisations involved the reduplication of one consonant category (this pattern was evident in 21/75 cases) in Group 1 and Group 2, perhaps indicating a preference for simple coordination, whereby only one type of gesture is produced in the vocalisation, in the lower ages. Lastly, a rare pattern in the data across groups was that only 15 out of 75 of vocalisations were vowel initial, and the trend indicates a contrast to the prediction of H2, a trend that did not vary across the groups: (Group 1 = 6, Group 2 = 4, Group 3 = 5).

#### *5.3.4.3 Vocalisation Sequences and Mean Babble Level*

Next, the composition of vocalisations is introduced across MBL to explore whether the sequential patterns changed based on the speech likeness of vocalisations across the 4 MBLs. The distribution of vowel categories and consonant gestures are both considered here, offering more detail than earlier sections in this chapter.

*Table 5.21: Phonetic and Vocalic Patterns Across MBL*

| | MBL1 | | MBL2 | | MBL3 | | MBL4 | |
|---|---|---|---|---|---|---|---|---|
| | **Pattern** | **Freq** | **Pattern** | **Freq** | **Pattern** | **Freq** | **Pattern** | **Freq** |
| **1** | R | 80 | CB | 925 | CR | 313 | CBCB | 21 |
| **2** | B | 77 | CR | 846 | CB | 235 | CRCR | 16 |
| **3** | C | 42 | CBCB | 167 | CR | 133 | CCR | 13 |
| **4** | M | 15 | CRR | 166 | CRR | 54 | CBC | 11 |
| **5** | RB | 6 | CM | 154 | CB | 52 | BCCR | 9 |
| **6** | RR | 6 | CR | 139 | CBCR | 42 | CRC | 8 |
| **7** | RM | 5 | CRCR | 93 | CBCB | 35 | CRCB | 8 |
| **8** | M | 4 | CBCR | 48 | GRCR | 34 | CBCB | 7 |
| **9** | BB | 3 | CB | 46 | CM | 34 | CRCB | 7 |
| **10** | BR | 1 | BCR | 41 | CBCB | 32 | CRRCRR | 7 |

To overview structures across different MBL scores, Table 5.21 shows that isolated vowels were most frequent in MBL1, and that front (R) and back (B) vowels were much more common than mid (M) vowels. H2 expected that central vowels would be more common than front and back vowels, but results show that mid vowels were rarer than back and front vowels, a trend that was robust to MBLs. The front and back vowels were the most frequent articulations (80 and 77 respectively), with mid vowels being much less used (15), in fact, the only two combinations in the high frequency vocalisations including mid vowels were glottal- or stop-initial monosyllables. The potential explanations for this are expanded on in relation to phonetic sequences (see Section 5.4.2.1) and in relation to the hypotheses motivated by the literature (see Section 6.1.2) later. The details of phonetic sequences are expanded on in detail in the final Analysis.

### 5.3.5 Conclusion

To conclude, the relationships that have been examined above illustrate some consistent findings with vocal patterns revealed in Analysis I, but, more valuably, they expose some clear trends regarding the vocalisation variables in question. Namely, there were strong relationships between MBL and vocal count, consonant inventory size, and vocal motor scheme repertoire. Table 5.22 presents the findings that correspond to the third research question.

*Table 5.22: Summary of Findings in Relation to RQ3*

| **ID** | ***Palatal Age (in months)*** | ***Palatal Group*** | ***MBL*** | ***FO*** | ***VMS Count (All)*** | ***VMS Count (True)*** |
|---|---|---|---|---|---|---|
| *1* | 7.33 | 3 | 2.56 | 12 | 6 | 2 |
| *2* | 7.23 | 3 | 2.01 | 11 | 2 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *3* | 7 | 3 | 2.59 | 14 | 4 | 2 |
| *4* | 6.13 | 3 | 2.8 | 13 | 8 | 3 |
| *5* | 5.87 | 2 | 2.83 | 14 | 6 | 4 |
| *6* | 5.03 | 2 | 3.01 | 14 | 5 | 3 |
| *7* | 5.67 | 2 | 2.35 | 11 | 3 | 1 |
| *8* | 4.83 | 2 | 2.51 | 13 | 0 | 0 |
| *9* | 6.7 | 3 | 2.34 | 10 | 1 | 0 |
| *10* | 4.17 | 2 | 2.62 | 11 | 5 | 2 |
| *11* | 4.90 | 2 | 2.47 | 11 | 4 | 2 |
| *12* | 5.17 | 2 | 2.6 | 14 | 2 | 0 |
| *13* | 4.23 | 2 | 2.14 | 9 | 2 | 0 |
| *14* | 4.10 | 2 | 2.74 | 10 | 5 | 2 |
| *15* | 4.73 | 2 | 2.54 | 15 | 1 | 0 |
| *16* | 3.43 | 1 | 2.9 | 14 | 5 | 3 |
| *17* | 3.89 | 1 | 2.5 | 11 | 7 | 3 |
| *18* | 2.37 | 1 | 2.16 | 8 | 2 | 0 |
| *19* | 2.7 | 1 | 2.18 | 10 | 3 | 0 |
| *20* | 2.63 | 1 | 2.51 | 13 | 6 | 3 |
| *21* | 1.77 | 1 | 2.17 | 8 | 3 | 1 |
| *22* | 1.30 | 1 | 2.3 | 10 | 3 | 1 |
| *23* | 6.03 | 3 | 2.21 | 11 | 1 | 0 |
| *24* | 11.45 | 3 | 2.84 | 16 | 7 | 4 |
| *25* | 9.03 | 3 | 2.52 | 9 | 3 | 1 |
| *26* | 2.37 | 1 | 2.32 | 11 | 2 | 1 |
| *27* | 6.03 | 3 | 2.57 | 13 | 7 | 3 |
| *28* | 2.83 | 1 | 2.33 | 11 | 2 | 0 |

To summarise, Analysis II revealed the following outcomes:

- There was a significant relationship between MBL and consonant inventory size at 14 months, suggesting that infants producing more mature, recognisable sequences were more likely to produce a greater number of consonants.
- The number of VMS consonants within an infant's repertoire significantly predicted phonetic inventory size at 14 months, which was a result that held over the three palatal

groups, indicating that infants producing more consistent consonants were also more likely to produce a greater number of consonants.

- Glottal initial monosyllables were most common, and consonants in initial position were most diverse in groups 2 and 3, illustrating patterns in support of H1.
- The frequency of mid vowels was lower than both back and front vowels, a trend that was robust to MBLs. This finding contradicts H2, implying that vowels are also affected by CP, and in similar locations to the most-reported alveolar and velar consonants in the literature.

Taken together these analyses contribute to RQ2, indicating support for H1 because the measures depend on the level of development (or mean maturity of vocalisations). Within the analysis of phonetic repertoire there were some surprising patterns, including a cross-group mode use of glottal articulations; a presence of stop consonant categories; an absence of fricatives; and vowels with a high acoustic-articulatory contrast, the two latter contrasted with the predictions of H1. Analysis II also revealed that the rarest sounds—such as post-alveolar fricatives—tended to be produced by infants with a higher number of VMSs in their repertoire, this outcome is in line with what we would expect because infants with the most speech-like vocalisations also had the rarest, later to emerge sounds. The impact of these outcomes in relation to the hypotheses, to the research questions, and to the typical trajectory are expanded on at length in Section 6.1.2. Briefly, typical infants, at 12 months inventory sizes were reported by Scherer to have a mean of 7.2 (2008, p. 832), however the number of emergent consonants from the phonetic inventories (explored in Section 5.3.2) had a mean of 10.01, revealing contention to H2, and support for the null hypothesis because they were likely to be close to the 14-month typical measure in this way.

The findings on consonant elements had resemblances with CLP influence at 16 months (Hardin-Jones et al., 2023) and challenged Zajac et al., (2021) in relation to the emergence of stop productions. More specifically, the vocalic elements contrasted to typical patterns in the low presence of mid-vowels, which tend to be the most frequent in babble (Ha and Oller, 2022, also see Chen and Kent, 2004). These concepts, along with the impact of palatal age on the vocalisation measures cannot be overlooked, especially given the highlighted outcomes from Analysis I. One potential reason for these unpredicted findings is concerned with the control of airflow and the ease of transitioning to vowels nearer to the consonant's place of articulation. This concept is returned to in more detail in the discussion (see Section 6.1.2).

## 5.4 Analysis III

Analysis III examines the elements of the 14-month-olds' syllables (as defined in Section 4.2.1.5) to explore the sequential properties of the vocalisations. Specifically, it examines the phonetic patterning of vocalisations by analysing sound combinations, including vowel harmony, consonant harmony, and transitional probabilities, that is, how likely certain types of consonants and broad (front, mid, back, as determined in Section 4.2.2.2) vowel categories are to occur next to each other. It then analyses the sequential elements against the variables highlighted as influential earlier (see Analyses 5.2 and 5.3)—MBL and consistent consonants (vocal motor schemes, VMS) by investigating their interaction with palatal ages and individual variability. This analysis therefore assesses the vocal patterns through three lines of enquiry: how syllable structures vary across different palatal ages; which phonetic patterns mirror or divert from the typical trajectory; and how well transitional probabilities captured the phonetic patterns in the data. Together, these three avenues offer more in-depth insight into the patterning of (non-)canonical vocalisations and determine the extent to which the phonetic sequences captured were consistent with the published CP patterns (see Section 2.2.3.1 for a reminder). Lastly, this chapter assesses whether transitional probabilities are valuable for visualising the details from vocalisation transcriptions or could reveal new insight into CP production patterns.

### 5.4.1 Harmony

This section investigates how harmonic the infants' vocalisations were across the sample, across palatal ages, and across MBL. Canonical babble often involves the reuse of phonetic structures and reflects a key milestone in vocal development (Oller and Eilers, 1988, p. 441). Vocalisations can be harmonic, on the syllable level /bibi/, or in terms of the relevant consonant level /babi/, or the relevant vowels /biki/ (and details on vocal harmony can be found in Section 4.2.1.2). Overall, harmony provides an indication on systematicity and the emergence of babble milestones because it involves repeated coordination of the articulators throughout a vocalisation. As such, this section assesses whether 14-month-old infants with a post repair CP exhibit the use of harmony and resemble the typical trajectory in their vocalisations.

#### *5.4.1.1 Vowel Harmony*

The production of vowels is variable in infancy (Nathani, Ertmer, and Stark, 2006 and Oller, 2000) therefore, in this research, vowel distinctions were made at a broad level of front, mid, and back to address both ability and variability (for more detail of these categories, see Section 4.2.2.2). *Vowel Harmony* (VH) was coded when one of the three vowel categories were used twice or more across a vocalisation—e.g., /b**æ**w**æ**/and /m**u**dæd**ʊ**/. Isolated monophthongs and diphthongs were excluded because for a vocalisation to be coded with VH, two harmonic vowels had to be separated by one (or more) consonant-like element(s). These instances (e.g., /u/ or /ei/) were not common. Given that they only occurred in <2% of the whole vocalisation data and, as such, vowel harmony was only applicable to 2 + syllable vocalisations.

### *5.4.1.2 Consonant Harmony*

For *Consonant Harmony* (CH) to be recorded, vocalisations were collapsed in the voicing distinction—consonants with the same place (PoA) and manner (MoA) of articulation but a different voicing setting—were noted as harmonic regardless of whether the sounds were voiced or voiceless. For instance, (/**p**a**b**u/ and /**b**a**b**u/ are both examples of vocalisations with CH. The distinction is based on the awareness that voicing contrasts tends to appear later in typical emergent consonants (Macken and Barton 1978). The decision also mirrored many infant studies which collapse voicing differences (e.g., Chapman et al, 2001) and therefore they illustrate manners and places of articulation to be valuable areas of research without distinguishing between voicing contrasts.

The final difference to VH was that monosyllables were included for the CH category; this distinction was made because consonants can have harmony either side of a vowel—as in /**d**u**d**/ or /**b**e**b**/—without requiring an additional syllable because they are separated by a vocalic element. Lastly, CH and VH were counted regardless of whether additional vowels/consonants were produced across the vocalisation (e.g., in /**p**idu**p**ə/ there is CH but no VH), if there was one harmonic pair across the sounds produced, this was sufficient. The measure did not distinguish non-contact harmony, therefore there were no limits on distance (i.e., vocalisation length or numbers of different vowels or consonants). Table 5.23 gives the frequencies of harmony from all vocalisations where harmony was applicable (i.e., vocalisations of two or more syllables) in the dataset. All of the following columns with harmony indicate that the sequences were produced with consistent phonetic qualities across vowel and consonant components.

*Table 5.23: Overview of Harmony Frequencies in All Vocalisations*

| | Vowel Harmony (VH) | Cons. Harmony (CH) | Total Harmony (W/WO) |
|---|---|---|---|
| **Count With (W)** | 2945 | 1800 | 4745 |
| **Count Without (WO)** | 1178 | 1821 | 2999 |

Overall, harmony was present in approximately 61% of the vocalisations. This is a finding that indicates a cross-group trend in favour of harmony. At the broad level it also illustrates that VH was more present than CH across these vocalisations. Perhaps more predictably, given the number of options in broad vowel categories (versus the consonant categories), vowel harmony accounts for 3 quarters of the V vocalisations, whereas consonant harmony equates to a near even split between harmonic and non-harmonic productions. To expand on the combination possibilities, if each syllable were to hypothetically occur at the same amount, the chances are 11/25, although this ratio is not adjusted for the chances based on the syllable combinations here, this amount does illustrate that the results exhibit more VH than we could expect. Given that 99.03% of vocalisations in the data were mono-, di-, or tri-syllabic, the further analysis concentrates on this selection of the data only. Table 5.24 gives the frequencies of these vocalisations, which comprised a total of 11809 syllables. These filtered data are therefore given in Table 5.24.

*Table 5.24: Overview of Harmony Frequencies in Mono - Tri-Syllables*

| | Vowel Harmony (VH) | Cons. Harmony (CH) | Total Harmony (W/WO) |
|---|---|---|---|
| **Count With (W)** | 2206 | 1125 | 3331 |
| **Count Without (WO)** | 1145 | 1740 | 2885 |

The longer, polysyllabic strings—e.g., those vocalisations with more than 3 syllables—were eliminated due to their lower frequency across the whole data (and due to the scope of this analysis), the ratios of with and without harmony look different. The overall distribution of harmony in this subset of data were more balanced than was expected and would be characteristic of canonical babble. To continue, with harmony occurring in 53% of vocalisations whereas vowel harmony dominated 66% of mono-tri syllable vocalisation data. In fact, consonant harmony was evident in only 40% of vocalisations.

One possibility for this lower percentage is that when a vocalisation had vowel harmony, it was less likely to have consonant harmony, too. Perhaps indicating that productions require a consistent articulation in order to use variation in the other domain. The explanations and contributions of these outcomes in response to RQ3 are given at the end of this section (before Section 5.4.2). The above exploration of harmony at the group level did not provide enough detail about its frequency across individual infants. Given that Analysis I showed that there was variation in the vocal count across infants, whether such variation was also present in the production of harmony needs exploring, to understand the vocal characteristics at the phonetic and sequential level. Therefore, Figure 5.28 and Figure 5.29 detail the spread of harmony across individual infants' vocalisations (see the key for infants) to explore the patterns.

The two figures present the frequencies of harmony with each infant stacked alongside another in the respective colours so that the values are visually comparable. Vocalisations with harmony are on the right half of the figure and vocalisations without harmony are on the left. Each infant is captured on both sides of the graph, indicating that all infants produced a vocalisation with and a vocalisation without harmony.

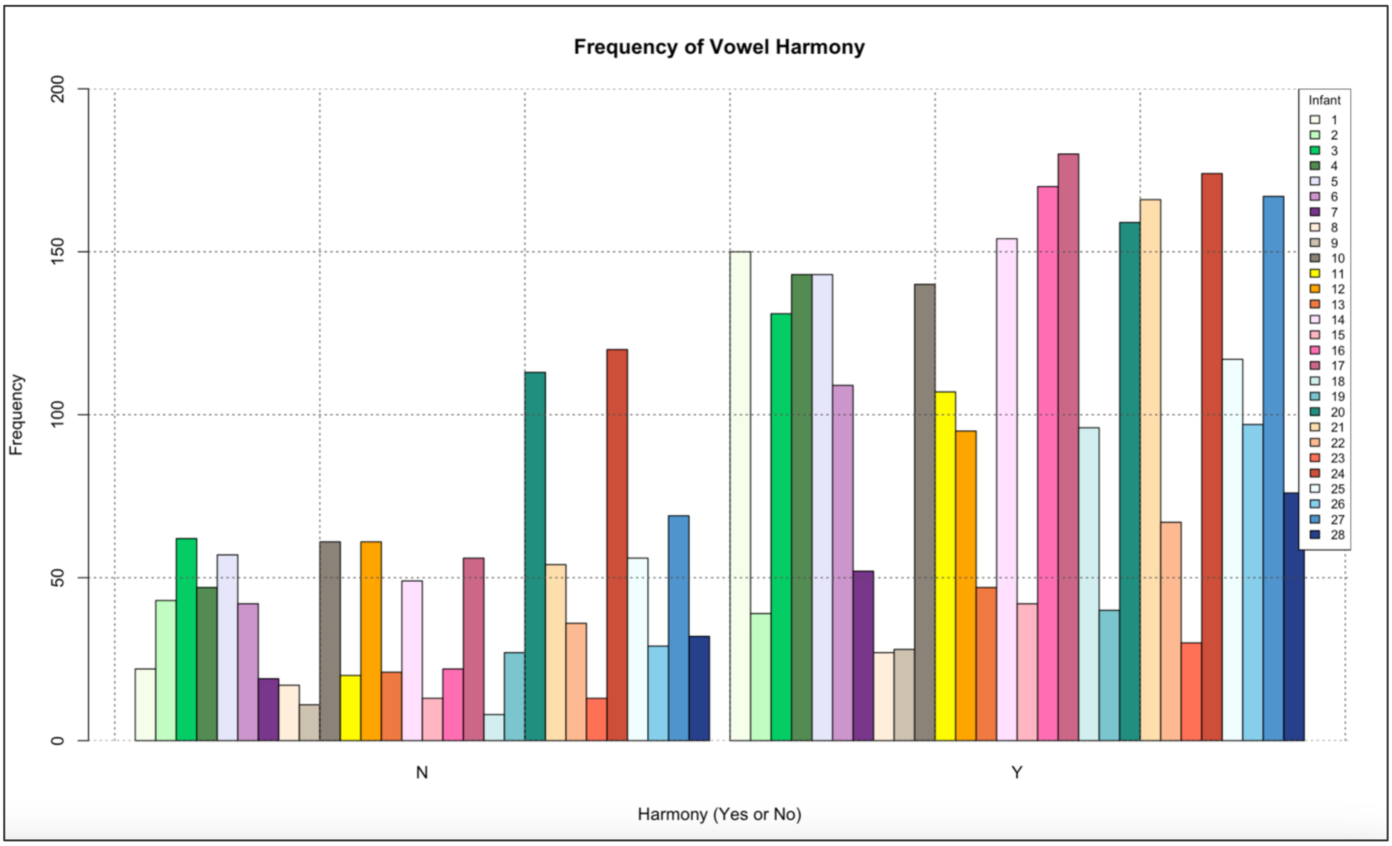



*Figure 5.28: A Stacked Bar Plot of Vowel Harmony Across Infants*

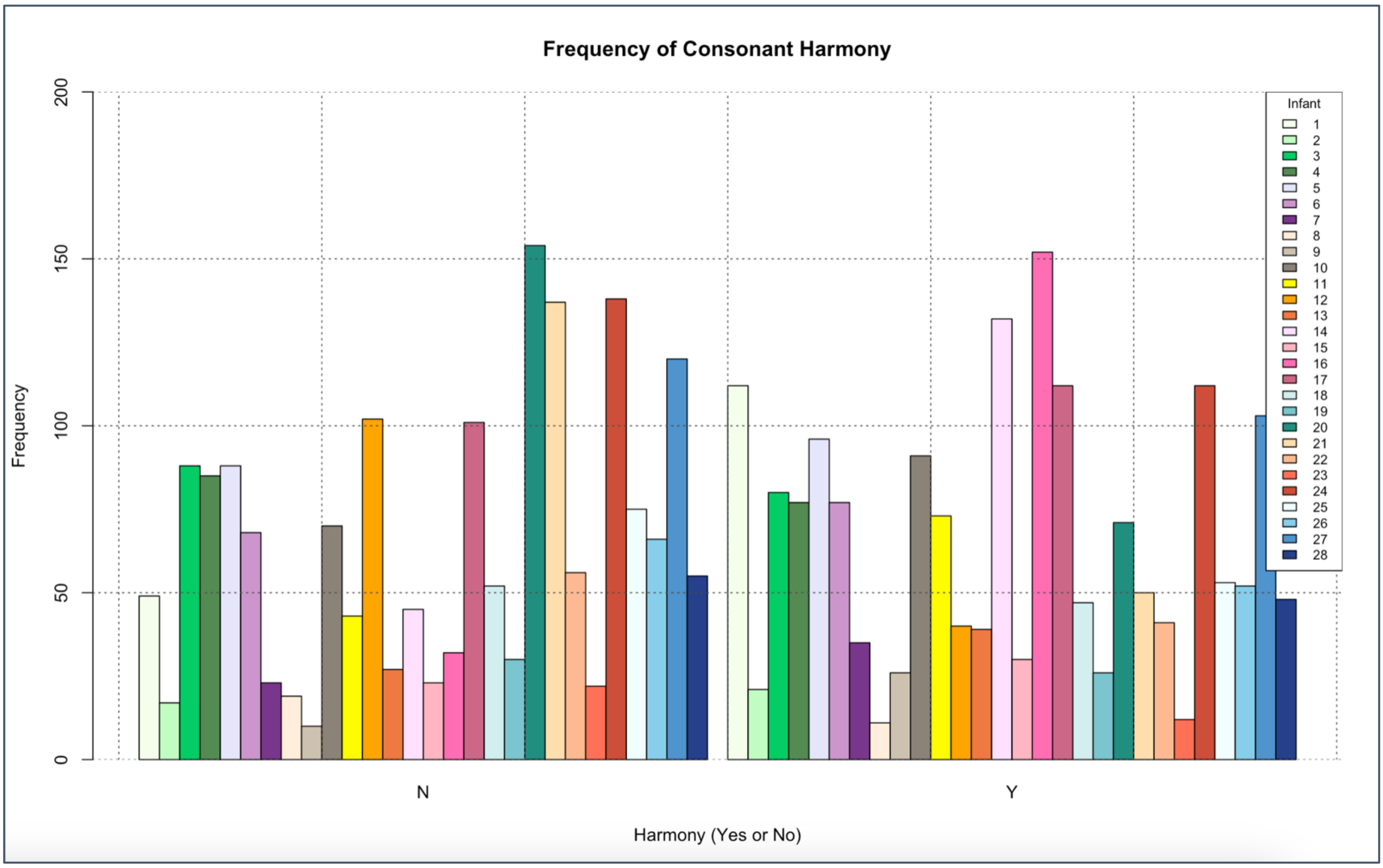



*Figure 5.29: A Stacked Bar Plot of Consonant Harmony Across Infants*

For all the infants, there were more vocalisations with VH than without VH and this distribution of VH was mirrored across different infants, which meant that the cross-group trend looked similar within individual infants' use of vowel harmony respective to the number of vocalisations. However, this distribution was not the case for CH, given that a majority was far less clear from Figure 5.29. While there was a slight, sample-wide trend of without CH, there were a few outliers that were inverted from the overall pattern (infants 1, 11, 14, and 16). These patterns may capture individual differences, or it might be that their productions were closer to the properties of canonical babble in these vocalisations. Overall, the vowels used across vocalisation demonstrate harmony to be robust to the amount of vocal data from each infant, however the trend was more mixed across consonant harmony. It might also be that palatal age (which stood out to be influential earlier) provides more valuable insight into the distribution of harmony than the individuals alone, given that palatal age has been so strongly related to vocalisation measures so far in the analyses (see sections 5.2 and 5.3 for a reminder).

As a reminder, the infants were subsetted by the number of months since surgery for groups one, two, and three (1-3 months, 4-5 months, and 6-9 months respectively). Figure 5.30 depicts two minor contrasts in relation harmony across palatal groups: there was marginally more VH in Group 1, marginally more CH (relatively) in Group 2, revealing a very common pattern in typical infants' early productions (Smith, 1973, Vihman, 1978, and Ingram 1974).

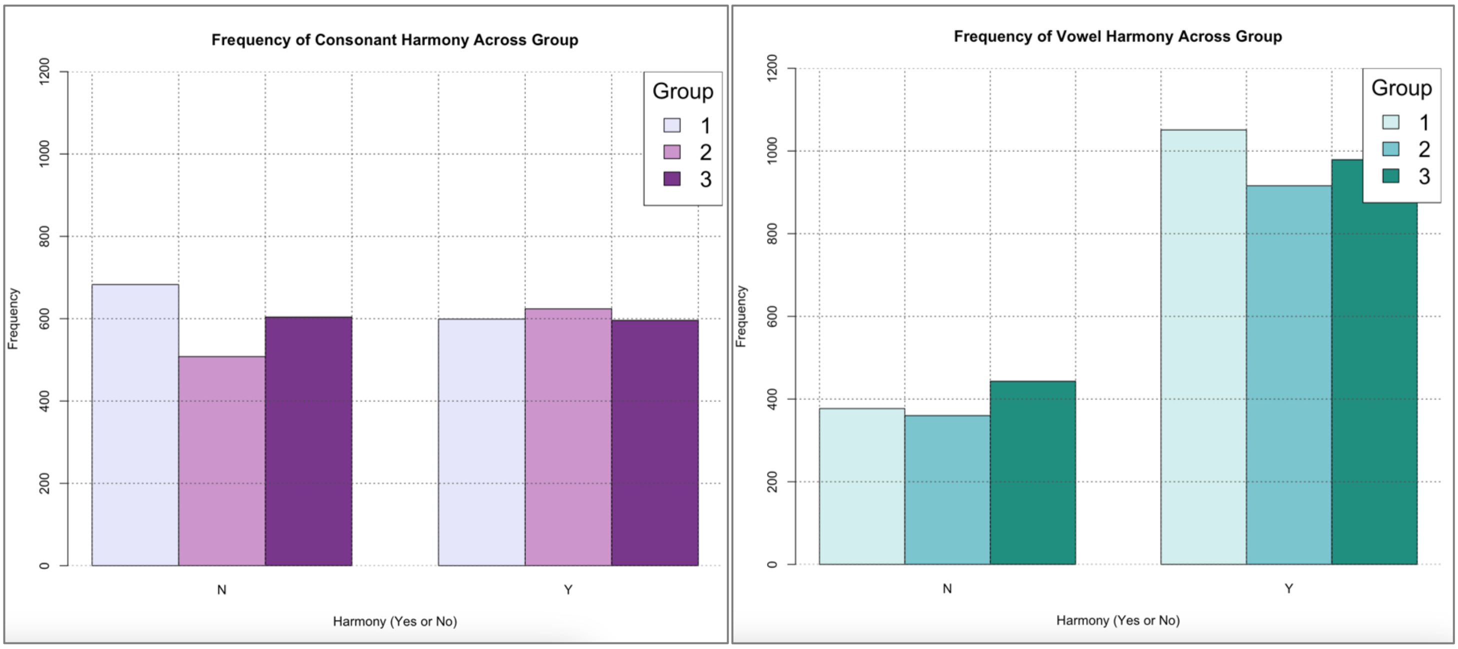



*Figure 5.30: Multiple Bar Plots of Consonant Harmony and Vowel Harmony Across Group*

The more frequent VH in younger palatal ages indicates higher use of vowel harmony in younger ages, which may be because vocalic elements were more salient to infants than consonants (which were less stable within their repertoire). Perhaps the salience of this sound was related to sounds that were easier for ICPs to vocalise (in light of Section 2.2.1), and/or that more harmony was present when infants have fewer within repertoire consonants. The latter may indicate that these vocalisations were more reflective of repeated, babble structures, given the near even spread between with and without CH. It could also be that infants had more harmony when they also had a greater selection of VMS consonants within their production output, but, given that harmony was not applicable to all monosyllables, these data may exclude several uses of VMS and consonant-like productions and therefore this relationship was not directly tested here. In fact, the relationship between harmony and the number of VMS consonants was very mixed and did not reveal any trends (see Appendix D in Section 9.4.2 for a visualisation). A suggestion for this pattern is that VMS consonants were more likely to occur in C + V sequences, perhaps, because they indicated more mature articulations that reflected first word qualities.

