Comparing Lexical and Phonological Development: A Longitudinal Study of Two Child Learners of English

by

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Abstract

In this thesis, I compare the lexical and phonological development of two child learners of English (Georgia and Charlotte) from the English-Davis corpus, available through the Phonbank database (http://phonbank.talkbank.org/). I analyze the structure and content of the children's expressive vocabularies at each relevant phonological milestone, which I compare to their development of consonants in syllable onsets. Very few correlations are found between the structure of the children's lexicons and their individual patterns of phonological development. These observations pose a challenge to the Lexical Restructuring Model (Metsala 1997), which posits the lexicon as the primary force driving children's phonological development. Instead, the data reveal that patterns of phonological development are best understood in terms of the perceptual-articulatory phonological categories they involve, independent of the learners' lexicons. These findings are discussed in light of the PRIMIR and A-map models of language development (Werker & Curtin 2005; McAllister Byun, Inkelas & Rose 2016).

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Chapter 1: Introduction

1. Scope and objectives

Several studies have highlighted bidirectional relationships between lexical and phonological development (Rescorla & Ratner 1996; Metsala & Walley 1998; Beckman, Munson & Edwards 2007). However, the actual nature of the relationship remains unclear, as studies typically only focus on either lexical or phonological development, generally without much regard to the other domain. Consequently, theories of acquisition currently lack a formal way to encode this relationship (Munson et al. 2011; Stoel-Gammon 2011). My research aims to address this issue, through parallel explorations of the development of lexical and phonological knowledge in young children, as stated in the following research question:

(1) General research question:
What is the relationship between lexical and phonological development?

In order to examine the present research question, it is necessary to discuss the potential influences that speech perception, the lexicon, and speech production have on the relationship between lexical and phonological development. Stoel-Gammon (2011) explores the bidirectional nature of the relationship and claims that not enough work has been done in the areas where phonological and lexical learning overlap (Stoel-Gammon 2011:1). For instance, most child-centered studies focus on the influence of prelinguistic development and the active role of the child throughout different stages of lexical and phonological development (e.g., Stoel-Gammon & Cooper 1984; Vihman et al. 1985). However, effects of the lexicon receive very little attention in these studies. As a result, these studies suggest that phonological development affects lexical acquisition to a greater degree than lexical factors affect phonological development. Conversely, many adult-based studies highlight the influence of the lexicon in the area of phonological processing (e.g., Garlock, Walley & Metsala 2001; Ellis 2002). However, these studies rarely consider the role of perceptual or lexical learning, and make no mention of its relationship with phonological development. Consequently, adult-based studies suggest that the structure of the lexicon itself affects phonological development to a greater degree than phonological knowledge affects lexical development. One can presume that the seemingly contradictory findings from these two fields of investigation are primarily a result of researchers using different methodologies, different datasets, and different analytical frameworks (Stoel-Gammon 2011).

Across most existing studies, the structure of the lexicon has primarily been discussed in terms of phonological neighbourhoods. Phonological neighbourhoods are defined as groupings of words which have strings of phonemes in common. A phonological form differs from its neighbour by the substitution or deletion of a single segment. For example, words like 'pit' and 'bit' reside in the same [ɪt] neighbourhood. Likewise, words like 'pin' and 'pit' reside in the same [pɪ] neighbourhood. Neighbourhood density refers to the number of words that belong within phonological neighbourhoods; words with many neighbours reside in high-density neighbourhoods, while words with few or no neighbours reside in low-density neighbourhoods. An example of a word within a high-density neighbourhood is 'cat' because it shares the same phonemic sequences as many other words in English (e.g., 'mat', 'hat', 'rat', 'fat', 'at', etc.). An example of a word that falls within both a low-density neighbourhood and a high-density neighbourhood is 'sphere'. The onset of 'sphere' contains the phonemic sequence [sf], which is extremely infrequent in English, as only a few words share this phonemic sequence (e.g., 'sphere', 'sphincter'). However, the rhyme of 'sphere' displays the [iɹ] sequence, which we also find in many other words (e.g., 'ear', 'fear', 'here', 'near', 'cheer', etc.). Therefore, by this measure, the word 'sphere' simultaneously belongs to a high-density neighbourhood as well.

It has been argued that neighbourhood density plays a major role in the development of children's phonological systems. Metsala (1997) claims that it is the presence of phonological neighbours that enables the development of a phonological system. According to this approach, as children begin to acquire phonologically similar words, they have to further specify the lexical representations of these words, in order to mark functional distinctions between them. This suggests that children's lexical representations are at first relatively vague and not yet composed of very many discrete sound categories. Children then restructure these lexical forms into more precise representations as the size of their vocabularies increases. This hypothesis has been supported by the fact that young children's early lexicons are much more sparse in comparison to the lexicons of adults, which is compatible with the idea that phonological neighbours are easier to distinguish in (sparse) child lexicons (Charles-Luce & Luce 1995). This hypothesis is also supported by the fact that words from dense neighbourhoods in the adult language are typically acquired before words from sparse neighbourhoods (Coady & Aslin 2003; Storkel 2004). In sum, the shape of the lexicon is taken as the driver of phonological development.

However, research has also shown that infants' phonological productive abilities affect their early lexical development. The phenomenon of lexical selection and avoidance suggests that children are more likely to acquire words which contain sounds that they are capable of producing before words which contain sounds that they are not capable of producing (Leonard et al. 1981; Schwartz & Leonard 1982; Schwartz 1988). For example, a child with the prespeech vocalization [ba] is more likely to acquire a word like 'ball' before a word like 'cheese', assuming the child is not yet able to produce affricates. Many other correlations also exist between infants' prelinguistic vocalizations and early lexical development. For instance, correlations have been found between the age of onset of canonical babbling and the age of onset of meaningful speech (Stoel-Gammon 1989:222). Correlations have also been observed between the number of different syllables produced by one-year-old children and the age of first word production (Stoel-Gammon 1989:222). These findings suggest that phonological knowledge may drive lexical development or, minimally, early patterns of lexical production.

In this thesis, I engage with this debate through qualitative and quantitative analyses of the emergence of both lexical and phonological units in the productions of two first language learners of English. As we will see, very few correlations can be found between the structure of these children's developing lexicons and that of their individual patterns of phonological development. This suggests that phonology may not be as tightly connected to the structure of the lexicon as the lexicalist approach implies. Building on these results, I explore alternative approaches that aim to address similar questions. Through this work, I hope to contribute to our understanding of the formal relationships that exist between lexical and phonological domains of language development.

2. Theoretical background

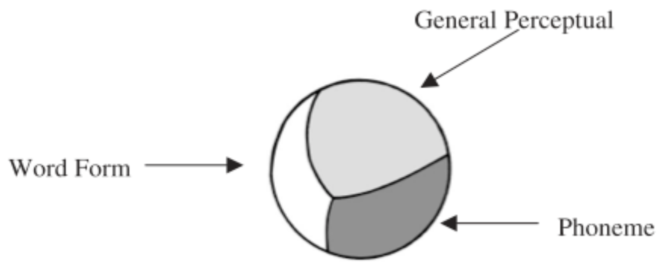
2.1 Lexical restructuring model

Metsala (1997) proposed the Lexical Restructuring Model (henceforth, LRM) in order to capture interactions between lexical and phonological development. According to the LRM, young children's early representations do not require detailed segmental knowledge in order to recognize and distinguish lexical items. Instead, Metsala suggests that during early stages of lexical development, children only encode global and holistic phonological representations for the words contained in their lexicons. As the lexicon grows in size, and children acquire more and more similar sounding words, holistic representations are no longer efficient. Children must then restructure their lexicons by making more fine-grained analyses of the phonological content of their words. This process results in the development of a more detailed system of phonological representations that, in turn, further aids children in expanding their current vocabularies. Thus, according to the LRM, the acquisition of phonological categories is dependent on the presence of phonological neighbours within the child's own lexicon. Charles-Luce & Luce (1995) support this hypothesis by measuring the density of phonological neighbourhoods in both adult and child lexicons. They demonstrate that the phonological neighbourhoods found in adult lexicons are much denser and evenly distributed than those in child lexicons. These quantitative differences lead Charles-Luce & Luce to claim that words in the developing lexicon are more easily differentiable than those in the adult lexicon. Based on this evidence, they claim that young children's lexicons do not require detailed phonological knowledge.

2.2 PRIMIR

Werker & Curtin (2005) have proposed the PRIMIR theoretical framework (*Processing Rich Information from Multidimensional Interactive Representations)*. In this framework, representations are multidimensional, interactive, and the result of statistical learning. Both lexical and phonological acquisition are divided into three main dimensions of learning. These three dimensions are illustrated in Figure 1.

Figure 1: PRIMIR's multidimensional planes (Werker & Curtin 2005:214)



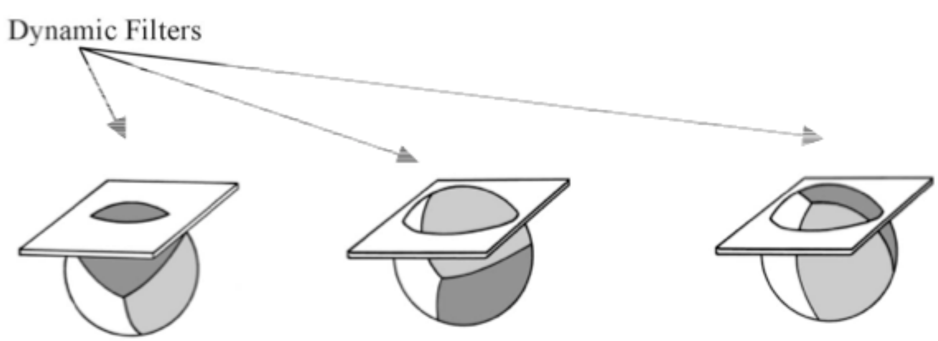
The first dimension that a child utilizes prior to the development of his or her lexicon is the General Perceptual Plane. This dimension serves to organize phonetic categories specific to the child's native language. The representations acquired using the General Perceptual Plane enable the next level of development, referred to as the Word Form Plane. This plane organizes word forms that have been extracted using the phonetic categories acquired from the General Perceptual Plane. Werker & Curtin (2005) suggest that as children learn more and more words that have phonological neighbours, higher order regularities emerge and gradually come together to form a system of contrastive phonemes in the Phonemic Plane. This system of phonological categories continually reinforces the acquisition of new lexical items in the Word Form Plane, which in turn further fine tunes the phonological categories of the Phonemic Plane. Although the PRIMIR model allows for restructuring of the lexicon, it is crucially different from the LRM because PRIMIR holds that detailed phonetic information is maximally encoded in early lexical representations (which the LRM does not allow).

Werker & Curtin (2005) propose that the emergence of these perceptual planes relies on three dynamic filters: initial language biases, the developmental level of the child, and the requirements of the specific language-learning task at hand. These filters are claimed to modulate the raw physical saliency (acoustic, phonetic, gestural, visual, etc.) of the information in the signal (Werker & Curtin 2005). In terms of the initial language-learning biases, Werker & Curtin

(2005) state that infants are endowed with evolutionary and epigenetically based linguistic biases. These biases include preferences for such phenomena as human speech, infant-directed speech, proper syllable form, and the ability to process rhythmic patterns (Werker & Curtin 2005). These initial biases, along with the developmental level of the infant and the specific language-learning task involved, act as filters that help evaluate many different aspects of the input simultaneously (Werker & Curtin 2005). An example of how one of these filters may operate is seen in Stager & Werker's (1997) study, which shows that 14-month-old infants confuse phonetically similar words when they are linked to objects, yet can easily discriminate these words when they are not linked to objects. Thus, the language-learning task involved acts as a filter that will either help or hinder children's linguistic performance.

Werker & Curtin (2005) claim that all three filters (initial language biases, the developmental level of the child, and the requirements of the specific language-learning task at hand) converge to direct children's attention to multiple planes in different measures. Figure 2 below illustrates how these filters (represented as squares) shift children's attention to various aspects of the three multidimensional planes.

Figure 2: PRIMIR's dynamic filters (Werker & Curtin 2005:220)



Werker & Curtin (2005) suggest that children's ability to shift their attention offers an extremely efficient developmental strategy, especially in terms of the emergence of phonemic categories. For example, the filters enable children to focus solely on the properties of sounds that are necessary to distinguish one word from another. Thus, Werker & Curtin propose that the emergence of the Phonemic Plane may be a major cause of the vocabulary spurt. That is, once children focus on the difference between phonological neighbours (e.g., 'pit' vs. 'bit') and begin to establish phonemic categories, these categories aid in the rapid acquisition of additional lexical items.

In the next chapter, I situate this line of research work within its larger context. I discuss a number of psycholinguistic and phonological studies that address potential relationships between lexical and phonological development.

Chapter 2: Previous studies

In this chapter, I outline studies in perception, word-learning, and production that are relevant to my current research question. This summary highlights interactions between lexical and phonological development which, together, establish the foundation and focus of the current research.

1. Studies in perception

1.1 Infants' sensitivity to perceptual cues

Studies on infant speech perception have revealed a great deal about young children's perceptual abilities. For instance, Jusczyk & Thompson (1978) found that infants younger than 0;6 could discriminate between trochaic and iambic stress patterns. Additionally, Jusczyk et al. (1993) observed that, by age 0;9, English-learning infants prefer trochaic stress patterns over iambic stress patterns. In fact, it is also at this age that children demonstrate preferences for phonotactic sequences that are legal and frequent in their native language (Jusczyk et al. 1993; Jusczyk et al. 1994). Not surprisingly, children at age 0;9 also listen significantly longer to high-probability non-words over low-probability non-words (Jusczyk et al. 1994). Thus, infants demonstrate awareness of the sound patterns of their native language prior to the development of an expressive or receptive lexicon (Stoel-Gammon 2011:22). This sensitivity to the phonotactics of the ambient language helps infants to discover the boundaries between adjacent words, enabling them to extract words from the speech stream. This bidirectional interaction between the acquisition of phonotactic probabilities and early word learning mutually reinforces lexical development and the emergence of the phonological system (Curtin & Zamuner 2014). However, young children also display perceptual asymmetries that may affect this bidirectional interaction. I discuss these perceptual asymmetries further in section 1.2.

Children also demonstrate an understanding of the appropriate phonological patterns for the words in their language. In a study conducted by MacKenzie et al. (2011), English-learning 12-month-olds accepted well-formed object labels (such as 'fep' and 'wug'), but rejected isolated speech sounds (e.g., [l]) and communicative sounds (e.g., 'oooh' and 'shhh') as possible object labels. It was also found that these children preferred mapping noun-like labels to objects more so than function word-like labels (such as 'iv', similar to 'of') to objects. In addition, MacKenzie et al. (2011) found that the children also rejected words with unfamiliar onset sequences, such as in the Czech form 'ptak', as a possible object label. However, the children were more flexible in their acceptance of irregular labels such as the Japanese form 'sika', which is phonetically atypical for English but contains legal phonotactic sequences (MacKenzie et al. 2011). This type of behaviour was also found in 18-month-old toddlers (Graf Estes et al. 2011). This suggests that young children are capable of tolerating a certain level of phonetic variability in the input while they engage in word learning, whereas any change in phonotactic legality seems to hinder word learning abilities (Curtin & Zamuner 2014).

As already mentioned, children also display sensitivity to phonotactic frequency. Gonzalez-Gomez et al. (2013) found that 14-month-old French-learning infants learn non-words with frequent phonotactic patterns more easily than non-words with less frequent phonotactic patterns. This behaviour persists until 16-months of age, when the children are finally able to learn both types of non-words. In a study by MacRoy-Higgins et al. (2012), it was found that children at 2 years of age detected mispronunciations in both real words and non-words with high phonotactic probability, but failed to do so with low probability words. Zamuner (2013) found that although 2-year-old Dutch-learning children detected segmental contrasts in both high and low probability non-words, the contrasts within the high probability non-words were perceived more accurately than those in the low probability non-words. Words with high frequency phonotactic probability also showed an advantage in word learning (Storkel 2001; 2003), however McKean et al. (2013) observed that, by age 5, children demonstrated an advantage for learning low probability words. This advantage has been found to persist through adulthood (Storkel et al. 2006). Many studies have also shown that children were more accurate when producing frequent structures as opposed to less frequent structures (Munson et al. 2005; Coady & Evans 2008; Zamuner 2009; Messer et al. 2010). In sum, the phonological properties of words influence speech processing and lexical development. I discuss perceptual issues in more detail in the following section.

1.2 Perceptual asymmetries

In order to gauge the level of phonological detail present in young children's representations, many studies have focused on children's abilities to perceive mispronunciations (Jusczyk & Aslin 1995; White & Morgan 2008; Swingley 2009). Largely, these studies have found that depending on the type and position of the mispronunciation in the word, the child's age, and the specific task involved, infants' representations of familiar words are fairly specific (Curtin & Zamuner 2014). For instance, Jusczyk & Aslin (1995) found that English-learning infants at age 0;7 did not recognize a familiar word (e.g., 'cup') when the first segment displayed the wrong place of articulation (e.g., 'tup'). Similarly, Swingley (2005) found that Dutch-learning children at age 0;11 preferred correctly pronounced words over mispronounced words where the word-initial segment was also changed in the place of articulation. However, when the place of articulation was changed in a word-final segment, infants in this study did not show a preference for the correct pronunciation over the mispronunciation. Additionally, Swingley (2005) showed that this behaviour remains constant until age 1;2, when children eventually become sensitive to mispronunciations in coda position as well. Thus, it appears that word onsets have an advantage in terms of being acquired by English and Dutch-learning children. It has also been found that French-learning children at age 0;11 fail to notice onset-mispronunciations when they occur in unstressed syllables (e.g., canárd 'duck' as ganárd) (Hallé & Boysson-Bardies 1996). Thus, sensitivity does not only depend on the phonological position of a mispronunciation (onset vs. coda); syllable prominence (stressed vs. unstressed) plays a role as well. This perceptual asymmetry may influence the interaction of lexical and phonological development. I address this observation in more detail in section 1.4. For now, I turn to a study suggesting that there are gradience effects in children's sensitivity to mispronunciations.

1.3 Children's sensitivity to varying degrees of mispronunciations

White & Morgan (2008) conducted several experiments which, together, highlight children's level of sensitivity to onset mispronunciations of varying degrees. They measured 19-month-old children's visual recognition of familiar English words when pronounced correctly vs. mispronounced. This study was divided into three separate experiments: The first experiment had three phases and dealt with mispronunciations measured in terms of phonetic features. Phase 1 involved one-feature mispronunciations (place), phase 2 involved two-feature mispronunciations (place + voicing), and phase 3 involved three-feature mispronunciations (place + voicing + manner). The second experiment looked at the effect of specific one-feature place, voicing, or manner mispronunciations. The third experiment looked at different combinations of two-feature mispronunciations (combination pairs of place, voicing, and manner). Examples of the experimental designs are shown in Tables 1-3 below.