Examining palatal group did not give new insight into differences (or variation) in the use of vowel or consonant harmony in the sample. It was expected that Group 3 were more likely to use harmony in their vocalisations because they were likely to have the most mature vocal stage, due to them having the most months with a repaired CP. However, this outcome was not a clear finding and meant that it was challenging to interpret here.

To expand this avenue, the next part of this analysis assessed whether there were differences in harmony depending on how mature the vocalisations were. The presence of harmony across vocalisations prompts the question of how harmony was distributed across different MBL scores. MBL was strongly related to vocal count, meaning that the more an infant vocalised, the more likely it was to be babble. To assess whether harmony has any trends with the phonetic components in syllables (i.e., the formation of vocalic and consonant elements) may indicate another way that MBL is a tool for vocalisation assessment and indicates whether the use of harmony is a feature of vocalisations that should be more thoroughly considered by researchers going forward.

Given that there were major differences in the vocal count for different MBLs in the raw MBL frequencies, the focus was on the MBL vocalisation categories: MBL1 did not apply to harmony, 2 = non-canonical, 3 = canonical, 4 = variegated. Figure 5.31 shows the ratios between each MBL scores and harmony and illustrates that the data were similarly reflected across vowel harmony for MBL2 and MBL3.

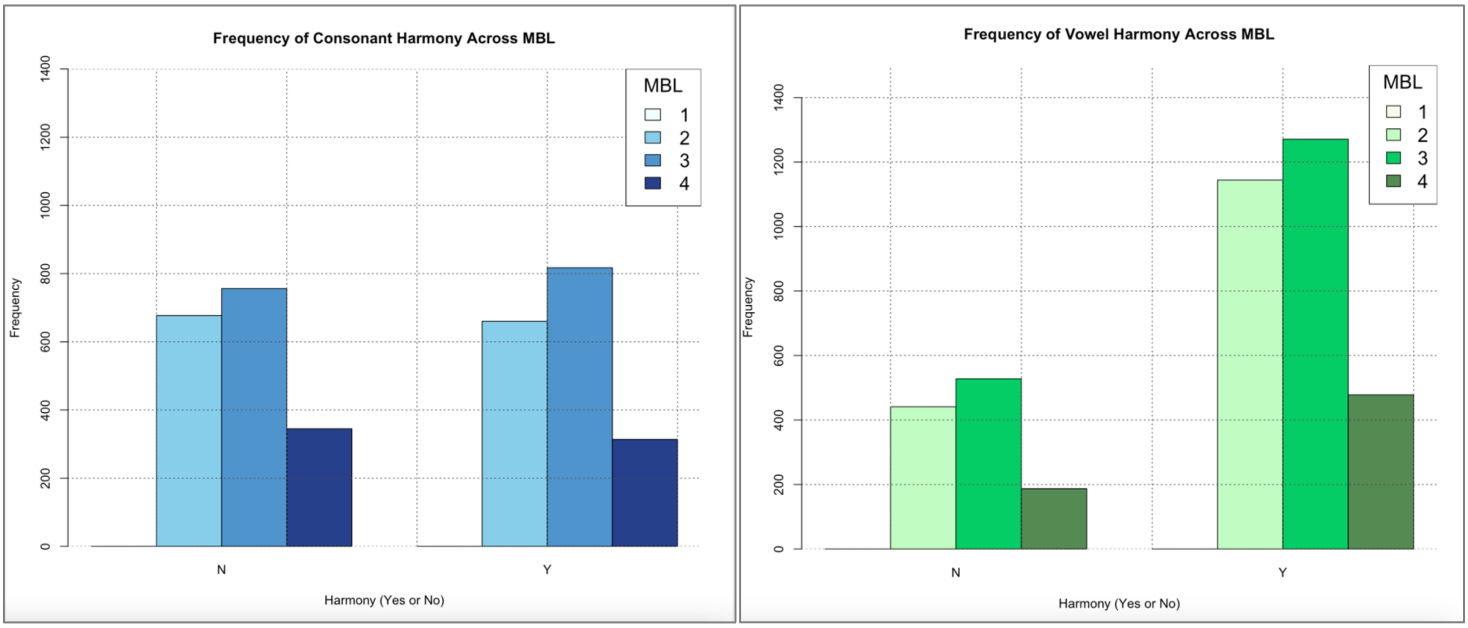



*Figure 5.31: Multiple Bar Plots of Consonant and Vowel Harmony Across Mean Babble Level*

Figure 5.31 illustrates a contrast in MBL4, which had a nearly even use across vocalisations with and without consonant harmony, rather than a clear majority in favour of vowel harmony. However, consonant harmony in MBL 4 included much fewer harmonic vocalisations (approximately 1/5) in total, perhaps showing different gestures and places of articulation to be most relevant to the more advanced (or speech-like) vocalisations. In other words, MBL4 disyllables were different, but trisyllables were more likely to consist of one harmonic element, as would be expected because this vocal category reflected variegated vocalisations. The takeaway here is that more options were available in a more mature system, revealing a pattern that is in line with the relationship reported in Analysis II between MBL and phonetic repertoire size and number of VMS and also one that corresponds to network growth models (which is an explanation that is elaborated on in Section 6.1).

Given the inclusion criteria for MBL4 (of 2 different, supra-glottal consonants in the vocalisation), it is unsurprising that consonant harmony was less common here. Regardless, it was still a possibility that tri-syllables had either consonant harmony only (e.g., /be**did**a/ or /ga**pip**u/), vowel harmony only (e.g., /b**i**g**i**da/ or /g**u**d**u**pi/) or both (e.g., /**bi**gu**bi**/). In these harmonic instances, there were two articulatory coordinations occurring: the production of 2 contrasting supraglottal consonants, and also the production of 2 harmonic consonants. The coordination of such features is necessary for articulating many multisyllabic words in English (e.g., banana, potato). Therefore, the evidence of harmony in MBL4 vocalisations exemplifies the articulatory coordination required to produce meaningful words within the most speech-like Babble of ICP.

In contrast, there was still much more harmony in vowels than in consonants and the distribution held across all MBL ratios. Perhaps this finding was underlined by the fewer constraints on MBL distinctions in the vowel criteria (i.e., MBL criteria was more dictated by consonant content than vowel categories), or the higher vowel harmony may illustrate that these vocalisations were influenced by the fact that there were fewer vocalic options. However, more specifically, in MBL2 and MBL3 vocalisations (where 2/3 of instances were harmonic), the distribution of harmony (where with and without are shown as Yes and No in the figures) was mirrored in both groups. This finding contrasts with MBL 4 (whereby Yes constitutes about 3/5 of instances), because the results showed that the more speech-like vocalisations were more likely to be harmonic. This contrast is representative of the variegated babble stage, where syllables have progressed from reduplicated syllables—which are present in the prior, canonical stage—into a mixture of different consonant and vowel combinations. It also illustrates, in relation to RQ3, that the composition of vocalisations had more regularity and repetition of vocalic elements across multisyllable productions than in consonants. This finding indicates more systematicity in vowel segments than consonant segments and could illustrate that vowel components are more challenging for ICPs than has previously been given credit (and is returned to in Section 6.1.3).

To add, the distribution of vowel harmony and consonant harmony was most evident in MBL4, meaning that vocalisations with more than one supraglottal consonant element had more vowel harmony than canonical and non-canonical productions, perhaps indicating that where consonants were more changeable within a vocalisation, vowel placements were more consistent. It may be that some of the findings depend on the number of settings required for consonants versus vowels, but the harmony still marks similarity in the placement of vowel articulations, illustrating a certain level of systematicity in harmonic vocalisations. The findings set a basis for systematic scaffolding explanations. The higher presence of vowels may also be illustrative of harmonic scaffolding, to some extent, whereby the use of harmony aids more complicated coordination of consonant-like gestures, and vice versa.

#### *5.4.1.3 Conclusion of Harmony Findings*

To summarise, the composition of syllables was more predictable across vowels than consonants, and the amount of overall harmony reduced with vocalisation maturity. H3 predicted that the vocal measures would overlap with each other, and these findings illustrate a mix of results in response to this prediction: VH was more present than CH in the more speech-like vocalisations, but this type of harmony was still within the expected outcomes, which meant that consonant harmony was very present in canonical syllables. Taken together, the results show that harmony across vocalisations may be a good indicator of the typical vocal trajectory, which is particularly evident before the variegated babble stage.

Further, harmony was distributed differently across the four MBLs, which suggests that harmony may assist with articulatory coordination and is a useful skill (Kent, 2021, Vihman, 2016) for progressing along the vocal trajectory. Such a relationship between the maturity of vocalisations and harmony could have implications for the support, assessment, and intervention for ICPs through vocal development. For instance, where infants were not yet exhibiting harmony in pre-word vocalisations, or even pre-canonical babble, the exposure to harmonic target forms in therapy or home play environments could involve more harmonic elements to boost awareness in this process. Harmony is an observable pattern for parents and noticing a change in its frequency through development (in the reduction of consonant harmony over development, or emergence of it) may offer them reassurance that their child is not vastly outside of the CP trajectory. In other words, greater exposure to harmony could be facilitative of sound segmentation and support infants' perception of reduplicated elements (as are a foundation for canonical babble), in the same way that infants have perceptual sensitivities to phonetic contrasts (Kuhl et al., 2006, Sundara et al, 2018).

### 5.4.2 Sequence Inventories

In this section, the sequential and transitional properties of vocalisations are explored to examine whether the specific, phonetic patterning of consonants (C), glottals (G) and vowels (V) were also indicative of the typical vocal trajectory. Later in this analysis, the presence of harmony will be returned to in order to assess production trends in the infants' vocalisations. Specifically, it was hypothesised (see Section 2.6.1) that the composition of ICPs' vocalisations would be dominated by vowel-initial structures, and that liquids and fricatives would be very frequent. This prediction was made because Zajac et al. (2021, p. 30) found that English infants' prevocalic (i.e., pre-vowel) stop consonants did not emerge until at least 9 months after repair. It also motivated Ha and Oller, who found that Korean ICPs post-surgery exhibit a preference for vowel-initial structures (2021, p. 10) Zajac et al.'s reported delay could be due to a difference in sequences vocalised prior to first words or even prior to surgery. Ha and Oller's reported deviance could also be explained by the need to remap sounds (including those vocalised pre-repair) and also the healing time required after surgery, these predictions exemplify divergences to the patterns in earlier stages of typical vocal development where C + V is typical because supraglottal stops were in onset position, and therefore overlooks the presence of glottal onsets. This trend is an example of the deviant patterns noticed by speech and language therapists (Southby, 2023, pc). As such, the predicted patterns would not only indicate delay if the infants have not reached variegated babble, but, more importantly, would illustrate deviance in the formation of syllables. The potential implications of glottal initial structures on remapping sounds, and the progression to first words are discussed later (in sections 6.1.1-6.1.3).

#### *5.4.2.1 Sequence Inventories: Most Common Sequences*

Next, the 25 most common syllables are explored; this section therefore sets a foundation for comparisons against MBL and palatal age. Such specific detail (including the transitions between phonetic components and their patterning with broad vocalic categories) is analysed later in this section in order to assess the more fine-grain phonetic composition of the syllables. Therefore, the ordering of vocalic and consonant-like elements across vocalisations are examined here.

Table 5.25 includes the first 25 most common sequences. These instances all occurred 10 or more times (N = 7461) across the whole cohort and are presented here because many structures were only produced once (N = 189) or even between 2 and 9 times (N = 234). In fact, the full table for the structures vocalised more than 10 times across the data are given in Appendix D (see Section 8.4.1). Plus, the excluded productions were least representative of vocalisation patterns because they were not repeated as much, therefore they did not reflect stable patterns within a single infant or across multiple infants' vocalisations. Based on published research, it was predicted by H2 that the infants' syllables would be dominated by vowel-initial structures, liquids, and fricatives. Liquids (or supraglottal liquids) are sometimes considered as a semi-vowel because of their vocalic resonance and gesture during production, which may indicate that they functioned as compensations to alveolar stops in these instances. Glottals were allocated to their own category because they were so prevalent in the data and were required to clearly gauge the extent of glottal and supraglottal articulation sequence patterns along with the potential compensations at play. They were also valuable to integrate because much linguistic research does not incorporate glottals into vocalisation measures (e.g., VMS classification, and the acquisition of stops).

*Table 5.25: Vocalisation Composition and Frequency*

| **Number (ordered by most frequent)** | **Phonetic Pattern** | **Frequency** |
|---|---|---|
| **1** | GV | 2082 |
| **2** | SV | 605 |
| **3** | GVGV | 464 |
| **4** | GVV | 318 |
| **5** | NV | 226 |
| **6** | LV | 217 |
| **7** | GVLV | 205 |
| **8** | VLV | 174 |
| **9** | V | 173 |
| **10** | SVSV | 171 |
| **11** | GVSV | 141 |
| **12** | GVNV | 116 |
| **13** | VNV | 116 |
| **14** | GVGVGV | 114 |
| **15** | SVV | 100 |
| **16** | VSV | 98 |
| **17** | SVGV | 88 |
| **18** | VGV | 85 |
| **19** | NVNV | 72 |
| **20** | SVLV | 54 |
| **21** | SVSVSV | 52 |
| **22** | LVLV | 51 |
| **23** | LVV | 48 |
| **24** | NVV | 43 |
| **25** | N | 42 |

*Glottals: G, vowels: V, stops: S, nasals: N, supraglottal liquids: L.*

In Table 5.25 the 25 most frequent sequences are ordered in the left column from most to least vocalised, with data collated from all vocalisations. It reveals the G + V combination to be the most common structure, comprising 1/8$^{th}$ of all vocalisations, which reflects the predicted pattern (and is returned to in Section 6.1.2). This most-common trend of glottal initials was followed by a stop and vowel, then by a nasal and vowel. Taken together, 4/6 of the most common structures illustrate an overall trend. Most monosyllables were composed of a consonant segment in initial position followed by a vocalic segment, which was the reverse of what was predicted by existing research on CP productions and illustrates the typical composition of babble.

In fact, in relation to H3 only 1/10$^{th}$ of structures were vowel-initial, and while this pattern was not the mode and vocalisation sequences were not dominated by vowel-initial syllables, they were used enough to reveal a trend in the data. The presence of vowel-initial vocalisations could be due to the lack of available gestures within the infant's repertoire. The pattern reflects the properties of earlier typical trajectory stages (including protophones, consisting of vowels, as well as vocal play) and might indicate some deviance to the C + V typical default syllable by these infants. There is a distinction here in relation to the onset of sequences, too, given that ~10% of vocalisations being vowel-initial is in line with the CP literature. Furthermore, even though the remaining ~90% of vocalisation were not vowel-initial, they did not all begin with oral consonants, revealing a contrast to the typical babble structure (Oller and Eilers, 1988). Instead, the onsets had high occurrences of glottal and liquid initials, which accords with the predicted outcomes.

Furthermore, it was predicted that liquids would be very frequent because of their close articulatory proximity to vowels. This prediction was, to some extent, what the data reveals, with liquids occurring in 6 of the most common 25 vocalisation structures. However, within this formation, there was variation regarding its position within the vocalisation sequence. The liquids occurred frequently in initial and medial position (both post- and pre-vocalic), meaning that their positioning in vocal structures was more versatile than predicted. This versatility indicates, perhaps, that the ICPs were more competent in using these sounds with variety and it echoes variegated babble in this way. In sum, (contradictory to H3,) liquids were not the most dominant manner of articulation across the mode cross-group vocalisation pattern, but glottals and stops were, revealing these articulations to be most common. While glottal stops and fricatives were by far the most used consonant-like segment, supraglottal fricatives did not feature at all in the top 25 most frequent vocal sequences. This pattern is in line with the typical orders of acquisition (Nathani et al., 2006). While fricatives tend to be a feature of the vocal play stage, they are not acquired until later (approximately 3 years) in typically developing infants (McLeod and Crowe, 2018), which perhaps explains this pattern. While oral pressure consonants were not predicted to be so common, the potential reasons for these results will be returned to and evaluated later in Section 6.1.3.

#### *5.4.2.2 Syllable Inventories and Mean Babble Level*

The ten most common sound sequences for each MBL are given in Table 5.26. There were unsurprising distinctions between the phonetic elements in vocalisations depending on MBL due to the inclusion criteria (given earlier in 4.2.1), however sequential compositions of vowel categories and consonant gestures provide some valuable opportunities for expansion. Here, the distribution of broad vowel categories (front = R, mid = M, and back = B) and consonant gestures (glottals = G, fricatives = F, liquids = L, nasals = N, supraglottal, oral stops = S) is considered across the 4 MBL vocalisation types. The colours for each type are used to boost ease of reading the patterns.

*Table 5.26: Mean Babble Level and Phonetic Structures Across Most Common Vocal Sequences*

| | **MBL1** | | MBL2 | | MBL3 | | MBL4 | |
|---|---|---|---|---|---|---|---|---|
| | **Pattern** | **Freq** | **Pattern** | **Freq** | **Pattern** | **Freq** | **Pattern** | **Freq** |
| **1** | R | 80 | GB | 925 | SR | 313 | SBSB | 21 |
| **2** | B | 77 | GR | 846 | SB | 235 | SRSR | 16 |
| **3** | N | 42 | GBGB | 167 | NR | 133 | NSR | 13 |
| **4** | M | 15 | GRR | 166 | SRR | 54 | SBS | 11 |
| **5** | RB | 6 | GM | 154 | NB | 52 | BNSR | 9 |
| **6** | RR | 6 | LR | 139 | GBSR | 42 | SRS | 8 |
| **7** | RM | 5 | GRGR | 93 | SBGB | 35 | SRSB | 8 |
| **8** | M | 4 | GBLR | 48 | GRSR | 34 | SBNB | 7 |
| **9** | BB | 3 | LB | 46 | SM | 34 | SRNB | 7 |
| **10** | BR | 1 | BLR | 41 | GBSB | 32 | GRRSRR | 7 |

Table 5.26 illustrates the data, with single nasals being the third most frequent phonetic structure. Glottals mostly occurred in onset position (7/10) for MBL 2, whereas the vocal structures were more mixed between nasals, stops and glottals in MBL 3. The combinations were more versatile in the highest MBL level, with stops mostly occurring in onset position (8/10) and the presence of glottals was very rare. This finding was novel, revealing that the higher speech-likeness of vocalisations related to more flexible phonetic combinations. The frequencies and combinations of vowel and consonant types and, especially, their recombinability are explored further across the infants in Analysis III in order to address H3.

Table 5.26 also shows that nasals were present in all MBL categories except 2, making it the consonant-like element perhaps most consistent across all four columns. Additionally, medial vowels were particularly rare in all vocalisations, which is a finding contradictory to the typical pattern (documented by Chen and Kent, 2004). It indicates that the most common syllable sequences across all infants' vocalisations included vowels with a high articulatory contrast to each other. Diphthongs (coded as either RR or BB in Table 5.26) were only present in vowel only vocalisations or with glottals, the only exceptions to this trend being SRR in MBL3, and GRRSRR in MBL4.

As was reported in Analysis I, most vocalisations in the sample were from MBLs 2 and 3. For the lower MBLs, the most common 4 structures account for nearly all the phonetic combinations, whereas there was a wider spread in the frequency of different phonetic structures in higher MBL scores. This pattern indicates more exploration and reuse of different sequences across vocalisations in higher mean babble structure. This was a novel finding, showing that infants with more speech-like vocalisations also produced their selection of sounds in flexible, variable sequences, utilising a combination of vowels and stops, nasals and glottals respectively. This was reinforced by the emergence of closed syllables (for example in instances 4 and 6) in the MBL 4 structures that reflects a shift from C + V babble-like sequences, to early word-like sequences. Its significance is discussed further in Section 6.1.3.

Another progression across higher MBL scores was in the substitution of glottals in MBL2 for stops in MBL3. This shift maintains similar syllable structures, given that vowels remain the same in terms of placement, use of diphthongs or repetition of vowels across the vocalisation. Liquids were only common in MBL 2 categories, and, by extension, it is possible that liquids were also replaced by stops in later stages of vocal development (vocalisations with higher speech-likeness), as they do not appear to be a common trait of any other MBL. They may provide a template-like stepping stone to more speech like vocalisations in the same combinations with vowels (see the Discussion for connections to scaffolding explanations).

Together, these likely substitutions of glottals and liquids in MBL2 to supraglottal consonants in MBL3 could be evidence of phonetic remapping post-surgery. Glottal articulations do not require coordination of the palate in articulation and may function as replacements to the (typically frequent) alveolar and velar sounds, which were less frequent than bilabials. This explanation would signal a diversion in the typical emergence of consonant-like closures, perhaps revealing a shift that is evident from birth and in effect until the palate fully stabilizes/heals. Such an explanation illustrates *bootstrapping*, whereby the already acquired phonetic structures (e.g., glottal + back vowel) provide the template for the addition of new supraglottal elements (e.g., stop + back vowel, Abend et al., 2017). As such, this replacement process reveals a typical development mechanism being used for atypical phonetic articulations. To conclude, the change in presence of liquids over MBL levels contradicts H3. These latter two reflections were given further explanation in Section 6.2.

### *5.4.2.3 Syllable Inventories and Palatal Age*

The twenty-five most common sound sequences for each palatal group are given in Table 5.27 to explore the combination of sounds across different palatal ages. It presents the commonalities of consonant gesture types and vowels and is most valuable for assessing the cross-group trends but was not balanced for the vocal count differences within each infant's vocalisations. It instead brings together a more balanced selection of trends within palatal group (as a reminder, the mean vocal counts for each palatal group were as follows: Group 1, 1-3 months post-surgery = 333; Group 2, 3-5 months post-surgery = 272; Group 3, 6-9 months post-surgery = 320).

*Table 5.27: Phonetic Gestures Across Palatal Group Across Most Common Vocal Sequences*

| Number by Freq. | GROUP 1 | | GROUP 2 | | GROUP 3 | |
|---|---|---|---|---|---|---|
| | **Patterns** | **Frequency** | **Patterns** | **Frequency** | **Patterns** | **Frequency** |
| **1** | GV | 916 | GV | 547 | GV | 532 |
| **2** | GVGV | 243 | GVV | 190 | SV | 175 |
| **3** | SV | 218 | SV | 189 | GVGV | 118 |
| **4** | GVLV | 109 | GVGV | 83 | NV | 101 |
| **5** | LV | 102 | SVV | 66 | SVSV | 82 |
| **6** | NV | 67 | NV | 55 | VLV | 74 |
| **7** | GVNV | 57 | LV | 46 | GVLV | 68 |
| **8** | GVSV | 57 | VLV | 45 | V | 61 |
| **9** | GVV | 54 | GVSV | 37 | GVV | 60 |
| **10** | GVGVGV | 52 | SVSV | 35 | LV | 58 |
| **11** | SVSV | 51 | NVNV | 30 | VNV | 45 |
| **12** | VLV | 43 | V | 28 | VSV | 43 |
| **13** | SVGV | 38 | GVGVGV | 27 | GVSV | 42 |
| **14** | VNV | 37 | VNV | 27 | GVNV | 37 |
| **15** | VSV | 33 | SVGV | 22 | VGV | 32 |
| **16** | SVSVSV | 29 | GVLV | 21 | GVGVGV | 31 |
| **17** | VGV | 28 | GVNV | 21 | NVNV | 26 |
| **18** | V | 27 | VSV | 21 | SVLV | 26 |
| **19** | LVLV | 22 | NVV | 19 | SVGV | 23 |
| **20** | N | 21 | VGV | 18 | LVLV | 21 |
| **21** | SLV | 16 | LVV | 16 | SVV | 20 |
| **22** | SVLV | 16 | SVVSVV | 14 | LVV | 17 |
| **23** | GVLVLV | 15 | LVSV | 13 | N | 17 |
| **24** | NVNV | 15 | GVVLVV | 34 | SVSVV | 17 |
| **25** | VSVSV | 14 | SVLV | 12 | GVN | 16 |

Table 5.27 shows consistent vocalisation lengths over the three palatal ages. While there are a few shorter vocalisations in Group 1, indicating consistency with Section 5.3.2.2 in that infants were more likely to produce shorter vocalisations sooner after surgery even though this finding

is slight. The table also reveals that there was repetition of one consonant category in 21/75 cases, indicating a typical feature of CP canonical babble because this pattern was a present trend across all palatal ages. Of the 32 vocalisations with only 1 consonant-like element, 19 of them were comprised of a CV or CVV[3] structure, again illustrative of a template that mirrors the typical trajectory. Diphthongs were determined by their audible syllabic presence and were guided by the waveform in ELAN; in cases where there was a weak glottal boundary, this was coded as ‘C’ because ICPs are likely to have glottal compensations (see sections 4.2.1.3, 4.2.1.5, 4.2.2, and 4.2.2.1 for these details). The majority (72/75) of vocalisations were vowel-final, illustrating the typical pattern, but much fewer of them were vowel-initial (15/75). While the latter result was not as dominant as the predicted pattern, vowel-initial sequences were a feature of vocalisations irrespective of palatal group. This pattern is of interest because, while it is a trait of vocalisations in this population, it was the reverse of the emergent babble pattern along the typical trajectory and reveals a contrast to typical vocalisation compositions. The implication of more-than-typical vowel initial productions is expanded on in Section 6.1.2.

The G + V structure was the mode across all three groups, with the monosyllable being most frequent, and with 300 + more productions than the second most common sound sequence, meaning that palatal age did not affect this pattern greatly. As was introduced in Section 5.4.2.1, it could be that the use of glottals with a vowel here mark the process of substitution or were targeted supraglottal consonants, or in other words, an unformed opening gesture. Such a pattern may relate to palatal ages as well as MBL, or it might be that the target vocalisation was in vowel initial/vowel only syllables, but glottal reinforcement was used as a mechanism to initiate phonation. A future study maintaining a focus on target forms and phonology would be necessary to address this, as the present exploration of vocal data does not assess these explanations directly.

Diphthongs were rare, equating to only 12 instances across the most common 75 vocal sequences. Liquids were more present in groups 1 and 2 than 3, however this difference appears to be marginal. To contrast, in groups 2 and 3, the stop- and nasal-initial syllables were more common than in Group 1, indicating that, these vocalisations often include a more speechlike element at the onset of the vocalisation, and mirroring the patterns overviewed in Analysis I and Analysis III indicating palatal age to be a predictor of MBL. Given that there were mixed differences in the phonetic structures depending on consonant categories, next, is an exploration of the most common structures across all mono-trisyllables, with more detail on

[3] For a reminder of when the number of syllables were discerned, see Section 4.2.1.5.

broad vowel categories. Other than the vowel categories (R = front, M = mid, B = back) the symbols in the *Sequence* column relate to the original IPA transcriptions. While there were hundreds of exact combinations using these categories, comparing the most common exact examples allows a fine-grain view of the sample.

*Table 5.28: Most Common Sequences: Phonetic Gestures and Vowel Types*

| | **Sequence** | **Frequency** |
|---|---|---|
| **1** | bR | 164 |
| **2** | bB | 141 |
| **3** | ʔR: | 100 |
| **4** | B: | 70 |
| **5** | dR | 54 |
| **6** | BhB | 38 |
| **7** | ʔB | 34 |
| **8** | BwR | 27 |
| **9** | dB | 24 |
| **10** | dRdR | 24 |
| **11** | BmR | 23 |
| **12** | bR: | 35 |
| **13** | bB: | 20 |
| **14** | bBhB | 20 |
| **15** | bRbR | 19 |
| **16** | BwB | 19 |
| **17** | BmB | 18 |
| **18** | dR: | 27 |
| **19** | BgR | 16 |
| **20** | ʔRM | 15 |
| **21** | bM | 14 |
| **22** | bRB | 12 |
| **23** | BwM | 12 |
| **24** | bBbB | 11 |
| **25** | bwR | 11 |

Table 5.28 reveals that /b/, /ʔ/, /d/, and /h/, were the most common consonant articulations. It also shows that the labial stop + front vowel was the most common articulation, which was closely followed by the labial stops + back vowel structure. It was predicted in H2 (see Section 2.6.1 for reference) that the infants would have a reduced number of stops, given existing findings, (e.g., Zajac et al. 2021, who found that 12-month-old ICPs, had smaller consonant inventories that were composed of fewer liquids and stops). The present data contradicts this hypothesis, given that labials dominated the supraglottal, consonant-initial articulations. On the

other hand, the third and fourth most common phonetic sequences were more aligned with the predicted outcomes. The glottal stop + front vowel, and the back vowel only, are illustrative of more rudimentary, non-speech-like vocalisations, and were not much less frequent than the supraglottal vocalisations.

A notable contrast to the typical trajectory was the combined use of supraglottal articulations with central vowels. In typically developing infants (between 7 and 10 months), labials + mid vowels and velars + mid vowels are most present in emergent babble (Chen and Kent, 2005), however, here there was instead a clear absence of mid vowels, a pattern which was evident across Table 5.28. Plus, velars were not common, which highlights two contrasts to patterns in the typical trajectory, regardless of any delayed production patterns. Table 5.28 illustrates an inverted pattern regarding the production of vowels in conjunction with any consonant-like segments. Rather than centralised vowels, the front and back vowels were most common across all MBL scores and palatal ages, and in fact, it was only in the higher MBL scores and oldest palatal age where mid vowels began to emerge, contrary to H2. A possible explanation for this was that the front and back vowels had high contrast to each other, making them more discernible from one another given that these require more articulatory movement as they are furthest apart in the oral cavity.

To summarise sections 5.4.1 and 5.4.2 together, Table 5.29 collates the findings so far in Analysis III in relation to the typical trajectory.

*Table 5.29: A Summary of Cleft Palate Vocalisation Patterns in Relation to Typical Patterns*

| | *Production Pattern* | *Hypothesis* |
|---|---|---|
| *Deviant* | Low occurrence of mid vowels and high occurrence of fronted and backed vowels | H2 |
| | Low occurrence of velar articulations | H2 |
| | 1/10$^{th}$ of structures were vowel-initial | H2 |
| | Glottal + Vowel was the most common syllable | H3 |
| *Delayed* | Potential substitutions of glottals and liquids in MBL2 to supraglottal consonants in MBL3 | H3 |
| | There was more vowel harmony than consonant harmony | H2 |
| *Typical* | Supraglottal fricatives did not feature in the top 25 most frequent structures | H3 |

While the data presented here on the most common syllable sequences offers compelling insight into alike patterns in the vocalisations of the ICPs, this section has only reviewed the most frequent, specific phonetic instances. In order to consider the research aims fully, the following section presents detailed statistics on the sequential features of all vocalisations from the whole pool of data.

### 5.4.3 Transitional Probabilities

This section builds on the understanding of the compositional and the sequential characteristics (i.e., the order of sounds) in vocalisations to assess the extent to which the sequential features of non-canonical, canonical, and true canonical syllables were consistent with published vocalisation patterns and therapeutic aims following CP repair. The sequences of phonetic elements are presented in this section in a selection of graphs using transitional elements (referred to as matrices) to view large amounts of data in an accessible way. The analysis will present how visualisation of transitional probabilities (as were introduced and evaluated in Section 4.3.2.5) extends the prior analyses in this thesis to summarise and reveal new insights into CP production patterns.

The value of transitional probabilities in this research is to view the phonetic elements in vocalisations at the sequential level, whereby the phonetic sequences are presented using transition matrices, allowing us to analyse sounds in context rather than in isolated sound repertoires. As discussed in Section 4.3.2.5, a transition matrix is a graph, which presents the probabilities of one sound occurring next to another. These transitional probabilities quantify the likelihood of sounds transitioning from one sound to another. The ‘>’ symbol denotes the start of the vocalisation, and the ‘#’ symbol indicates the end of a vocalisation. Thicker lines denote higher likelihoods (though they are to be treated carefully as darker colours might look thicker) and are paired with a probability value. Each oval is referred to as a ‘node’ and the total probability value that can exit each node is 1. For instance, if every syllable in the data began with a vowel, the line between the start and V would be thick and have a value of 1, because there was a 100% probability that vowels would occur at the start of the vocalisation. Any values under .01 were excluded from the visualisations to improve readability, and because their frequencies were so low that they did not reflect the cross-group trends sufficiently.

To overview the data in their sequential detail, transitional graphs were generated. Throughout this section, these graphs are presented using a range of subsets and groups of the data in order to examine the relationships considered by this thesis. In the figures, all syllables are categorised into consonant types (glottals, liquids, fricative, stops, and nasals) and vowel positions (front, mid, and back). The consonant categories allow for distinctions between non-canonical (with all glottals and all liquids) and canonical vocalisations (with all fricatives, stops, and nasals). The letters in Figure 4.36 (as well as all further transitional graphs) are henceforth assigned these categories: G = glottals, L = liquids, N = nasals, S = stops, F = fricatives, R = Front Vowels, M = Mid vowels, B = Back vowels. The colours do not indicate any consistent variables but are given for the readability of multiple lines. Figure 5.32 summarises the transitional probabilities from mono-trisyllables across all vocalisations.

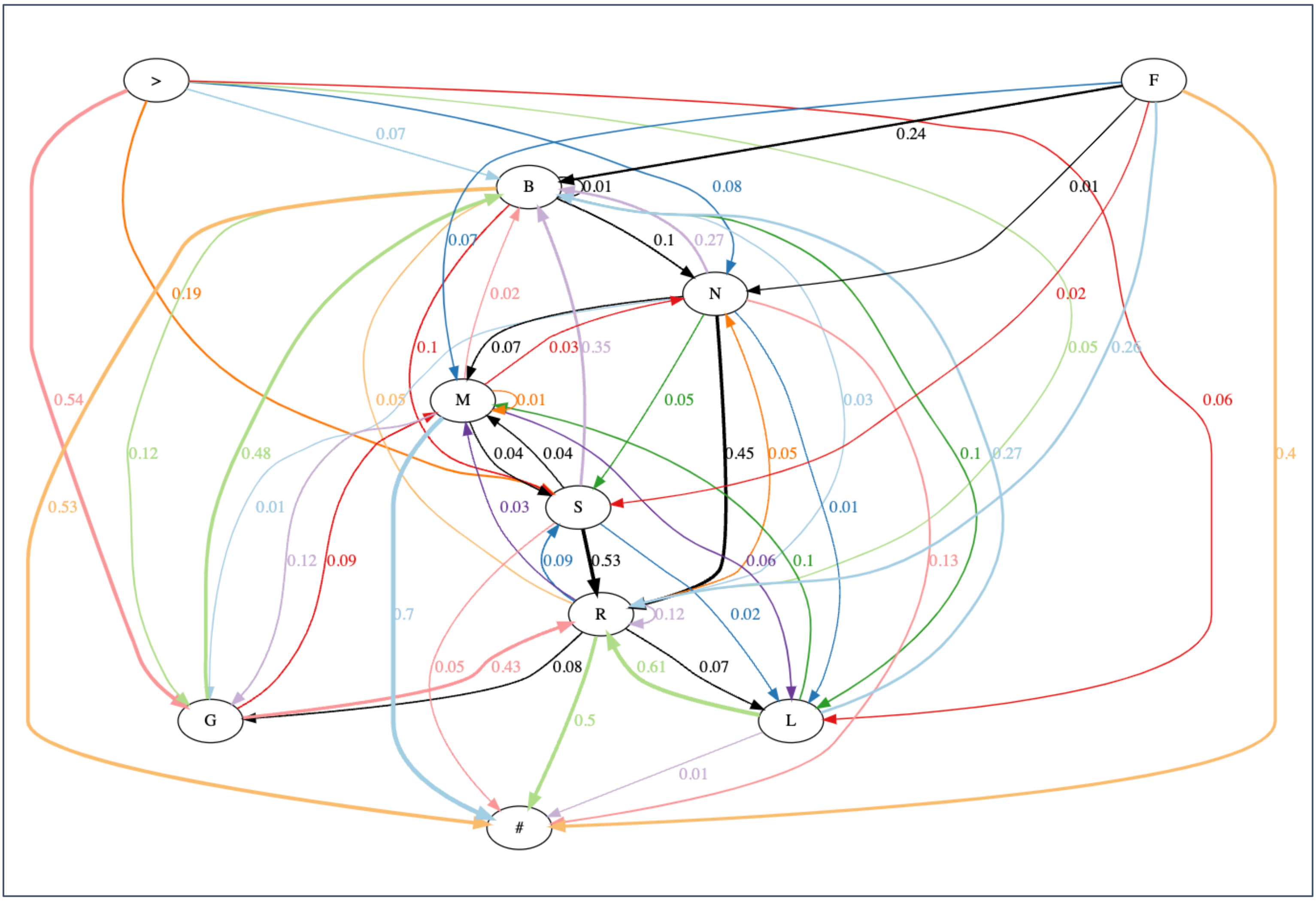

































































*Figure 5.32: A Transition Matrix of Phonetic Elements from All Vocalisations*

Figure 5.32 shows that the most common sound in onset position was glottals, represented by the thickest line (and highest value), with 54% of the whole data. This high frequency of glottals indicates that even vocalisations with supraglottal articulations within them were initialised with a glottal production, which is in line with the data presented in sections 5.2 and 5.3. The second most likely sound in onset position across all vocalisations was the stop (.19), indicating that a fifth of the vocalisations were stop initial, suggesting a contrast to the expectations of H2. The likelihood of the remaining sounds was much lower (<.01 to N, L or B), given that the sample of infants under exploration are known to have difficulty with stops (Eshghi et al., 2017; Lee et al., 2019). The probabilities here mirror the clinical literature overall because their presence of stops was greater than liquids and vowels in initial position, which tend to be the formation of rudimentary forms (see Section 2.2.2), and as such the sequences that stop-initial productions paired with are expanded on below. Glottals, stops, and liquids were mostly followed by the front or back vowel, with the mid vowel being much more uncommon overall, including at the onset of vocalisations, where it did not occur.

Back and front vowels were most present in the vocalisations, and medial vowels were much less present. However, when they were produced, they were mostly in final position. 14 % of vowels were diphthongs. A high proportion of vowels were in final position, with them most likely to occur at the end of a vocalisation. This trend was most evident in mid vowels (.7), followed by back vowels (.53), and then front vowels (.5). Additionally, nearly no consonant-like elements occur in final position, meaning that the open-ended syllable (e.g., C + V) was the most common structure. Similarly, and in line with the inability for glottals to occur at the end of syllables, glottals never occurred in final position, and liquids were very rare at the end of vocalisations too. The probable patterns from all vocalisations largely mirrored those in mono-trisyllables (see Appendix D in Section 9.4.3) and given that these constituted nearly all the vocal data, the following graphs represent this subset of data only.

#### *5.4.3.1 Transitional Probabilities and Mean Babble Level*

First, for MBL 1, as foregrounded by Analyses I and II, isolated monophthongs were most frequent, with single nasals being the third most frequent phonetic structure. The front and back vowels were the dominant vowel articulations (.80 and .77 respectively), with mid vowels being much less frequent (.15).

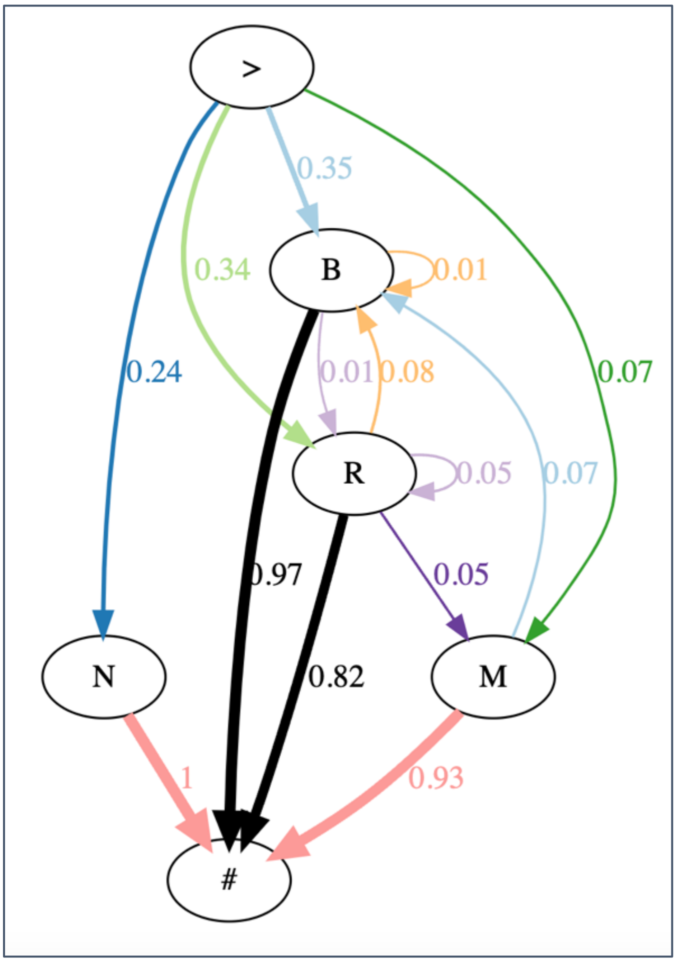



*Figure 5.33: A Transition Matrix Illustrating the Phonetic Sequences in MBL 1*

Figure 5.33 captures the phonetic details from all MBL1 vocalisations. It highlights that most articulations were front and back vowels (.34 and .35 respectively). These high contrast vowels appear to be most frequent in MBL1 vocalisations, with nasal articulations totalling nearly a quarter of this vocalisation category, which indicates a contrast to the predicted dominance of mid-vowels from H2. Furthermore, the figure shows that MBL1 vocalisations most closely resembled the reflexive vocalisation stage (Nathani et al., 2006 and Iverson, 2010) along the typical trajectory, thus the high proportion of shorter vocal strings visible here was predictable, given that all but the diphthongs were composed of one element. All the infants' MBL means were above 2, therefore MBL2 is considered next.

Figure 5.34 illustrates that 83% of vocalisations were liquid and glottal-initial, marking maturation from MBL1, and illustrative of the vocal play stage (Papaeliou, Minadakis, and Cavouras, 2002 and Vihman, 2014).

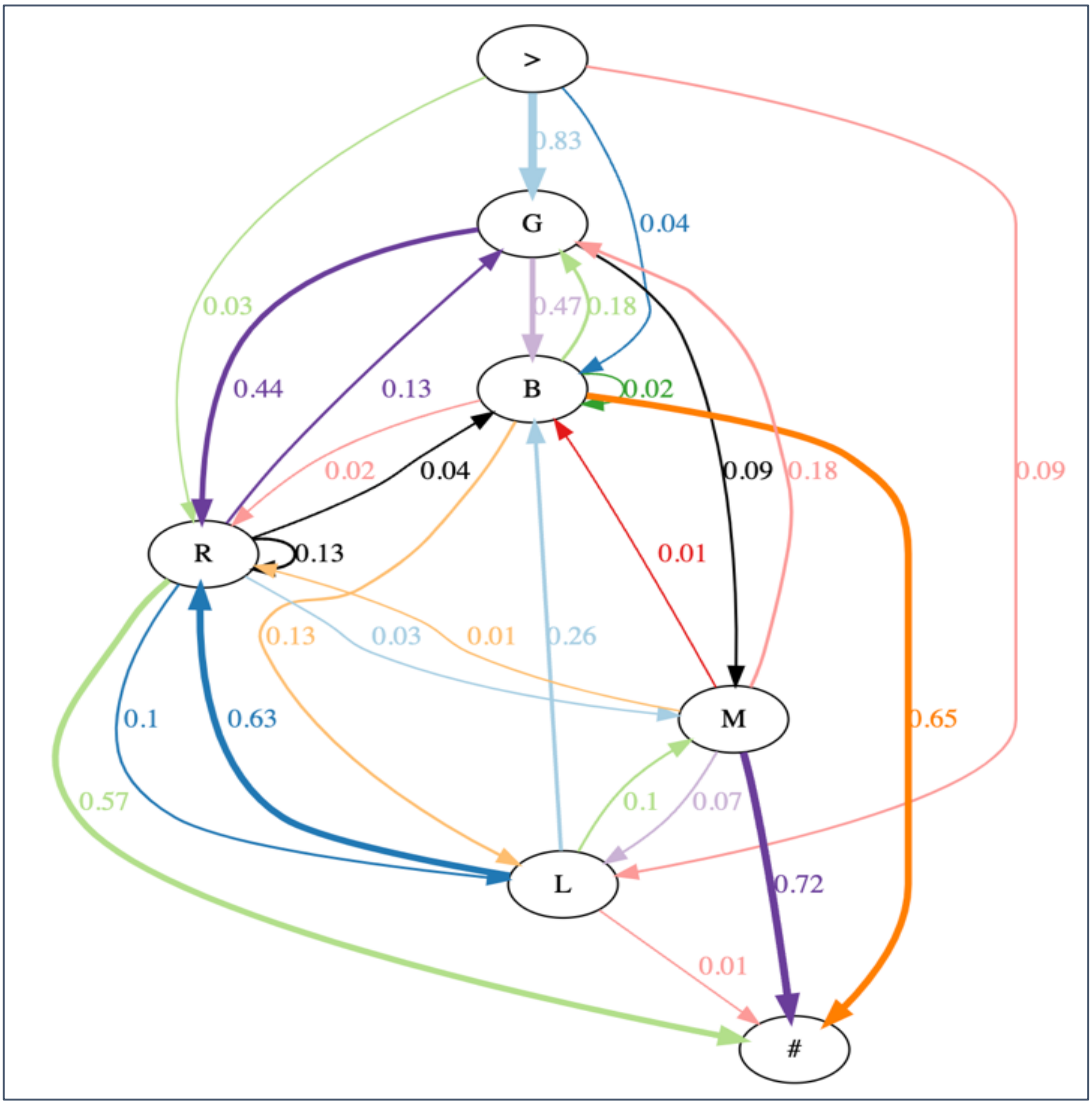




*Figure 5.34: A Transition Matrix Illustrating the Phonetic Sequences in MBL 2*

More specifically, it shows that 7% of MBL2 structures were vowel-initial, a pattern that was lower than the predicted trend from H3. Only 15% of vowels included a diphthong, which taken together indicate that MBL2 vocalisations tended to include one vocalic component after a liquid or glottal, and in 1/5 of instances were followed by glottal stops or glottal fricatives in medial position as part of a di- or tri-syllable vocalisation.

In addition, for MBL2 structures, glottals mostly occurred in onset position (83%), and, as in MBL 1, front and back vowels were much more common (illustrated by the higher probabilities of them occurring after glottals in initial position). Also, on the rare occasion that mid vowels were produced in this babble level, they only occurred in mid or final position, unlike the other two vowel categories, perhaps indicating that this later to emerge—or less frequent—vowel type was only produced in conjunction with elements that were more stable within consonant categories, and would not occur in isolation, even if they were a rarer sound. These outcomes were again not predicted by the hypothesis, possible explanations for the low presence of mid vowels are discussed in Section 6.1.2. The transitional probabilities at this level set a basis for the higher MBL vocalisations that were more speech-like, too, in case they present a contrast to this trend in common vowel placements.

For MBL3, there was a shift in the most likely onset phonetic segment; the most common pattern was stop + vowel.

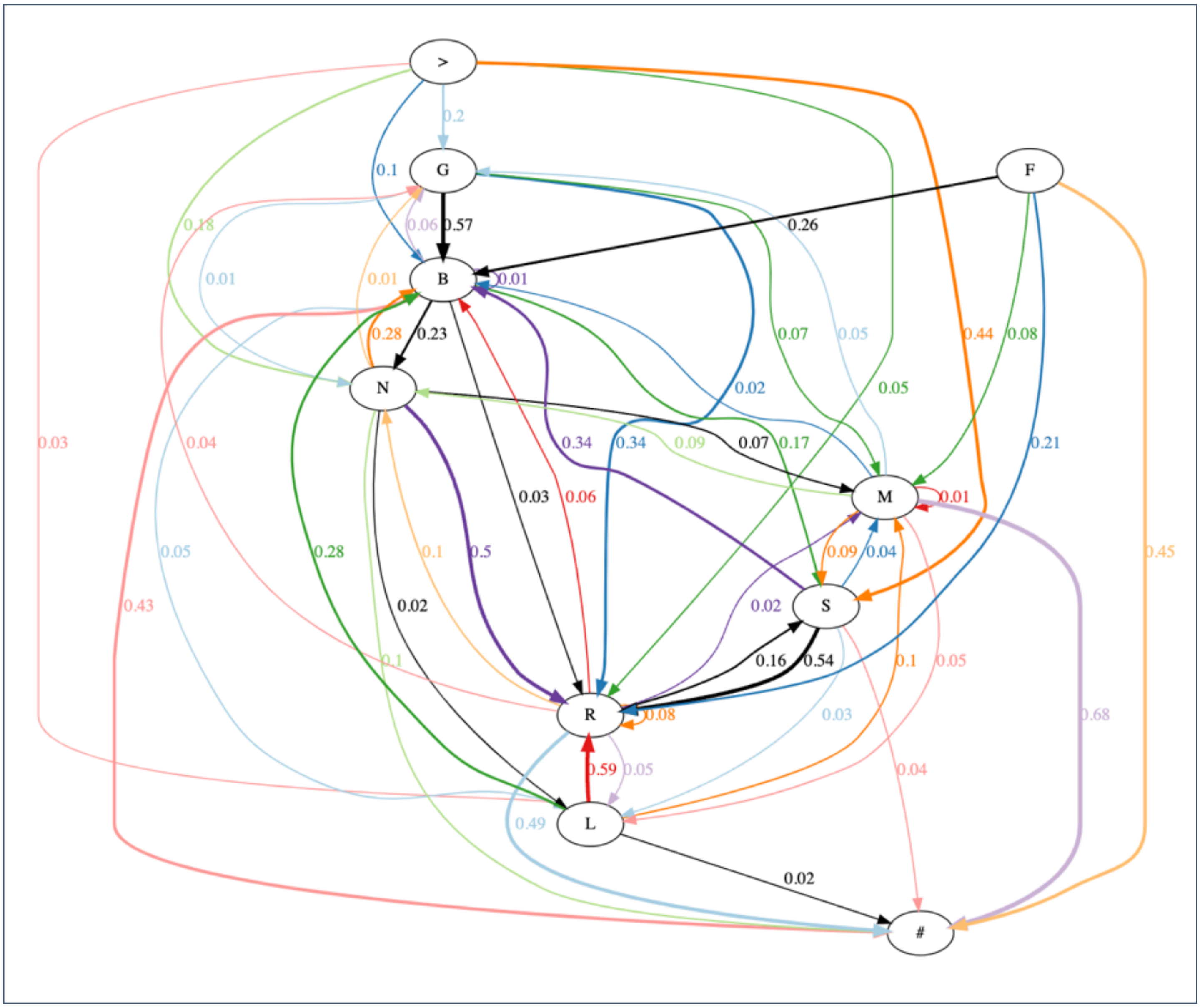



*Figure 5.35: A Transition Matrix Illustrating the Phonetic Sequences in MBL 3*

Figure 5.35 shows that fricatives were very infrequent (<.1) in initial position as well as any other position (as there were no arrows pointing towards the F node), but within their infrequent occurrences, they were followed by a vowel, or were the stand-alone bilabial fricative. Glottals were more common and did occur in initial position (20%), followed by nasals (18%), and then either back or front vowels (15%). Nasals were mainly followed by vowels (which total to 87%) and were mostly produced in medial position. While nasals were more common in final position than stops, they were relatively infrequent at the end of vocalisations, meaning that most vocalisations ended in (front and back) vowels, which is a structure that mirrors typical babble well.

The notable shift between MBLs 1 and 2 to 3, is not just the presence of supraglottal articulations, but is the mixture of nasals, stops and glottals in MBL 3 which indicates a more stepwise increase in the combination of sounds at this babble level. This mix of consonant types appears to increase and diversify as MBL increases. Such a pattern suggests the reuse—or continuation—of rudimentary forms with supraglottal consonants in MBL3 when compared to MBLs 1 and 2. This pattern also reflects a minor deviation from the typical tendency here within canonical babble features, because the collection of sounds is more integrated across gesture type than the typical oral stop emergence.

Figure 5.36 visualises that it was more likely that there would be a wider variety of sound sequences in the most speech-like vocalisations.