Table 1: Experimental design of experiment 1

Familiar target	One-feature change (place)	Two-feature change (place & manner)	Three-feature change (place, voicing, manner)
ball	[gɔl]	[zɔl]	[ʃɔl]

Table 2: Experimental design of experiment 2

Familiar target	One-feature change (manner)	One-feature change (voicing)	One-feature change (place)
keys	[hiz]	[giz]	[tiz]

Table 3: Experimental design of experiment 3

Familiar target	Two-feature change (place & voicing)	Two-feature change (voicing & manner)	Two-feature change (place & manner)
fish	[zɪʃ]	[bɪʃ]	[tɪʃ]

In order to measure word recognition, each child was presented with both a familiar image and an unfamiliar image. The unfamiliar image was a key aspect of this study because it enabled the possibility for the child to perceive the mispronounced form as a label for the unknown image, as opposed to a label for the known image. The three different experiments allowed the researchers to determine the level of feature manipulation required for children to treat the utterance as a new lexical association, as opposed to simply a mispronounced form. This notion of different levels of sensitivity to phonological change is known as graded sensitivity, and has been demonstrated in adults in previous studies (Connine et al. 1997; Milberg et al. 1988). That is, adults have the most difficulty in recognizing a mispronounced familiar word if the mispronunciation is severe (such as a three-feature change).

White & Morgan (2008) found that, like adults, 19-month-olds are sensitive to the degree of phonological mismatch of a single segment. Thus, the more severe the mispronunciation (calculated by the degree of feature mismatch), the less the child would fixate on the target/familiar image. As the results of Experiment 2 and Experiment 3 suggest, this decrease in looking was not caused by a particular combination of features (place, voicing, and/or manner) but simply by the degree of mismatch (one-, two-, or three-feature changes). Although children decreased their fixation of the target image from the correct condition to the one-feature manipulation condition, they did not associate the mispronunciation with the unknown image. The same was found for the two-feature manipulation condition. Children did, however, increase their attention to the unfamiliar image during the three-feature mispronunciation phase. The findings of this study are illuminating because the design of the experiments are quite similar to the real world situations young children face when they are acquiring new lexical representations. White & Morgan (2008) suggest that children's detailed phonological sensitivities aid the process of lexical acquisition. From this study, they conclude that children as young as 1;7 have highly detailed, adult-like representations of words (White & Morgan 2008), a conclusion which contradicts the earlier experimental evidence from the 1990s cited above (e.g., Hallé & Boysson-Bardies 1996).

1.4 Sensitivity to onset and coda mispronunciations

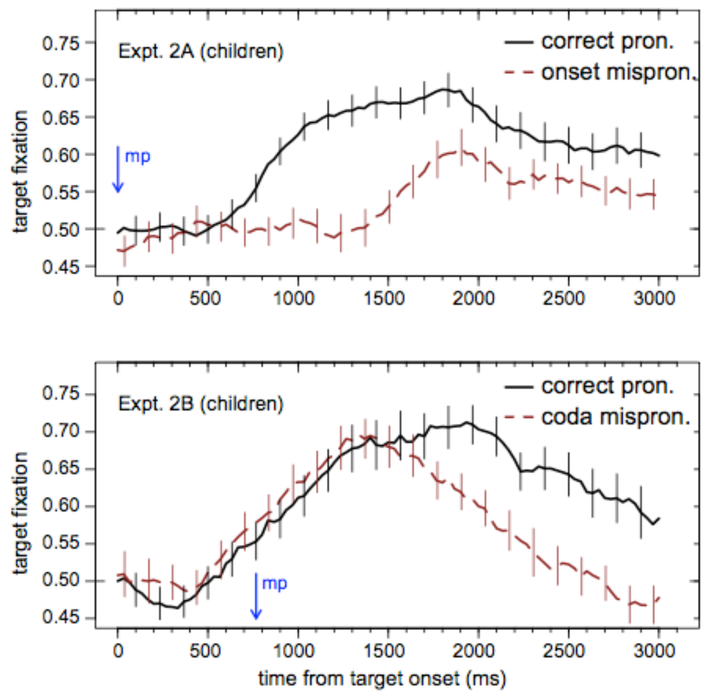
Swingley's (2009) study of English-speaking toddlers from 14 to 22 months of age also offers evidence for the hypothesis that young children encode detailed phonological knowledge in their lexical representations. Similar to White & Morgan (2008), Swingley analyzed children's recognition of mispronounced words using a visual fixation task. However, the main purpose of his study was to determine the effect of mispronunciations in both onset and coda positions. As discussed in section 1.2, infants exhibit a perceptual asymmetry that favours the acquisition of onsets over the acquisition of codas. Although infants as young as seven months of age can perceive mispronunciations in onset position, mispronunciations in coda position are not perceived until 14 months of age. Thus, the goal of the study was to determine whether 14-

month-old children are better at perceiving mispronunciations in onset position over mispronunciations in coda position. Additionally, Swingley calculated the neighbourhood density of the test words using a corpus of 14 mothers' American English infant-directed speech (Brent & Siskind 2001). According to a study by De Cara & Goswami (2002), phonological neighbours most often differ by a contrast in the onset (pig-big-dig) as opposed to a contrast in the rhyme (bit-big-bid, bed-bad-bead). Thus, Swingley predicted that if the LRM is correct, children should have more detailed representations of word onsets than word offsets.

Swingley conducted two experiments, one with adults (the comparison group) and one with children between the ages of 14 and 22 months. Half the participants were randomly assigned to an 'onset' condition, and the other half were assigned to a 'coda' condition. Each trial involved the presentation of two familiar images. The target image represented the word being produced (either correctly pronounced or mispronounced). As the child was presented with the two images, a recording instructed them to look for the target image (e.g., "Where is the ___?"). Half of the time the target was pronounced correctly, the other half of the time it was mispronounced (with an incorrect consonant in either the onset or coda position).

The results show that both children and adults reacted similarly. They both looked more at the target image over the distractor image when it was pronounced correctly, and looked less at the target image when it was mispronounced. Most importantly, the position of the mispronunciation (onset or coda) did not have an effect on looking behaviour. In other words, mispronunciations of an onset consonant did not have more of an effect on looking behaviour than mispronunciations of a coda consonant. Figure 3 below illustrates this finding by showing the time-course of children's fixation on the target image upon hearing the correct pronunciation or a mispronunciation. Children decreased their fixation on the target image once the mispronunciation was heard in both onset and coda conditions. The results of looking behaviour are relative to when the mispronunciation actually occurred which, of course, is later in the coda condition than in the onset condition. Swingley concludes that both younger and older one-year-olds know the phonological characteristics of familiar words well enough to be hindered in recognition when those words are pronounced with a substituted consonant either in onset or coda position (Swingley 2009:265).

Figure 3: Time-course of children's target fixation (Swingley 2009:263)



Thus, the results of Swingley's (2009) study are in line with the work by White & Morgan (2008). Both studies support the claim that children as young as 1;2 possess detailed perceptual knowledge. The children in these two studies displayed a fine-tuned phonetic sensitivity that enabled their recognition of lexical representations. This knowledge is substantial enough to disrupt their recognition of familiar words when a single segment is mispronounced in either the onset or coda position. Swingley also notes that children's knowledge of codas is relatively surprising given that, in children's lexicons, neighbours which differ in coda position are so much less dense than neighbours which differ in onset position (Swingley 2009:266). Yet, without the benefit of having multiple phonological neighbours in codas, children were equally hindered by both onset and coda mispronunciations. Thus, children do not seem to require a higher number of neighbours in order to develop detailed representations of the coda segments. Based on these results, Swingley (2009:266) proposes that children do not rely solely on the presence of neighbours in order to develop a detailed phonological system. In fact, similar observations were also made in previous studies by Swingley, Pinto & Fernald (1999) and Swingley & Aslin (2000). These two studies both found that children between 18 and 24 months of age were able to perceive mispronunciations regardless of the sizes of their respective vocabularies (Swingley, Pinto & Fernald 1999:89; Swingley & Aslin 2000:162); even children with less dense phonological neighbourhoods (i.e., smaller vocabularies) demonstrated detailed phonological knowledge of familiar lexical items. Swingley concludes that even very young children's lexical representations are adequate, in principle, for supporting the phonological function of lexical contrast (Swingley 2009:266).

2. Studies in word learning

2.1 Effects of neighbourhood density and phonotactic probability on word learning

Hollich et al. (2002) examined how 17-month-old children acquired non-words from both dense and sparse neighbourhoods. The target non-words 'tirb' and 'pawch' were chosen for this study because they are both from low density and low frequency neighbourhoods in English. During the familiarization phase, children were presented with one of two lists containing 12 CVC non-words (See Table 4). One list contained words that were very phonologically similar to the target words (a dense neighbourhood), whereas the other list contained nine filler words and only three phonologically similar words (a sparse neighbourhood). In the list of dense neighbours, four words differed in the initial consonant, four words differed in the vowel, and four words differed in the final consonant. As only three words from the list of sparse neighbours were phonologically similar to the target word, they each differed in initial consonant, vowel, and final consonant, respectively. The nine other filler items were phonologically unrelated words.

Table 4: Word lists (Hollich, Jusczyk & Luce 2002:317)

High density word lists (mostly minimal pairs)	
tirb	**pawch**
tirng	pawv
tirch	pawth
tirth	pawng
tirsh	pawch
lirb	thawch
thirb	rawch
mirb	nawch
shirb	sawch
tahb	paych
tuhb	pech
tib	poych
toyb	puch

Low density word lists (mostly filler words)	
tirb	**pawch**
hoyv	tav
deeve	weem
tirng	pawng
koys	fahsh
laze	cheth
nith	soyng
shirb	nawch
rauch	tich
shawg	muhl
tahb	pech
zope	bauch
girj	koeth

During Experiment 1, children were familiarized with both a dense neighbourhood list and a sparse neighbourhood list, to which they were exposed six times each, with random ordering in each block. In the training phase, each target word (either 'tirb' or 'pawch') was associated with a computerized image. First, the children were presented with a single image and the associated target word of one of the conditions (e.g., the dense target word 'tirb'). They were then presented with the image of the target word from the other condition (e.g., the sparse target word 'pawch'). The target words were repeated three times each during the six-second period in which each image appeared on the screen. In the testing phase, the split-screen preferential looking procedure was used to determine if the children had successfully learned the referent associated with the target words. Hollich et al. presented both images and measured the children's looking time after playing the target word. In a control study, the same training and test phases were used, but in the familiarization phase children were instead exposed to two lists of filler items.

It was found that children looked longer at the target over the non-target only in the low-density condition (Hollich et al. 2002). This means that children only acquired the target words when they were presented with the list of sparse neighbours associated with that word in the familiarization phase. Interestingly, Hollich et al. also found that children performed better when they were familiarized with some neighbours as opposed to no neighbours at all. Therefore, these scholars suggest that children were sensitive to the phonotactic probabilities of the word lists during familiarization. For instance, in the low density condition of Experiment 1 (for 'tirb') infants had been exposed to the '–irb' sound pattern, the 'tir' pattern, and the 't_b' pattern six times each. Hollich et al. suggest that it may be the familiarity with these co-occurrences of phonemes that helped infants recognize and process the target word 'tirb' faster. Although this cannot be the only factor at play, if we consider that the children also heard the '–awch' pattern, the 'paw-' pattern, and the 'p_ch' pattern 24 times each, and did not perform well in this high-density condition. Thus, while there appears to be a competitive/inhibitory effect of density, there may also be a facilitation effect for phonotactic probabilities (Hollich et al. 2002).

In order to test this hypothesis, Hollich et al. conducted a second experiment, in which the children heard each list of stimuli only once during the familiarization phase. In contrast to Experiment 1, children looked significantly longer at the target over the non-target in the high-density condition only. This means that children acquired the target word only when they were presented with the list of dense neighbours associated with that word in the familiarization phase. Thus, these studies suggest that children acquire a non-word only when briefly exposed to a dense neighbourhood, or when continuously exposed to a sparse neighbourhood. Hollich et al. reason that brief exposure to dense lexical neighbourhoods produces benefits at the phonotactic level, facilitating the learning of new words. In contrast, they conclude that more prolonged exposure to dense lexical neighbourhoods induces lexical competition effects, inhibiting the learning of new words (Hollich et al. 2002:322).

In order to further distinguish between the effects of phonotactic probability and neighbourhood density, McKean et al. (2013) specifically analyzed the individual effects of these factors in a word learning task. They created non-word stimuli that varied orthogonally in terms of phonotactic probability and neighbourhood density, and assessed children's fast-mapping of these novel words. McKean et al. (2013:312) refer to fast-mapping as the first stages of word learning that occur in the first few exposures of a novel word. Building on the PRIMIR framework, McKean et al. (2013) predicted that the influence of phonotactic probability and neighbourhood density on word learning would be separable, interactive, change with age, and be affected by the nature of the task (McKean et al. 2013).

The study tested 38 children between the ages of 3;1 and 5;2 on the eight target words shown in Figure 4 below. The words were presented in the context of a story about two aliens named Jim and Bob that go shopping. Each word was paired with a novel referent, which belonged to one of four categories: toys, pets, vehicles, or food. Each semantic category contained two novel object-word pairings that contrasted either high and low phonotactic probability or high and low neighbourhood density. The experimental stimuli are illustrated in Figure 4.

Figure 4: Experimental stimuli (McKean et al. 2013:317)

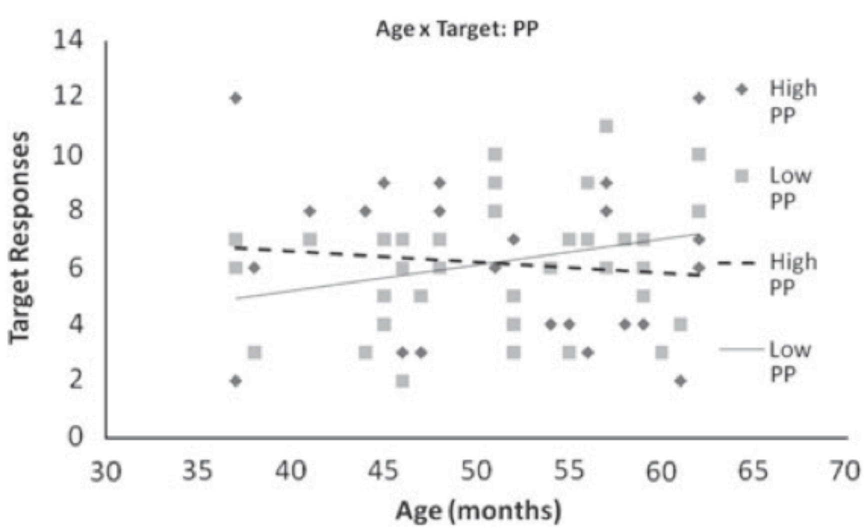
	Word	ND*	Log normalized PP[a]	Positional segment frequency[b]	Biphone frequency[b]	Referent category	Referent
High ND High PP	teɪn	34	0.6232	0.1698	0.0042	toy	
	baɪn	38	1.0597	0.1816	0.0071	pet	
Low ND Low PP	hɔɪf	4	−1.6534	0.0625	0.0042	toy	
	jɔʃ	7	−1.607	0.0321	0.0006	pet	
High ND Low PP	heɪm	25	−0.6206	0.1180	0.0026	food	
	ʃeɪt	29	−0.0386	0.1049	0.0037	vehicle	
Low ND High PP	hɑn	9	0.7673	0.1960	0.0156	vehicle	
	gek	13	1.0869	0.1524	0.0076	food	

NOTES: [a] CELEX; [b] Hoosier Mental Lexicon.

In addition to the reading of the story, a 'storyboard activity' was also completed by the children. This involved having the children move small figures of Jim and Bob along a board that illustrated all of the locations mentioned in the story. The children were encouraged to move the alien figures along, pausing at each location to give the correct object to the correct alien. At each location, the children were presented with a choice of objects. These objects included all eight target words presented in the story, as well as an additional eight 'alien' objects that did not appear in the story. In terms of exposure to the target words, every target word was repeated eight times each within the story, and repeated two additional times when the children were asked to choose the appropriate object. Therefore, the children heard novel word-object pairings a total of 10 times each.

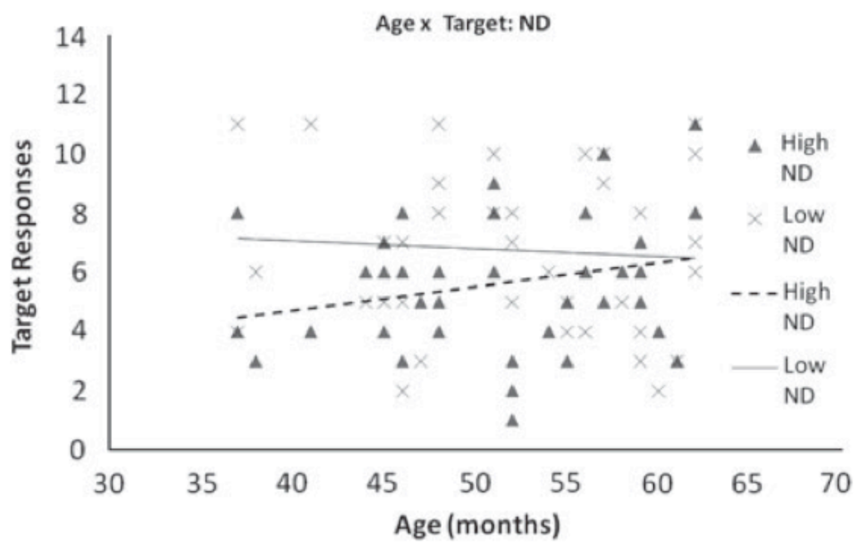
The results of this study confirm McKean et al.'s hypothesis that phonotactic probability and neighbourhood density exert separable influences on the fast-mapping abilities of children. Specifically, they found that the younger children demonstrate an advantage for words with high phonotactic probability whereas the older children demonstrate an advantage for words with low phonotactic probability (see Figure 5). McKean et al. (2013) propose that children may switch learning strategies over the course of development because a learning strategy that favours high phonotactic probabilities may become inefficient when their vocabulary reaches a substantial size. That is, children are eventually forced to learn words with a wider range of phonotactic patterns, and thus, words with low phonotactic probability become more salient at this point in development. McKean et al. (2013) claim that younger children can be considered 'statistical learners' who are primed to learn many new words at a very fast rate, and that older children can be considered 'novelty learners' who learn words only when novelty has been identified (McKean et al. 2013:326). This reversal in word learning patterns is illustrated below in Figure 5.