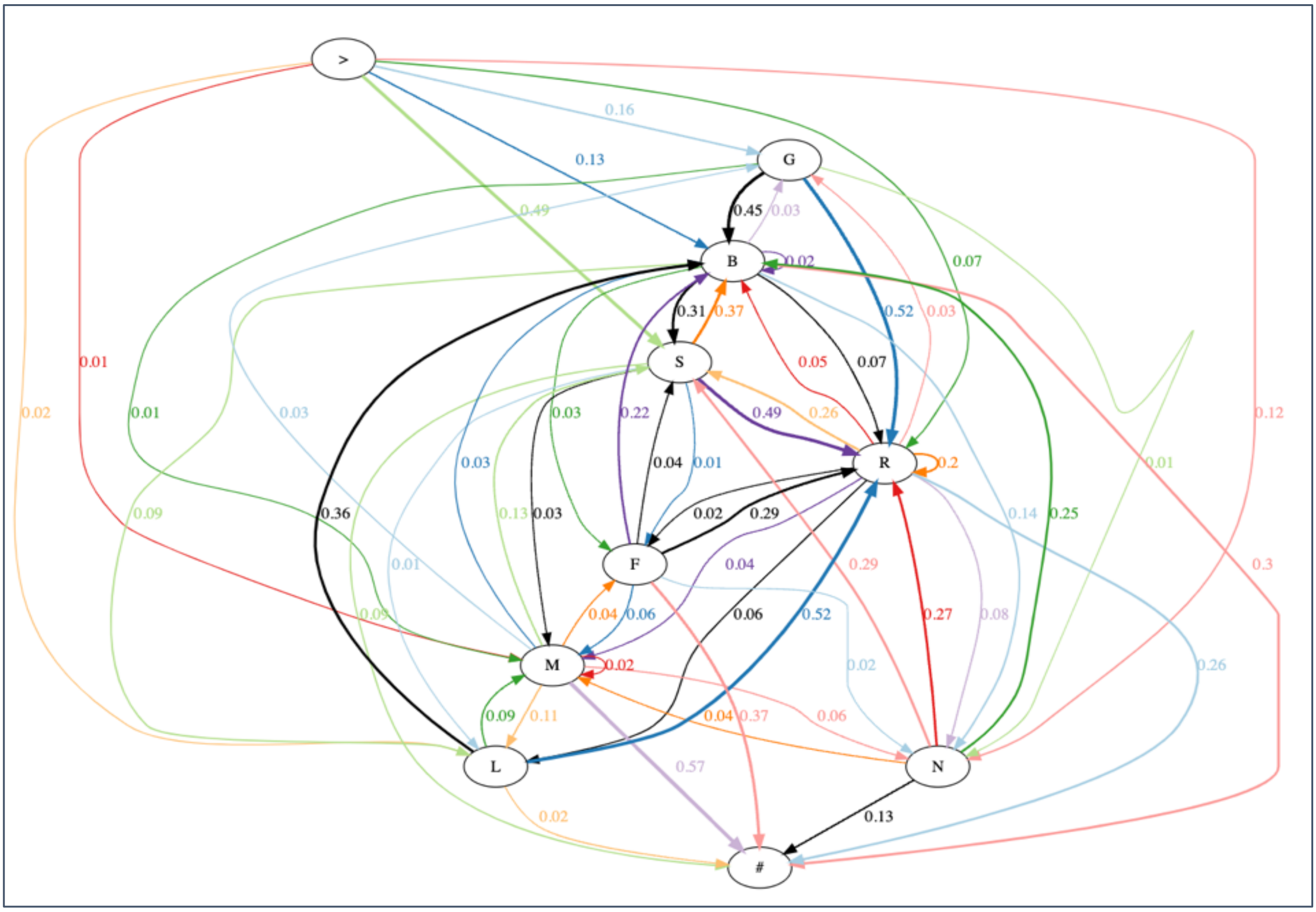


*Figure 5.36: A Transition Matrix Illustrating the Phonetic Sequences in MBL 4*

Figure 5.36 indicates that non-glottal stops occurred most in initial position, a trend that is inconsistent across the other three MBLs but illustrates a steady decline in glottal initials as MBL increased. Next, supraglottal consonants occurred more than previous MBL scores in initial position and were used substantially more than vowels in this sequence. In such instances where MBL4 vocalisations were vowel initial (.21), they were mostly initiated by back vowels. Vowels overall, however, were favoured in final position.

More specifically, the vowels that followed true consonants (S) were most likely to be front vowels, then back vowels, and lastly mid vowels. However, despite being the rarest vowel type, when mid vowels *were* produced, they followed nasals and fricatives, interestingly revealing that it was rarer that mid vowels would occur after glottals and liquids and more likely to occur with a supraglottal articulation, (i.e., a more mature one) despite being a rarer sound overall. Therefore, there was a higher likelihood of G-R and G-B syllables, which exemplifies high vowel contrasts to be a highly probable combination, as the vowel was either closest in tongue placement or furthest away at the front to the consonant release.

Of the vocalisations with 2 + supraglottal consonants, nearly half had a stop in onset position, whereas one third had either a glottal or liquid in initial position. These transitional probabilities reflect a shift from MBL3 as they point to glottals being a less effortful onset of the vocalisations that include more complex, supraglottal articulations. Similarly, to the frequent G + V sequences, stops were followed by F vowels (with a probability of .49) and B vowels (of .37), which reinforces earlier patterns and shows deviation to the typical vowel productions (given in Section 5.4.2.2). The remainder of phonetic elements in initial position were split evenly across nasals and vowels, indicating these elements to be rarest in initial position in the more speech-like babble level.

To conclude, this section of Analysis III shows that the more speech-like (MBL4) vocalisations were, the more variety there was between different phonetic sounds, as we would expect. This finding means that infants who produced a greater number of supra-glottal sounds also produced more combinations of C + V sequences, which illustrates higher articulatory coordination. It was evident from the greatest number of lines between nodes in the transitional probability matrix when compared to the lower three MBLs, and also by the higher probabilities between nodes. In drawing connections between the transitional probabilities across MBL levels, and the outcomes from Analysis II, we can confidently accept H2, that the relationship between canonicity and VMS consonants, and also H3 that infants with higher babble levels (e.g., variegated vocalisations as are evident in Figure 5.36) also have a wider range of emergent consonants and VMS consonants than those with lower MBL scores.

### *5.4.3.2 Transitional Probabilities and Palatal Age*

Lastly, here the transitional probabilities are considered across the palatal ages, to assess whether, when we look at the entire data together in these phonetic categories, any other sequential patterns were present based on palatal age.

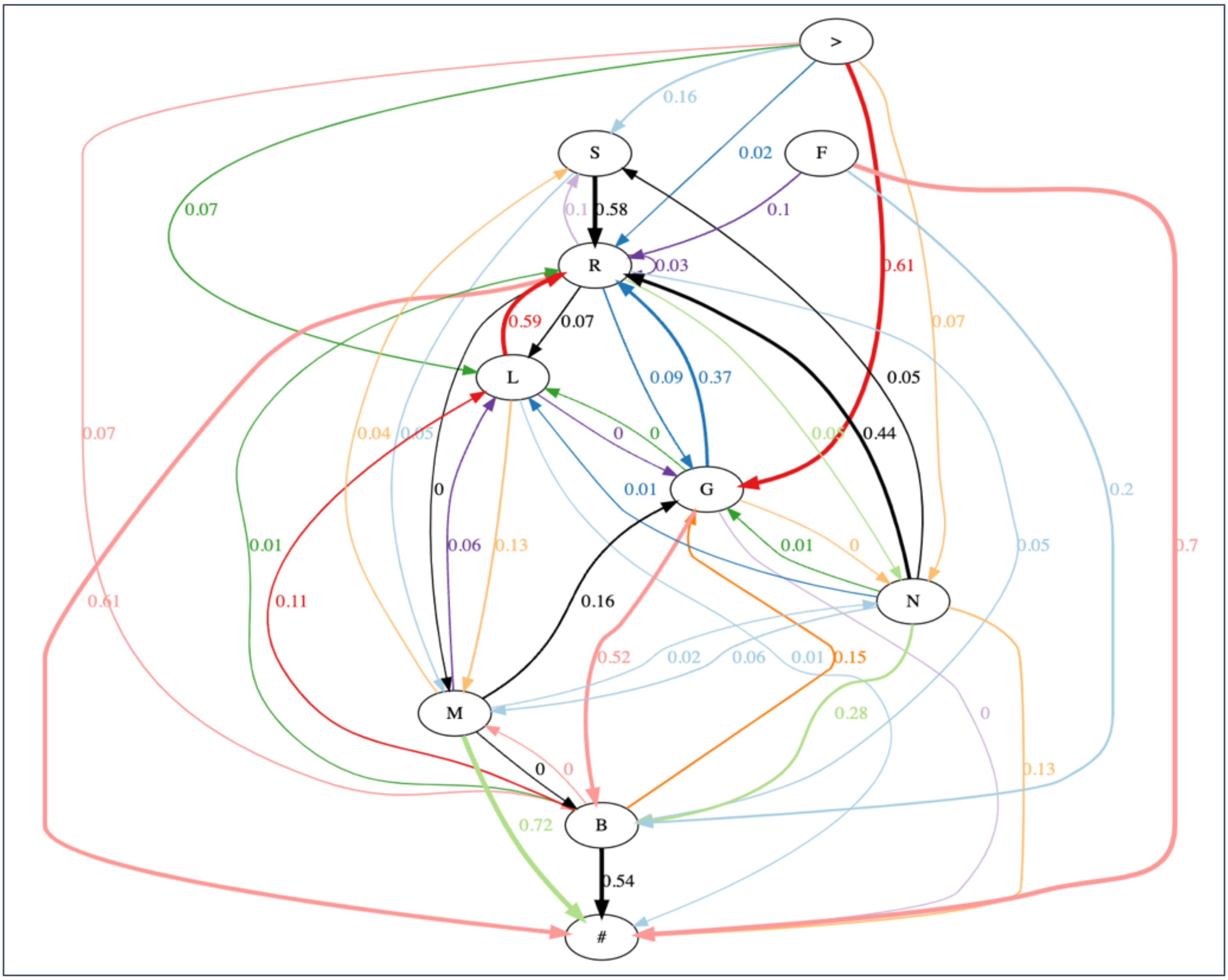



*Figure 5.37: A Transition Matrix of All Phonetic Segments in Group 1 (1-3 Months Post-Surgery)*

Figure 5.37 presents that it was most likely that vocalisations were liquid or glottal initial in Group 1, which was followed by stops and vowels (both equally likely to occur in onset position), perhaps indicating that true consonants were not yet being produced in a typical babble structure. In fact, vowel-initial structures were as frequent as stops, which reveals a pattern that reflects the vocal play stage in the typical trajectory (e.g., a stage prior to the canonical babble stage, but beyond protophones) because stops did occur as did nasals. When we look at the lower frequencies of nasals and stops, this figure paints a similar picture.

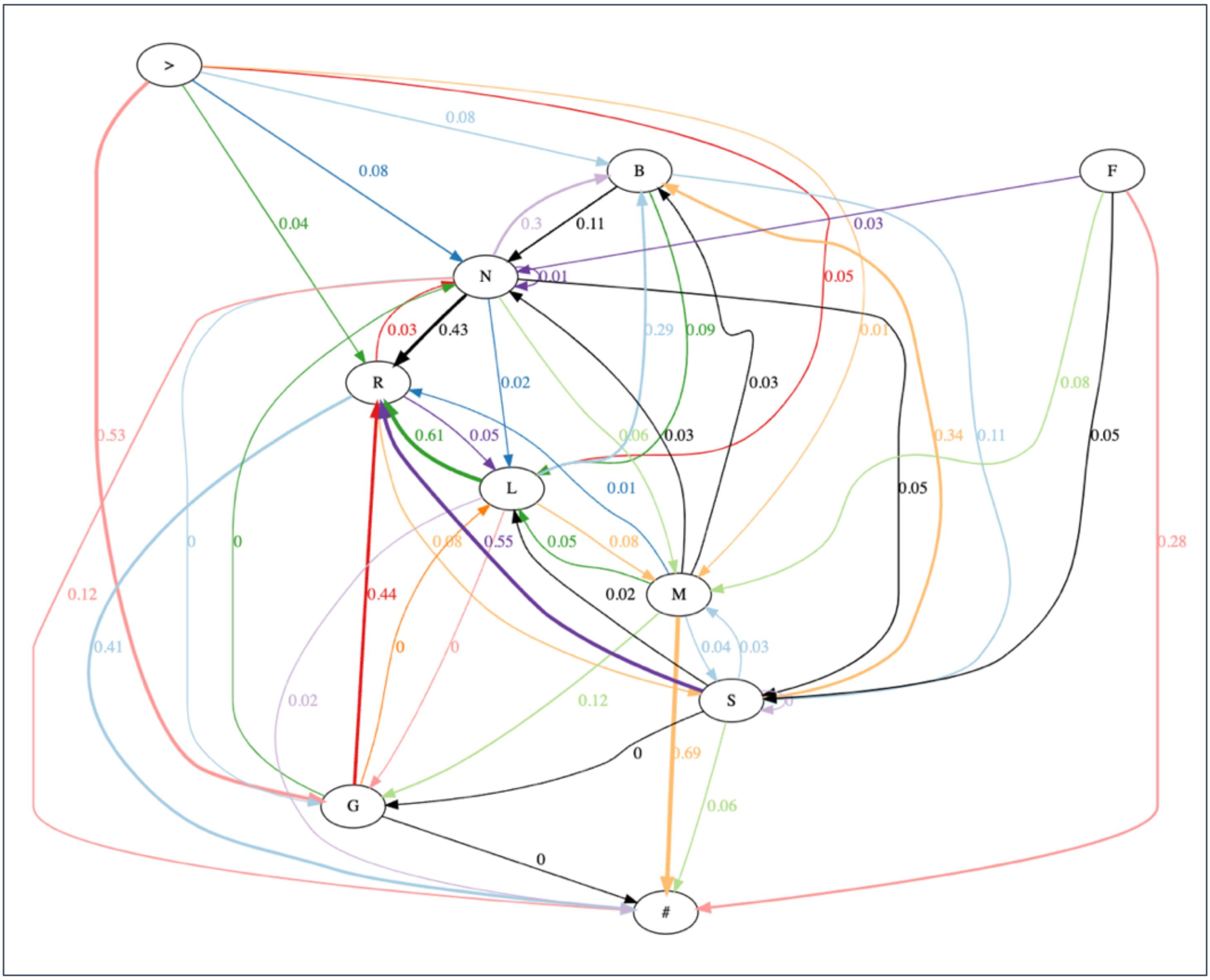



*Figure 5.38: A Transition Matrix of All Phonetic Elements in Group 2 (3-5 Months Post-Surgery)*

Figure 5.38 presents the results for Group 2, the most likely onset of vocalisations was glottal-initial, followed by nasal-initial, closely followed by vowel-initial. Stops were not common in initial position here. Interestingly, this indicates that while statistically there was a .82 probability that these structures would be consonant initial, only .29 of these were supraglottal releases, which are considered to be true consonants, and highlight a dip in the probabilities given for Group 1. This pattern therefore indicates that true consonants were similarly as likely in initial position as vowels, but glottal and liquids formed the main patterns here. It perhaps illustrates higher variability, and lower speech-likeness in vocalisations in the middle palatal ages, as was predicted by Analysis I.

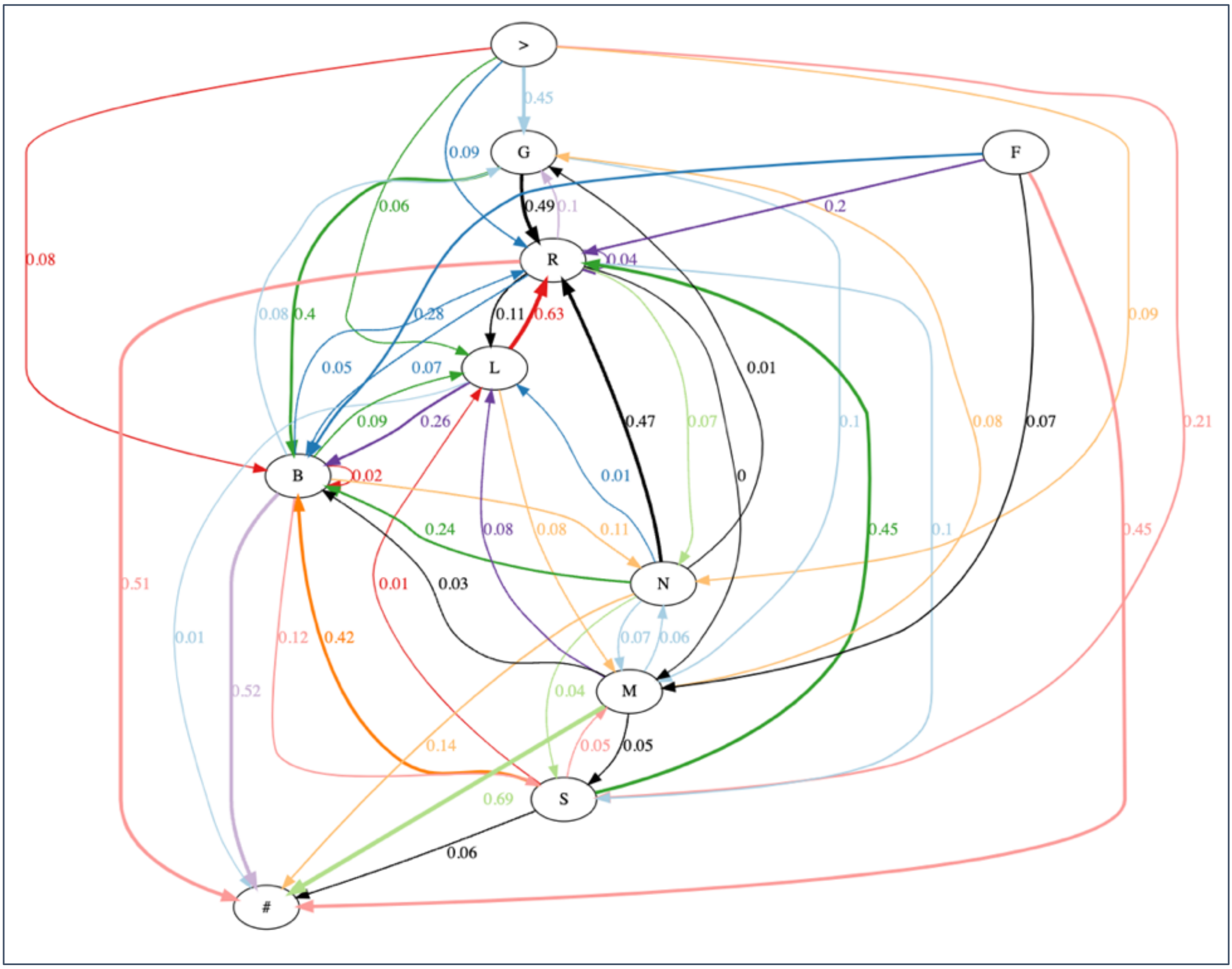



*Figure 5.39: A Transition Matrix of All Phonetic Elements in Group 3 (6-9 Months Post-Surgery)*

Finally, for Group 3, Figure 5.39 highlights fewer glottals and liquids than in Group 2, but also a minor increase in vowel-initial structures, a trend which was not visible from the data analysed in Section 5.4.2. Stop-initial vocalisations seemed to contrast across Group 2 and 3's vocalisations, however the trend that mid vowels seemed consistent in both its rarity and placement in final position holds in Group 3, as did the overall high likelihoods of vowels in final position. The distinctions between syllable composition and consonant transitions did not greatly alter depending on palatal age, and the data presented here on transitional probabilities mirrors the overall trends given in Section 5.4.2.3.

At a broad level, there was a clear increase in vocalisations with supraglottal consonants as palatal age increased, and there was a relative decline in the number of vocalisations without these consonants too. In addition, the usage of supraglottal consonants increased with palatal age, moreover, the position of supraglottals seemed to be much more flexible, too. As such, as MBL scores increased, the transitional probability visualisations reveal a more complex, integrated system of phonetic sequences, reflected by thicker lines between more nodes, as shown in Figure 5.39. This change to lower MBLs were not captured by the mean babble measure alone and therefore the value of viewing the results in this way foregrounds the method's value. The patterns across vowel placement remained consistent, illustrating that this analysis has presented some distinctions to the hypothesised outcomes, and some deviations to the typical trajectory, too. Namely, the contrasts to the hypothesis included the low presence of mid vowels, the low occurrence of vowel-initial structures, and the higher emergence of liquids and glottals when compared to the typical stop emergence at this time window, all contributing to the goals of this analysis.

### 5.4.4 Conclusion

In sum, Analysis III has explored the sequential elements of the 14-month-olds' syllables and Table 5.30 collates the explored findings.

*Table 5.30: Summary of Findings in Relation to RQ4*

| ID | *Palatal Age (in months)* | *Palatal Group* | *MBL* | *VMS Count (All)* | *VMS Count (True)* | *True Canonical Babble Ratio (TCBR)* |
|---|---|---|---|---|---|---|
| *1* | 7.33 | 3 | 2.56 | 6 | 2 | .46 |
| *2* | 7.23 | 3 | 2.01 | 2 | 0 | .15 |
| *3* | 7 | 3 | 2.59 | 4 | 2 | .52 |
| *4* | 6.13 | 3 | 2.8 | 8 | 3 | .56 |
| *5* | 5.87 | 2 | 2.83 | 6 | 4 | .63 |
| *6* | 5.03 | 2 | 3.01 | 5 | 3 | .63 |
| *7* | 5.67 | 2 | 2.35 | 3 | 1 | .37 |
| *8* | 4.83 | 2 | 2.51 | 0 | 0 | .28 |
| *9* | 6.7 | 3 | 2.34 | 1 | 0 | .34 |
| *10* | 4.17 | 2 | 2.62 | 5 | 2 | .57 |
| *11* | 4.90 | 2 | 2.47 | 4 | 2 | .34 |
| *12* | 5.17 | 2 | 2.6 | 2 | 0 | .41 |
| *13* | 4.23 | 2 | 2.14 | 2 | 0 | .15 |
| *14* | 4.10 | 2 | 2.74 | 5 | 2 | .61 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *15* | 4.73 | 2 | 2.54 | 1 | 0 | .5 |
| *16* | 3.43 | 1 | 2.9 | 5 | 3 | .74 |
| *17* | 3.89 | 1 | 2.5 | 7 | 3 | .47 |
| *18* | 2.37 | 1 | 2.16 | 2 | 0 | .52 |
| *19* | 2.7 | 1 | 2.18 | 3 | 0 | .2 |
| *20* | 2.63 | 1 | 2.51 | 6 | 3 | .43 |
| *21* | 1.77 | 1 | 2.17 | 3 | 1 | .24 |
| *22* | 1.30 | 1 | 2.3 | 3 | 1 | .27 |
| *23* | 6.03 | 3 | 2.21 | 1 | 0 | .32 |
| *24* | 11.45 | 3 | 2.84 | 7 | 4 | .56 |
| *25* | 9.03 | 3 | 2.52 | 3 | 1 | .51 |
| *26* | 2.37 | 1 | 2.32 | 2 | 1 | .35 |
| *27* | 6.03 | 3 | 2.57 | 7 | 3 | .5 |
| *28* | 2.83 | 1 | 2.33 | 2 | 0 | .29 |

Analysis III also revealed the following findings:

- Harmony was a prominent characteristic in vocalisations and indicated higher MBL vocalisations to have more systematic production of vowels. The presence of vowel harmony across vocalisations with multiple consonant segments marked a reflection of typical, variegated vocalisation (present in non-CP 8-12-month-olds). It may be a valuable guide for ICPs particularly before the variegated babble stage.
- The syllable inventories found (in more detail than Analysis II) that labials dominated the supraglottal, consonant-initial articulations with the labial stop + back or front vowel being the most common sequence.
- The low presence of mid vowels and velars, the latter of which did not pattern with any particular vowel, signified novel findings in relation to the typical and CP literature, and overall, the sequence inventories presented that where (consonant or vowel) sounds were not frontal or backed, the cooccurring element was, which potentially makes room for scaffolding explanations.
- There were changes in transitional probabilities depending on the vocal features, including a lower presence in glottals in older palatal age; increased connectivity between speech sounds in older palatal ages; and higher connectivity in higher MBLs, signifying more complex sequences in more mature, syllable productions.

The findings on vowel harmony may indicate when CP syllables have progressed from reduplicated syllables to more versatile, variegated combinations. As such, it provides evidence that, while higher MBL vocalisations resemble delay of approximately 4-8 months, they still mirror the typical syllable features of phonetic connectivity along with the boost in VMS and true VMS count highlighted by Analysis II. The findings reveal the use of recombinability in the productions, which is a necessary skill for acquiring proto-words and is evidence that some of these infants were producing speech-concurrent sounds.

Analysis III then examined syllable inventories, illustrating that phonetic sequences across different palatal ages and across VMS count were mixed, but that the sequential features of vocalisations across different MBL scores encourage simplification and bootstrapping explanations, which is new insight into the clinical population's vocalisations discussed in more detail later (see Section 6.1.2). Lastly, this analysis investigated transitional probabilities, a novel mechanism for investigating the phonetic elements of ICPs' vocalisations. The approach sheds light on whether their sequential components withstand the measures earlier shown as influential to development (e.g., MBL, palatal age, and VMS). It presented some clear trends, including a linear decline in glottal initials across palatal groups, and an increase in connectivity as palatal age increased. But, perhaps most interestingly, it found that some syllable patterns exhibit delayed mirroring of the typical trajectory, while others (prominently including the absence of central vowels and the presence of vowel initials) illustrate compensatory deviations to the typical production processes. This pattern was interesting as it indicates a lack of flexibility (or optionality) within the sequences that infants were producing, which could have a knock-on impact on their transition to early words.

While typically developing infants do produce non-target structures as well, these 'errors' are often predictable (Namasivayam et al, 2020, p. 11) because they mainly include simplification of multisyllabic target forms. There was some evidence of these predictable, conforming processes (a consistent commonality of G + V or C + V monosyllables), and the transitions between switching of glottals for stops). However, some patterns appear to be less systematically typical, e.g., the lack of central vowels in place of fronted and/or backed contrasting vowels, an overall absence of velar articulations, and a small trend of vowel initial structures. The formation of rudimentary structures is influential on the production of early words and were examined across palatal groups, MBLs, and the extreme points within the data. They show mixed comparisons to the structures from Ha and Oller's (2021) recent and novel finding of a vowel-consonant preference (in Korean-acquiring ICPs). The outcomes also give further detail to the compositional and sequential components syllables produced by ICPs, and—along with those from analyses I and II—will be brought together in Chapter 6 for a critical and theoretical discussion of findings to assess how they mirror the typical trajectory.

# 6 Discussion

This chapter critically interprets and presents potential explanations for the findings from Analyses I-III. It draws comparisons between the reviewed published studies in Chapter 2 and the results in Chapter 5 to examine the vocal behaviour of 28 infants after full CP repair. It proposes empirical and theoretical explanations for the phonetic, sequential, and combinatory properties of the vocalisations of ICPs post repair, and how these measures hold across palatal groups 1, 2, and 3 (that were 1-3 months, 4-5 months, and 6-9 months respectively post-op). The discussion will review the three hypotheses (see Section 2.6.1 for a reminder) in turn and provide an assessment of whether (and to what extent) vocal patterns echo those documented along the typical speech trajectory. It will also examine whether the actual usage of speech sounds in our naturalistic data aligns with published outcomes and begin to make suggestions for future work. Section 6.1 discusses the analytic results in line with the three subsidiary research questions, Section 6.2 addresses and fulfils the main research question.

## 6.1 Findings in Response to the Research Questions

This section presents a recap of the three subsidiary research questions (RQ2, RQ3, and RQ4) and their corresponding hypotheses, followed by the discussion of how all these findings feed into the main research question (RQ1), and what insight it can bring to the research field of the speech development of ICPs.

### 6.1.1 Research Question Two (Analysis I)

As seen in Chapter 2, RQ2 asks how the vocalisation measures of vocal count, vocalisation length, and MBL vary with palatal age, and whether the inclusion of these measures reveal new insights into typical infants' and ICPs' trajectory of known vocalisation patterns. H1 predicted that the ICPs' vocal count, vocalisation length, and MBLs (the measure for canonicity) at 14 months would be lower than typical amounts, and lower than measures that typically occur earlier. This prediction was fuelled by the influence of palatal age on vocal rates and by the age at onset of canonical babble in the population of ICPs (Ha et al., 2021, and Scherer et al., 2008). Specifically, H1 predicted that palatal age would be a better indicator of vocal count and vocalisation length than chronological age. Motivation for the relationship was encouraged by literature on how the age at repair impacts the timing of new sound emergence and size of phonetic inventory (Chapman et al., 2001, and Jones et al., 2003).

The results indicated that MBL variability was less stable in the 14-month-olds with more times since surgery at the point of data collection, revealing a contrast to the spread of variability in vocal count and vocalisation length across the sample. In fact, the variability across both vocal count and vocalisation length stabilised and appeared more systematic across the sample from 4 + months post-repair. This result indicates a more consistent window across the two measures post-surgery than was evident for MBL, after which there is a shift to variability in canonicity. This shift could mean that within the four-month timeframe post-op, infants are stabilising the amount of production, after which, their focus energy moves to the diversity of their productions.