Figure 5: Trajectory of influence of phonotactic probability on fast-mapping ability as measured by number of correct (target) responses (McKean et al. 2013:322)



In terms of effects of neighbourhood density, McKean et al. (2013) found that children showed an overall advantage in learning words from low-density neighbourhoods. Figure 6 illustrates this finding and also shows that the disadvantage of learning words from high neighbourhood densities appears to be decreasing with age. McKean et al. contend that if they used a larger sample size with a wider age range, the influence of neighbourhood density could be shown to decrease over development, or, in fact, switch from a low density advantage to a high density advantage (McKean et al. 2013:328).

Figure 6: Trajectory of influence of neighbourhood density on fast-mapping ability as measured by number of correct (target) responses (McKean et al. 2013:322)



McKean et al. (2013) suggest that these results arise from changes in children's processing at the phonetic/indexical level of lexical representation. They argue that these changes are driven by other changes at the sublexical/phonemic level of processing (McKean et al. 2013:327). This change in processing explains why younger children benefit from learning words from low-density neighbourhoods: it is easier for younger children to make distinctions between words from low-density neighbourhoods and the words already present in their lexicons. According to McKean et al., children appear to experience lexical competition effects when learning words from high-density neighbourhoods as they are unable to represent their words with sufficient levels of contrast.

Thus, when phonotactic probability and neighbourhood density are separated as distinct factors in terms of word learning, younger children benefit from learning words with high phonotactic probability and low neighbourhood density. However, as they age, children begin to show an advantage in learning words with low phonotactic probability, and the advantage in learning words from low-density neighbourhoods decreases slowly over time. Most importantly, McKean et al. (2013) were able to determine the specific effects of phonotactic probability and neighbourhood density on word learning, which are two variables that have often been confounded in previous research (McKean et al. 2013; Curtin & Zamuner 2014).

Both Hollich et al. (2002) and McKean et al. (2013) show that young children benefit from learning words within low density neighbourhoods. Both studies also demonstrate that young children benefit from learning words with high phonotactic probability.[1] Although the children in Experiment 2 of the Hollich et al. (2002) study performed better in the brief-exposure high-density condition as opposed to the brief-exposure low-density condition, it may be the case that brief exposure to dense neighbourhood items yields a priming and processing advantage, which itself leads to better performance in the recognition of similar sounding words. This does not necessarily mean that children are better at acquiring target words from high-density neighbourhoods, but rather that the brief exposure to the same sound sequences primes the children and helps them process and recognize the target word more easily. This is likely the case, given that the robust findings from Experiment 1 of Hollich et al. (2002) and McKean et al.

1 Note, however, that in Hollich et al.'s (2002) study, the phonotactic probability was based on the frequency of exposure during the training phase and not based on real English phonotactic probabilities.

(2013), which both demonstrate the advantage of learning words from low-density neighbourhoods.

3. Studies in production

3.1 Neighbourhood density and the developing lexicon

As discussed in section 1.2, children exhibit a perceptual asymmetry that favours the acquisition of onsets over the acquisition of codas. This is an important aspect to consider in terms of the role that perceptual abilities play in lexical development. As Zamuner (2009) claims, infants' perceptual sensitivity influences the development of their lexical representations. By virtue of this, Zamuner suggests that young children's lexicons should display patterns that reflect performance in infant speech perception. She elaborates by outlining two important findings that are central to her hypothesis. The first is that infants appear to have weaker lexical representations of codas, and the second is that infants also become attuned to their language-specific vowel categories before their language-specific consonant inventories. Zamuner (2009) proposes that if children have richer representations of phonetic information in certain word positions (such as onsets) or for certain word segments (such as vowels), then they will be more likely to acquire more words that are distinguished by these phonemes or features. Zamuner (2009) thus proposes that word onsets will form denser neighbourhoods in children's lexicons than word offsets, and that vowels will form denser neighbourhoods in children's lexicons than consonants.

To test this hypothesis, Zamuner (2009) conducted an analysis on English-learning children's receptive and expressive lexicons. The children in the study ranged from ages 1;4 to 2;6. It is important to note that Zamuner redefined the traditional definition of a phonological neighbour by only analyzing CVC words that differ only in the substitution of a single segment.

Therefore, words contrasted through a difference in syllable structure (e.g., 'bread' vs. 'red') were excluded form the analysis because they differ by the presence of an additional segment as opposed to the substitution of a single segment. The purpose of this redefinition was to analyze neighbourhoods the way infant speech perception tasks analyze the phonemic contrast of single segments. Rhyme neighbours involved the substitution of the initial consonant only (such as the neighbours 'pin' and 'bin'). Consonant neighbours involved the substitution of the vowel only (such as the neighbours 'pin' and 'pan'). Lastly, lead neighbours involved the substitution of the final consonant only (such as the neighbours 'pin' and 'pit'). Table 5 below summarizes these neighbour types.[2] Although neighbourhoods were analyzed in terms of the children's receptive and expressive lexicons, note that Zamuner calculated the neighbourhoods according to what the target words should be, not what the child produced.

Table 5: Neighbour types

Rhyme neighbours	**Consonant neighbours**	**Lead neighbours**
pin - bin	*pin - pan*	*pin - pit*

The results of this analysis only provide partial support to Zamuner's hypotheses. As predicted, word onsets (rhyme neighbours) form denser perceptual neighbourhoods than word offsets (lead neighbours). Although this pattern is found in the adult lexicon as well, the distribution is even more skewed in the children's lexicons. Zamuner highlights that despite the fundamental desire to communicate, children's vocabularies have a more polarized distribution of neighbours than what is found in the target language (Zamuner 2009). As for her predictions regarding vowels (consonant rhymes), her claim was not supported by the evidence. That is,

2 The notion of a consonant neighbour in this study may have motivations for statistical processing but seems questionable from the perspective of phonological theory, as phonological patterns in adult systems do not, to my knowledge, involve the simultaneous consideration of onset and coda consonants within the same syllable.

consonant neighbours were not more dense than rhyme or lead neighbours. Zamuner proposes that this evidence may lend support to the view that consonants are more important than vowels for lexical distinction (Nespor, Peña & Mehler 2003). More evidence for this claim comes from a study by Mani & Plunkett (2007), who found that children at age 1;3 struggled to recognize mispronunciations of word-medial vowels in familiar words, but were good are recognizing mispronunciations of consonants.

By analyzing the nature of neighbourhoods, rather than just the number of different neighbourhoods, Zamuner found that children's lexicons are qualitatively similar to adult lexicons (Zamuner 2009:15). Although she found that word onsets (rhyme neighbours) form significantly more dense neighbourhoods in the child lexicon, the difference is only quantitative, as rhyme neighbours are the most dense in the adult lexicon as well. In fact, the evidence suggests that there are no striking qualitative differences between child and adult lexicons. Thus, the importance of onsets for lexical distinction is observed early in infant speech perception and is a continuous trend across early lexical and phonological development. Zamuner claims that the PRIMIR model best explains this integration of infant speech perception in lexical development. She argues that context-specific phonetic representations aid the development of word-form representations and the development of lexical neighbourhoods (Zamuner 2009:16). Thus, the nature of the neighbourhoods in children's lexicons is established by children's early perceptual sensitivities, which provide a foundation for lexical development. As a result, the nature of the neighbourhoods in children's lexicons reflects those in the adult lexicon.

3.2 The effect of phonological abilities on lexical development

As mentioned in section 1 of Chapter 1, longitudinal studies have revealed correlations between the following behaviours (Stoel-Gammon 1992):

(2) Behavioural correlations between lexical and phonological development (Stoel-Gammon 1992:442–449)

a. The amount of vocalization at age 0;3 and vocabulary size at age 2;3.

b. The age of onset of canonical babble and the age of onset of meaningful speech.

c. The number of CV syllables at age 1;0 and age of first word production.

d. Use of consonants at age 1;0 and phonological skills at age 3;0.

e. Diversity of syllable and sound types at ages 0;6–1;2 and performance on speech and language tests at age 5;0.

These correlations suggest that when infants have a greater number of prelinguistic vocalizations with a variety of consonants and vowels, they have acquired a greater number of 'building-blocks' that aid in the production of real words (Stoel-Gammon 2011:8). This pattern, observed in typically developing children, is even more evident in children with speech-language disorders (Stoel-Gammon 2011:8). Several interrelated factors may contribute to these correlations. One aspect to consider is that prelinguistic vocalizations are often phonetically identical to children's early word productions. For instance, babbling at age 0;6-0;7 and early word productions both tend to have a high proportion of stops, nasals and glides, a predominance of CV syllables, a high rate of consonants that are produced at the front of the mouth, and a lack of fricatives and liquids (Oller et al. 1976; Stoel-Gammon 2011). Therefore, it is common for a prelinguistic vocalization (e.g., [mama]) at age 0;7 to be phonetically identical to a real word production (e.g., [mama]) at age 0;10 when the child learns to associate the meaning to the sound. Further evidence for the continuity between babble and speech is that child-specific prelinguistic vocal patterns in place and manner of articulation of consonants, syllable shape, and vocalization length are carried forward to the production patterns observed in first words (Stoel-Gammon & Cooper 1984;

Vihman et al. 1985; Kern & Davis 2009; Davis & Bedore 2013). Thus, it is clear that babbling provides a basis for the phonological patterns of early word productions.

Babbling also provides motor practice for early word productions (Davis & MacNeilage 1995; Vihman 2014). The more often a child practices the movements required to shape the vocal tract to produce a specific sound, the more automatic those movements become and the easier it is to execute them while producing meaningful speech (Vihman 1992). Babbling also helps form an auditory-articulatory feedback loop that is fundamental to lexical and phonological development (Fry 1966; Stoel-Gammon 1998). When infants vocalize, not only do they hear their own acoustic output, they also become aware of the tactual and kinaesthetic sensations that are associated with their productions. This auditory-articulatory feedback loop draws the child's attention to the adult words that are phonetically similar to their own productions. This link provides the basis for the stored representations that are needed for the comprehension and production of words in the ambient language (Locke 1993; Stoel-Gammon 1998; Vihman 2014).

As mentioned in section 1 of Chapter 1, children are likely to acquire words which contain sounds that are present in their prespeech repertoire before words which contain sounds which are not present in their prespeech repertoire. This suggests that children have a working knowledge of their own phonological abilities and that this knowledge influences the words they acquire. As previously discussed, this may lead to the phenomenon of lexical selection and avoidance. Another form of lexical selection has been observed in children who have a preference for certain types of syllable or stress patterns as opposed to a preference for specific consonants or vowels (Stoel-Gammon 2011). For example, Stoel-Gammon & Cooper (1984) reported on the first words of three children, one of whom had a high proportion of words ending in the velar stops [k] or [g] (e.g., 'quack', 'rock', 'clock', 'sock', 'whack', 'milk', 'frog', 'yuk', 'block'). Of this child's first 50 words, 22% ended in a velar stop compared with 8% and 4% of velar-final words for the other two children. This particular type of lexical selection is noteworthy as it has been observed to persist beyond children's first 50 words, throughout a period of rapid lexical growth (Stoel-Gammon 2011:15). Taken together, these studies of children's productive abilities suggest that lexical development in production may be influenced by children's phonological productive abilities.

4. Interim summary

As we saw from the survey of literature above, while several lines of research have entertained potential relationships between phonological and vocabulary development, relatively few of these studies could substantiate this relationship. In the remainder of this thesis, I detail a study based on production data alone, by comparing children's development of their productive vocabulary with the development of their phonological productive abilities. As we will see, in line with most of the research presented above, vocabulary development alone appears to be a rather weak predictor for the children's patterns of phonological development.

Chapter 3: Methodology

1. Outline

In this chapter, I describe the methods involved in the current study. First, I discuss the nature of the corpus that I used for analysis. This includes a description of the annotated phonological data that I used to assess the children's phonological abilities, as well as the lexical data that I used to assess the development of their productive lexicons. I then move the focus to my analysis, and how I prepared the data in order to extract the necessary information for my study.

1.1 Corpus data

To address my current research question, I used a subset of the English-Davis corpus available through the PhonBank database (http://phonbank.talkbank.org/). The subset of this corpus I analyze below consists of annotated transcriptions documenting the language development of two English-learning children, Georgia and Charlotte, the properties of which were first reported by Davis & MacNeilage (1995), and Davis, MacNeilage & Matyear (2002).

To ensure that the children were within the range of normal cognitive development, a hearing test and the Battelle Developmental Screening Inventory were administered. In addition, parent case history reports were issued. The original data recordings were conducted in the children's homes during natural interactions. These interactions were centred around the daily activities of the children (e.g., playing, reading, etc.). A total of 44 sessions were collected from Charlotte, with data ranging from age 0;10 to 2;11. For Georgia, a total of 45 sessions were collected, with data ranging from age 0;8 to 2;11. The data were subsequently transcribed phonetically. These transcriptions provide a basis for the assessment of the children's phonological development over time.

To examine the data, I used Phon (https://www.phon.ca/), a software program designed to facilitate a number of tasks associated with phonological analysis, including multimedia linkage, utterance segmentation, multiple-blind transcription, automatic labelling of syllabification data, and systematic comparisons between target and actual forms (Rose et al. 2006; Rose & MacWhinney 2014). Using Phon, I was able to systematically compare the target forms with the children's actual produced forms. Further details on the method of my analysis are described in section 1.5.

1.2 Communicative development inventories

In addition to the annotated transcriptions, I examined the children's lexical knowledge as measured by the MacArthur-Bates Communicative Development Inventory (henceforth CDI; Fenson et al. 1993; Fenson, Marchman & Thal 2007).[3] The CDI is a monthly parental report that assesses the child's expressive vocabulary over time (i.e., the words attempted by the child). CDI data were collected on 37 reports documenting Georgia's lexical development between the ages of 0;8.26 and 2;11.25. The data for Charlotte consist of 32 reports collected between the ages of 1;0.26 and 2;7.23. While not all of the words included on the CDI are attested in the corpus data, the combination of both corpus and CDI data provide a fair assessment of the children's developmental lexicon. In this context, it would have been ideal to have access to data on the children's receptive vocabulary as well; however, this is not an option given the present data. In spite of this limitation, the current study provides methodological grounds for an eventual larger study which would incorporate assessments of the receptive lexicon, the expressive lexicon, and phonological abilities in production.

3 The CDI data were most generously provided by Dr. Barbara Davis, University of Texas, Austin.

1.3 Focus of analysis

Using both the CDI data and the annotated transcriptions, I generated reports of each child's lexical knowledge and phonological abilities throughout the period documented by the corpus. The lexical reports assess the children's expressive lexicons in terms of the presence and size of their phonological neighbourhoods. Because of practical constraints, and in keeping with Zamuner's (2009) observation that phonological neighbourhood development in English should be favoured in onsets, I limited my investigation to this context only. Additionally, for the sake of feasibility, I also limited my analysis to word-initial singleton onsets. In order to categorize each child's phonological neighbourhoods, I identified five different neighbourhood types based on the vowel within each syllable. Table 6 below outlines these categories, which include the neighbourhoods A, E, I, O, and U. For example, the vowels [i] and [ɪ] are both assigned to the I category.

Table 6: Neighbourhood vowel categories

Category	Vowel
A	[æ], [ɑ], [aɪ], [aʊ]
E	[e], [ɛ], [ə], [eɪ]
I	[i], [ɪ]
O	[o], [ɔ], [ʌ], [oʊ], [ɔɪ]
U	[u], [ʊ]

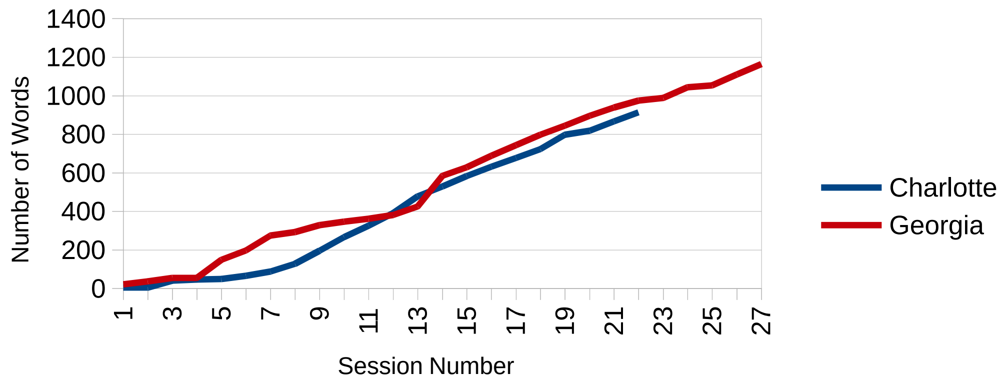
Coming back to the notion of neighbourhoods, the monosyllabic words 'see' and 'she' are grouped together as they share the same rhyme (e.g., [si] vs. [ʃi]). According to the LRM, these neighbours theoretically offer enough contrast for the child to distinguish between the consonants [s] and [ʃ]. Thus, by using this measure of analysis, I was able to determine whether the child possessed enough lexical information in theory to fine-tune her knowledge of the target consonants.

In addition to the lexical analysis outlined above, I produced qualitative and quantitative descriptions of each child's target onset productions. In order to capture descriptions that are as accurate and representative as possible, the analysis included singleton and branching onsets in both word-initial and word-medial positions. However, the approximants [l], [ɹ], [w], and [j] were only analyzed in contexts where they appeared in singleton onsets, as they often behave differently in the second position of a branching onset. The lexical and phonological reports were then evaluated and compared longitudinally in order to determine the potential effect of neighbourhood density on phonological development.

1.4 Data preparation

To build the lexical inventories for each child, I combined the CDI data with the words attempted in the IPA transcriptions. This enabled me to generate a representation of the children's expressive lexicons that is as rich and accurate as possible. I then organized the lexical inventories by individual months. Each one-month session documents all of the words the child has attempted that month, as well as all of the words attempted in previous months, without any duplication. This resulted in increasingly large session files in Phon, as illustrated in the following figure.

Figure 7: Georgia's and Charlotte's word inventories across one-month sessions

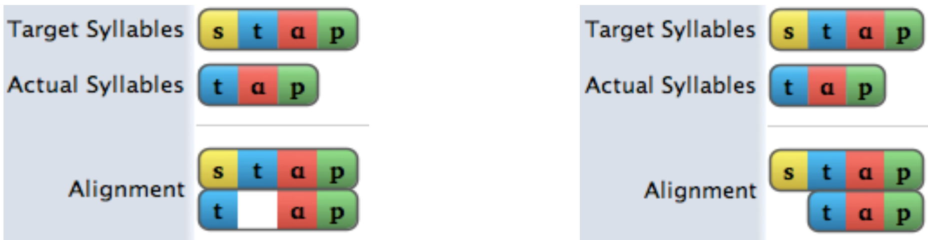


This comprehensive representation of the children's lexicons made comparisons across lexical and expressive domains much more efficient. After generating these lexical inventories, I used Phon to add IPA targets for each word in the lexicon. This allowed me to search for the phonological targets contained within each child's lexicon. In addition to preparing the lexical data, I also prepared the production data by merging the IPA transcription files into monthly datasets (as opposed to individually recorded session dates).

As mentioned in section 1.1, I used Phon to systematically compare children's actual productions with their corresponding target forms. Phon is designed to assist in this task by using pairwise alignments between target phones and those recorded in the child's produced forms. This enables the user to efficiently search for sounds that have been deleted or mispronounced in the child's speech. However, as this alignment is automatically generated by the program through probabilistic analyses, some productions which deviate from the target words may be incorrectly aligned and therefore require adjustment. Figure 8a represents a case in which the alignment was incorrectly performed, and Figure 8b shows the proper adjustment for this case. To verify that the alignment was correct, I reviewed the data recordings in each session before proceeding with my queries.

Figure 8: Alignment in Phon

a. Automatic alignment b. Adjusted alignment



1.5 Data extraction

In order to build inventories that represent the children's phonological neighbourhoods, I used the newly generated lexical reports described above. With these comprehensive lexical reports, I used Phon to extract every word-initial CV string from both monosyllabic and multisyllabic words. Using the neighbourhood categories shown in Table 6 above, I organized the data in a spreadsheet which represented the phonological neighbourhoods within each child's expressive lexicon. Because the lexical data that I used adds up from session to session, the neighbourhood data also increases at a rapid rate between sessions. This means that each month includes all of the word-initial CV strings that are present that month, as well as those that are present in all previous months. This way, the neighbourhood data are more representative of the child's actual lexicon.

Turning now to the assessment of the children's phonological development, I used Phon to generate data on each child's production of the target consonants over the course of development. Figure 9 shows an example of the type of queries that I used in order to generate this information. This particular example is a query that searches for all approximants occurring in singleton onsets. These queries enabled me to produce aggregated reports that organized the data into comprehensive tables. Figure 10 illustrates an example of the type of aggregated report produced by these queries. I then converted these tables into developmental timelines in order to illustrate each child's production over time. Using these timelines, I determined the relative prominence of every phonological pattern observed. This allowed me to characterize the children's phonological abilities as they progressed over the time period documented by the corpus.

Figure 9: Query for all approximants in singleton onsets

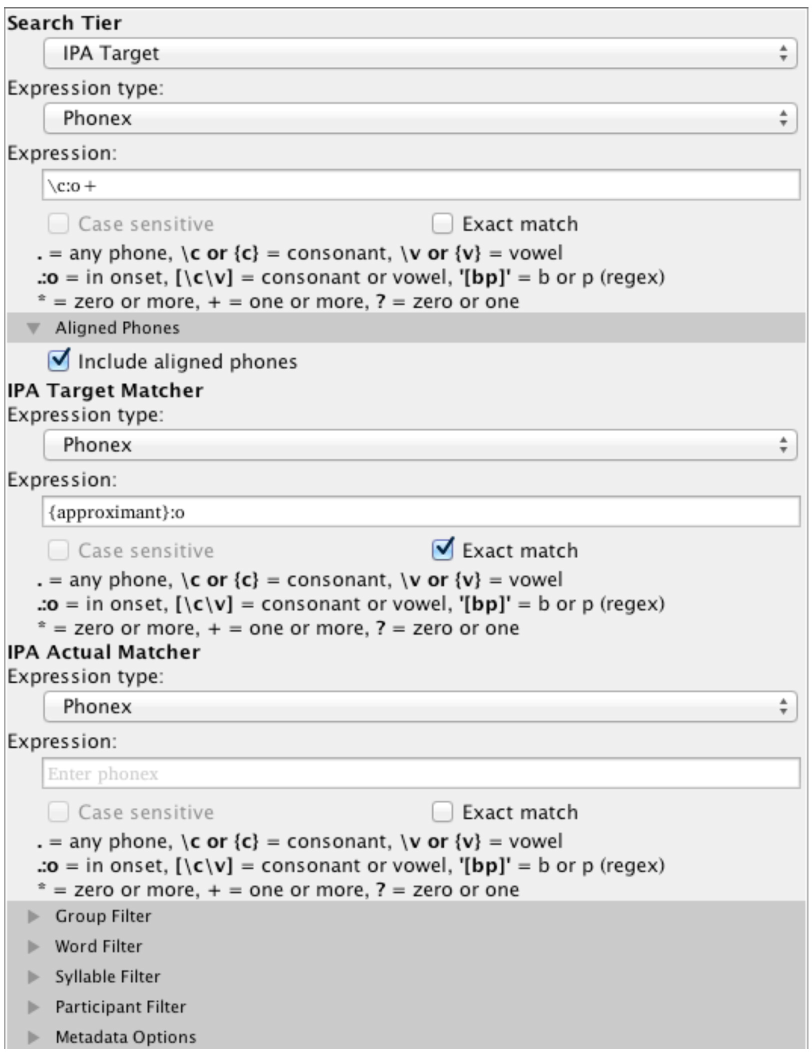


Figure 10: Sample of aggregated data

	2;01	2;02	2;02
ɹ ↔ ɹ	4	14	9
ɹ ↔ w	1	0	0
ɹ ↔ ∅	10	18	11

The developmental timelines of Georgia's and Charlotte's consonantal acquisition are described in the following two chapters. Once the phonological profile of each child is established, I discuss the distributions of their respective phonological neighbourhoods, in order to determine whether the building of these neighbourhoods may have influenced the children's phonological development over time. As we will see, the evidence from both the children's expressive vocabularies and usage (in production) fails to provide any reliable basis for predicting patterns of phonological development. In contrast to this, many regularities within each child's phonological system in fact point to well-established, phonologically-defined classes of phones. I conclude that models of phonological development which embrace phonetic categories (perceptual and articulatory) at their core are better equipped to account for patterns of phonological development than approaches based solely on properties of the child's lexicon.

Chapter 4: Georgia's phonological development

1. Introduction

In this chapter, I describe Georgia's phonological development of onsets across all word positions (i.e., word-initial and word-medial onsets). This analysis includes both singleton and branching onsets, with the exception of [l], [ɹ], [w], and [j]. These consonants are analyzed only in contexts where they appear in singleton onsets, as they often behave differently in the second position of branching onsets. Flap [ɾ] is also not included in this analysis, as this allophonic variant of /t,d/ displays variable behaviours, which may be the result of the variability in the treatment of coronal stops across flapping and non-flapping positions. Therefore, the input forms cannot be identified as either a flap or a coronal stop.

My description of Georgia's phonological system begins with an outline of the sounds she acquired early in her development. These early acquired sounds are organized and discussed in terms of their manner of articulation (e.g., stops, nasals, fricatives, affricates, and glides). This is followed by the sounds which Georgia acquired later, or failed to master, during the period documented in the corpus. The qualitative and quantitative descriptions that follow offer a basis for our understanding of how Georgia acquired her consonantal system. As we will see, Georgia first acquired her target stops, nasals, glides, affricates, and voiceless fricatives at an early stage in her development. However, she showed more variability in her development of the voiced fricatives [z] and [v], as well as liquids [l] and [ɹ], as these sounds were acquired much later in her development. Lastly, Georgia failed to acquire the interdental fricatives [θ] and [ð] within the period documented by the corpus.

1.1 Early acquired sounds

As we can see in Table 7 below, Georgia shows mastery of the majority of her voiced and voiceless stops as early as her first documented attempts at these phones. Her development of [p] offers a prime example of early mastery, the production of which remains accurate throughout the corpus. Although the data are sparse at the beginning of the observation period, we can see that Georgia was able to produce [p] as early as 1;02.

Variability among Georgia's productions of obstruent stops can be largely explained by intervening factors. For example, while [b] is deleted 28 times throughout the corpus, 14 of these instances are the result of Georgia's attempts at producing the word 'banana' (e.g., [bəˈnænə] produced as [nʌnʌ] at 1;10). This deletion can be explained by the fact that the [b] is located in a word-initial unstressed syllable. Despite this variability, her mastery of [b] occurs early.

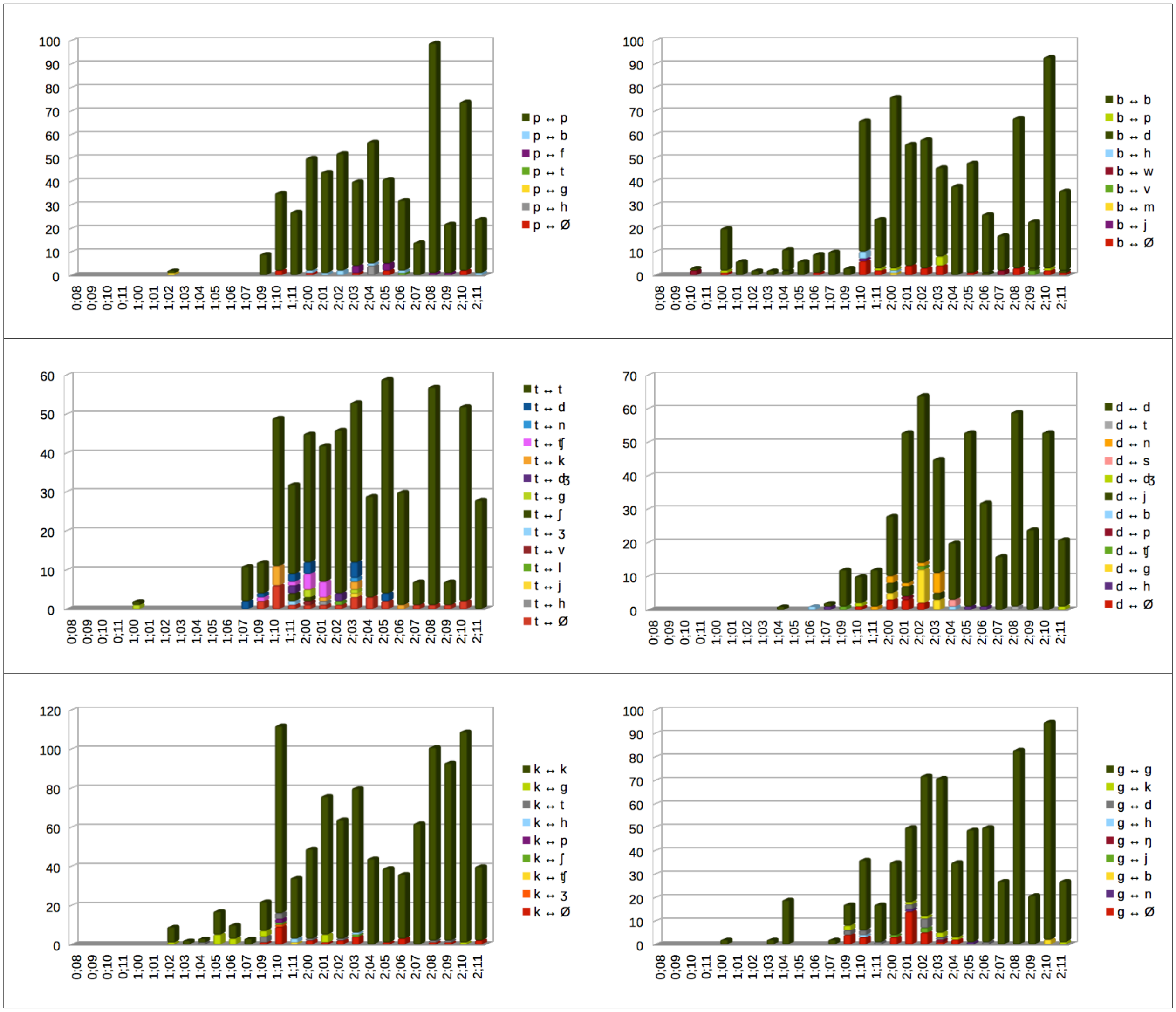
Further, we can see in Table 7 that [t] is the most variable of the target obstruent stops. Georgia's most frequent pattern of variation is deletion, which occurs a total of 25 times throughout the corpus. However, 14 of these deletions occur when an [s] (either in coda position or in an sC cluster) precedes the [t] in onset (e.g., 'thirsty' at 1;10, and 'still' at 2;04). Despite these variable contexts, the vast majority of Georgia's productions of [t] in onset are accurate throughout the dataset. As the data are sparse at the beginning of the observation period, there were only two attempts at [t] recorded before 1;07. However, within these two attempts (at age 1;00), one production of [t] was accurate and the other was produced as [g] as a result of consonant harmony within the word 'tiger' ([taɪgəɹ] produced as [gaga]). As consonant harmony is an independent factor and does not accurately reflect Georgia's ability to produce [t], it can be argued that Georgia was able to produce [t] as early as 1;00.

While Georgia's productions of [d] were fairly consistent, we observe a noticeable period of variability between ages 2;00 and 2;03. During this period, a total of 43 instances of substitution/deletion occurs, 15 of which are a result of her producing the contracted form 'don't'. Also, during this period, Georgia produced [d] as [g] 13 times in her attempts at the word 'duck'. This velarization, a case of consonant harmony, does not accurately reflect Georgia's knowledge of target [d]. Despite these lexical and phonological exceptions, Georgia's mastery of [d] occurred early.

Unlike her production of [k], which is extremely consistent, Table 7 shows that Georgia's production of [g] is much more variable early on. However, this variability is largely due to the deletion that occurs at 2;01 and 2;02. [g] is deleted 19 times during this period, and 14 of these deletions occur when Georgia attempted the word 'hungry' (e.g., [ˈhʌŋgɹi] produced as [hʌŋi] at 2;00). During this time, she also deleted the [g] in the word 'fingers' (e.g., [ˈfɪŋgəɹz] produced as [fɪŋz]). This suggests that the [ŋ] which precedes the [g] in onset yielded this deletion pattern.

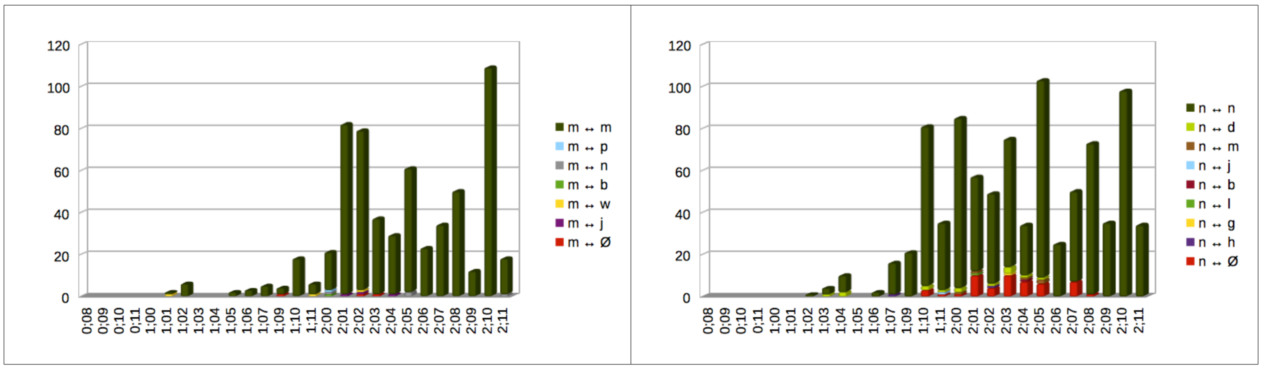
In sum, the data in Table 7 reveal a certain degree of variability within the development of each consonant. However, the most central observation is that Georgia's overall development of the target obstruent stops took place at an early stage.

Table 7: Georgia's production of voiced & voiceless stops



Moving on to Georgia's development of target nasals [m] and [n], Table 8 shows a relatively similar picture. Her accuracy with these sounds remained consistently high, despite some deletion of [n] between 2;01 and 2;07, during which [n] is deleted a total of 44 times. However, these deletions are largely due to Georgia's attempts at producing the same few words. For example, 20 of these deletions are a result of her production of the word 'need'. Similarly, 10 other deletions are attributed to Georgia's attempts at the word 'animals', and seven further deletions arise from her attempts at the word 'gonna'. Georgia's behaviours with regard to these three words account for 84% of all cases of [n] deletion. Considering that the overwhelming majority of her attempts were produced accurately, these deletions were likely due to issues regarding the lexical representations of these words, as opposed to issues regarding her production of [n] more generally.

Table 8: Georgia's production of nasals



Despite the phonological and lexical exceptions affecting Georgia's early development of the target stops and nasals, her accuracy with these sounds remained extremely high throughout the observation period.

Similarly, Georgia acquired both fricatives and affricates early on; however, her development of these sounds is more variable overall. Given that her development of the fricatives and affricates is more variable in comparison to her development of stops and nasals, understanding her developmental patterns becomes slightly more complex.

Table 9 illustrates Georgia's early acquisition of fricatives [s], [ʃ], [h], [f], and affricates [ʧ] and [ʤ]. Although the data display some variability at 1;05 and 1;06 in her production of [s], all of these instances relate to her attempts at the name 'Sadie' ([sædi] produced as [ʃædi]). This substitution occurs 16 times at 1;05, and once at 1;06. However, after this brief period, Georgia's performance at [s] is consistently accurate. Thus, it is likely that Georgia had issues in terms of her lexical representation of the name 'Sadie'.

In contrast, [ʃ] was at first produced correctly, but Georgia began to occasionally substitute it with [s] from 1;11 until 2;06. This phenomenon is observed a total of 16 times, seven of which relate to her attempts at the word 'sure' ([ˈʃʊɹ] produced as [səɹ] at 2;02). Despite this particular substitution, her overall production of [ʃ] remained strong throughout the observation period. Therefore, much like a number of other words in her lexicon, Georgia likely struggled with her lexical representation of the word 'sure'.