Interestingly, palatal age was positively correlated with vocal count and MBL, despite the flexible variability across the measures. This finding reveals novel results to the literature, as the only known study to consider canonicity in this population at this timeframe (Ha and Oller, 2021) did not include English monolinguals in their sample. The Spearman correlation indicated that palatal age may explain some of the vocalisation length variation, too. The implications of these findings suggest that the impact of palatal age merits further consideration in future research. Infants' prelinguistic vocalisations can be highly variable (Hunter et al., 2019, Vihman and Keren-Portnoy, 2013), so the presence of variability in itself is unsurprising, but the window at which we can expect variability to decline (at palatal ages after 4 months) is consistent across the whole sample and may be a generalisable outcome.

In relation to RQ2, the results revealed that chronological age strongly and positively correlated to vocal count ($R(26) = .79$, $p = .053$), with a slightly weaker, but still moderate, positive relationship indicated between vocal count and palatal age ($R(26) = .41$, $p = .16$ ), providing the first contribution to the research hypothesis. Although chronological age had the stronger relationship of the two age variables, both of them provide evidence in favour of H1. The finding illustrates consistency with the clinical literature that palatal age may influence vocalisation milestones (Fell et al., 2022, Zajac et al., 2021) because the results hold across the vocal count of infants at 14 months. This outcome extends the impact that palatal age may have had on previous studies, as well as on the present results, thereby enforcing the importance of rehearsal on how vocal infants were. It also highlights a similarity between published patterns from clinical settings and this new evidence from naturalistic, at-home data.

In addition, the present findings reflect this relationship at an earlier stage than most published studies. The contribution of which includes novel findings suggesting that infants may capitalise on similar features to the typical mechanisms (including VMS and the babbling stages). Specifically, the moderate relationship between palatal age and vocal count foregrounds that the amount of rehearsal opportunity post-repair may in fact have a greater impact on (pre-)babble vocalisations than surgical age. It further establishes that in relaxed environments, infants may exhibit more advanced productions than in therapeutic settings, which should encourage research to integrate more naturalistic environments into future work, though noted are the practical limitations of this. It may also be that the guidelines on healing timeframes do not always directly impact all types of canonical sounds, and certain sounds may emerge within more typical timeframes than others. This line of enquiry is returned to in Section 6.1.2.

H1 also expected palatal age to predict vocalisation length. The findings from Analysis I revealed that palatal age did not significantly relate to vocalisation length, but illustrated that older palatal ages had a higher number of syllables per vocalisation than younger palatal ages. This trend is another novel outcome compared with the clinical literature and indicates palatal age to be relevant to the vocal count and vocalisation length measures explored by Analysis I. One possibility for this relationship is that higher palatal ages have more established breath control, which is an articulatory skill inherently required to produce longer vocalisation strings (as considered in sections 2.2.1) as well as a wider range of speech sounds. To continue, the finding aligns with the pre- and post-repair outcomes in the literature. Specifically, Hariharan et al. (2015) reported that ICPs who do not receive repair produce fewer polysyllables than monosyllables when compared to controls, a difference that declined over a 7-month window but was still evident at 18 months.

Analysis I presented evidence of tri-syllables in the dataset, but also that longer, continuous babble strings were overall considered as outliers. As such, the present findings present a mix in relation to the literature. Polysyllables typically require a medial consonant closure to separate vocal elements, which could be an articulatory skill is needed before first words. By this explanation, the shorter, monosyllabic vocalisations produced by infants with younger palatal ages in the sample could highlight lower rehearsal of consonant closures. It could also be that the lower presence of polysyllables imply that these infants had fewer options (and lower abilities) to separate vowel elements within a vocalisation, which would result in shorter productions, and fewer reduplications of typical, consonant-onset babble productions. The relationship between palatal age and vocalisation length therefore implies that younger palatal ages were less likely to produce consonants in medial position.

The low occurrence in polysyllables is of interest regardless of whether vocalisations were canonical, or un-canonical, because semi-vowels (or liquids) were captured in non-canonical productions in the data. It might be that palatal age impacts opportunities to rehearse the coordination of longer, well-timed units, which are a typically common feature of the canonical vocalisation stage as well as of (later-acquired) multisyllable words. The finding also suggests that the infants may have less rhythmicity, which is a specific skill necessary for the eventual mastery of native language sounds. The dominance of shorter syllable productions in vocalisations reveals a difference that could impact the flow and pace of speech, or at least speech-likeness of pre-linguistic vocalisations. First words often resemble babble formations (McNeil 1970, p. 23), and they often reuse existing structures to form proto words (Laing and Bergelson, 2020 and Oller, 2000). By extension, it is possible that infants with fewer polysyllables in their repertoire post-repair may reach the speech-concurrent babble stage later, a milestone which eases the transition from babble to early words and may be a marker that infants are behind (or divergent) in their progression through the typical stages. By this explanation, it may be that some of the infants are producing shorter units, but without the clarity of first word features (see Section 2.2.3.1), perhaps indicating that they are yet to produce longer, polysyllabic strings and are delayed in refining their vocalisations to the C + V strings required in first words. These findings also provide further evidence that we can accept H1 and reject the null hypothesis. As such, the reduced usage of polysyllables, medial consonants, and overall vocal count in younger palatal ages maps out a pattern of delay, based on the amount of time since palatal repair.

Also relevant to RQ2 is whether vocal count related to canonicity. Analysis II revealed a positive (Pearson's) correlation between vocal count and MBL, revealing the relationship to be marginally significant, highlighting that the more an infant vocalised, the more likely they were to babble, or at least, the more likely it was for their babble to be more canonical (speech-like) in its composition. While ICPs may not vocalise significantly less than their typical peers (Ha and Oller, 2022), this finding illustrates that the vocal count may impact the likelihood of sounds that infants produce. In fact, motor explanations interpret babble (and vocalisation) patterning as a direct result of anatomical movements in the mouth. They suggest that the articulatory constraints on early productions have motor level implications on the shape of structures which go beyond Boysson-Bardies and Vihman (1991, see also Davis and MacNeilage, 1995). Moreover, if early ICPs' vocalisations are especially restrained by motor factors, they may be even less malleable for reaching first word target forms.

While motor explanations interpret babble sequences to a certain extent, they cannot solely explain the revealed patterns: even typical infants produce different babble forms to each other at the different stages in vocal development. Consequently, motor explanations may partially explain the value of rehearsal (illustrated by vocal count) for producing more stable, speech-like vocalisations, as infants are beginning to refine motoric coordination of sounds. The present outcome stresses that MBL could be a valuable measure for vocalisation assessment and one that may be of value to parents and therapists of infants who are exhibiting moderate to extreme patterns of delay.

To extend the discussion of canonicity in relation to the typical and CP trajectory, the findings of mean babble scores across the samples are examined next. Analysis I revealed that infants in the sample had a mean MBL of 2.48 (a score which translates to 1.48 according to Scherer 2008's criteria, p. 830) and a standard deviation of .26 and 16/28 (57%) of these infants had a scores of 2.5 (corresponding to 1.5 by Scherer) or over. This comparable result means that, on the whole, infant vocalisations were closest to canonical babble than the other vocalisation stages. The canonicity outcomes in the present study mirror Scherer (2008) who collated MBL scores from 30-minute samples from 6- and 12-month-olds with repaired CLP. The published study found that CLP infants had an average MBL of 1.2 (with .13 SD), while non-CLP controls had scores of 1.5 (with .17 SD). The typically developing infants at 12 months had slightly higher canonicity scores than the ICPs at 14 months, however, at 6 months, the controls had lower canonicity scores than the infant vocalisations under exploration in the current thesis (at 1.2). The comparison of these measures reveals that the margins between infants with CLP at 12 months and ICPs at 14 months appears to be slight, even with only 2 months difference in age at collection.

To my knowledge, this outcome has not been explicitly compared or reported by published research, potentially due to the time-consuming nature of sampling, transcription, or mixed approaches to data foci. As a result, the findings boost the level of detail available from this selection of infants' vocalisations and illustrate the minor differences given the included cleft type in the present study. Moreover, together these patterns illustrate that 14-month-old ICPs' vocalisations in the current study closely match the MBL results of typical babble at 12-months, indicating 2 months of delay in canonicity, which was predicted by H1. However, it also reveals that the ICPs had more canonicity on average at 14 months (1.48) in the present study than typical infants at 6 months (1.2)—as from Scherer (2008)—which indicates a contrast to the hypothesised pattern. While the standard deviation was higher in the present results, indicating more variability, the CP 14-month-olds were closest to the variability seen in typical infants from Scherer's study at 6-month babbling scores, again signalling delay to the typical trajectory.

In fact, when discussed in relation to babble ratios, as was reported on naturalistic samples by Chapman et al. (2001), the CP 14-month-olds in the present study appear to be marginally ahead of 8-month-old typically developing infants. Chapman and colleagues reported 8-month-old controls to have a true-canonical babble ratio of .37 (sd .18), and in Analysis I when the comparable measure for true canonical vocalisation ratio was generated, the mean across the sample was .43 (sd .15), a result that was only .06 different to typical participants at 8-months. In other words, given that 43% of the vocalisations featured a canonical syllable with a supraglottal consonant, the presence of babble was mixed across the sample when all vocalisation types were considered together. When discussing what vocal ratios indicate about the CP trajectory, infants present as less than 6 months delayed because they produced higher canonical ratios than are typical at 8 months. The impact of a potential 6-month delay to the typical trajectory is substantial, given how much production progress occurs in the onset of babble (from 6 months) to the onset of first words (from 12 months). Therefore, this comparison places much importance on understanding how babble progresses in ICPs. It poses potential long-term differences in how ICPs reach their first words after repair. It even suggests that ICPs may progress through the stages faster than typical through the post-repair period, in order to align with the reported overall outcomes (Williams, Harding, and Wren, 2021).

Lastly, by H1 it was predicted that the number of consonants in the productions from ICPs would depend on the stage of vocal development they have reached but that inventory sizes would be smaller than typical regardless. The results from Analysis II found that MBL scores *significantly* increased with inventory size, suggesting evidence in favour of research H1. Analysis I also presented evidence foregrounding a positive relationship between vocal rehearsal opportunities and the production of high-pressure, supraglottal consonants, indicating that more articulatory practise may be more valuable than previously thought. These outcomes illustrate that infants who produced vocalic segments with more audible resonance and a higher frequency of vocalisations containing a supraglottal consonant *also* had a greater number of different consonants within their phonetic inventory of sounds. In other words, there was a clear pattern across the sample that infants producing more consonant productions, were also producing vocalisations of a more mature, speech-like nature, a finding separate to the amount and length of vocalisation. It remains unclear which of the two elements drives the other due to the snapshot nature of this study, however, it did reveal that clinical phonetic reports appear to be compatible with the MBL measures used in the current study.

Interestingly, Kent explains that speech sounds at different stages of typical development are directly due to the impact of anatomical growth on the vocal tract (Kent, 2021), a process which, by extension, would be mirrored for ICPs. Chronological ages are very close across the sample however, palatal ages have a wider range. Given that most articulators have a similar anatomical timepoint, Kent's explanation is less useful in explaining this result and the propensity of sounds appears to relate more closely to time available for production rehearsal, than motor explanations alone. The potential importance of palatal age and chronological age on the explored MBL, vocal count and length is extended further in light of the ToPS study by Gamble et al. (2023). Given that surgical timing may influence healing and recovery, too, depending on whether surgery was completed at 6 or 12 months, the published findings add weight to the presented outcomes. Each contribute evidence that there may be an impact of surgical timing *and* palatal age on production outcomes, both being potential reasons for variability in the data, e.g., variation stabilisation in vocal count and length 4+ months following surgery. It exemplifies that the amount of time since surgery plays a role and could be further explained by the different ages at surgery, too.

In summary, the main findings show some central influences of palatal age on the vocalisation measures explored in Analysis I:

- Vocal count had a moderate, positive relation to palatal age, meaning that the amount of vocalisation and canonicity related closely to each other.
- MBL was positively related to palatal age, with a marginally significant relationship suggesting that as palatal age increased, so did MBLs.
- There was a significant relationship between MBL and consonant inventory size at 14 months, showing novelty to the CP literature as to how soon interactions between canonicity and sounds within repertoire seem evident.
- Palatal age did not significantly relate to vocal length, but the trends may explain some of the variation in mean vocalisation lengths. There was also novelty in the consideration of vocalisation length alongside both count and canonicity, which further confirmed the importance of palatal age in influence of these vocal measures at ~14 months.

Published milestones, MBLs and vocal ratios in the analyses present mixed findings in relation to how many months behind typical levels the infants are. H1 predicted that ICPs at 14 months would be lower than typical vocal measures at that age, which was confirmed across many outcomes, however, the extent of differences against typical milestones was not lower than measures that typically occur at 8 months. Collectively, by the explored results in this section, H2 is accepted, and the null hypothesis rejected, because infants exhibited 2-6 months delay and palatal age did have significant effect on the explored vocal measures of vocal count, vocalisation length, and canonicity.

### 6.1.2 Research Question Three (Analysis II)

In RQ3, the focus was to ascertain the phonetic and organisational components of inventories and the components from ICPs (i.e., babbled 'consonants' and 'vowels'). H2 predicted that phonetic inventories would be smaller than typical infants' at and before 14 months. To recap, typically at 12 months, inventory sizes range between 5 and 9 sounds, with a mean of 7.2 (Scherer 2008, p. 832). In Analysis II, inventory sizes ranged between 6 and 15 with a mean size of 10.01 (these acquired consonants were produced 2 + times, in line with Scherer's measure), revealing evidence supporting H2 to be rejected, and the null hypothesis accepted because they also had more emergent consonants than the typical data from 2 months earlier. However, the vocal count this data represented was greater than previous work has explored, and as such the conclusions may provide more comprehensive insight across the most vocal hour of data. The present findings are somewhat in line with 12-month-olds post-CP repair in that they had smaller consonant inventories than typical infants (Zajac et al. 2021) and thus exemplifying that the present infants also had fewer canonical options for babble. The published work reported also that infants had slower emergence of stops (along with Chapman et al., 2001), which is reflected on shortly, and is enlightening about how close to typical the CP inventories were. Additionally, there was more variability across inventory size in palatal ages up to 4 months, but after this palatal age bracket the variation was more stable, which is a trend also present in vocal count and vocalisation length.

To continue, Analysis II revealed that inventory size increased with palatal age, however this outcome was not significant, indicating a novel relationship between inventory size and palatal age that may be a better benchmark for assessing the vocalisation progress of ICPs than chronological or surgical age alone. This finding suggests that the duration of time infants have had to rehearse the production of sounds since repair may substantially contribute to canonicity and inventory size and to a greater extent than chronological age. It thus emphasises the importance of palatal age as a factor to include in studies. This relationship echoes discussions from Section 5.1.1 but is beneficial to keep in mind when addressing RQ3 as it explains some of the variation across inventory sizes and phonetic composition according to palatal ages. The overall stabilisation pattern across palatal age may indicate a shift in the phonetic and organisational components within vocalisations, too. Given that palatal age related to vocal count and given that babble was more frequent the more an infant vocalised, a connection between inventory size and the phonetic composition of syllables is likely, even if it is not logically necessary.

Stop consonants were present across the sample, especially when the analysis did not distinguish for the voicing distinction and focused on placement of articulation. In fact, the present patterns were strikingly similar to Hardin-Jones et al. (2023) who researched 16-month-olds with CLP 2-6 months post repair. To continue, the distribution of sounds produced twice or more by infants in Hardin-Jones et al.'s data gave these results respectively: 70%, 64%, and 70%. In the present study, there was 76.8, 67.8, and 53.7, which illustrates that the data resembles the published trend for bilabials and velars. While bilabials were the mode PoA was mode in the results, it was not in Hardin-Jones et al.'s finding, perhaps illustrating that alveolars were most challenging for ICPs. The biggest difference here appeared to be in the lower than predicted presence of alveolars in the current data which perhaps lends an explanation for the highest presence of bilabial and higher presence of velar stops. The study included information on palatal age, but it did conflate different cleft types in the sample. Their findings are consistent with the current results which indicate that at 14 months (~ 5 months post repair) infants produced more bilabials and velars, but fewer alveolars than reported by Hardin-Jones et al. (2023). What is compelling about this comparison is that the impacted area in the present sample of infants with unilateral CP only affects a smaller range of the articulator than in the craniofacial anomalies pooled together in Hardin-Jones et al. (2023). One suggestion for this contrast is that the more confined area of unilateral CPs restricts the movement and extent of articulation delay differently.

In fact, the infants with the latter had a more balanced emergence of the three stop placements in Hardin-Jones et al. (2023), whereas in the present study, infants with unilateral CP produced more bilabials and velars, but the alveolars were still emerging and stabilising in their output, potentially revealing that these were not the focal point of production or were more recently rehearsed sounds. The outcomes from Hardin-Jones et al. (2023) reported on some infants with only one sound within their repertoire, which could more likely be attributed to their sampling method as 10-minute samples were taken from 2-4-hour recordings and potentially did not capture the point where infants are most vocal in the day. While there will always be discrepancies in naturalistic studies over whether an infant was 'at their best' or 'regular' on the day of collection, this variation cannot be fully fixed in infant language research.

Also consistent with Hardin-Jones et al. (2023) were the findings in Analysis II which reflect a consistent preference for voiced sounds over voiceless ones, a pattern well established in typical sound acquisition (Barton, 1980; Eilers et al. 1984; and Stoel-Gammon, 1984). Such a preference for sonorants in the early words of ICPs could indicate the sorts of sounds that are typically replaced, including nasal substitutions for stop consonants in their preceding babble (Hardin-Jones and Chapman, 2018), which might be why the presence of bilabial stops and velar stops is higher in the current results. Nasals are also substituted for liquids, glottals, and fricatives (ibid), however, this trend was far less amplified in the phonetic composition of productions in the data, as supraglottals liquids and fricatives were particularly rare.

To continue, in relation to RQ3, it was expected by H2 that most syllables of ICPs post-repair would be composed of fricative-, liquid-, and vowel-initial syllables and fewer stop-, liquid-, and velar-initials; a prediction that is in accordance with published clinical reports on phonetic repertoire and misarticulations (Zajac et al. 2021, Kaiser et al., 2017, Scherer, Boyce, and Martin, 2013, Willadsen, 2012). As a reminder of the motivating literature for H2, for most ICPs, prevocalic stop consonants did not emerge until at least 9 months after repair (Zajac et al. 2021, p. 30) and ICPs exhibited a preference for vowel-initial structures before this timeframe (Ha and Oller, 2022, p. 10).

The findings from Analysis II illustrated that the phonetic segments in initial position varied with palatal groups (1, 2, and 3, henceforth G1, G2, and G3):

- syllables were equally composed of vowel and stop initial segments in G1,
- stop initial syllables were less frequent in G2, which reflects some of the G2 variability in vocal count illustrated by Analysis I,
- there were much fewer glottal initials overall in G3 (between 6-9 months post-op).

The presence of stop-initials across all groups contradicts the nine-month emergence timeframe post-repair mapped out by Zajac et al., (2021), revealing opposing evidence that infants *between* one- and nine-months post op did produce stops, with 100% of infants producing them twice or more. This decline in glottals across G1, G2, and G3 overlaps with Ha and Oller's finding that syllables including glottals decreased from 4-6 months post-repair (at 16-18 months in Korean-acquiring infants, 2021, p. 1296), suggesting cross-linguistic consistencies in the phonetic composition of C + V syllables. Moreover, this gradual decline over the three palatal groups in syllables with glottals (most notably by 6 months post-repair) adds a new layer to this pattern revealed by Ha and Oller, because it suggests that the presence of glottals alone may not indicate an 'issue'. Instead, it may be a cause for concern if the presence of glottals did *not* change within these time frames (either by chronological ages of 16-18 months, but more compellingly by 6-9 months post-repair).

To continue the discussion, some Analysis II results could be explained by bootstrapping explanations. Bootstrapping is the term for acquisition through exposure to forms alongside structured representations (Abend et al., 2017), its focus involves the experience of familiar phones alongside newly acquired ones, which involves relying on a familiar template. The gradual decline in glottal initials is seemingly 'replaced' across vocalisations at higher MBL scores, from glottal to stop initial syllables and structures over older palatal ages. That is, in older palatal ages, similar vowels across similar vocal structures are used but with stop-initial syllables rather than glottals. Such a process reduces the coordination 'workload' for infants when they are acquiring new sounds and could be explained with existing production repertoire as a springboard to more speech-like segments.

While the literature indicates that oral stops emerge spontaneously for the majority from 2 months to 8-11 months post-repair (Hardin-Jones and Chapman, 2018), these published timeframes did not discern cleft type and included cleft lip, yet predictions on this pattern are especially relevant to examine in CP only infants. Consequently, it was expected by H2 that most syllables of ICPs post-repair will be composed of fricative-, liquid-, and vowel-initial syllables and fewer stop-, and velar-initials, however, Analysis III revealed mixed evidence for this prediction in the consistency of consonant productions across palatal groups. The glottal fricative and glottal liquid were the most common VMS (number of consonants that were produced 50 + times in an hour) sounds across the sample, which is in line with H2. However, the next most, consistent consonants were stops: /m/, /b/, /g/, and /d/, none of which fit the 2 manners of articulation that were predicted to be most frequent. The remaining VMS sounds did include the predicted liquids (/w/, /j/, and /l/), but no fricatives were consistently produced (50 + times per hour) other than the glottal production /h/. While these patterns in themselves somewhat contradict patterns forecasted by the literature, to directly address RQ3, however, the combinations and positioning of sounds require further consideration.

H2 expected the structural and phonetic properties of CP syllables at 14 months to be akin with ones typically present earlier in vocal development. Unsurprisingly, this prediction implies that the infant would be delayed and, as such, will not have reached variegated babble, which would be expected for typically developing infants at the 14-month mark. However, the prediction that vowel-initial structures would be common extends the concept of phonetic preferences onto a structural preference because it differs from the typical CV structure, which is a predictable non-target pattern within the typical trajectory (Namasivayam et al., 2020, p. 11. The presence of such a pattern would illustrate a deviation from the typical stages of vocal development as outlined earlier (in Section 2.2). In the results, vowel-initial sequences were a feature of vocalisations irrespective of palatal group. Such a presence of vowel-initial vocalisations across the sample could be due to the lack of available gestures within the infants' post-repair repertoire. Additionally, it reflects the properties of earlier typical trajectory stages (including protophones that consist of vowels, as well as vocal play) and might indicate some deviation to the C + V typical default syllable by these infants. The pattern is also the reverse form of the emergent babble pattern along the typical trajectory, revealing an area that may have an impact on the progression of ICPs through the typical vocal stages.

While the presence of vowel-initial sequences was important to address, there were more prominent trends revealed by Analysis II. The glottal + vowel combination was the most common structure, comprising $1/8^{th}$ of all vocalisations. This pattern was followed by stop and vowel, then by a nasal and vowel, and finally by a liquid and a vowel. Such sample wide patterning involved a high presence of monosyllabic, open-ended syllables, a pattern reflected in typical babble, however, the overwhelming majority of glottals is a much less typical trait. Similarly, it revealed that only $1/10^{th}$ of the most common 25 vocal structures were vowel-initial, again less characteristic of typical babble. These cross-group trends represent an aspect where sequences deviate from traditional babble sequences, they do not follow the typical consonant onset, which could indicate why difficulties persist in some productions of ICPs. In sum, this pattern shows consistency with Ha and Oller (2021) that vowel-initials were present and reveals a sequential difference to TD infants. Together with the frequency of liquid-initial and glottal-initial sequences, these divergences from true and oral onset consonants may have implications for subsequent production development.

If ICPs produce glottal-, liquid-, and vowel-initial structures much more than typical infants do, it may reduce their ease in transitioning to first words. This explanation is encouraged by research on how typical infants reach their early words; given that infants use structures that are familiar to them from babble to form words (Laing and Bergelson, 2020). To add, these familiar structures typically involve true consonant-initial structures as well as consonants that are frequent or preferred from an individual infant's repertoire in babble (Scherer, 2018). As discussed, the ICPs' vocalisations included many glottal, liquid and vowel onsets, which may impact the opportunities the infants have to engage with the typical (true) consonant + vowel formation. As such, there may be a knock-on impact on ICPs who are nearing the speech-concurrent babbling stage as well as nearing proto and first words. Further, the impact may be especially evident for individuals who were producing more vowel initial sequences, which are less common in very early vocabularies (Ramsdell et al., 2012, Boysson-Bardies and Vihman, 2001).

While H2 anticipated fewer stops, the most frequently occurring one was /d/ which appeared in 20% of the VMS consonants across the sample, revealing a surprising and novel outcome. This result opposed the anticipated one and highlights a potential difference depending on the context of production, for instance, literature often captures vocalisations from isolated and prompted interactions, which may not reflect the full and extensive output available in naturalistic babble. Specifically, this outcome was surprising as it contradicts the literature on CL + P infants (across which there is likely to be resemblances with CP only cases). It reported fewer oral stops and vocalisations with more labial sounds than alveolar, palatal, or velar ones in typical productions (Hardin et al., 2023), perhaps giving room to consider the impact of different cleft types, or the inclusion of cleft lip in Chapman et al's (2001) sampling, on these different phonetic outputs. The results from Analysis II showed that the two most frequent consonants were those that had clear visual cues during articulation because they were bilabial productions, perhaps due to their high frequency in the input (DePaolis, Vihman, and Nakai 2013, p. 647). These articulations offer a visual aid during interaction with other speakers, which may attract more attention than more ambiguous places of articulation, such as velar or glottal ones.

On the other hand, looking at the absence of certain sounds is revealing, too. In particular, post-alveolar fricatives were the rarest sound across the infants' vocalisations and were only produced by those with a higher number of VMS consonants within their repertoire. This pattern may be because they have more coordination of the articulators after acquiring a selection of consistent consonants, again amplifying the significance of rehearsal in vocal development. It may also be due to this selection of infants being more advanced in their experience in expanding the production of sounds from existing inventories, or even that there is a triggering impact on babble after CP repair has been completed (in line with Löfkvist et al., 2020).

Lastly, by H2, it was expected that mid vowels will be more common than front and back vowels across the sample. In typical development the central vowel is most prominent in 7-10-month-olds' pre-linguistic syllables, and therefore the concerned hypothesis predicts deviation to this pattern (Ha and Oller, 2022) in ranges of vowel production (see also Chen and Kent, 2004) in this population. The exploration of H3 will provide novel insight on CP syllables, and the C + V combinations in pre-word vocalisations.

The prediction that the frequency of mid vowels would not be different to typical infants contrasted to the main findings, which illustrated that mid vowels were rare, suggesting that they emerge later or are an articulation that ICPs have difficulty navigating in articulation. One possibility for this contrast to the hypothesis is that the combination of consonants and vowels sequences are easier to produce when they have a shorter articulatory distance between them (for instance, when alveolar articulations are produced next to mid vowels, or when velar productions are produced with back vowels) because these productions rely less on the coordination of airstream and pressure control. In this way, the lack of mid vowels may be associated to the lower frequencies of alveolar articulations, if indeed the placement of consonants is more easily produced at similar vowel placements.

The production of vowels may also rely on the pressure of airflow more than considered and predicted in Section 2.2.1, too. As such, this difficulty may be due to negative association, where infants associate vowels at the middle of the palate with the healing process post-op, and therefore produce compensatory vowel placements in place of mid vowels (which, with the slight exception of /ə/ were very rare). The lack of vowels in the middle of the palate could be understood by this explanation as can the high frequency of contrasting vowels. This clear presence of high contrast vowels could also be motivated by perceptual constraints as a result of delayed production patterns. By this possibility, the absence of mid vowels that was still evident in the palatal ages of 6-9 months could illustrate more delay to the typical trends. These reasons may give insight into the ways ICPs' productions deviate to early emergent vowels in typically developing infants.