We also note some variability in Georgia's production of [h]. For instance, at 1;05, [h] undergoes deletion 16 times as a result of Georgia's attempts to produce the word 'here' (e.g., [ˈhɪɹ] produced as [ɪ]). At 1;07, Georgia continued to delete [h] four times in her attempts to produce the word 'hello' (e.g., [həˈloʊ] produced as [əwo]). In both cases, it is plausible that she faced difficulty in her lexical representation of these words, as target [h] is likely to appear in unstressed syllables in both cases. While this is obvious from the target 'hello', where the initial structure falls in a position similar to the 'ba' of 'banana' discussed above, the word 'here' often appears in phrases such as 'come here', where sentential focus is more likely to be on the verb. Aside from these few instances of variation, however, her production of [h] is very consistent across the dataset. Indeed, while we further observe that, at 1;10, [h] undergoes deletion three times in attempts at the word 'here', and 10 times in attempts at the word 'he' (each of which may be related to prosodic conditioning as just discussed), Georgia's overall accuracy remains high, with 75% of her total attempts produced correctly during this period (41/55).

Unlike her acquisition of [s], [ʃ], and [h], Georgia's development of [f] is consistently accurate as early as her first documented attempt. In contrast, her development of [ʧ] displays some variability. However, this variability may itself relate to her lack of attempts overall, especially between ages 1;06 and 1;11. During this period, [ʧ] is only attempted a total of four times. After this period, however, the majority of her attempts are correctly produced. However, it is important to note the variability which occurs at 2;05, when [ʧ] is substituted with [s] four times. This substitution is a result of Georgia's attempts at the word 'touching' (e.g., [ˈtʌʧɪŋ] produced as [tʌsɪŋg]). In fact, three additional substitutions occur at 2;00 in Georgia's attempts at the word 'watching' (e.g., [ˈwɑʧɪŋ] produced as [wʌʃɪn]). Thus, it is likely that Georgia had difficulty producing [ʧ] when it occurred between two vowels within an onset of an unstressed syllable, similar to other observations discussed above.

Lastly, Georgia's development of [ʤ] also displays variability at times. For instance, [ʤ] is substituted as [d] a total of 12 times throughout the corpus. However, six of these instances are related to her attempts at producing the word 'just' (e.g., [ˈʤʌst] produced as [dɪs] at 2;05). [ʤ] is also produced as [ʒ] a total of nine times, four of which are related to her attempts at producing the word 'jumping' (e.g., [ˈʤʌmpɪŋ] produced as [ʒʌmpɪn] at 2;02). Thus, it is likely that Georgia had issues related to the lexical representation of these words, as opposed to an issue with producing [ʤ] more generally, as her production of this affricate in other words is largely unproblematic.

In sum, as with observations made for other sounds discussed above, the variability shown in Table 9 can be explained by issues regarding lexical representation and prosodic conditioning. In spite of these factors, however, Georgia's accurate production of these consonants is attested at an early stage in her development.

Table 9: Georgia's production of fricatives and affricates

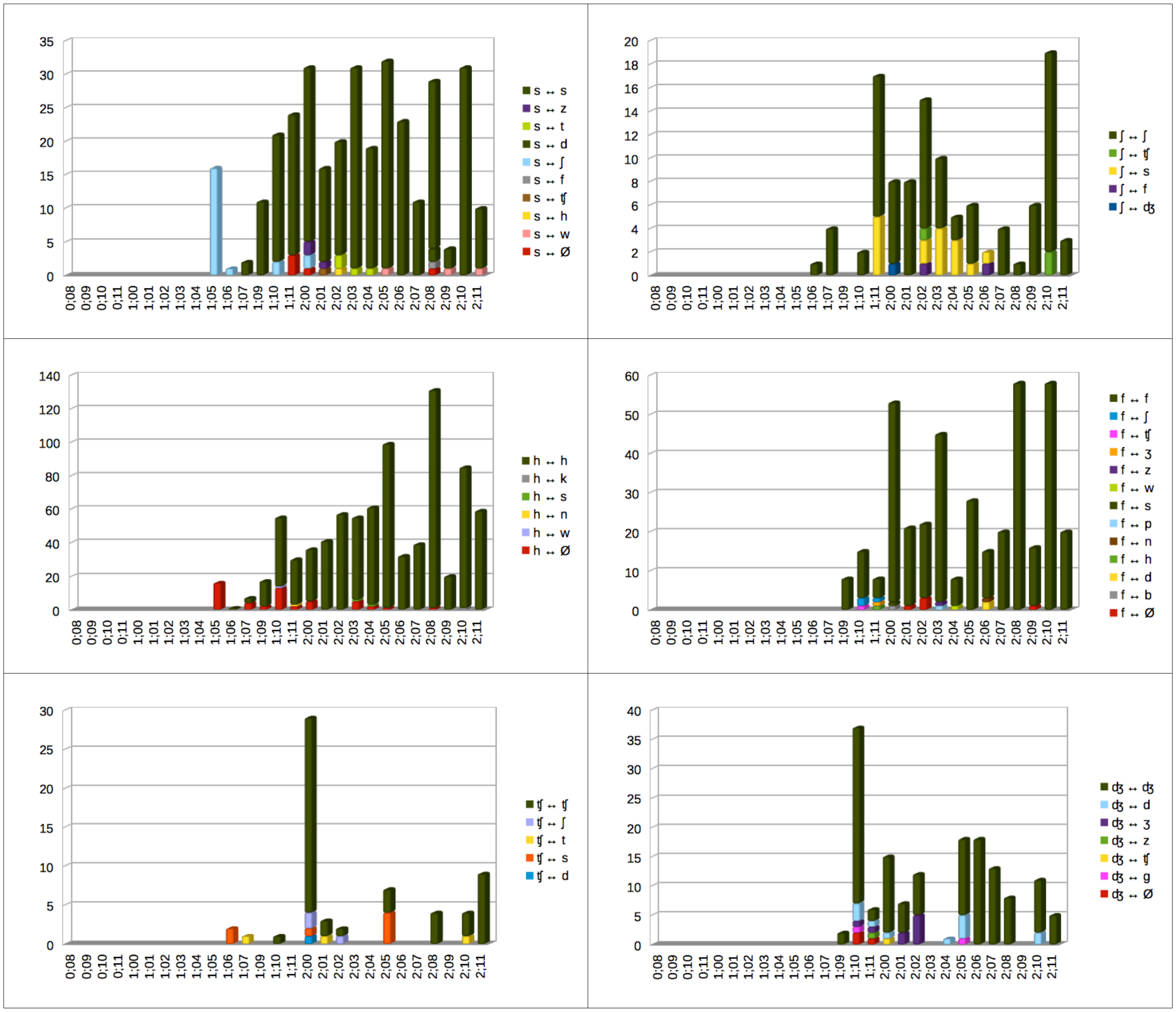
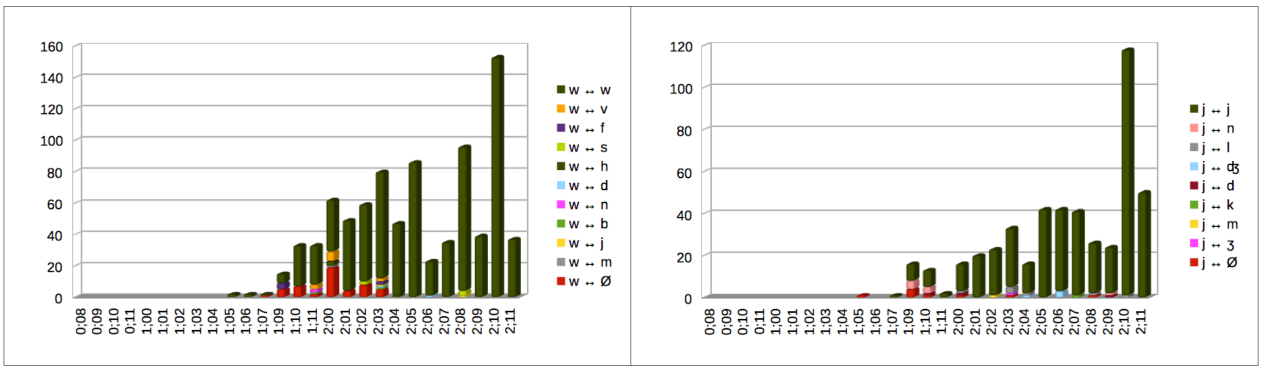


Table 10 illustrates Georgia's early development of the glides [w] and [j]. Her production of [w] is largely accurate; however, there is some notable variability between ages 1;09 and 2;03. During this period, [w] undergoes deletion 50 times, with 24 (48%) of these deletions related to Georgia's attempts at producing the contracted form 'what's'. An additional 15 (30%) deletions are a result of her attempts at producing the word 'where'. Thus, 78% of the deletions are attributed to her attempts at producing these two frequently used words, something surprising in light of current approaches to phonological development based on usage frequency (see, however, Menn

& Matthei (1992) on exceptional behaviours observed in high-frequency words; it may also be the case that the grammatical category of these two wh-forms is implicated in this observation). The same also holds in the context of target [j], which is substituted with [n] a total of eight times throughout the corpus, seven of which are related to her attempts at the word 'yum' (e.g., [ˈjʌm+ˈjʌm] produced as [namnʌm] at 1;09). Despite these few instances of variation early in the data, we can argue that Georgia acquires [j] at 1;07.

Table 10: Georgia's production of glides



1.2 Later acquired sounds

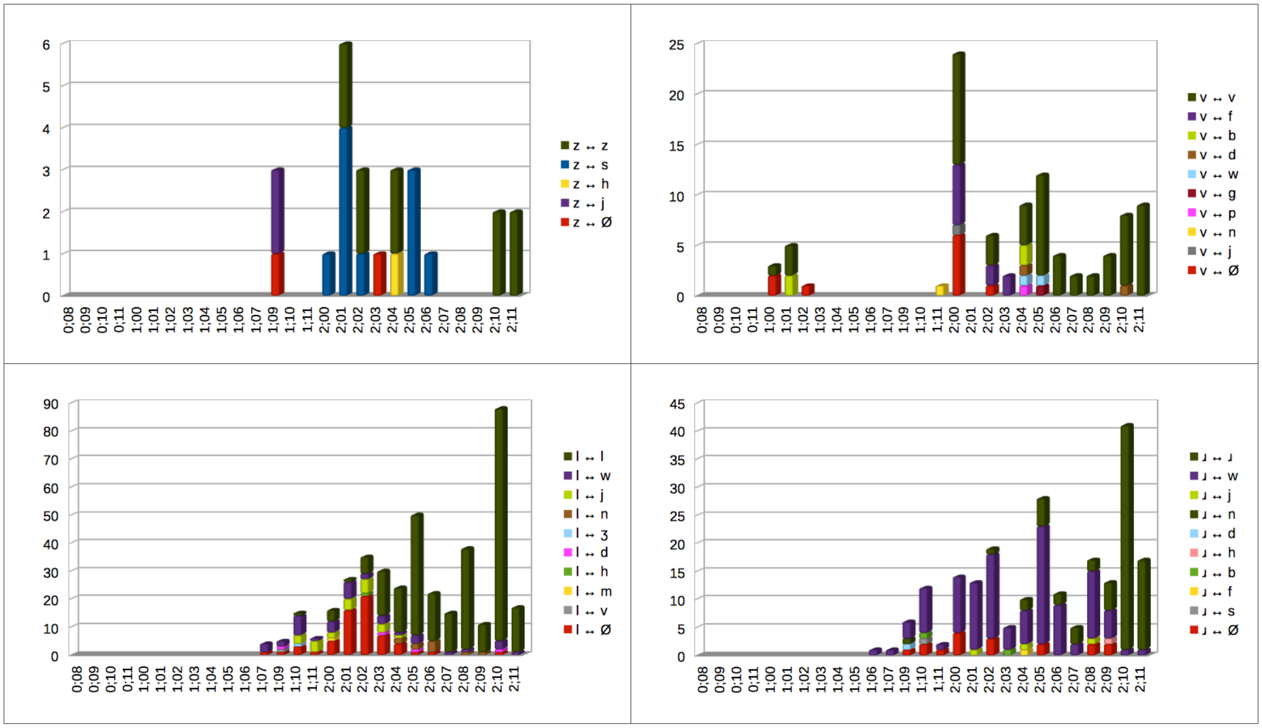
In contrast to the early acquired sounds discussed above, Table 11 illustrates Georgia's consistent variability in her production of fricatives [z] and [v], and liquids [l] and [ɹ], which are all acquired at a later stage in her development. Also, due to the overall lack of attempts at [z] throughout the corpus (only 25 total attempts), Georgia's productions appear very irregular. The most frequent substitute for [z] is [s], which occurs 10 times in total, with six of these substitutions related to her attempts at the word 'pretzel' (e.g., [ˈpɹɛtzəl] produced as [pwɛsəl] at 2;05). However, I do not consider this variability in voicing to be problematic, as it is suggestive of a covert contrast and does not accurately reflect Georgia's phonological knowledge of [z] (Scobbie et al. 1996). Thus, with the exception of this voicing variability, [z] can be considered to be acquired at 2;01.

Georgia's corpus also contains very few attempts at [v]. At 2;00, she deletes the voiced labiodental target six times in her attempts at the word 'movie'. However, in each case, this deletion occurs because Georgia deletes the second unstressed syllable of the word (e.g., [ˈmuːviː] produced as [mu]). Similarly, she deletes the second syllable of 'everyone' at 2;02 (e.g., [ˈɛvɹiːˌwʌn] produced as [awan]). Thus, these cases of deletion are not really representative of Georgia's proficiency at producing target [v], but rather of her difficulty with producing these multisyllabic words. Georgia's next most frequent pattern of variation is her substitution by [f], which occurs a total of 10 times throughout the corpus. However, nine (90%) of these cases arise from her attempts at the word 'over' (e.g., [ˈoʊvəɹ] produced as [ofəɹ] at 2;00). Therefore, it is likely that Georgia had incorrectly mapped the target sound for this specific word. By acknowledging these exceptional cases in her development, it can be argued that Georgia acquired the target [v] as early as 2;00.

Similar to the voiced fricatives described above, Georgia's production of [l] is also highly variable, and is not acquired until 2;03. In earlier recording sessions, Georgia deleted target [l] frequently, with a total of 62 cases throughout the corpus. However, 39 of these deletions (63%) come from her attempts at words which contain an [s] that precedes [l] in syllable onset (e.g., 'sleep' and 'slide'). In terms of the total amount of [l] substitutions throughout the corpus (n=78), 38 attempts (49%) are produced as [w], and 22 attempts (28%) are produced as [j]. Despite the exceptional sC cluster context, Georgia's performance of [l] is highly inconsistent until 2;03, when the target is finally acquired.

Lastly, Georgia displays a general pattern of [ɹ] substitution by [w] across the dataset. In fact, of the 139 cases of non-target productions, 112 (81%) consist of her productions of [ɹ] as [w]. Georgia's second most frequent behaviour is deletion, observed in 17 (12%) of the cases. While target [ɹ] begins to emerge at 2;02, it is not fully mastered until much later, at 2;10.

Table 11: Georgia's production of later acquired sounds

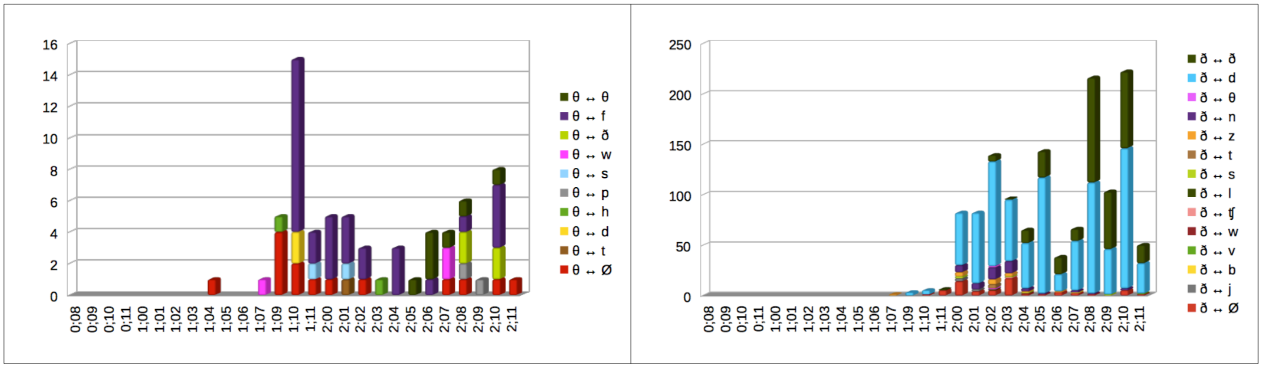


1.3 Sounds not acquired during the observation period

As illustrated in Table 12, Georgia failed to master the interdental fricatives [θ] and [ð] during the period documented by the corpus. In her attempts to produce [θ], she frequently substituted the target with [f]. In fact, this substitution contributes to 51% of the total variation observed (31/61). The next most frequent behaviour in her attempts to produce [θ] is deletion, which contributes to 22% of the total variability (14/61). Although the target [θ] emerges at 2;05, it is never fully acquired during the observation period.

Similarly, Georgia consistently produced [ð] as [d], which contributes to 86% of the total variation observed (844/986). An additional 6% is attributed to deletion (60/986), and a further 5% is related to her substitution by [n] (46/986). Despite the fact that target [ð] emerges at 2;02, Georgia never fully mastered it during the observation period.

Table 12: Georgia's production of interdental fricatives



To conclude, Georgia acquired her target stops, nasals, and glides at an early stage. She also acquired the voiceless fricatives [s], [ʃ], [h], and [f], as well as the affricates [ʧ] and [ʤ], early in her development. In contrast, Georgia showed more variability in her development of the voiced fricatives [z] and [v], as well as liquids [l] and [ɹ], as these sounds were acquired much later. Finally, Georgia failed to acquire the interdental fricatives [θ] and [ð] within the period documented by the corpus.

1.4 Summary of Georgia's phonological development

Table 13 illustrates Georgia's overall phonological development. For sake of clarity, this table excludes all cases of lexical and prosodic exceptions discussed in this chapter. The green signifies a majority of accurate target productions, the yellow represents a majority of substitutions, and the red indicates a majority of deletion of the target sounds. The numbers within each cell represent the number of times that a specific target consonant was attempted by the child within each monthly sample.

Table 13: Georgia's phonological development in relation to her attempts

	0;08	0;09	0;10	0;11	1;00	1;01	1;02	1;03	1;04	1;05	1;06	1;07	1;09	1;10	1;11	2;00	2;01	2;02	2;03	2;04	2;05	2;06	2;07	2;08	2;09	2;10	2;11
p	0	0	0	0	0	0	2	0	0	0	0	0	9	35	27	50	44	52	40	57	41	32	14	99	22	74	24
b	0	0	3	0	20	6	2	2	11	6	9	10	3	66	24	76	56	58	46	38	48	26	17	67	23	93	36
t	0	0	0	0	2	0	0	0	0	0	0	11	12	49	32	45	42	46	53	29	59	30	7	57	7	52	28
d	0	0	0	0	0	0	0	0	1	0	1	2	12	10	12	28	53	64	45	20	53	32	16	59	24	53	21
k	0	0	0	0	0	0	9	2	3	17	10	3	22	112	34	49	77	64	80	44	39	36	62	101	93	109	40
g	0	0	0	0	2	0	0	2	19	0	0	2	17	36	17	35	50	72	71	35	49	50	27	83	21	95	27
f	0	0	0	0	0	0	0	0	0	0	0	0	8	15	8	53	21	22	45	8	28	15	20	58	16	58	20
v	0	0	0	0	3	5	1	0	0	0	0	0	0	0	1	24	0	6	2	9	12	4	2	2	4	8	9
θ	0	0	0	0	0	0	0	0	1	0	0	1	5	15	4	5	5	3	1	3	1	4	4	6	1	8	1
ð	0	0	0	0	0	0	0	0	0	0	0	1	3	5	6	82	82	139	96	65	143	38	66	216	103	222	50
s	0	0	0	0	0	0	0	0	0	16	1	2	11	21	24	31	16	20	31	19	32	23	11	29	4	32	10
z	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	6	3	1	3	3	1	0	0	0	2	2
ʃ	0	0	0	0	0	0	0	0	0	0	1	4	0	2	17	8	8	15	10	5	6	2	4	1	6	19	3
h	0	0	0	0	0	0	0	0	0	16	1	7	17	55	30	36	41	57	55	61	99	32	39	131	20	85	59
ʧ	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	35	3	2	0	0	7	0	0	4	0	4	9
ʤ	0	0	0	0	0	0	0	0	0	0	0	0	2	37	6	15	7	12	0	1	18	18	13	8	0	11	5
m	0	0	0	0	0	2	6	0	0	2	3	5	4	18	6	21	82	79	37	29	61	23	34	50	12	109	18
n	0	0	0	0	0	0	1	4	10	0	2	16	21	81	35	85	57	49	75	34	103	25	50	73	35	98	34
l	0	0	0	0	0	0	0	0	0	0	0	4	5	15	6	16	27	35	30	24	50	22	15	38	11	88	17
ɹ	0	0	0	0	0	0	0	0	0	0	1	1	6	12	2	14	13	19	5	10	28	11	5	17	13	41	17
w	0	0	0	0	0	0	0	0	0	2	2	2	15	33	33	62	49	60	80	47	86	23	35	96	39	153	37
j	0	0	0	0	0	0	0	0	0	1	0	1	16	13	2	16	20	23	33	16	42	42	41	26	24	118	50

Chapter 5: Charlotte's phonological developmental

1. Introduction

In this chapter, keeping with the general outline of Chapter 4, I describe Charlotte's phonological consonantal development in both singleton and branching onsets across all word positions. As already stated in section 1 of Chapter 4, [l], [ɹ], [w], and [j] are only analyzed within singleton onsets. Also, flap [ɾ] is excluded from this analysis due to its allophonic nature.

I begin with the sounds that Charlotte acquired at an early stage in development, which are organized in terms of their manner of articulation (e.g., stops, nasals, fricatives, affricates, and glides). I then discuss the sounds she acquired at later ages, or failed to acquire during the period documented by the corpus. As we will see, Charlotte's phonological development is very similar to that of Georgia's. Both children first acquired the target stops, nasals, glides, and voiceless fricatives [s], [ʃ], [h], and [f] at an early stage in development. They also both acquired the targets [v], [z], and [l] at a much later stage in development. However, the children also differ with respect to a number of target consonants. For instance, Georgia acquired [ɹ] at a later stage in her development, and failed to acquire both [θ] and [ð] during the observation period. In contrast, Charlotte acquired both [θ] and [ʤ] at a later stage in her development, and failed to acquire [ð], [ʧ], and [ɹ] during the period documented by the corpus.

1.1 Early acquired sounds

Similar to Georgia, Charlotte has mastered the majority of her voiced and voiceless stops by her first documented attempts at these sounds. Table 14 illustrates this early developmental pattern, in spite of some variability within the dataset. However, as with Georgia's data above, the bulk of this variability can be explained qualitatively, as follows.

Although [p] emerges early, Charlotte shows a large amount of substitution/deletion at the beginning of the observation period. During this time, she mispronounced [p] a total of 49 times. However, 40 (82%) of these attempts are related to the word 'please'. It thus appears that Charlotte had issues related to her lexical representation of this word.

In contrast, Charlotte's production of [b] is much less variable, with the exception of her performance at 2;07, when [b] is substituted by [d] nine times. However, eight of these instances are due to her attempts at producing the name 'Big Bird'. She attempted the name three times, and in each case she produced both [b]s as [d] (e.g., [ˈbɪg+ˈbʌɹd] produced as [dedɛt]).

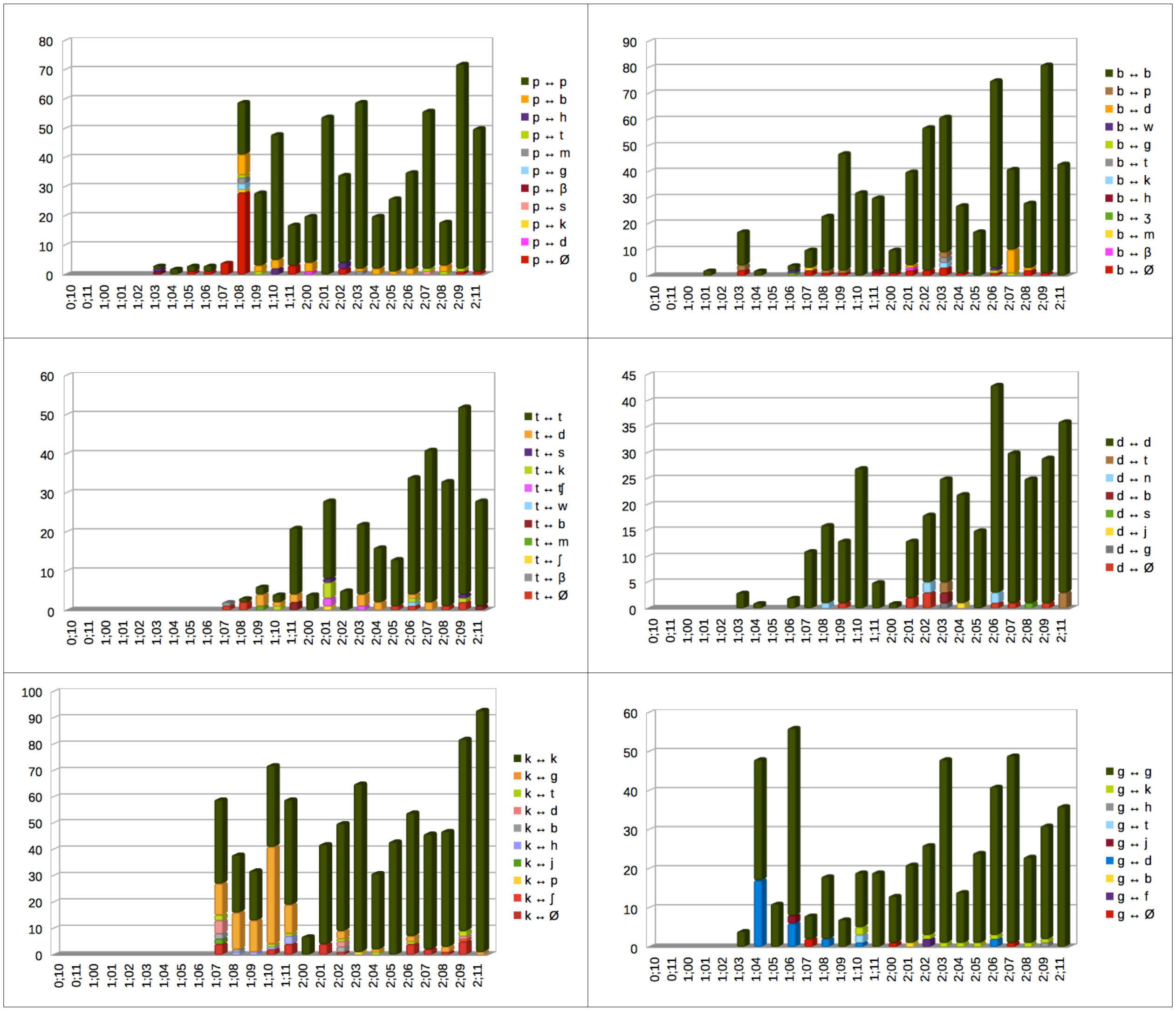
Although there is some variability in her production of [t] early in the dataset, Charlotte acquired the voiceless alveolar stop early in her development. Her most common substitute for [t] is [d], which occurs 14 times within the corpus. However, 10 (71%) of these cases relate to her attempts at words which contain an [s] (either in coda position or in an sC cluster) that precedes the [t] in onset (e.g., 'Stella' at 1;09, and 'mustard' at 2;07). As discussed in 1.1 of Chapter 4, a very similar phenomenon is observed in Georgia's production of [t]. However, Charlotte did not substitute [t] with [d] in these contexts, as Georgia did. Instead, Charlotte deleted [t] in these environments. Thus, it is likely that, for both children, the preceding [s] contributed to issues in their perception and/or production of the following [t]. With the exception of these few cases, however, Charlotte acquired [t] early in the observation period.

The voiced alveolar stop [d] was also acquired at an early stage in Charlotte's development. In fact, Charlotte showed mastery of this sound as early as her first documented attempts at 1;03. Of the 24 cases of non-target production, nine cases (38%) relate to her attempts at the contracted form 'don't', similar to what we observed in Georgia's data.

In contrast, we observe a sizeable amount of variability in Charlotte's development of [k] from age 1;07 to 1;11. During this period, [k] undergoes a total of 116 substitutions and deletions. However, 94 (81%) of these cases result from her attempts at producing the word 'cookie', which she generally produced with voiced velars (e.g., [ˈkʊkiː] produced as [gʊgi]). After this time, however, Charlotte's production of [k] was consistently accurate. In spite of this voicing variability, we can argue that Charlotte acquired [k] by 1;07.

At 1;04 and 1;06, Charlotte substituted [g] with [d] 23 times, and with [j] twice. However, every instance of these substitutions comes from her attempts at producing the word 'again' (e.g., [əˈgɛn] produced as [ədɪ] at 1;04), which points to issues with her lexical representation of this word. Her production of [g] is extremely consistent throughout the remainder of the dataset.

Table 14: Charlotte's production of voiced & voiceless stops



Turning to Charlotte's acquisition of the target nasals [m] and [n], Table 15 shows that, like her early mastery of obstruent stops, she also acquired [m] and [n] early in her development. Her production of [m] is very consistent throughout the data. However, at 2;03, she substituted [m] with [w] six times in her attempts at the word 'monkey' (e.g., [ˈmʌŋkiː] produced as [wʌki]). Additionally, at 2;11, she substituted [m] with [d] eight times in her attempts at the word 'my' (e.g., [ˈmaɪ] produced as [daɪ]). Despite these few examples, which are likely related to lexical representational issues, she mastered [m] at a very early stage.

Charlotte's production of [n] is slightly more variable, as [n] undergoes deletion 25 times from ages 2;06 to 2;11. However, 10 of these deletions are a result of her attempts at the word 'animals', and six of these deletions arise from her attempts at the word 'unicorn'. In both cases, [n] is located in the onset of an unstressed syllable, immediately following the stressed syllable. As I previously discussed in section 1.1 of Chapter 4, in the context of Georgia's production patterns, unstressed syllables are likely to undergo segmental deletion. Thus, despite her difficulty to produce these specific words and some slight variability earlier in the corpus, we can make the claim that Charlotte had segmentally mastered [n] as early as is evidenced in her first documented attempts at words containing this consonant.

Table 15: Charlotte's production of nasals

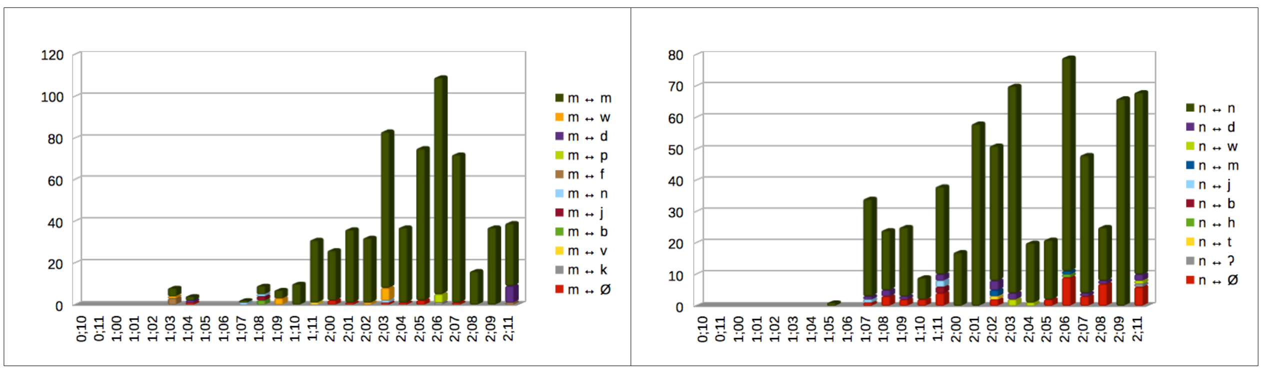


Table 16 illustrates Charlotte's mastery of the voiceless fricatives [s], [ʃ], [h], and [f], all of which were acquired early. For instance, Charlotte's acquisition of [s] occurs as early as the first documented attempts at 1;08. Even at 2;02, the recording session with the highest amount of variation for this consonant, her accuracy rate remains relatively high at 69% (11/16).

In contrast, Charlotte's production of [ʃ] appears more variable, a fact that may be compounded by her fewer attempts at this consonant overall. At 2;04, Charlotte produced [ʃ] as [s] three times, two of which relate to her attempts at producing the word 'washing' (e.g., [ˈwɑʃɪŋ] produced as [wasɪn]). Thus, as many other cases discussed previously, it is likely that Charlotte had issues with the lexical representation of this word. Despite a few instances of variation throughout the data, Charlotte produced 78% of her total attempts accurately (39/50).

The laryngeal fricative [h] was also acquired early, as evidenced by Charlotte's first documented attempts. Of the 15 instances of [h] deletion throughout the corpus, nine (60%) result from Charlotte's attempts at producing the pronoun 'he', whose production may be constrained by prosodic factors as discussed in section 1.1 of Chapter 4 already.

Charlotte's production of [f] is also very consistent throughout the data. In fact, the only notable period of variation is at 1;09, when she attempted the words 'frog' and 'flower' (e.g., [ˈfɹɑg] produced as [nʌg], and [ˈflaʊəɹ] produced as [wat]). It is likely that the liquids in the branching onset following [f] in each case contributed to issues in terms of her perception and/or production of these words. Despite this small amount of variability, her production of [f] is accurate throughout the remainder of the corpus.

Table 16: Charlotte's production of fricatives

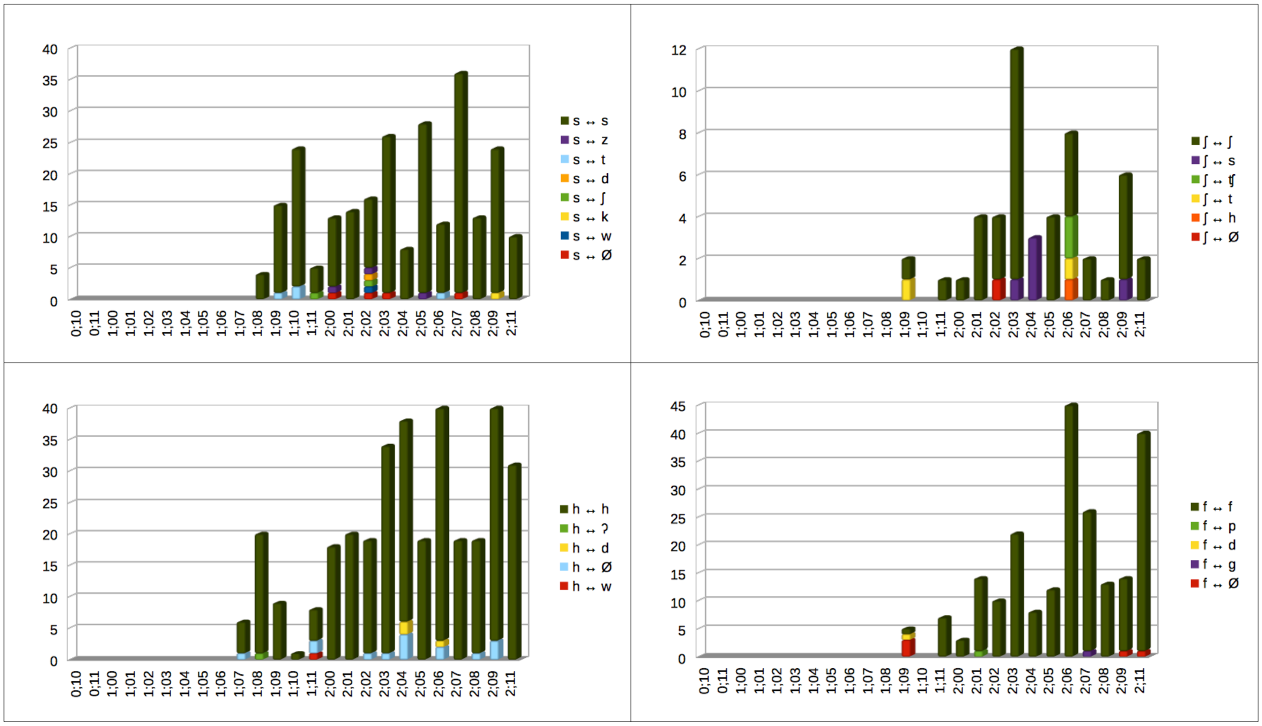
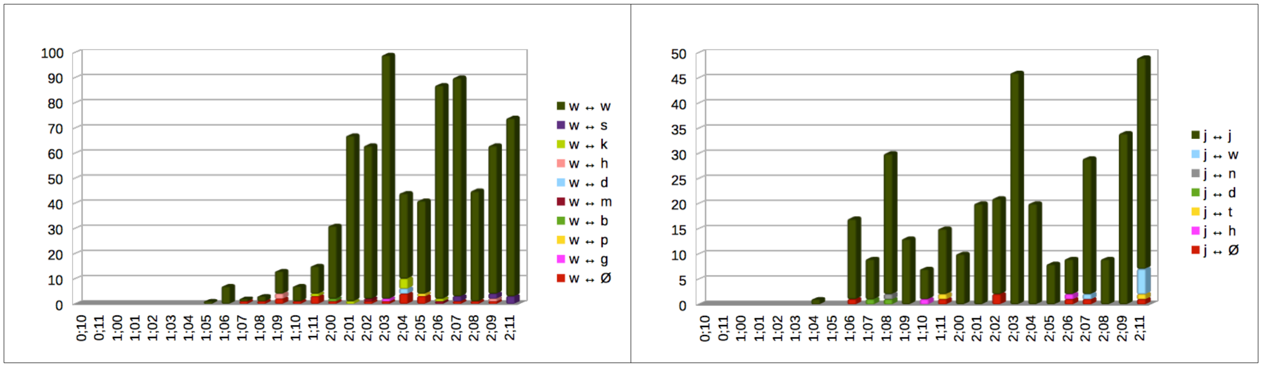


Table 17 illustrates that the glides [w] and [j] were also mastered as early as her first documented attempts. In fact, Charlotte exhibits very minimal variability in her production of both glides. The only variable productions of [w] are at 2;04. During this period, Charlotte produced 10 variable instances; however, five of these are related to her attempts at the word 'washcloth', and two others arise from her attempts at the word 'wash'. Thus, as discussed previously regarding her development of [ʃ], it is likely that Charlotte was struggling with her lexical representation of the word 'wash' more generally. Similarly, the only period of notable variability in her production of [j] is at 2;11. During this period, Charlotte substitutes [j] with [w] five times in her attempts at producing the word 'unicorn' (e.g., [ˈjuːnɪˌkɔɹn] produced as [wekoɹn]). Despite this lexical exception, she acquired both glides very early in her development.