In addition, the vowel frequencies also deviate from the frequencies of vowels in English documented by Wells (2000). The higher frequencies of /æ/ and /ɛ/ echo the more frequent vowel sounds of English. However, in contrast, the second and third most common /ʊ/ and /u/ vowels across ICPs' vocalisations are not among the most common sounds (and in fact are 10 and 11$^{th}$ most common respectively) in English. By extension, this comparison indicates that these patterns deviate to the patterns of the ambient language suggesting that motoric explanations may not fully explain the frequent vowel productions in the vocal data. On the other hand, the front vowel /ɪ/ and back vowels /æ/, /u/, and /ʊ/ were much more common. Post repair, the central vowel typically requires the least effort from the passive and active articulators, therefore the findings here were surprising and mixed in relation to H2.

Interestingly, the three mode vowel placements had high contrast to each other, highlighting that produced vowels were easier to discern acoustically from each other, a combination that may be preferable because they are produced with the most articulatory ease. It could also be the case that an acoustic contrast paired with the sensorimotor feedback from articulatory contrasts is beneficial for producing a selection of vowels. The overall pattern held that the mid vowel (from the broad category of /ə/) was rarest. Interestingly, when mid-central vowels did occur, they were never used in isolation or in initial position, meaning that they were only produced in conjunction with elements that were more stable within consonant categories. By this finding, it could be that the later sounds to emerge slot into more complex (or speech like) structures, and that later acquired sounds are used more flexibly across vocalisation combinations.

Finally, the organisation of vowels in Analysis II revealed differences in the use of harmony: a higher proportion of all 2 + syllable vocalisations had vowel harmony (61%) compare with 39% of consonant harmony. This outcome indicates that vocalisations were more likely to have a shared placement for vowels within a vocalisation than a shared place and manner of articulation in consonants. The interpretation of this distribution is that there was more systematicity used in pre-babble sounds with vowels than consonants. Additionally, the phonetic content of vowel similarity versus contrast across the vocalisation depended on the focus on consonant sounds. Higher babble level vocalisations were more likely to have consonant harmony, a trend that was especially noticed by more consonant harmony in MBLs 2 and 3. The pattern shows overlapping babble stages and may indicate scaffolding or bootstrapping of the changeable element with a consistent vowel. This is discussed further in relation to transitional probabilities and RQ4 in Section 6.1.3.

In summary, the main findings show central patterns involving the presence of harmony and the influence of palatal age explored in Analysis II:

- The most frequent consonant elements in sequence-initial positions were glottals, stops, nasals, vowels, and liquids, illustrating clear divergences to the typical C + V babble structure.
- Vowel harmony was more prevalent than consonant harmony, and higher MBL levels were more likely to have more consonant harmony.
- Mid-central vowels were rarer than predicted, but of all the palatal ages, the oldest had a higher use of them. More frequently in lower palatal ages, vowels with high contrast to each other were produced.

Given the emergence of stops in the ICPs, it could be that palatal healing and recovery timeframes (as outlined in 2.2.1.2) are currently too generous for a collection of atypical infants included in the present study (Cooper-Brown et al., 2008 and Goyal et al., 2012). If indeed, infants with a higher proportion of vowel-initial structures in this short, post-repair window end up with lower speech and language levels later on, it might mean that the focus of therapeutic targets could be altered and of benefit to the infants’ progression through the vocal milestones sooner. Regardless of whether this explanation is the case, the absence of mid vowels was still a clear pattern in the older palatal ages (6-9) months as well as the younger ones. As such, the delayed medial vowel emergences indicate more delay to the typical trend even though older palatal ages have had more healing, recovery, and rehearsal time. Analysis II revealed a mixture of explanations for the patterns as well as their potential impacts on nearing early words, the following section discusses the final analysis chapter to address H3.

### 6.1.3 Research Question Four (Analysis III)

The final subsidiary research question examined the extent to which sequential features of non-canonical, canonical, and true canonical syllables show consistencies with published CP patterns and the therapeutic aims post-repair. It also explores whether the visualisation of transitional probabilities—a method for visualising phonetic and sequential details from vocalisation transcriptions—benefit the analysis of and reveal new insights into CP production patterns. H3 also expected that MBL measures would be more strongly related to VMS count than palatal age because vocal rehearsal and babbling ability is possibly more influential than palatal age in determining stable consonants post-surgery. The third hypothesis therefore predicted that infants with higher babble levels (e.g., variegated vocalisations) would have a wider range of emergent consonants and more consistent, VMS consonants than those with lower MBL scores.

By extension, H3 predicted that the relationship between canonicity and stable consonants (MBL and VMS count respectively) would be evident earlier in the vocal trajectory than existing research has yet determined. This prediction is encouraged by the awareness that palatal age is a significant predictor of later vocal measures (Fell et al., 2022 and Zajac et al., 2021), and further, that babble in TD is also a predictor of early vocabulary and later speech outcomes (McGillion et al., 2017; Wu and Gros-Louis, 2014). Analysis II's findings revealed that MBL did significantly relate to VMS count because higher MBL scores patterned with a greater number of consistent consonants ($R(26) = .76$, $p > .001$). By this outcome, infants with more speech-like vocalisations overall, were more likely to have more consistently produced consonants in their production repertoire, too. In fact, the relationship between MBL and true VMS was even more statistically significant and these relationships between consistent vocalisation and mature vocalisation encourage considerations about how soon ICPs post-repair seem to engage in specific, articulatory rehearsal, which is key for advancing to sound combinations and early words. As such, these findings motivate H3 to be accepted, because MBL scores *predicted* VMS count, a result that was even more convincing for true VMS (that is VMS consonants that only included supraglottal productions), which affirms the relationship between canonicity and consistency of consonant production.

The strength of the relationship between true VMS and MBL implies a synergy between the range of articulatory coordination and the repetition of executing the same phonetic gesture, both skills necessary for the coordination of babble and speech. The findings also foreground evidence—for the first time—that ICPs use vocal motor schemes, a framework that is well-explored in their typically developing peers. Consequently, given that nearly all infants (93%) had 1 or more glottal VMS, and nearly half (46%) had one or more supraglottal VMS, the data analysed in Chapter 5 present the VMS results to have a few absences to the typical trends, and mostly illustrated the typical tendencies. The consistent production of consonants in vocalisations therefore appears to be a clear process following CP repair, this pattern is especially evident because it occurred across all palatal ages (between 1-9 months post-surgery). The findings surrounding VMS levels embolden the need for integration of standard, typical measures more in clinical and linguistic avenues of CP research, and suggest that typical processes may drive production processes, even where cleft characteristics are evident in vocalisations.

It was also predicted that liquids would be very frequent because of their close articulatory proximity to vowels with the results revealing that liquids occurred in 5 of the most common 25 vocalisation structures, which is a weaker distribution than predicted. These sounds occurred in initial and medial position (both post- and pre-vocalic), therefore their positioning in vocal structures was more versatile than predicted. In sum, liquids were not the most dominant manner of articulation across the most common cross-group vocalisations, but glottals and stops were more common, revealing these articulations to be most common. While glottal stops and fricatives were by far the most used consonant-like segment, supraglottal fricatives did not feature at all in the top 25 most frequent vocal sequences, despite being a sound that TD infants would typically produce at this chronological age, which provides evidence in contention with H3. This contrasting pattern raises the possibility that the pressure control required for oral fricative production is too challenging at this stage in development, a trend which is also present in the typical trajectory. By this interpretation, it could be that ICPs form compensatory articulations of rudimentary sounds using sounds at the extremes of the articulators (either fronted or highly backed), but not sounds that typically emerge later in the trajectory.

The substitutions of glottals and liquids in MBL2 to supraglottal consonants in MBL3 maintain similar syllable structures, the finding could be evidence of phonetic remapping post-surgery. It signals a diversion in the typical emergence of consonant-like closures that is illustrative of bootstrapping. The repetition of syllables in bisyllables with either a glottal or a stop with the same vowel were also common between MBL2 and 3, offering a possible explanation of substitutions of glottals and liquids across MBL2 to supraglottal consonants in MBL3. Such a pattern accords with phonetic remapping post-surgery: glottal articulations do not require coordination of the palate in articulation, they require novel coordination. This explanation points to a difference to the typical emergence of consonant-like closures, and a shift that could be evident from birth and in effect until the palate fully stabilizes and/or heals, because it diverges from the typical emergence of supraglottal stops in babble. Bootstrapping explanations here involve a typical development mechanism being used for atypical phonetic articulations.

The transitional probabilities in Analysis III further depicted the shapes and sequences of vocalisation visually. The results found that the more speech-like vocalisations (MBL4) had the most variety between different phonetic sounds, evident from the greatest number of lines between nodes in the transitional probability matrix (see Section 5.4.3.1) when compared to the lower three MBLs, and also by the higher probabilities between nodes. This outcome is what we would expect from a more mature system. Just three of the infants only had glottals or liquids in their VMS repertoire, perhaps indicating a less mature system, with potential for patterns of glottal reinforcement or glottal substitution for supraglottal targets. In addition, the usage of supraglottal consonants increased with palatal age, moreover, the position of supraglottals varied across palatal ages and groups, too. This difference was not captured by the mean babble measure, foregrounding the importance of transitional probabilities as a visual method. The patterns across vowel placement remained consistent, illustrating that this analysis has presented some distinctions to the hypothesised outcomes, and some deviations to the typical trajectory, too.

Furthermore, Analysis III revealed that higher MBL vocalisations had more presence across a wider range of structures, indicating less predictable sequences here than for the most rudimentary vocal forms; in MBLs 3 and 4 specifically, there was more exploration of different sequences. This is a novel finding, showing that speech-like vocalisations had wider selections of sounds in versatile, variable sequences, utilising a combination of contrasting vowel placements (front and back) and consonants (stops, nasals and glottals, in that order of frequency). This trend is reinforced by the presence of closed syllables located in the MBL 4 structures, which reflects a shift from C + V, babble-like sequences, to C + V + C, early word-like sequences. Its significance is that the order of these forms align with the voicing preference patterns in typical orders of acquisition. Voiceless sounds tend to emerge later than voiced ones, and this pattern is especially the case at the end of words (Zamuner and Kharlamov, 2016), which emphasises that C + V + C forms typically indicate a more mature system of vocalisation. Moreover, more mature, speech-like forms, were not fully absent between 6-9 months post repair, a time frame that is earlier than the published literature indicates.

The presented results are consistent with growth network (or emergent dynamic system) models. One possibility is that existing consonants become attractor states (i.e., articulatory places where productions are drawn to), whereby vocalisation combinations are favoured over others in a somewhat systematic way (Fourtassi et al., 2020, Siew and Vitevich, 2020, and Laing, 2024). Such studies consider the connectivity between networks, including different motives for growth, the aspects of which may be determined differently due to palatal age, MBL and also the number of VMS consonant within repertoire. In this way, the results encourage that flexibility in the phonetic composition of vocalisations may also grow based on how many sounds were consistently produced, or indeed, may become more connected when more vowel categories emerge. With the consideration of computational models, future research could explore the first word patterns of ICPs in order to understand articulatory attractor states in more detail. Such work may shed light on which phonetic and sequential features have higher levels of potential growth in the developing production system, which may even be an area that therapy could capitalise on in new research.

To conclude 6.1.3, together the discussed outcomes suggest that we can accept research H3 that MBL predicted VMS count and reject the null hypothesis that the impact of MBL scores on VMS was not significantly different to chance levels. To add, the inclusion of transitional probabilities benefits babble analyses; it provides an accurate and detailed reflection of the ordering of sounds within vocalisations, not simply the level of canonicity alone. The visualisation approach can also be a subset (e.g., group, MBL) to explore whether categories in a sample had any novel relation to vocal sequences, which is a valuable possibility for production analyses.

To that end, in line with Research Questions and Hypotheses, H3 predicted that MBL and vocal sequences would both be better measures (and even more influential) than palatal age in determining stable consonants, which was motivated by the Analysis II findings on VMS and phonetic inventory, as well as the development in structures over MBLs. In addition, H3 made the prediction that palatal age would relate to vocalisation measures at 14 months. Analysis III presented a steady decline in glottal initials across palatal groups and an increase in connectivity as palatal age increased, illustrating evidence in favour of this prediction, but with indicated delay to the typical trajectory structures here. It also illustrated potential compensatory deviations to the typical production processes (prominently including the absence of central vowels and the presence of glottal-, liquid-, and vowel-initials) which were forecasted by H2. Lastly, the relationships discussed in Analysis III located relationships between the vocalisation variables that emerged earlier in the cleft vocal trajectory than existing research has determined, given the sample criteria. The outcomes reinforce the view that babble in ICPs is a predictor of early vocabulary and later speech outcomes as in typical infants (McGillon et al., 2017).

## 6.2 Response to the Central Research Question

The question at the centre of this thesis asks the following: to what extent do the phonetic and sequential properties of syllables produced by ICPs across palatal ages post-repair resemble the typical path of vocal development? This section explores the vocal measures which deviated from typical babble patterns to highlight how soon post-repair cleft characteristics are evident in productions. It also considers the impact of several relationships between vocalisations and palatal age, placing weight on how this variable influences the frequency, maturity, and composition of vocalisations. As such, it stresses the overlooked role in much published research on The vocalisations of ICPs. Most of all, it integrates the discussed outcomes and interpretations from Section 6.1 in order to address the research question.

This discussion has indicated that the phonetic elements have some deviations to the typical patterns of development, particularly including the high presence of glottal articulations, which potentially mark a redirected and/or temporary replacement pattern for absent, typical emergent babble components. The absence of mid-central vowels, velars, voiceless sounds in conjunction with mid- vowels also together indicated a deviation to the typical path of development. In contrast, there was an overwhelming dominance of monosyllables, and a greater use of voiced sounds over voiceless ones which reflect the typical trajectory more widely. As did the portion of infants who produced consistent supraglottal consonants which resembles more speech-like, canonical vocalisations. Specifically, it showed compelling consistencies with Hardin et al.'s (2023) CLP infant research in relation to the range of sounds produced twice or more. In sum, the current infants had higher canonicity on average than CLP infants at 12 months, and comparable canonicity to typical 8-month-olds, but there was more variation across the sample here.

This discussion has also shown convincing evidence that the production of infants' syllables related to palatal age, with particular respect to the vocal count, VMS, and the overall speech-likeness of individuals' syllables. The strong, positive relationships between palatal age with vocal count and canonicity foregrounded that the amount of rehearsal opportunity since repair could have a greater impact on (pre-)babble vocalisations than age at surgical age or chronological age. Evidence was also presented, for the first time, that ICPs have vocal motor schemes, a typical mechanism in vocalisation development, signalling that the acquisition and production of VMS consonants is a part of CP development, too, even if it occurs at a later stage than the typical trajectory involves. The extent to which 14-month-olds with a CP were producing VMS appeared dependent on how speech-like their overall vocalisations were, too, with higher babble level relating to larger inventory size and higher number of consistent consonants.

# 7 Reflections

The overall scope of this thesis has enabled an in-depth exploration of the phonetic characteristics across twenty-eight infants' vocalisations post CP repair. However, there were some limitations in light of the research process that impacted the extent to which the research question was addressed, and the generalisability of the findings. Section 7.1 evaluates the impacts of the data from an empirical and reflective perspective; it acknowledges the limitations in turn and responds to them with the mitigation strategies undertaken (where possible). The section presents these empirical limitations in relation to sampling and methodological factors such as individual differences; the validity of LENA recordings; data quality and the categorisation of canonicity; phonetic inventory comparisons; and sample size. It is then followed by Section 7.2 which underlines recommendations for future work with infants following CP repair. The section, and thesis on the whole, is brought to a close in the conclusion, where a summary on research goals, questions, and thesis contributions is given in Section 7.3.

## 7.1 Limitations and Acknowledgements

Even in research on typical populations, the issue of individual differences is a limitation that can impact results. In this thesis's sample, individual differences were therefore even more limiting because the clinical variables at play are complex and different to one another, potentially having a greater impact on the data and generated results. The extent of interference from clinical and infant variables—such as feeding ability, dental details, weight, and birth position—was not addressed in the research design because these variables are so idiosyncratic in the population of ICPs. One factor that could have had impact on the results is in the individual variation across healing timeframes, these may explain outliers at individual levels, given that professionals wait for inflammation and swelling to go down because the required therapeutic treatment may be too intrusive straight after surgery (Jahanbin et al., 2014). Healing timeframes are likely to fluctuate across the sample, limiting the direct comparability of results.

Similarly, each CP—even within the unilateral category—is different in shape, placement, and size, which may have repercussions on articulatory impacts, and, consequently, the presented findings. While this was not an obstacle exclusive to this study, it challenges the extent of generalisability in the claims and explanations discussed. Another aspect brought into question is in the exclusion of infants with a hearing impairment. The impact of hearing impairment on ICPs is more common than in typical infants Baker et al. (2021), however it was not considered in the present research. While hearing impairment impacts were excluded from the research, the decision to exclude this proportion of infants could reduce the extent to which the current sample represents the national pool of ICPs. The benefit on the other hand, is that this study reduced the impact of auditory-perceptual constraints on the vocal outputs. To continue, the impact of individual differences within the included medical criteria were somewhat mitigated by using palatal age across the sample characteristics, however, the complexities of individual differences were not wholly addressed here. The conflict of clinical variables is a difficulty for all studies working with ICPs (and atypical populations) and therefore, individual variation is acknowledged, but the study is sufficiently robust to indicate patterns worthy of future research given the extent of the eligibility criteria and the implementation of consistent measures.

Furthermore, a strength of the LENA recordings is that they offer a rich insight into naturalistic vocal data (see Section 4.1.5 for a reminder of the reasons) and have been explored in detail for the first time by this thesis. Naturalistic data benefits research outputs through the reduction of experimental impacts and boosted ecological validity, though, as with any sample, the present data set had a few unavoidable drawbacks. One limitation of the sample was that the data explored is secondary, which meant that decisions surrounding variable inclusions, and resampling parts of lower audio quality data were not available. The matter of acoustic and phonetic clarity, given the audio quality of samples alongside more messy, rudimentary articulations made the coding process challenging at times. The transcription approach tackled some of these difficulties because it involved auditory and impressionistic, phonetic transcriptions from one coder, and did not rely on discrete acoustic analysis distinctions throughout. More specifically, given the transcription design, categorising syllable boundaries, vowel resonance, voicing categories, and inter-vocalic classification cannot be fully guaranteed, which is a limitation of the study. However, in place of such acoustic, automated transcription methods, the limitations are mitigated by their benefits, too: they offer insight into the sorts of sounds that parents experience of infant vocalisations (by recording within messy environments); they are more attuned to the individual infant than automated analyses offer (in auto-generated child vocal count from LENA); and they are more attuned to discerning environmental sounds (e.g., objects hit during play) over produced sounds (e.g., voiceless consonants) than acoustic analyses.

A limitation of this thesis was that it did not carry out inter and intra-reliability measures on 20% of the vocalisation transcription and analysis, meaning that the presented results do not reach scientific publication standards. As a result, the research would have been strengthened by reliability checks from a blind or naïve coder to strengthen the reliability of the coded phonetic material. To continue, while the accuracy of transcription detail is a concern with any study investigating canonical and non-canonical vocalisations at this phonetic level, it was not viable to carry out such additional reliability checks for the phonetic transcription and/or coding.

A particularly prominent limitation in categorising sounds was coding for glottal detection at the onset of syllables, which is a challenge even within acoustic analysis software (such as PRAAT). ICPs have the tendency to use glottal reinforcement, however, the extent of its presence is a challenge to confidently confirm in lower-level audio quality data, with overlapping, similar sounds to glottal fricatives, e.g., in infants with heavy breathing sounds. The inclusion of laughter may also have interfered with some sound determination because it sits on the boundary between canonical and non-canonical sounds. Overall, the methodology has attempted to clarify many ways to determine canonicity with certainty from the messy data, but in infant research, discriminating categories with certainty is an unavoidable limitation.

To continue, while the decision to class only broad vowel categories was well motivated, not all the vowel specificities (or contrastive placements) are captured by the transitional probability diagrams in Analysis III. Consequently, it is possible that some infants were producing more mature coordination of vowels than was captured in the three broad categories analysed by the harmony and transitional probability analyses. Despite the limitations of phonetic categorisation and formant analyses, recent work with a similar design still suggests that typical infants might be more capable of vowel distinctions than previously thought (e.g., Polka, Masapollo, and Ménard, 2022). However, the production of infant vowels is variable and challenging to code, therefore capturing the vocalic detail for every detail was outside the scope of this study.

Another limiting element of the sample was that the participants were not reduced to include only infants whose chronological age was 14 months. In this way, it is difficult to assess the impact of cognitive and social development on the vocalisation patterns across the older chronological ages, and therefore draw concrete conclusions across the sample. However, it is acknowledged that infant data are very challenging to sample for many known reasons such as illness, parent availability, drop-out rates, and so on. It could have been strengthened by removing the oldest chronological ages and concentrating on the 14 infants with the exact ages of 14-month-olds, but this would have skewed the distribution of palatal ages and reduced the sample size. Therefore, while the included age range is a limitation, many infant studies are not able to attain perfectly aged samples, therefore this study is still sufficiently akin to much published work.

The penultimate limitation relates to vocalisation measures and the validity of phonetic inventory collection methods. The professional, ancillary consonant inventories in the sample at 24 and 36 months were limited in consistency: some reports were incomplete, some carried out online, or not taken at exact months needed to maintain sufficient control over these measures. Moreover, the inventories from the primary corpus data were taken in clinical contexts, whereas those collated for Analysis II were extracted from the unsolicited naturalistic vocalisation data. Therefore, the comparability of the two inventory types with the naturalistic inventory measure at 14 months was low and confusable because of missing entries and multiple elicitation methods in the older SLT measures. While there is value in the uniform, professional ratings on consonant inventories from the CC-SLC, the issues of compatibility and comparability with the 14-month measure meant that these results were not reliably integrated or fully examined in the final thesis, which limited the longitudinal extent of the presented and discussed results.

Finally, the statistical power is limited due to sample size and variability (as indicated by the standard deviation outputs), which means that the significant results should be treated as illustrative rather than definitive. This thesis included in depth phonetic detail from 28 infants, from a potential pool of 40. The level of detail captured meant that the quality of data was prioritized over quantity and consequently, the extrapolation of results and weight of significant results should not be relied on solely, bearing in mind the sample size was small when compared to sample sizes in typical development studies.

The sampling limitations are to an extent balanced by the strengths of the work. The data samples were taken from long, naturalistic recordings, offering the ability to select the most vocal hour from each infant. As such, the research maximised the vocal sample from each child. The size of the sample was not large enough to treat statistical results with high confidence or to confidently reflect on the impact of an individual's own repertoire, but the sample size overall was appropriately sized to be able to carry out transcription on a wide variety of measures, based on that transcription, and large enough to provide results which could be generalisable if the most illuminating analyses were replicated in a larger sample. The sampling design included processes to narrow the sample, meaning that it excluded participants with certain characteristics from the analyses which might skew the results. With any clinical sample, defining the inclusion criteria is a challenge, and in this thesis, the sampling choices were made to reflect a wide selection of the population. It also attempted to reduce the mix of additional clinical variables that may have direct differences on the results. Regardless of these intentions, the skew of the sample may impact the reported outcomes.

## 7.2 Suggestions for Future Research

Recommendations are now made for future work in light of the limitations and results yielded. First are the empirically related suggestions for future studies, followed by some theoretical considerations. In light of the findings, the consistent consideration of palatal age is strongly encouraged in future work. The relationships between vocalisation measures (including VMS and MBL) were related to palatal age throughout the analyses, which stresses the key influence is can have on (pre-)babble and post-babble outcomes. As a result, future studies on ICPs should incorporate sampling approaches that consider this variable in relation to the results. In similar studies without a discrete control group, subcategories for palatal ages, surgical ages, and chronological ages are recommended in order to reduce conflicting variables; it is a straightforward implementation that can yield very different outcomes overall. This research has also laid the ground for more longitudinal research that extends the consideration of naturalistic data to include interaction. While these elements were outside the scope of the present study, the results provide motivation for this avenue in future work.

To continue, the inclusion of standardised vocalisation measures pre-repair is recommended to studies aiming to examine mechanistic understandings of vocal development, e.g., pinpointing the extent of the result of the repair, or changes in patterns due to substitutions or transitions in bootstrapping. Some work has considered pre- and post-repair data (Lohmander, Olsson and Flynn, 2011; Eshghi et al., 2017; Hardin-Jones et al., 2023), however, none have done so at the fine-grained level of vocalisation measures, or in such a specified sample (e.g., cleft type, syndromic status, and palatal age) addressed by this thesis. Therefore, it is recommended that future clinical (pre-)babble research integrates subgroups within samples as well as pre- and post-repair data.

Next, for future work implementing the snapshot approach to researching vocal recordings, it is encouraged that multiple days are recorded to select samples from. This design would boost certainty that infants were 'at their best' or 'usual' production levels across the selected samples. Such an approach would also reduce the possible explanations for outliers surrounding the infant's temperament or health level when LENA recordings were carried out because it discounts low energy windows of time (e.g., napping, or 'bad days') and is a consistent measure across the audio selection. In addition, more work is required control the quality of the environment captured by LENA (or alike) recordings (e.g., to discern siblings' interference in the speech, and reduce unattended and/or irrelevant noises in the overall environment). While the inclusion of phonetic transcription reduces limitations in speaker identification (see Section 6.1.1 for a reminder), it still caused difficulty in the vocal classification process. Consequently, the inclusion of set activities is recommended to increase consistency across recordings regarding the number of speakers present, interference of sounds when infant is being transported, and so forth.

Lastly, it is recommended that future work using LENA collection to explore vocal development should employ a higher number of recording time points, in order to bring a more longitudinal nature in different interactional contexts into the frame of pre-linguistic CP research. Such an approach would especially be of interest for investigating the onset of vocal motor schemes across the population as well as the onset of canonical babbling, and/or later first words. As such, follow up audio recordings at 1-month intervals post-repair would enable researchers to assess when/whether shifts occur in substitution, deletion, and misarticulation patterns and how stable the vocal measures presented in this thesis are. In a similar way, it is recommended that studies with aligned aims to the present thesis should collect naturalistic phonetic and syllable inventories from shorter intervals (e.g., 3 months or 6 months) to yield comparable measures of inventory sizes over time. Such an approach would allow researchers to assess the progression of sound sequences against measures that better reflect the rehearsal process than isolated, clinical measures.

In light of the discussion, theoretical models may be of additional benefit in future research in order to extend evidence-based research further. Understanding patterns in the data through different mechanisms may help to interpret the process of vocal development. It is recommended that such theories maintain an anatomical focus (such as sensorimotor feedback theories, the motor model, and frame-content theory), which are inherently relevant to the clinical group, but also perception-production models, as proposed in the literature (see Section 2.2.3.1). For instance, during and after CP repair, infants experience new, sensorimotor input (i.e., motor feedback on what their articulators feel like when they produce sounds, Bruderer et al., 2015) to what was familiar from birth and pre-repair. Such changes could cause a similar impact to the triggering effect of cochlear implantation (Löfkvist et al. 2020, p. 2) because when infants have access to newly altered input in their auditory environment, an exploratory response is 'triggered'. It is possible that sensorimotor impacts are at play when ICPs following repair gain new, altered articulatory options, too. Future work should explore this possibility directly to ascertain whether higher experimentation rates post-repair may be due to physical feedback on their own vocalising, resulting in them exploring more sounds with more direct control, leading to an eventually fuller repertoire. The combination of theoretical explanations along with data on the timeframes in which infants acquire a set of stable consonants would build a better picture of vocalisation characteristics. To conclude, further research should integrate these motoric feedback models to gain an insight into the possible processes experienced by ICPs.