Table 17: Charlotte's production of glides



1.2 Later acquired sounds

Table 18 illustrates the sounds which Charlotte acquired later in her development. For instance, despite the fact that [v] emerges at 2;02, the variability in her production persists until 2;09, when she acquired the consonant. At 2;11, Charlotte deleted [v] seven times in her attempts at producing the word 'favourite' (e.g., [ˈfeɪvəɹət] produced as [fe]). As explained in Charlotte's development of the target nasal [n], unstressed syllables are more likely to undergo segmental deletion. Thus, in Charlotte's attempts at producing the multisyllabic word 'favourite', she produced only the initial stressed syllable and deleted the following unstressed syllables.

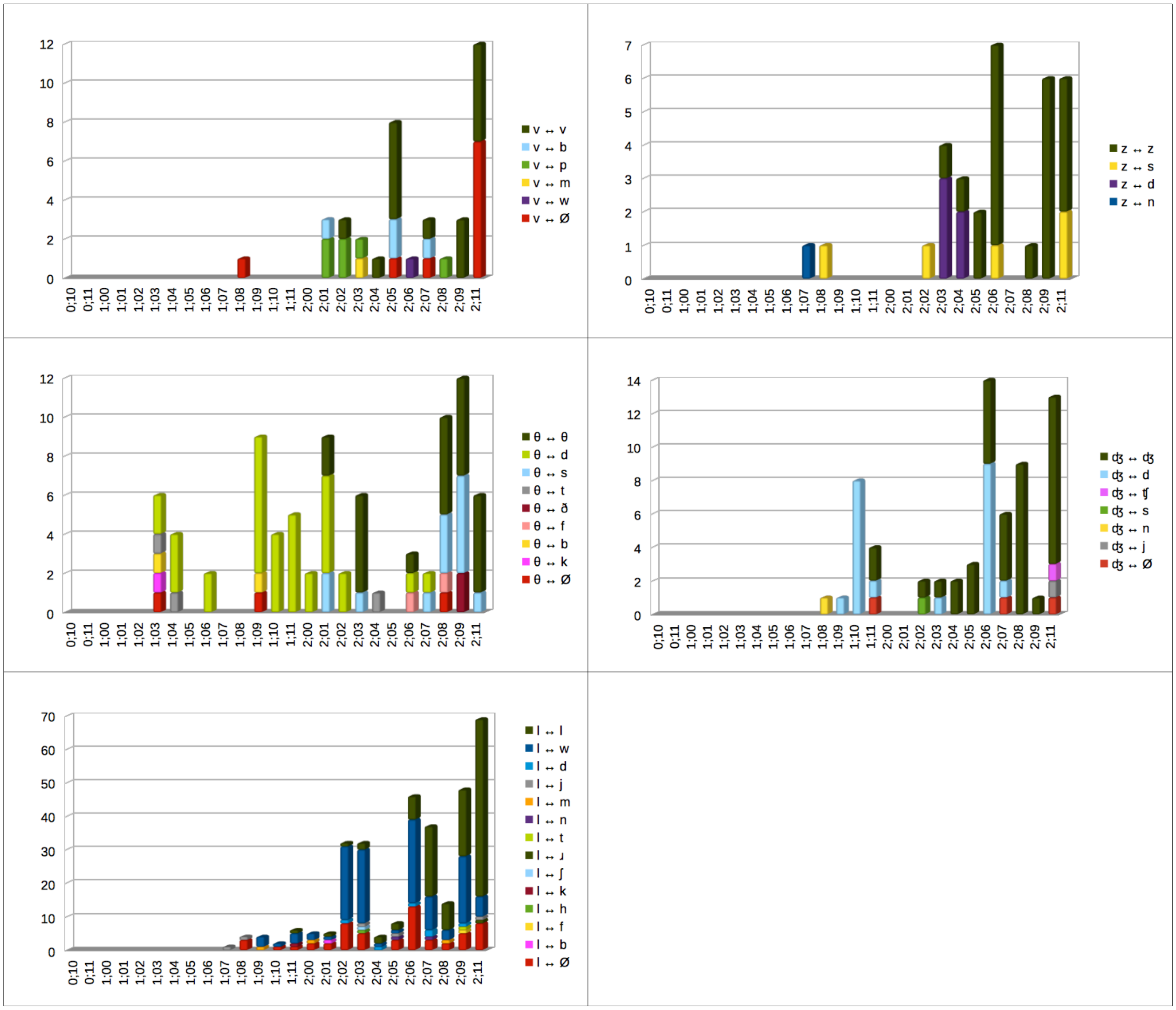
Similar to her acquisition of the voiced fricative [v], Charlotte also acquired the voiced fricative [z] later in her development. Like [v], her late acquisition of [z] may also be exacerbated by the overall lack of attempts at this consonant. Although Charlotte exhibits a few different patterns of production for target [z], none occur systematically enough to warrant a detailed description.

Another sound that is not acquired until much later is the voiceless interdental fricative [θ]. Although [θ] emerges at 2;01, Charlotte did not actually acquire it until 2;09. Before this time, she consistently substituted [θ] with [d]. This substitution occurs 34 times throughout the observation period; however, 24 of these instances relate to her attempts at producing the phrase 'thank you' (e.g., [ˈθæŋk ˈjuː] produced as [dekju]). [θ] is also substituted with [s] a total of 13 times in words such as 'three' (e.g., [ˈθɹiː] produced as [swiː] at 2;08) and 'thing' (e.g., [ˈθɪŋ] produced as [sɪŋg] at 2;09). Thus, Charlotte arrived at different pronunciations for the target consonant in different words (or positions within these words). This variability persists until 2;09, when the majority of errors relate to Charlotte's production of the word 'thing'.

Charlotte also exhibits a lot of variability in her production of [ʤ], which is not acquired until 2;07. Before this, she frequently substituted [ʤ] with [d]. In fact, of the 28 total instances of non-target productions observed, 21 (75%) can be described as deaffrication to [d]. This phenomenon is also observed in Charlotte's production of the voiceless affricate [ʧ], which she frequently produced as [t] (this is further discussed in section 1.3 below). Although 11 of these 21 substitutions arise from her attempts at producing the word 'juice' (e.g., [ˈʤuːs] produced as [dus] at 1;10), the remaining 10 cases affect other words such as 'giraffe' and 'Daisy Joe'.

Lastly, [l] was also acquired much later, as Charlotte did not acquire this liquid until 2;07. Before this, she consistently substituted [l] with [w] in both word-initial and word-medial onsets (e.g., 'leaf' [ˈliːf] produced as [wif] at 2;03, and 'colour' [ˈkʌləɹ] produced as [kowə] at 2;02). In fact, this substitution contributes to 60% of the total variability observed (120/199). Additionally, another 28% of the total variation relates to her deletion of [l] (56/199). This deletion also occurs in both word-initial and word-medial onsets (e.g., 'sled' [ˈslɛd] produced as [sɛd] at 2;06, and 'silly' [ˈsɪliː] produced as [sɪi] at 2;02).

Table 18: Charlotte's production of later acquired sounds



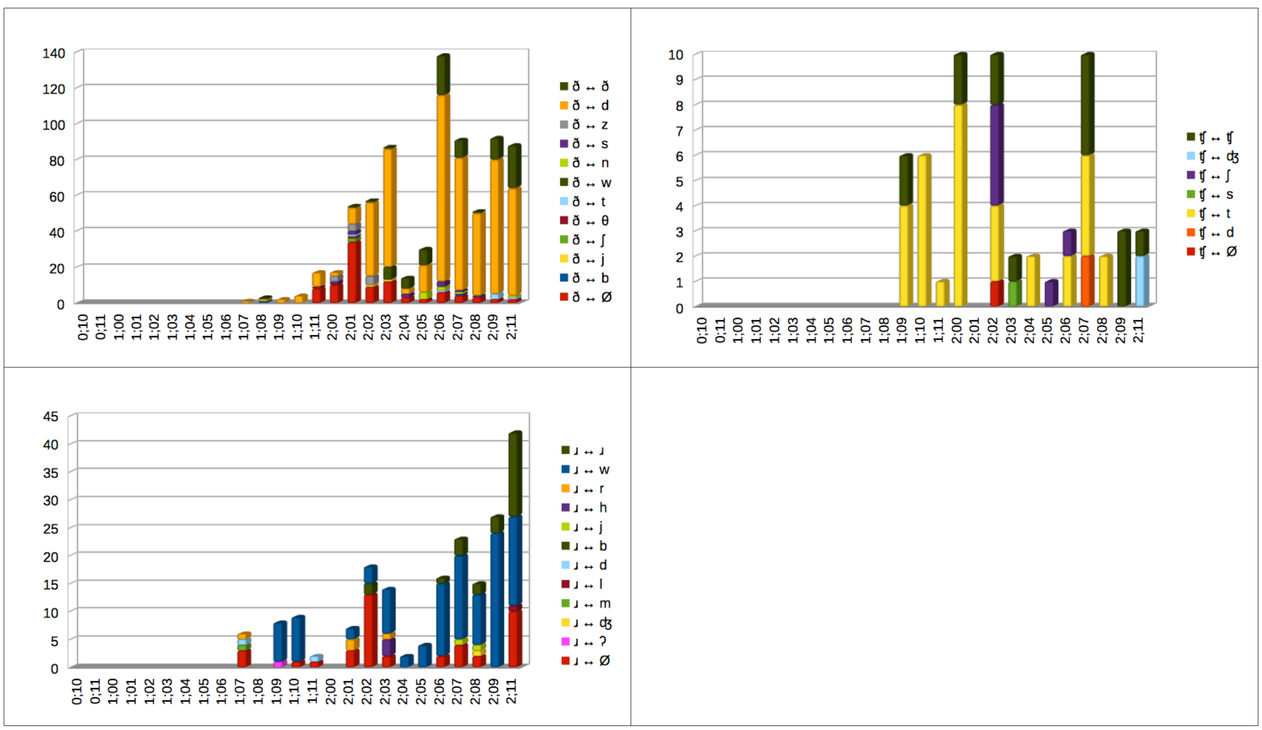
1.3 Sounds not acquired during the observation period

Unlike the consonants discussed in sections 1.1 and 1.2, those described in this section are not acquired at all during the period documented by the corpus. As shown in Table 19, these are [ð], [ʧ], and [ɹ]. Although [ð] began to emerge at 2;04, her production remains highly variable by the end of the corpus at 2;11. Charlotte's most frequent substitute for [ð] is [d], which contributes to 78% of the total variation throughout the corpus (511/658). Her next most frequent behaviour in her attempts at producing [ð] is deletion, which contributes to 14% of the total variation (95/658).

The target affricate [ʧ] also emerged earlier, at 1;09; however, Charlotte never fully acquired it by the end of the corpus. Throughout the observation period, she consistently substituted [ʧ] with [t]. This type of substitution contributes to 73% of the total variation observed in the data (32/44). Charlotte's next most common substitute for [ʧ] is [ʃ], which contributes to 14% of the total variation (6/44).

Lastly, Charlotte also failed to acquire [ɹ] within the observation period. Her most common substitute for [ɹ] was [w], which contributes to 66% of the total variability (111/169). She also deleted [ɹ] frequently, which contributes to 24% of the total variation (41/169).

Table 19: Charlotte's production of sounds not acquired during the observation period



To conclude, Charlotte acquired the target stops, nasals, glides, and voiceless fricatives [s], [ʃ], [h], and [f] early in her development. However, she showed much slower patterns of development for [v], [θ], [z], [ʤ], and [l]. Lastly, Charlotte failed to acquire [ð], [ʧ], and [ɹ] during the observation period.

1.4 Summary of Charlotte's phonological development

Table 20 summarizes Charlotte's overall phonological development. As explained for Georgia's phonological summary in section 1.4, this table excludes all cases of lexical and prosodic exceptions discussed in this chapter. The green indicates a majority of accurate target productions, the yellow represents a majority of substitutions, and the red signifies a majority of deletions. The numbers within each cell indicate the amount of times a specific target consonant was attempted within each period.

Table 20: Charlotte's phonological development in relation to her attempts

	0;10	0;11	1;00	1;01	1;02	1;03	1;04	1;05	1;06	1;07	1;08	1;09	1;10	1;11	2;00	2;01	2;02	2;03	2;04	2;05	2;06	2;07	2;08	2;09	2;11
p	0	0	0	0	0	3	2	3	3	4	59	28	48	17	20	54	34	59	20	26	35	56	18	72	50
b	0	0	0	2	0	17	2	0	4	10	23	47	32	30	10	40	57	61	27	17	75	41	28	81	43
t	0	0	0	0	0	0	0	0	0	2	3	6	4	21	4	28	5	22	16	13	34	41	33	52	28
d	0	0	0	0	0	3	1	0	2	11	16	13	27	5	1	13	18	25	22	15	43	30	25	29	36
k	0	0	0	0	0	0	0	0	0	59	38	32	72	59	7	42	50	65	31	43	54	46	47	82	93
g	0	0	0	0	0	4	48	11	56	8	18	7	19	19	13	21	26	48	14	24	41	49	23	31	36
f	0	0	0	0	0	0	0	0	0	0	0	5	0	7	3	14	10	22	8	12	45	26	13	14	40
v	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	3	2	1	8	1	3	1	3	12
θ	0	0	0	0	0	6	4	0	2	0	0	9	4	5	2	9	2	6	1	0	3	2	10	12	6
ð	0	0	0	0	0	0	0	0	0	1	3	2	4	17	17	54	57	87	14	30	138	91	51	92	88
s	0	0	0	0	0	0	0	0	0	0	4	15	24	5	13	14	16	26	8	29	13	37	13	24	10
z	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	4	3	2	7	0	1	6	6
ʃ	0	0	0	0	0	0	0	0	0	0	0	2	0	1	1	4	4	12	3	4	8	2	1	6	2
h	0	0	0	0	0	0	0	0	0	6	20	9	1	8	18	20	19	34	38	19	40	19	19	40	31
ʧ	0	0	0	0	0	0	0	0	0	0	0	6	6	1	10	0	10	2	2	1	3	10	2	3	3
ʤ	0	0	0	0	0	0	0	0	0	0	1	1	8	4	0	0	2	2	2	3	14	6	9	1	13
m	0	0	0	0	0	8	4	0	0	2	9	7	10	31	26	36	32	83	37	75	109	72	16	37	39
n	0	0	0	0	0	0	0	1	0	34	24	25	9	38	17	58	51	70	20	21	79	48	25	66	68
l	0	0	0	0	0	0	0	0	0	1	4	4	2	6	5	5	32	32	4	8	46	37	14	48	69
ɹ	0	0	0	0	0	0	0	0	0	6	0	8	9	2	0	7	18	14	2	4	16	23	15	27	42
w	0	0	0	0	0	0	0	1	7	2	3	13	7	15	31	67	63	99	44	41	87	90	45	63	74
j	0	0	0	0	0	0	1	0	17	9	30	13	7	15	10	20	21	46	20	8	9	29	9	34	49

Chapter 6: Exploring Georgia's and Charlotte's phonological neighbourhoods

1. Comparison of Georgia's & Charlotte's phonological development

Before discussing Georgia's and Charlotte's respective neighbourhood data, it is important to compare their phonological development as outlined in Chapter 4 and Chapter 5. In the interest of clarity, Table 21 reports these data across three general time periods: the consonants acquired before the age of 2;0, those acquired after that age, and those which were not yet mastered by the end of the documented period, at 2;11. For both Georgia and Charlotte, early-acquired consonants include all target oral and nasal stops, glides, as well as voiceless alveolar fricatives. In contrast, both children show slower development for voiced fricatives, liquids, and interdentals. Finally, concerning the development of affricates, Charlotte displays a more drawn-out developmental pattern than Georgia. Thus, both children exhibit systematic patterns of acquisition. In the following section, I assess these developmental patterns in light of the children's neighbourhood data.

Table 21: Georgia & Charlotte's phonological acquisition

	Early (prior to 2;00)	**Later** (after 2;00)	**Not acquired** (by end of observation period)
Georgia	[p] [b] [t] [d] [k] [g] [m] [n] [s] [ʃ] [h] [f] [w] [j] [ʧ] [ʤ]	[v] [z] [l] [ɹ]	[θ] [ð]
Charlotte	[p] [b] [t] [d] [k] [g] [m] [n] [s] [ʃ] [h] [f] [w] [j]	[v] [z] [θ] [ʤ] [l]	[ð] [ʧ] [ɹ]

2. Addressing phonological development in light of neighbourhood data

In this section, I discuss the children's phonological development in light of their neighbourhood data. By analyzing these two aspects of lexical and phonological development longitudinally, I will be able to assess the predictions of the Lexical Restructuring Model. According to the LRM, as stated in section 2.1 of Chapter 1, children only acquire detailed phonological categories if they possess sufficiently dense phonological neighbourhoods to highlight the contrasts between target sounds. For example, the words 'pit'/'bit' [pɪt/bɪt] both reside in the same [-ɪt] neighbourhood, within which the [p/b] neighbours must be differentiated. Phonological development is thus dependent on the presence and density of phonological neighbourhoods. In order to test this prediction, I analyze Georgia's and Charlotte's developing lexicons in light of these two factors, and compare the findings to the children's age of mastery of each consonant.