## 7.3 Conclusion

This thesis has researched vocalisation data from the under explored population of ICPs post-repair. It has analysed production patterns by applying them to standardised measures from typical development research and by presenting new visualisation approaches to capturing large amounts of phonetically transcribed data. The prelinguistic vocalisation period is a well-established contributor to stable, speech-like vocal production, and is well documented in the acquisition of early words and associated to later speech outcomes. This thesis has given new insight into overlapping patterns between ICPs post repair and typically developing infants.

It has examined the vocalisation characteristics of twenty-eight 14-month-olds with a repaired CP. The present research has explored the relationships between vocal count, babble levels, and phonetic sequences in a more selective clinical sample than the literature currently offers. Moreover, this thesis has presented novel findings on naturalistic data from twenty-eight infants' vocalisations; in this way, it provides detail that speech and language phonetic inventories do not cover and at an earlier timeframe than many clinical measures explore. More specifically, this discussion has foregrounded the significant impact of palatal age on how much infants vocalised at 14 months of age. It crucially illustrated its impact on the phonetic composition of vocalisations, insofar as higher palatal ages produced more speechlike vocalisations (on average) and also had a greater repertoire of stable, consistent, supraglottal consonant articulations. The impacts of this temporal matter exemplified how the amount of time post-surgery (or indeed the number of opportunities an infant has for vocal rehearsal) relates to more speechlike vocalisations in sequences that reflect the typical trajectory more closely.

The analyses revealed patterns that encourage mechanistic understanding, too. Later acquired consonants often emerged in a greater number of sequences, namely, medial position consonants, which require more articulatory coordination between closure and opening of the vocal tract than monosyllables. This development was present in older palatal ages, illustrating more connected and more phonetically mature sequential systems, in line with network models, sensorimotor theories, and also scaffolding explanations. The inverted results, that is the lower canonicity of younger palatal groups, instead illustrated substitution and redirection explanations, as their transitional probabilities deviated to the typical consonant + vowel structures that emerge in the canonical babble stages. Longer vocalisations also presented less in younger and more in older groups, posing that as phonetic coordination and maturity stabilises, infants produce longer strings (e.g., polysyllables versus the former monosyllables (Hariharan et al., 2015), illustrating gained breath control.

In summary, this thesis' findings have pointed to areas of delay (in MBL when compared to control groups and also in number of VMS consonants acquired by ~14 months), and areas of deviation to the typical trajectory (absences of mid vowels, higher presences of vowel-, liquid-, and liquid/glottal-initial syllables). Both of these comparisons to the typical trajectory were especially evident across younger palatal groups, revealing that palatal age influenced the production milestones as reflected by the explored vocal patterns. Overall, these typical milestones did not appear entirely clean cut in the sample (even within the palatal groups); a reflection that is perhaps unsurprising given the many clinical variables in play. Despite this broader conclusion, the measure of mean babble level was illustrated to offer objective comparison to typically developing 12-month-olds, as well as more heterogeneous and CP 12-month-olds (Scherer et al., 2008), with the scope of many more comparable ages and groups. The mechanism of transitional probabilities for displaying the data also provided an effective and efficient way to view data across these variables and could be of value to future phonetic and phonological studies of atypical populations. Moreover, the results from MBL scores, coupled with evidence of vocal motor scheme production by the ICPs, presents results for (what is known as) the first time that these infants do produce canonical syllables, with a range of idiosyncratic consonant consistencies and variation within the first months after surgery.

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# 9 Appendices

## 9.1 Appendix A - Cardiff University Ethics Forms

### 9.1.1 Ethical Approval Certificate, from ENCAP Ethics Committee

Cardiff University
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School of English, Communication and Philosophy
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Monday, 14 February 2022

Dear Ms Alice Langner,

**Research project title:** Patterns of speech sounds after surgery: Investigating infants' phonological development following full cleft palate restorative surgery

**SREC reference:** ENCAP/Langner/14-02-2022

The ENCAP Research Ethics Committee reviewed the above application via its proportionate review process.

**Ethical Opinion**
The Committee gave a favourable ethical opinion of the above application on the basis described in the application form, protocol and supporting documentation

**Additional approvals**
This letter provides an ethical opinion only. You must not start your research project until all appropriate approvals are in place.

**Amendments**
Any substantial amendments to documents previously reviewed by the Committee must be submitted to the Committee (encap-researchintegrity@cardiff.ac.uk) for consideration and cannot be implemented until the Committee has confirmed it is satisfied with the proposed amendments.

You are permitted to implement non-substantial amendments to the documents previously reviewed by the Committee but you must provide a copy of any updated documents to the Committee (encap-researchintegrity@cardiff.ac.uk) for its records.

**Monitoring requirements**
The Committee must be informed of any unexpected ethical issues or unexpected adverse events that arise during the research project. Researchers are responsible for ensuring that they adhere to the procedures set out in approved applications. The Committee must be informed when your research project has ended. This notification should be made to ENCAP's Research Office (encap-res@cardiff.ac.uk) within two months of research project completion. You should confirm that data collection has ended and submit a final report of any amendments to the research procedure.

**Documents reviewed by Committee**
The documents reviewed by the Committee were:

| Document | Date |
|---|---|
| Research Ethics Approval Application Form (Revised) | 11/02/2022 |
| Certificates of training completion | 03/02/2022 |
| The Cleft Collective Speech and Language Study Documents (participant-facing documents and ethical approval letter) | 03/02/2022 |

**Complaints/Appeals**

If you are dissatisfied with the decision made by the Committee, please contact Dr Tereza Spilioti in the first instance to discuss your complaint. If this discussion does not resolve the issue, you are entitled to refer the matter to the Head of School for further consideration. The Head of School may refer the matter to the to the Open Research Integrity and Ethics Committee (ORIEC), where this is appropriate. Please be advised that ORIEC will not normally interfere with a decision of the Committee and is concerned only with the general principles of natural justice, reasonableness and fairness of the decision.

Please use the Committee reference number on all future correspondence.

**The Committee reminds you that it is your responsibility to conduct your research project to the highest ethical standards and to keep all ethical issues arising from your research project under regular review.**

**You are expected to comply with Cardiff University's policies, procedures and guidance at all times, including, but not limited to, its Policy on the Ethical Conduct of Research involving Human Participants, Human Material or Human Data and our Research Integrity and Governance Code of Practice.**

Yours sincerely,

Dr Tereza Spilioti, Chair of ENCAP Research Ethics Committee

Cc ENCAP's Research Office

*Figure 9.1: Cardiff Ethics Form*

### 9.1.2 Research Integrity Completion, Ahead of Data Access


Research and Innovation Services

This is to certify that

Alice Langner

has successfully completed

Research Integrity Training (Student)

on

2nd December 2021

*Figure 9.2: Cardiff Research Integrity Certificate*

## 9.1.3 Research Proposal - For Ethics

**Research Proposal – Ethics Application to ENCAP Research Committee**

The integration of language theory for the exploration of early speech sounds is commonplace in typical developmental research. However, as of yet, very little research on atypically developing populations integrates theoretical perspectives to offer fresh insight into the persistent difficulties that many individuals experience in phonological advances. In order to broaden our understanding of cleft palate (CP) infants' development post-surgery, my research will investigate speech sounds at 13-4 months by using a relevant, established theoretical perspective at the centre of its methodology. To determine which speech acquisition theory is most robust, suited, and workable, a selection of frameworks (e.g., Frame-Content Theory, Vocal Motor Schemes, The Articulatory Filter Hypothesis, and Production-Perception/ Sensorimotor Feedback Theory) will be piloted on 1 or 2 sample infants before carrying out the main study (in autumn 2022).

The CC-SL data offers valuable, naturalistic speech data from a sample that can be controlled for a range of (potentially conflicting) features, most crucially these include researching infants with CP only; with no other known disorders/difficulties; with English as the only language spoken in the home; and (if possible) with a similar size of opening in the palate. The stability of consonant productions (or vocal motor schemes) can be assessed by this data because of its desirable duration in the hour-long speech recordings. Additionally, the hour-long segments used will be from when each infant is most vocal (from day-long recordings that are 12-16 hours in length), which is a consistent approach to many typical babble studies, including those that take a theoretical stance. The corpus data is also fitting to the exploration of CP infants' input speech because the LENA recordings capture caregiver speech/vocalisations in close proximity to infant productions; this aspect lends itself to the AFH, Perception-Production Theories and Sensorimotor Feedback Theory especially. Lastly, the automated analysis from LENA data will allow for comparison of speech variables across the sample—particularly the distribution and rate of infant vocalisations throughout the whole day; number of conversational turns; and adult word count—which should indicate how well the hour-long recordings represent the infants' babble behaviours overall as well as how caregivers interact with infants. To summarise, the research will allow me to investigate CP speech from a theoretical perspective and will allow me to explore whether this new perspective could impact our understanding of the developmental processes of children with speech disorders. This may support clinical intervention and provisions for infants after cleft palate repair.

**Research Questions**

1. In what ways do the phonetic properties of babble at 13-14 months (i.e., the articulatory properties of babbled consonants) differ between typically developing infants and infants after cleft palate repair?
2. Do rates of vocalisation, canonical babble ratios, and consonant repertoire show consistencies with previous research (i.e., Korean-speaking infants in Ha and Oller 2021)?
3. To what extent are the acoustic properties of CP infants' syllables similar to those produced by typically-developing infants?
4. To what extent do CP infants respond to the sounds of caregiver speech in their own babble (following the framework set out in Laing and Bergelson, 2020)?
5. In what ways can the phonetic/phonological patterns in CP babble contribute to existing theories of speech acquisition, (these theories will be piloted: Frame-Content Theory, Vocal Motor Schemes, The Articulatory Filter Hypothesis/Sensorimotor Feedback Theory, and Production-Perception theories)?

**Data**

Research will analyse data from the CC-SL hour-long speech recordings LENA analysis from day-long recordings from cleft palate infants at 13/14 months of age. The use of a language environment analysis—or LENA—device (LENA Research Foundation, 2018) is relevant to this research focus because it captures caregiver speech in the infant's environment, as well as their own vocalisations, in a naturalistic setting. The additional variables on demographic, psychological, surgical, hearing, and speech/language data may be beneficial for the consideration of research and sampling methods.

I will use a sample of 42 cleft palate (only) infants in total. The sample will be controlled on the following variables: infants born with CP only; infants with no other known disorders/difficulties; and infants with English as the only language spoken in the home. If possible, it would also be good for infants to have a similar the size of opening in the palate, in order to control for articulatory potential following surgery.

PILOTS, 2 infants - The integration of the potential speech theories will be explored through initial pilot studies in Spring 2022, which these will be carried out on 1 / 2 infants (separate to the other 40) as a means of justifying the methodological / theoretical direction of the main project.
MAIN STUDY, 40 infants – Although this exact number may change following pilot, this is the approximate sample size I aim to use in order to phonetically transcribe and analyse infant and caregiver vocalisations and investigate speech patterns at 13-4 months.

**Methodology**

In order to examine the phonetic properties in CP infants whilst integrating a theory of speech acquisition, qualitative, statistical, and corpus analysis approaches will serve to explore some main variables in CP vs. TD infants with a mixed methods approach:
1: the acoustic-phonetic properties of infant babble produced in early vocalisations
2: the contingency between caregiver input and infant vocalisations.
3: the stability/frequency of produced consonants (or regularity of speech repertoire)
4: the co-occurrence patterns of babbled structures/syllables
Analyses include the following stages:

- Acoustic phonetic analysis—using PRAAT (Boersma et al. 2019)—of consonant inventories at 13-14 months.
- Phonetic transcriptions—using ELAN (2020)—to investigate infant productions.
- Transcription of congruent/incongruent caregiver input preceding infant vocalisations, adapted from Laing and Bergelson (2020).
- Comparisons of consonant inventories at 13-14 months across CP and TD infants
- Comparisons of VMS patterns in CP infants 13-14 months with TD infants at a younger age.
- Comparisons of syllable structures in CP infants 13-14 months with TD infants at a younger age/and with the literature on typical acquisition patterns.

**Impact**

My proposed research will bring a new perspective to an established theory of speech acquisition by considering an existing framework in the context of a clinical speech disorder. I will explore the patterns of infant's own vocalisations and their resemblances with caregiver vocalisations, to examine phonological proficiency after cleft palate restoration. In the longer term, my research could impact our understanding of the perception-production relationship and auditory-phonetic/articulatory feedback in the developmental processes of children with speech disorders. This may support clinical intervention and provisions for infants after cleft palate repair and has potential for extending findings onto other speech disorders.

*Figure 9.3: Research Proposal*

## 9.2 Appendix B - Cleft Collective Ethics Forms

### 9.2.1 Ethical Approval from The Cleft Collective Corpus

NHS
**Health Research Authority**
**NRES Committee South West - Central Bristol**
Bristol Research Ethics Committee Centre
Whitefriars
Level 3, Block B
Lewin's Mead
Bristol BS1 2NT
Email: nrescommittee.southwest-bristol@nhs.net

Telephone: 0117 342 1335
Facsimile: 0117 342 0445

01 April 2014

Dr Yvonne E Wren
Senior Research Speech & Language Therapist
North Bristol NHS Trust
Bristol Speech & Language Therapy Research Unit
Frenchay Hospital
Bristol BS16 1LE

Dear Dr Wren

| | |
|---|---|
| **Study title:** | **Identification of factors associated with PSD of known origin in the UK Cleft Gene Bank study** |
| **REC reference:** | **14/SW/0050** |
| **IRAS project ID:** | **135015** |

The Research Ethics Committee reviewed the above application at the meeting held on 28 March 2014. Thank you for attending with Professor Sandy to discuss the application.

**Issues discussed:**

1) Parents would know when they were being recorded: what about other people who might be around?
*Voices would not be picked up unless individuals were quite close to the child. The recording needed to reflect an "everyday situation". You would listen to very short segments, with attention being given to the baby rather than anyone else.*

2) *Upon query, you confirmed the full 16 hours of recording would be archived indefinitely. Personal details would also be archived for use when sending out information to parents.*

3) A lot of data was being collected: what analyses would be undertaken?
*Outcome data at 3yr would be compared with that at 13 months. Babble patterns, consonant, and vowels would be examined. Data collected at 13mo would be related to speech at age 3yr.*

4) What about other siblings at the time of recording?
*You would be able to identify the child in question; it would be possible to tell how far from the baby the other person was. The recording would pick up other noises such as those made by the microwave, refrigerator, etc.*

5) It was noted that the 16-hour recording would be undertaken when the child was not in childcare. If the child attended nursery (as opposed to being an only child with the parents) would this be a confounding factor?
*You advised this data would be collected via questionnaire at 18 months.*

6) Members were advised that the relevant Speech & Language Therapy clinic would be informed of the child's participation in this study.

7) The consent form mentioned participants could withdraw, but this was not mentioned in the PIS.
*You agreed to include this.*

**Ethical opinion**

The members of the Committee present gave a favourable ethical opinion of the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

**Ethical review of research sites**

NHS Sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

**Conditions of the favourable opinion**

The favourable opinion is subject to the following conditions being met prior to the start of the study.

**Conditions specified by the REC:**

1) The participant information sheet (PIS) should mention that participants could withdraw at any time without giving a reason……etc.

2) It was noted that data would collected via a questionnaire at 18 months (point 5 above): this needs to be clearly stated in the PIS. A copy of this questionnaire should be submitted to the Ethics Office.

3) Confirmation was required that permission has been obtained to use the photograph of the girl in the PIS.

**You should notify the REC in writing once all conditions have been met (except for site approvals from host organisations) and provide copies of any revised documentation with updated version numbers. The REC will acknowledge receipt and provide a final list of the approved documentation for the study, which can be made available to host organisations to facilitate their permission for the study. Failure to provide the final versions to the REC may cause delay in obtaining permissions.**

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

*Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.*

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

*Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.*

*For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.*

*Sponsors are not required to notify the Committee of approvals from host organisations*

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database within 6 weeks of recruitment of the first participant (for medical device studies, within the timeline determined by the current registration and publication trees).

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g. when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non clinical trials this is not currently mandatory.

If a sponsor wishes to contest the need for registration they should contact Catherine Blewett (catherineblewett@nhs.net), the HRA does not, however, expect exceptions to be made. Guidance on where to register is provided within IRAS.

**It is responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).**

**Statement of compliance**

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

**After ethical review**

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details, unless you expressly withhold permission to do so. Publication will be no earlier than three months from the date of this favourable opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to withhold permission to publish, please contact the REC Manager Mrs Naazneen Nathoo, nrescommittee.southwest-bristol@nhs.net.

Reporting requirements

The attached document "After ethical review – guidance for researchers" gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The NRES website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the website.

Further information is available at National Research Ethics Service website > After Review

| **14/SW/0050** | **Please quote this number on all correspondence** |
|---|---|

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

With the Committee's best wishes for the success of this project.

*Enclosures:* *"After ethical review – guidance for researchers" [SL-AR2]*

*Copy to:* *Helen Lewis*
*Nicola Williams*

**NRES Committee South West - Central Bristol**

**Attendance at Committee meeting on 28 March 2014**

**Committee Members:**

| *Name* | *Profession* | *Present* | *Notes* |
|---|---|---|---|
| Dr Kay Barnard | Ex-research scientist | Yes | |
| Dr Robert Beetham | Retired Consultant Clinical Biochemist | Yes | |
| Mr Trevor Beswick (AV-C) | Director - SW Medicines, Information & Training | Yes | |
| Dr Pamela Cairns (Chair) | Consultant Neonatologist | No | |
| Mrs Angela Clarke | (Ex-social worker) | Yes | |
| Dr Simon Croxson | Consultant Physician | Yes | |
| Dr Ian Davies | Consultant in Cardiac Anaesthesia & Intensive Care | Yes | |
| Dr Michael Halliwell | Medical Physicist (retired) | No | |
| Mr Geoffrey Jones | Retired solicitor | Yes | |
| Dr Adrian Kendrick | Clinical Scientist | Yes | |
| Mr Paul Lewis | Patient Involvement Coordinator | Yes | |
| Mr Brian Pixton | Retired solicitor | Yes | |
| Dr Colette Reid | Research Fellow in Palliative Medicine | Yes | |
| Dr Margrid Schindler (V-C) | Consultant Senior Lecturer | No | |

**Also in attendance:**

| *Name* | *Position (or reason for attending)* |
|---|---|
| Mrs Naazneen Nathoo | REC Manager |



*Figure 9.4: Cleft Collective Ethics Approval*

### 9.2.2 Child Consent Form from The Cleft Collective Corpus

Appendix R_Child Consent Form CC SL_Version 1_18/02/2014_REC No: [14/SW/0050]

Study number: ☐☐☐☐☐ - ☐☐ **The Cleft Collective Speech and Language Study**
version.1.0

**CHILD – Speech and Language**
The Cleft Collective Speech and Language Study
Consent Form for Child

Name of child: ______________________________

Child's date of birth: ______________________________

Parent/guardian name: ______________________________

Relationship to child: ______________________________

We will **not** share your contact details with a third party.

For each statement please **initial** in the box if you give consent. Thank you.

| **Your involvement in the study** | **Please initial** |
|---|---|
| I confirm that I have read and understood the information sheet dated 18/02/2016 (version 3) and have had the opportunity to ask questions. | |
| I understand that my child's participation is voluntary and that I am free to withdraw my child at any time, without giving any reason, without their medical care or legal rights being affected. | |
| I understand that any information about my child will be kept confidential. | |
| I understand that The Cleft Collective Speech and Language Study would like to keep my contact details so that they can contact me in the future about this study and to keep a record of my child's involvement in the study. | |
| I understand that the recording of my child will be considered a gift but I will have the right to withdraw permission for analysis. | |
| I understand that all the information from the recording and questionnaires given to The Cleft Collective Speech and Language Study will be stored in Bristol and analysed for research purposes only. | |
| I understand that my child's anonymous recording and data will only be shared with researchers who are conducting projects approved by a research ethics committee. Researchers have no access to my child's personal information. | |
| I agree to my child's data and recordings being stored and analysed for future cleft related research in the UK and abroad that has been ethically approved. | |
| **Digital Audio Recording** | **Please initial** |
| I give permission for my child to be audio recorded for one whole day using an audio recorder worn in customised clothing which will be provided. | |
| I understand that audio recordings will be analysed by members of the research team, which may include transcription (making a written copy), and these will be made anonymous with any personal identifying information removed for reporting. | |
| I understand that the sounds made by my child may be quoted in publications, reports, and other research outputs and these will have any identifiable information | |

Page **1** of **2**

Study number: [ | | | | ] - [ | ] **The Cleft Collective Speech and Language Study**
version.1.0

| | |
|---|---|
| removed. | |
| I understand that the research is designed to promote scientific knowledge and I agree that the Bristol Speech and Language Therapy Research Unit/Cleft Collective can keep and use the data my family provide for research purposes only. | |
| I understand that the Bristol Speech and Language Therapy Research Unit/Cleft Collective may use the data collected in this study in future research projects but that the conditions on this form still apply. | |
| **Records from other professionals** | **Please initial** |
| I confirm that I am happy for the research team to inform my child's speech and language therapist about our involvement in this study. | |
| I confirm that I am happy for the speech and language therapist who assesses my child at age 2 (if applicable) and age 3 to share assessment and intervention data with this study. | |
| I confirm that I am happy for information on my child's hearing assessments to be shared with the study. | |
| **Other consents** | **Please initial** |
| If at any point during the study I lose capacity to consent, I agree that my child's data and the recordings already collected can be retained and used in the study. | |
| I understand that if I wish to withdraw my child from the study in the future, I agree that the recordings may be retained and used unless I specifically request they are destroyed. In this instance, we will make every effort to do so and ensure that no further analysis is conducted on your child's data. | |
| I understand that responsible individuals may look at sections of my child's study and medical records. This will only be where it is relevant to taking part in this research. These individuals will either be representatives from the research sponsor, ethics committee or carrying out research monitoring. | |

I agree that my child will take part in this research.

Name: Date:____________________

Signature:

Page **2** of **2**

*Figure 9.5: Cleft Collective Child Consent Form*

### 9.2.3 Parent Consent Form from The Cleft Collective Corpus

Appendix S_Parent Consent Form_Version 3_18/02/16_REC No: [14/SW/0050]

Study number: [ | | | | ] - [ | ] **The Cleft Collective Speech and Language Study** version.2.0

**PARENT – Speech and Language**
The Cleft Collective Speech and Language Study
Consent Form for Parents

*N.B. This form needs to be completed by your child's main carer(s).*

Your name: ______________________________

*We may need to contact you with regard to delivery of the LENA recorder. Please can you provide the following contact details:*

Telephone number: ______________________________

Mobile number: ______________________________

Email address: ______________________________

Your date of birth: ______________________________

Address: ______________________________

______________________________

*(This information is needed to ensure that we link this form with the rest of the data on the Cleft Collective database and to contact you. We will **not** share your contact details with a third party.)*

For each statement please **initial** in the box if you give consent. Thank you.

| **Your involvement in the study** | **Please initial** |
|---|---|
| I confirm that I have read and understood the information sheet dated 18/02/2016 (version 3) and have had the opportunity to ask questions. | |
| I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. | |
| I understand that any information about me will be kept confidential. | |
| I understand that The Cleft Collective Speech and Language Study would like to keep my contact details so that they can contact me in the future about this study and to keep a record of my involvement in the study. | |
| I understand that all the information from the recording and questionnaires that I give to The Cleft Collective Speech and Language Study will be stored in Bristol and be analysed for research purposes only. | |
| I understand that my anonymous recordings and data will only be shared with researchers who are conducting projects approved by a research ethics committee. Researchers have no access to my personal information. | |
| I agree to my data and recordings being stored and analysed for future cleft related research in the UK and abroad that has been ethically approved. | |
| **Digital Audio Recording** | |

Study number: ☐☐☐☐☐ - ☐☐ **The Cleft Collective Speech and Language Study**
version.2.0

*Please also provide the following information which will assist us in providing the LENA equipment:*

1. **What size vest would you like for your child** (please tick one):

Age 6-9 months ☐ Age 9-12 months ☐ Age 12-18 months ☐

2. **When will your child be aged 13 months?** (Please specify dates, e.g. 12th September 2014 – 11th October 2014)

……………………………………………………………………………………………………

3. **Please specify a date during this month when it would be the best time for you to carry out the LENA recording?** (Remember it needs to be a day when your child is with you rather than receiving childcare).

……………………………………………………………………………………………………

4. **Which day in the week before this date would be the best for us to send you the LENA equipment and for you to return it to the post office a week later?** (Remember you will need to be at home until the courier has delivered the package). Please tick one box. (It is not possible for the equipment to be delivered on a Monday or at the weekend.)

| Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ |

5. **Where would you like us to send the LENA equipment?** This can be your home address or another address if that is more convenient. Please provide the complete address for delivery, including postcode, below:

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Thank you for your help. We will be in touch when we have arranged for delivery of the LENA equipment to your address.

Study number: [ | | | | | ] - [ | ] **The Cleft Collective Speech and Language Study** version.2.0

| | |
|---|---|
| In giving permission for my child to be audio recorded over the course of one day, I understand that some of my speech and that of others who talk close by to my child will also be recorded. | |
| I understand that the audio recordings will be analysed by members of the research team, which may include transcription of my child's speech (making a written copy), and these will be made anonymous with any personal identifying information removed for reporting. | |
| I understand that I will be required to complete a questionnaire on my child's language skills and that these data will be linked to my child's recording but all identifying information will be removed when carrying out research. | |
| I understand that the research is designed to promote scientific knowledge and I agree that the Bristol Speech & Language Therapy Research Unit/ The Cleft Collective can keep and use the data my family provide for research purposes only. | |
| I understand that the Bristol Speech & Language Therapy Research Unit or the Cleft Collective may use the data collected in this study in future research projects, or in publications, presentations and training, but that the conditions on this form still apply. | |
| I understand that I will need to return the recording device and customised clothing to my local post office using a prepaid envelope addressed to the research team that will be supplied to me following my child's participation in the study. | |
| **Records from other professionals** | **Please initial** |
| I confirm that I am happy for the speech and language therapist who assesses my child at age 2 (if applicable) and age 3 to share assessment and intervention data with this study. | |
| I agree to take the hearing record to all hearing assessment appointments and to ask the audiologist to complete this. | |
| **Other consents** | **Please initial** |
| If at any point during the study I lose capacity to consent, I agree that my data and the recordings already collected can be retained and used in the study. | |
| I understand that if I wish to withdraw from the study in the future, I agree that the recordings may be retained and used unless I specifically request they are destroyed. In this instance, we will make every effort to do so and ensure that no further analysis is conducted on your data. | |
| I understand that responsible individuals may look at sections of my study and medical records. This will only be where it is relevant to taking part in this research. These individuals will either be representatives from the research sponsor, ethics committee or carrying out research monitoring. | |

I agree to take part in this research.

Name: Date:____________________

Signature:

Page **2** of **3**

*Figure 9.6: Cleft Collective Parent Consent Form*

### 9.2.4 Participant Information Sheet from The Cleft Collective Corpus

Appendix P_Participant Information Sheet CC SL_Version 3_18/02/16_REC No: [14/SW/0050]

The Cleft Collective
Closing the Gap in Cleft Research
A Healing Foundation Initiative

Participant Information Sheet

## The Cleft Collective Speech and Language Study

**You are being invited to take part in a research study about speech and language development in children born with cleft palate**

- Before you decide whether to take part, it is important for you to understand why the research is being carried out and what it will involve.
- Please take some time to read the following information carefully and discuss it with others if you wish.
- You are free to decide whether or not to take part in this research study. If you choose not to take part this will not affect the care you receive.
- You are free to withdraw from the study at any time without giving a reason.
- Please ask us if there is anything that is not clear or if you would like more information.
- Thank you for reading this information sheet. If you decide to take part you will be given a copy of this information and asked to sign a Consent Form.

**Important things that you need to know**

- This study is being carried out by the Bristol Speech and Language Therapy Research Unit in partnership with The Cleft Collective Birth Cohort Study.
- This study will follow the development of speech and language from birth to age 3 in children born with cleft palate who are participating in the Cleft Collective study. All families who are participating in the Cleft Collective Birth Cohort study are being invited to participate in this study.
- This research will help us find out more about how speech and language develops in children who are born with cleft palate and to identify which factors are most helpful in promoting speech and language development for these children.
- We are asking families to record their baby's speech over the course of a day, using specially designed recording devices.
- We are also asking families' permission to access their speech and language therapy and hearing records.

**Contents**



**How to contact us**

If you have any questions about this study, please speak to your cleft team, or contact Yvonne Wren at:

The Cleft Collective
University of Bristol
Oakfield House
Oakfield Grove
Clifton
Bristol, BS8 2BN, UK

Website: www.bristol.ac.uk/cleft-collective
Email: cleft-collective@bristol.ac.uk
Telephone: +44 (0)117 331 0025
Or join us on:
Facebook: www.facebook.com/CleftCollective
Twitter: @CleftCollective

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## 1. Why are we doing this study?

This study is interested in trying to understand how speech and language develops in young children born with cleft palate. We also want to find out how much the environment, e.g. interactions with others, affects development.

Approximately 50% of children born with a cleft palate have persisting difficulties with their speech or language at age 5. This can place them at risk when they start school and later in life. We want to understand more about what helps children with their speech and language development in the early years.

The research will ultimately help to improve care for those who are born with a cleft palate and their families.

## 2. Why are we asking you to take part?

You are being invited to participate because you have a child who has been diagnosed with a cleft palate and you and your baby are participants in the Cleft Collective Birth Cohort study.

## 3. What will I need to do if I take part?

The time line provided with this information sheet explains what type of information will be collected at each time point and how that fits with the main Cleft Collective Birth Cohort study.

**Recording your child's interactions**

The first time collection point will be when your child is aged 13 months. We will send you a digital recording device and customised clothing for your child to wear for one whole day. This recording device is about the same size as a small mobile phone and weighs only 60 grams (2 ounces). This is placed in a small pocket on the front of the clothing which will be sent to you. The customised clothing is a type of vest worn over the top of your baby's other clothes.

The recording device is simple to use. It has a power button and a recorder button. You will be sent instructions with the device but all you will need to do is switch the power button on and then press the record button. The recording device will then record continuously for 16 hours.

It is best to select a typical day when your child is with you to carry out the recording. You do not need to do anything special or different to normal but it does need to be a day when your child is with you rather than with a childminder or at nursery.

You need to take the vest off your child if they go for a sleep or you go in the car, and place it with the recorder still inside near to your child. Otherwise you can leave it on all day. The device will turn itself off automatically when it has recorded for 16 hours.

The recording device that your child will wear will record his or her speech plus that of anyone who is close by. The recordings which are collected will be analysed by software which calculates the number of vocalisations (child-like speech) that your child uses throughout the day. It will also measure the amount of speech spoken to him or her and the level of noise in the environment. From one whole day recording, we will identify a small number of specific 5 minute segments when your child has been most vocal and will listen to these segments, transcribe your child's speech (i.e. write down what sounds and noises they make) and analyse them in terms of the number and type of sounds used by your child. We don't know how many 5 minute segments we will need to listen to yet as this is one of the things we need to find out. However, it is anticipated that a maximum of 10% of the total recording time will be listened to in this way, meaning that most of the recording will only be analysed automatically by the software and will not be listened to by a human.

If your child is not yet making sounds, we will still be interested to know about how he interacts with others and the recorder will be able to pick this up.

We will ask you which day you would like the device sent to you and when you would like to carry out the recording. The recording device will be sent by courier but we will ask you to return the device to your local post office. We will provide you with a prepaid envelope for this purpose.

**Hearing Record**

It is important for us to know about your baby's hearing and how it changes over time as this can have an impact on their speech and language development. We will send you a hearing record card and covering letter for you to take to hearing assessment appointments when your child is aged approximately 18 months and 3 years.. The person carrying out the hearing test will be able to fill in the card with information about your child's hearing and return the hearing record to the Cleft Collective base.
.

**Speech and Language Questionnaire**

When we send you the recording device, we will also send you a questionnaire about your baby's early speech and language development. This will give us some extra information about how your baby is developing in this area which we will be able to use to supplement the information from the recording. This will be collected at the same time as the recording device. We will ask you to complete this questionnaire again just before your child is 3.

If you decide to take part in this study, we will ask you to complete a consent form for you as the parent and also another one on behalf of your child. Although either parent can choose to participate in the study, it will need to be the parent who spends most time with the child on the day of the recording who provides the parental consent. We will also ask you to answer some questions which will provide us with the information we need to send out the recording device.

## 4. What will happen to my information?

**What happens to the recordings?**

The recording devices and questionnaires will be delivered to the Cleft Collective research team at the University of Bristol where they will be processed using specially designed software and stored securely and anonymously.

The recordings and questionnaires will be labelled with a number and only The Cleft Collective team in Bristol will be able to link the data back to any other information that you have given us.

Anonymous recordings, questionnaire and hearing data from your family may be shared with other researchers in the UK and abroad to promote research, in particular in relation to cleft. All researchers will need approval from a research ethics committee to make sure your rights are protected. These researchers will never have access to your personal data.

You will be asked to indicate on the consent form if you give permission for the storage and analysis of your recordings in future, ethically approved cleft related research.

**How long will the recordings be stored for?**

Unless you request otherwise, we will store your recordings indefinitely. Future research may be able to use the data to understand other aspects of children's early speech and language development in relation to cleft palate, leading to improvements in management.

**Accessing Speech and Language Therapy data**

It will help us to understand the pattern of your child's speech and language if we are able to have information from your assessments with your local and cleft centre speech and language therapy team. We have worked with the lead speech and language therapy managers in each cleft centre to agree what information would be useful and have devised a specific form for them to record this information.

We will ask for your consent for us to inform your child's speech and language therapist about your involvement in this study. We will also ask for your consent for the speech and language therapist who assesses your child to share information with us at two specific time points: 24 months (2 years) and 36 months (3 years). Not all children are assessed by a speech and language therapist at 24 months, but where they are we will ask for permission to access this information. Nearly all children are seen either at or soon after their third birthday and therefore we will ask for your consent for the speech and language therapist to share information from this time point.

In addition, we will ask for your consent to obtain information from your speech and language therapy team about the type of intervention you have received from them up to age 3.

**Accessing data from the main Cleft Collective study**

It is helpful for us to link any information you provide us with that in the Cleft Collective Cohort studies. This will reduce the amount of duplication of questions and enable us to more fully explore the factors which impact on speech and language development.

For this reason, we will link the data we collect as part of the Speech and Language Study with the Cleft Collective main birth cohort study.

**How do we make sure your data stays confidential and protected?**

All the information we have about you, and the recordings and other data we collect from you, will be stored securely and confidentially, as is required by law in the Data Protection Act. A unique ID number will be the only way the information can be linked to you. Only the Bristol Cleft Collective research team will be able to link you to the unique ID number; this is important so that we can contact you in the future.

You will be asked to indicate on the consent form if you give permission for your data to be stored and analysed in future, ethically approved cleft related research. Only anonymous recordings and data will be shared with researchers. They will not have access to your personal information.

## 5. What are the possible benefits and disadvantages of taking part?

There may be no direct advantage to you or your child of taking part. However, you will be helping us to provide improved knowledge and support for all those affected by cleft palate in the coming years.

We do not see any major disadvantages to you of taking part in the study. However, the study will require some of your time. The research will not interfere with your child's cleft treatment which will take place as normal.

Please note: according to child protection laws if anything arises during the study which suggests a child is at risk from harm, the research team will discuss this with you and report it to the appropriate authorities. The lead researcher has a criminal records check and child protection training

## 6. Sharing the results and keeping in touch.

**What will happen to the results of the research?**

The anonymous findings of this research will be reported in professional publications, meetings and conferences. Results may also be shared with charities and with members of the general public, but you will not be personally identified in any report, presentation or publication.

We will also report anonymous summaries of the research findings via The Cleft Collective website (www.bristol.ac.uk/cleft-collective), the Bristol Speech and Language Therapy website (www.speech-therapy.org.uk) and via newsletters that will be emailed/posted to you unless you choose not to receive them.

**Keeping in touch**

An important part of The Cleft Collective is to keep in touch with those who have agreed to take part. This will tell us more about your child's treatment journey and about how your child is developing. We initially have funding for this project for three years; however, if we can secure further funding then we would like the study to continue indefinitely so that we can collect more information from you and your family. To help us keep in touch, we will use information held by the Cleft Collective main study.

## 7. How is this study funded and managed?

The Cleft Collective Speech and Language Study is run by Dr Yvonne Wren from the Bristol Speech and Language Therapy Research Unit, North Bristol NHS Trust. It is linked to the Cleft Collective Birth Cohort Study and as a consequence, is supported by the lead scientists on this study: Professor Jonathan Sandy and Professor Nichola Rumsey.

This research project was reviewed and approved by:

- The National Institute of Health Research before they agreed to provide the funding
- The NRES Committee South West – Central Bristol; an independent group who look at all research involving NHS patients and who are there to protect your safety, rights, well-being and dignity.

We also ask parents of children born with a cleft palate to give us their advice on aspects of this study and our study materials, for example, this information sheet.

The research is funded as part of a National Institute of Health Research Post-Doc Fellowship and is supported by the University of the West of England and the University of Bristol. The study is sponsored by North Bristol NHS Trust. The research is also supported by the Cleft Lip and Palate Association and involves all of the cleft teams around the UK.

**Contact for further information**

If you have any questions about this study and what you are being asked to consider, or if you have any queries/concerns at any point now or in the future, please contact the researchers at The Cleft Collective research centre in Bristol (details provided on front sheet).

If you have a complaint and you do not wish to speak to The Cleft Collective Team, you can contact your cleft team.

If you feel distressed and would like extra support at any time, you can contact:

- Your cleft team – most cleft teams have a Psychologist, but another member of the team may also be able to help you.

- The Cleft Lip and Palate Association (CLAPA) – the only UK-wide voluntary organisation set up to specifically help those affected by cleft lip and palate.

  Web: www.clapa.com

  Phone: 020 7833 4883

  Email: info@clapa.com

- Your GP (doctor)

Thank you for reading this information sheet. Please keep it for future reference.



*Figure 9.7: Cleft Collective Participant Information Sheet*

## 9.3 Appendix C - Supporting Materials

### 9.3.1 ELAN Tier Template Example

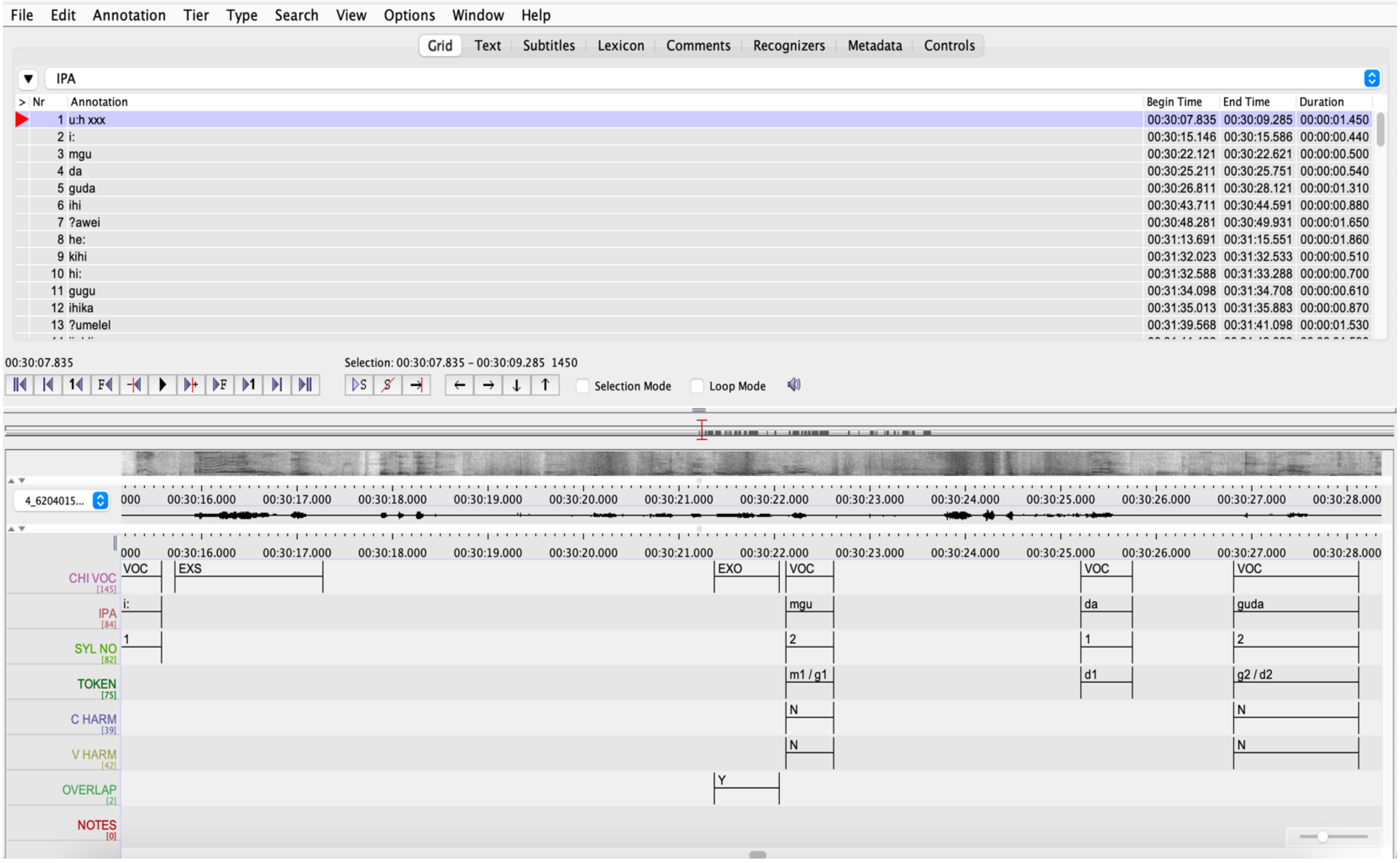

*Figure 9.8: Screenshot of ELAN Tier Format*

The template for this study (with optional tiers for caregivers' productions is available at the osf repository (Langner, 2024).

### 9.3.2 List of Abbreviations

The abbreviations for the terminology used, for Table 4.1, Chapter 4:

| | |
|---|---|
| CC-SLC Number | Pre-assigned participant number from CC-SLC |
| PP | Number assigned to final 28 infant sample |
| Order | Systematic/random order |
| Sex | Sex assigned at birth |
| Surgical Age | Surgical Age (in months) |

| | |
|---|---|
| Intertub. | Intertubosity (length of CP opening, in mm) |
| LENA Age | Age at data recording (in months) |
| Pal Age | Palatal Age at data recording (in months) |
| Cleft Type | |
| Ethnicity | |
| Mat. Ed. | Mother's education level.<br>, according to criteria in Table 4.1 |
| Eng. 1st Lang | English as first home language |
| Part. Ed. | Partner's education level, according to criteria in Table 4.1 |
| 24m Data | SLT assessment data from CC-SLC at 24 months |
| 36m Data | SLT assessment data from CC-SLC at 36 months |

Abbreviations for the Ed variable in  Table 4.1, Chapter 4

| | |
|---|---|
| First degree: | Higher degree: e.g., MA, PhD, postgraduate PGCE |
| Higher degree: | Higher degree: e.g., MA, PhD, postgraduate PGCE |
| 2 + A Levels: | 2 + A Levels Two or more A Levels/Four or more AS Levels/Higher School Certificate |
| Other qual: | Other qualification e.g., City and Guilds, RSA/OCR, BTEC/Edexcel |
| 1+ GCSE: | One or more O Levels/CSEs/GCEs any grades |
| 5+ GCSEs: | Five or more O Levels/CSEs grade 1/GCSEs grades AC/School Certificate |
| NVQ Level 2/Int. GNVQ: | NVQ Level 2/Intermediate GNVQ |
| NVQ Level 3/Adv. GNVQ: | NVQ Level 3/Advanced GNVQ |

## 9.4 Appendix D - Supporting Data Visualisations

This section contains the Appendix examples signposted throughout the thesis.

### 9.4.1 A Table of Most Common Sequences that Occurred 10 or More Times

*Table 9.1: Most Common Sequences (with 10 + Uses)*

| Order by Most Frequent | Sequence | f | Order by Most Frequent | Sequence | f | Order by Most Frequent | Sequence | f |
|---|---|---|---|---|---|---|---|---|
| **1** | GV | 2082 | **27** | GVN | 35 | **53** | VNVNV | 16 |
| **2** | SV | 605 | **28** | SVS | 35 | **54** | GVVV | 15 |
| **3** | GVGV | 464 | **29** | SLV | 33 | **55** | NVGV | 15 |
| **4** | GVV | 318 | **30** | GVVLV | 30 | **56** | SVSVS | 15 |
| **5** | NV | 226 | **31** | SVNV | 27 | **57** | GVGVLV | 14 |
| **6** | LV | 217 | **32** | GVGVV | 26 | **58** | GVNVV | 14 |
| **7** | GVLV | 205 | **33** | GVVGVV | 26 | **59** | GVGVNV | 13 |
| **8** | VLV | 174 | **34** | GVLVLV | 25 | **60** | GVSVSV | 13 |
| **9** | V | 173 | **35** | LVGV | 23 | **61** | LVLVLV | 13 |
| **10** | SVSV | 171 | **36** | SVSVV | 23 | **62** | SVGVGV | 13 |
| **11** | GVSV | 141 | **37** | VLVV | 23 | **63** | VN | 13 |
| **12** | GVNV | 116 | **38** | SVSVSVSV | 21 | **64** | F | 12 |
| **13** | VNV | 116 | **39** | GVVLVV | 20 | **65** | GVLVGV | 12 |
| **14** | GVGVGV | 114 | **40** | LVSV | 20 | **66** | GVSVV | 12 |
| **15** | SVV | 100 | **41** | NVN | 20 | **67** | LVNV | 12 |
| **16** | VSV | 98 | **42** | SVVSVV | 20 | **68** | SVVLV | 12 |
| **17** | SVGV | 88 | **43** | NVLV | 19 | **69** | VNSV | 12 |
| **18** | VGV | 85 | **44** | VLVLV | 19 | **70** | GVVGV | 11 |
| **19** | NVNV | 72 | **45** | GVNVNV | 17 | **71** | GVVGVV GVV | 11 |
| **20** | SVLV | 54 | **46** | GVVSVV | 17 | **72** | GVVSV | 10 |
| **21** | SVSVSV | 52 | **47** | NSV | 17 | **73** | NVNVNV | 10 |
| **22** | LVLV | 51 | **48** | VGVGV | 17 | **74** | NVNVNV NV | 10 |
| **23** | LVV | 48 | **49** | VNVV | 17 | **75** | SVLVLV | 10 |
| **24** | NVV | 43 | **50** | GVS | 16 | **76** | SVN | 10 |
| **25** | N | 42 | **51** | NVSV | 16 | **77** | SVVS | 10 |
| **26** | GVLVV | 39 | **52** | SVSVSVSV SV | 16 | | | |

### 9.4.2 A Bar Plot of Consonant and Vowel Harmony Across VMS Number

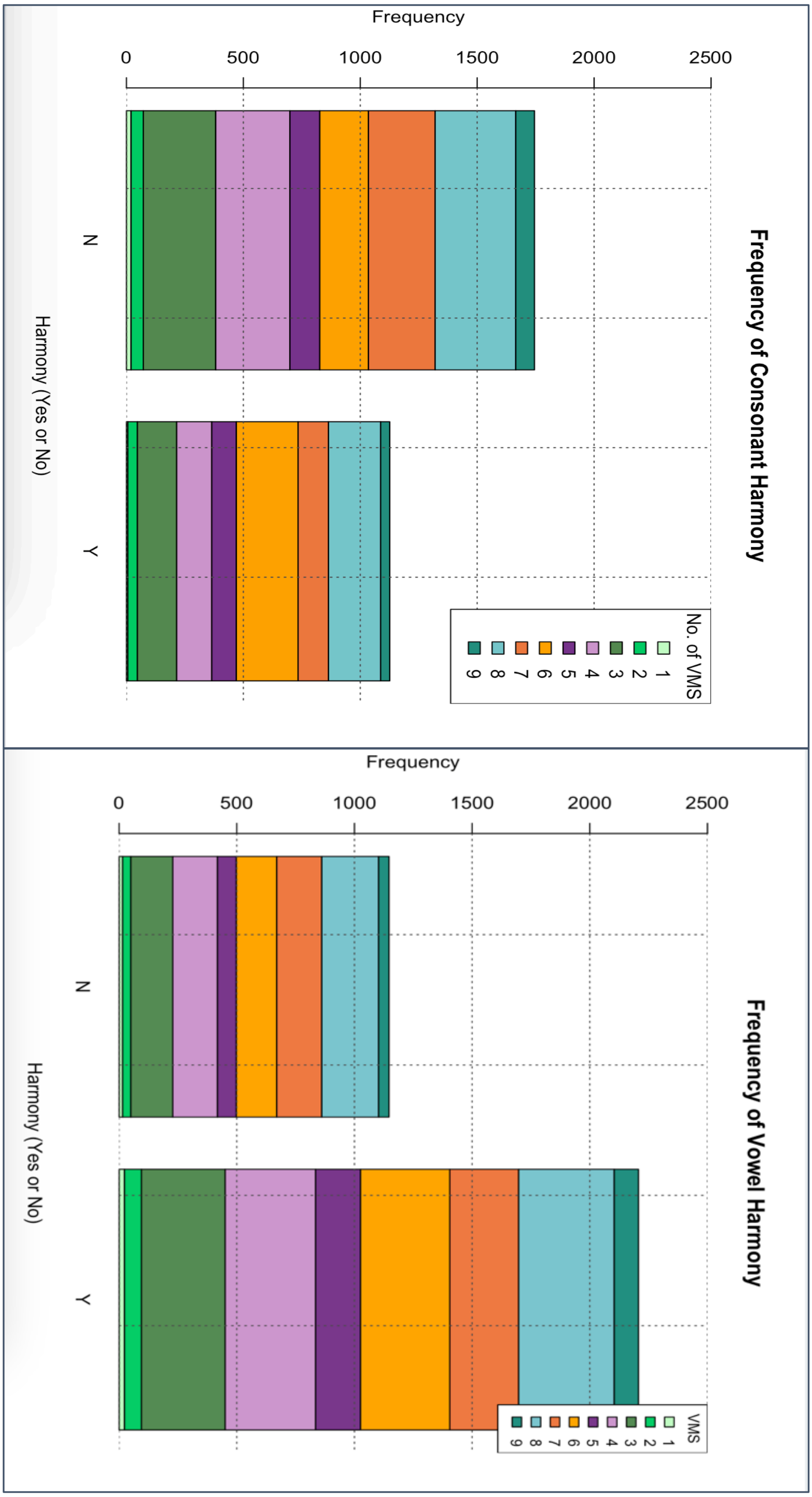


*Figure 9.9: A Stacked Bar Plot of Consonant and Vowel Harmony Across VMS Count*

### 9.4.3 A Transition Matrix Vowel Elements in Mono-Tri Syllables

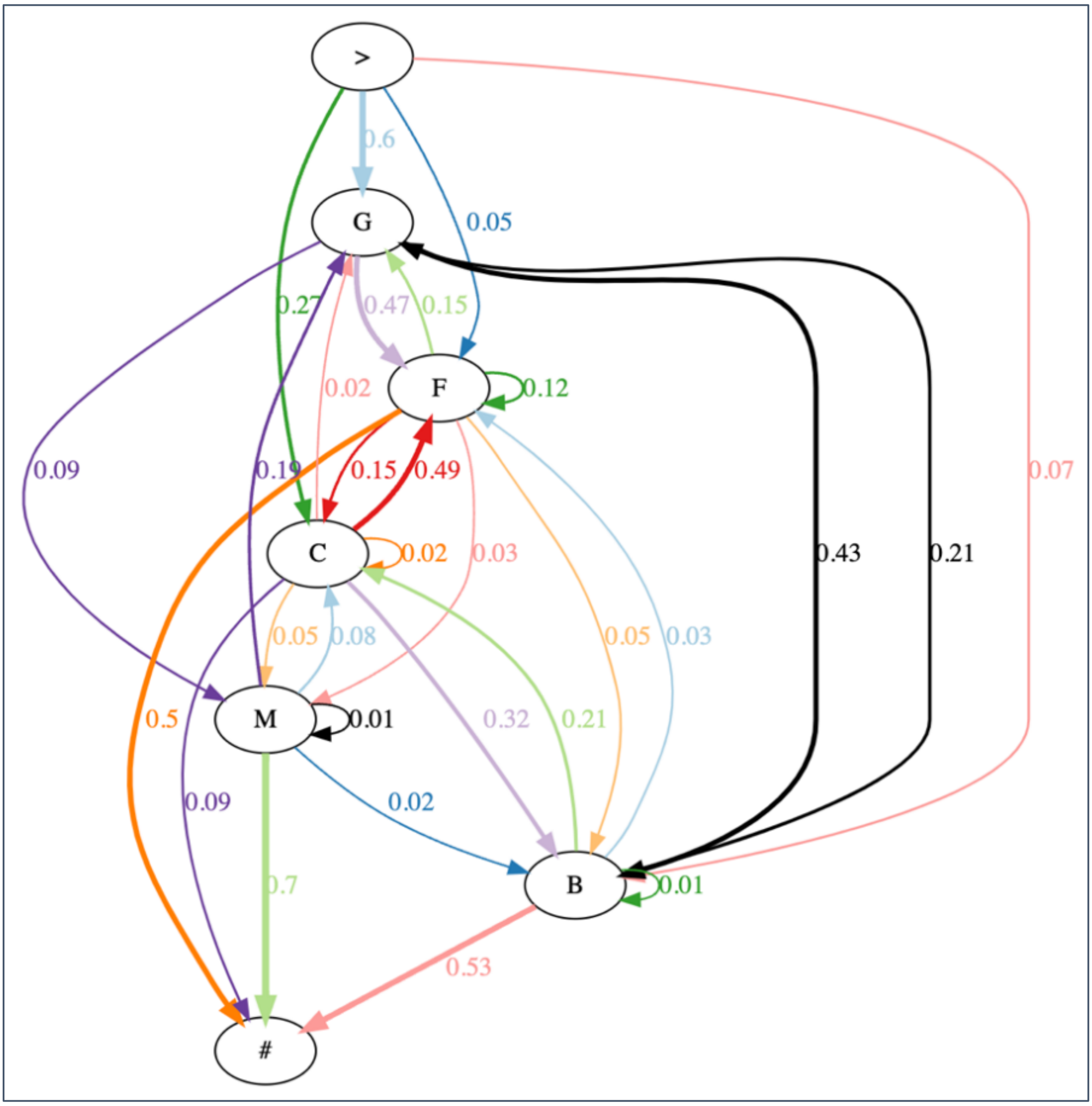


*Figure 9.10: A Transition Matrix Vowel Elements in Mono-Tri Syllables*