2.1 Georgia's neighbourhood analysis

In order to better understand the relationship between Georgia's lexical and phonological development, we must compare and contrast her neighbourhood data with her ages of acquisition for all target consonants. First, Table 22 provides a summary of Georgia's phonological development for all target onset consonants at the time they were mastered or, concerning the last two consonants, at the end of the observation period. The first four columns list (a) the relevant target consonants, followed by (b) the child's age when these consonants are first attested in the expressive vocabulary, (c) when they are first produced in a target-like fashion, and (d) when these consonants are mastered by the child, with mastery determined based on a majority of target-like productions within the current and subsequent sessions, as described in the last two chapters. The last two columns list (e) the number of times each consonant was present in onset position within attempted forms, and (f) the number of attestations of each consonant in word-initial position within the child's recorded vocabulary at the age of mastery. Additionally, Table 23 to Table 27 compare and contrast Georgia's neighbourhood densities with her phonological mastery of target consonants.

Table 22: Georgia's lexical and phonological development of consonants

Target	First attestation in vocabulary	First target-like production	Mastery	Recorded attempts at mastery	Attestations in vocabulary at mastery
b	0;08	0;10	1;00	23	18
g	0;08	1;00	1;00	2	4
t	0;08	1;00	1;00	2	9
m	0;08	1;01	1;01	2	6
k	0;08	1;02	1;02	9	13
n	0;08	1;02	1;02	1	9
p	0;08	1;02	1;02	2	15
d	0;08	1;04	1;04	1	13
w	0;08	1;05	1;05	2	13
ʃ	0;09	1;06	1;06	1	7
h	0;08	1;06	1;06	17	24
j	0;08	1;07	1;07	2	4
s	0;09	1;07	1;07	19	12
f	0;10	1;09	1;09	8	16
ʤ	0;08	1;09	1;09	2	8
ʧ	0;08	1;10	1;10	4	9
v	1;00	1;00	2;00	34	4
z	1;02	2;01	2;01	10	2
l	0;08	1;10	2;03	138	26
ɹ	0;08	2;02	2;10	198	32
θ	0;08	2;05	N/A	(68)	(5)
ð	1;01	2;02	N/A	(1317)	(12)

The first general observation we can draw from this table is that the age at which phones are first attested within the child's lexicon does not predict order of acquisition. For instance, although [b] and [ɹ] are both attested early in Georgia's lexicon (at 0;08), [b] is mastered early, at 1;00, whereas [ɹ] is not acquired until much later, at 2;10. Similarly, [θ] also first appears in the lexicon early at 0;08 but is not acquired during the period documented by the corpus. More generally, most target consonants are attested relatively early within the lexicon, at which point they either show mastery or a more drawn-out developmental pattern, which I discuss further in section 4.

As discussed in section 2.1 of Chapter 1, the LRM posits that as neighbourhood density increases, the learner must encode additional detail within phonological representations, which leads to further phonological development, toward mastery. Thus, it is important to consider the relative density of the phonological neighbourhoods within Georgia's lexicon throughout her development. A complete list of Georgia's neighbourhood densities throughout development is provided in the Appendix. For sake of convenience, I have selected specific consonants in order to compare and contrast potential effects of neighbourhood density on Georgia's phonological acquisition of these phones. Table 23 to Table 27 below outline the progression of Georgia's neighbourhood densities across development. The first three pairs of consonants (reported in Table 23 to Table 25) were selected in order to include a variety of places and manners of articulation. The last two pairs of consonants (in Table 26 and Table 27) were selected in order to discuss phones that Georgia did not acquire during the observation period ([θ] and [ð]) as well as her respectively most frequent substitutions of these sounds ([f] and [d]). Note that, in the tables that follow, I consistently list neighbourhoods following the A, E, I, O, U order. In case no data are attested for a given neighbourhood, this neighbourhood is not represented within the relevant table.

Table 23: Contrasting phonological neighbourhoods of [s] and [t] in Georgia's lexicon

1;00	**1;01**	**1;02**	**1;03**	**1;04**	**1;05**	**1;06**	**1;07**
	A (s=2, t=3)	A (s=2, t=3)	A (s=2, t=3)	A (s=2, t=3)	A (s=3, t=3)	A (s=3, t=3)	A (s=3, t=3)
		E (s=1, t=3)	E (s=1, t=4)	E (s=1, t=4)	E (s=1, t=4)	E (s=1, t=4)	E (s=1, t=4)
I (s=1, t=2)	I (s=2, t=2)	I (s=3, t=2)	I (s=4, t=3)	I (s=5, t=3)	I (s=5, t=3)	I (s=5, t=3)	I (s=5, t=3)
O (s=1, t=2)	O (s=1, t=6)	O (s=2, t=8)	O (s=2, t=8)	O (s=2, t=8)	O (s=3, t=9)	O (s=3, t=9)	O (s=3, t=10)

As outlined in Table 22, [t] is mastered at 1;00 and [s] is mastered later, at 1;07. However, as Table 23 shows, both [t] and [s] are contrasted in neighbourhoods A, I, and O as early as 1;01, which continue to grow in density at 1;02. Despite the presence of these contrasting neighbourhoods, Georgia acquired [s] seven months later than [t]. Thus, Georgia's acquisition of the voiceless plosive [t] and the voiceless fricative [s] does not seem to be captured by the LRM.

Table 24: Contrasting phonological neighbourhoods of [b] and [m] in Georgia's lexicon

0;08	**0;09**	**0;10**	**0;11**	**1;00**	**1;01**
A (b=1, m=1)	A (b=3, m=1)	A (b=5, m=1)	A (b=5, m=1)	A (b=9, m=2)	A (b=9, m=2)
				I (b=1, m=1)	I (b=3, m=1)
		O (b=2, m=1)	O (b=2, m=1)	O (b=3, m=3)	O (b=3, m=3)

Unlike the contrast between /t/ and /s/, there is no strong cluster of contrasting neighbourhoods between [b] and [m]; they are rather dispersed across sessions. A contrast first appears in neighbourhood A as early as 0;08. From 0;10 to 0;11, [b] and [m] are contrasted in neighbourhoods A and O. At 1;00, when [b] is acquired, we find contrasts within neighbourhoods A, O, and I. The same contrasts are present one month later at 1;01, when [m] is also acquired. These observations do not directly undermine or support the LRM. However, they do highlight a practical yet central question regarding the LRM: How many neighbours, or how dense a neighbourhood, does a child theoretically require in order to acquire a target consonant? Is contrast between two phones within one neighbourhood sufficient? If so, Georgia's acquisition of the plosive [b] and the nasal plosive [m] would not support the LRM, as these consonants are contrasted as early as 0;08 but are not acquired until 1;00 and 1;01, respectively. However, if more than one neighbourhood is required to trigger acquisition, this example could potentially support the argument of the LRM. One related question, also difficult to answer, concerns the amount of time that a learner might need between the introduction of sufficient contrasting elements and the development of the relevant phones in production. Until these details are clarified, it is difficult to provide a completely fair assessment of the model. In the interim, we can minimally criticize it for being too vaguely defined.

Table 25: Contrasting phonological neighbourhoods of [l] and [ɹ] in Georgia's lexicon

1;01	**1;02**	**1;03**	**1;04**	**1;05**	**1;06**	**1;07**	**1;09**	**1;10**	**1;11**	**2;00**
A (l=1, ɹ=1)	A (l=2, ɹ=3)	A (l=3, ɹ=3)	A (l=4, ɹ=4)	A (l=4, ɹ=4)	A (l=4, ɹ=4)	A (l=4, ɹ=4)	A (l=4, ɹ=4)	A (l=6, ɹ=5)	A (l=6, ɹ=5)	A (l=6, ɹ=6)
	E (l=1, ɹ=1)	E (l=1, ɹ=1)	E (l=1, ɹ=2)	E (l=1, ɹ=2)	E (l=1, ɹ=4)	E (l=1, ɹ=6)	E (l=1, ɹ=7)	E (l=2, ɹ=7)	E (l=2, ɹ=7)	E (l=5, ɹ=7)
			I (l=2, ɹ=1)	I (l=2, ɹ=1)	I (l=2, ɹ=1)	I (l=2, ɹ=1)	I (l=2, ɹ=1)	I (l=3, ɹ=1)	I (l=3, ɹ=1)	I (l=3, ɹ=1)
O (l=2, ɹ=1)	O (l=2, ɹ=1)	O (l=2, ɹ=1)	O (l=2, ɹ=1)	O (l=2, ɹ=1)	O (l=2, ɹ=1)	O (l=2, ɹ=1)	O (l=2, ɹ=1)	O (l=2, ɹ=2)	O (l=2, ɹ=2)	O (l=2, ɹ=2)
							U (l=1, ɹ=1)	U (l=1, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)

2;01	**2;02**	**2;03**	**2;04**	**2;05**	**2;06**	**2;07**	**2;08**	**2;09**	**2;10**
A (l=6, ɹ=9)	A (l=7, ɹ=9)	A (l=10, ɹ=9)	A (l=11, ɹ=10)	A (l=12, ɹ=10)	A (l=12, ɹ=10)	A (l=12, ɹ=10)	A (l=15, ɹ=10)	A (l=15, ɹ=11)	A (l=15, ɹ=11)
E (l=6, ɹ=7)	E (l=7, ɹ=7)	E (l=7, ɹ=7)	E (l=7, ɹ=7)	E (l=7, ɹ=7)	E (l=10, ɹ=7)	E (l=10, ɹ=7)	E (l=11, ɹ=9)	E (l=11, ɹ=9)	E (l=12, ɹ=9)
I (l=4, ɹ=1)	I (l=4, ɹ=1)	I (l=5, ɹ=1)	I (l=7, ɹ=1)	I (l=8, ɹ=1)	I (l=8, ɹ=2)	I (l=8, ɹ=2)	I (l=9, ɹ=3)	I (l=10, ɹ=3)	I (l=11, ɹ=5)
O (l=2, ɹ=2)	O (l=2, ɹ=3)	O (l=2, ɹ=3)	O (l=3, ɹ=4)	O (l=4, ɹ=4)	O (l=4, ɹ=4)	O (l=4, ɹ=4)	O (l=4, ɹ=4)	O (l=4, ɹ=4)	O (l=4, ɹ=4)
U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=3)	U (l=2, ɹ=3)	U (l=3, ɹ=3)

As shown in Table 22, [ɹ] is mastered at 2;03 and [l] is mastered later at 2;10. However, as Table 25 shows, the two consonants are contrasted much earlier at 1;01 in neighbourhoods A and O. The relevance of these contrasts continues to increase with both consonants contrasting in neighbourhoods A, O, and E at 1;02, and in neighbourhoods A, O, E, and I at 1;04. Again, similar to the example shown in Table 23, the presence of contrasting neighbourhoods does not predict Georgia's mastery of the liquids [ɹ] and [l].

Table 26:   Contrasting phonological neighbourhoods of [θ] and [f] in Georgia's lexicon

1;00	**1;01**	**1;02**	**1;03**	**1;04**	**1;05**	**1;06**	**1;07**	**1;09**	**1;10**	**1;11**	**2;00**
A (θ=1, f=1)	A (θ=1, f=1)	A (θ=1, f=1)	A (θ=1, f=1)	A (θ=1, f=3)	A (θ=1, f=3)	A (θ=1, f=3)	A (θ=1, f=3)	A (θ=1, f=5)	A (θ=1, f=5)	A (θ=1, f=7)	A (θ=1, f=7)
O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=2, f=2)	O (θ=2, f=3)

2;01	**2;02**	**2;03**	**2;04**	**2;05**	**2;06**	**2;07**	**2;08**	**2;09**	**2;10**	**2;11**
A (θ=1, f=7)	A (θ=1, f=10)	A (θ=1, f=11)	A (θ=1, f=12)	A (θ=1, f=13)	A (θ=1, f=13)	A (θ=1, f=13)	A (θ=1, f=13)	A (θ=1, f=13)	A (θ=1, f=14)	A (θ=1, f=15)
I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=2, f=12)	I (θ=2, f=12)
O (θ=2, f=4)	O (θ=2, f=4)	O (θ=2, f=5)	O (θ=2, f=6)	O (θ=2, f=6)	O (θ=2, f=7)	O (θ=2, f=7)	O (θ=2, f=7)	O (θ=2, f=8)	O (θ=2, f=8)	O (θ=2, f=8)

Table 12 in Chapter 4 shows that [θ] was not acquired during the observation period, and that [f], acquired at 1;09, was Georgia's most frequent substitution for [θ]. As Table 26 shows, these consonants are contrasted much earlier, at 1;00, in neighbourhoods A and O. Additionally, starting at 2;01, [θ] and [f] are contrasted in neighbourhoods A, O, and I, and yet [θ] is never acquired despite this relative density of contrasts.

Table 27:   Contrasting phonological neighbourhoods of [ð] and [d] in Georgia's lexicon

1;09	**1;10**	**1;11**	**2;00**	**2;01**	**2;02**	**2;03**	**2;04**
E (ð=3, d=1)	E (ð=4, d=1)	E (ð=4, d=1)	E (ð=5, d=1)	E (ð=5, d=1)	E (ð=6, d=2)	E (ð=7, d=3)	E (ð=7, d=3)
I (ð=2, d=2)	I (ð=2, d=3)	I (ð=2, d=3)	I (ð=2, d=3)	I (ð=2, d=4)	I (ð=2, d=5)	I (ð=2, d=6)	I (ð=2, d=6)
			O (ð=1, d=8)	O (ð=1, d=8)	O (ð=1, d=9)	O (ð=1, d=10)	O (ð=1, d=10)

2;05	**2;06**	**2;07**	**2;08**	**2;09**	**2;10**	**2;11**
E (ð=7, d=3)	E (ð=7, d=3)	E (ð=7, d=3)	E (ð=8, d=3)	E (ð=8, d=3)	E (ð=9, d=3)	E (ð=9, d=4)
I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)
O (ð=1, d=10)	O (ð=1, d=10)	O (ð=1, d=11)	O (ð=1, d=12)	O (ð=1, d=12)	O (ð=1, d=12)	O (ð=1, d=13)

Table 12 in Chapter 4 also shows that [ð] was not acquired during the observation period, and that [d], acquired at 1;04, was Georgia's most frequent substitution for [ð]. As Table 27 shows, these consonants are contrasted at 1;09 in neighbourhoods E and I and, from 2;00 onward, in neighbourhoods E, I, and O. Despite this level of contrast early in Georgia's development, [ð] is not acquired during the observation period.

In sum, for both early- and late-acquired consonants, there appears to be a lack of correlation between Georgia's phonological neighbourhood density and her mastery of the target consonants. Similar observations arise from Charlotte's data, which are discussed in the following section.

2.2 Charlotte's neighbourhood analysis

Following the outline of Georgia's analysis above, Table 28 provides a summary of Charlotte's phonological development for all target onset consonants at the time they were mastered or, concerning the last three consonants, at the end of the observation period. As listed in section 2.1 above, the first four columns list (a) the relevant target consonants, followed by (b) the child's age when these consonants are first attested in the expressive vocabulary, (c) when they are first produced in a target-like fashion, and (d) when these consonants are mastered by the child, with mastery determined based on a majority of target-like productions within the current and subsequent sessions. The last two columns list (e) the number of times each consonant was present in onset position within attempted forms, and (f) the number of attestations of each consonant in word-initial position within the child's recorded vocabulary at the age of mastery. Additionally, as in section 2.1 above, Table 29 to Table 33 compare and contrast Charlotte's neighbourhood densities with her phonological mastery of target consonants.

Table 28: Charlotte's lexical and phonological development of consonants

Target	First attestation in vocabulary	First target-like production	Mastery	Recorded attempts at mastery	Attestations in vocabulary at mastery
b	1;01	1;01	1;01	2	1
p	1;03	1;03	1;03	3	1
d	1;03	1;03	1;03	3	3
g	1;03	1;03	1;03	4	1
m	1;03	1;03	1;03	8	2
j	1;03	1;04	1;04	1	1
n	1;01	1;05	1;05	1	2
w	1;05	1;05	1;05	1	1
k	1;03	1;07	1;07	59	24
h	1;03	1;07	1;07	6	6
s	1;03	1;08	1;08	4	3
ʃ	1;03	1;09	1;09	2	4
t	1;03	1;08	1;09	11	7
f	1;03	1;09	1;11	12	6
z	1;07	2;03	2;05	12	2
ʤ	1;08	1;11	2;07	43	10
l	1;03	1;11	2;07	186	21
θ	1;03	2;01	2;09	77	6
v	1;08	2;02	2;09	26	4
ð	1;07	1;08	N/A	(746)	(9)
ʧ	1;03	1;09	N/A	(59)	(17)
ɹ	1;03	2;06	N/A	(193)	(25)

Once again, we observe a general lack of correlation between the appearance of phones in Charlotte's lexicon and her acquisition of these phones. For example, although both [θ] and [p] appear early in the lexicon (at 1;03), [p] is mastered early at 1;03, but [θ] it is not acquired until significantly later, at 2;09. Similarly, both [ʧ] and [ɹ] also appear in the lexicon early (at 1;03), but neither was acquired during the remainder of the observation period.

However, in spite of this overall lack of correlation in the data, it is also important to discuss aspects of these data in which it appears that the lexicon may have had some influence on Charlotte's phonological development. For example, many target sounds in Charlotte's data were acquired at the same age at which the relevant target first appears in the lexicon. At first, this may appear as though it is the presence of the consonant in the lexicon alone that is enabling her acquisition. However, it is important to note that Charlotte's CDI data are much more sparse overall in comparison to Georgia's, so, this could potentially be an issue related to the parents' reliability and accuracy in terms of completing the CDI. Additionally, due to the fact that I merged the CDI data with the children's productive attempts (as described in section 1.4 of Chapter 3), many of the words in the children's lexicons are present because they were attempted by the children in production. Thus, for Charlotte's acquisition of [b], [p], [d], [g], [m], and [w], these sounds appear in the lexicon at the same age that they are acquired because her attempts at words containing these sounds is largely what constitutes her lexicon. While this calls into question CDI-based approaches to assessing lexical knowledge, solutions to this problem lie beyond the limits of this thesis.

As explained in section 2.1 above, the effect of the presence of phones within the lexicon alone does not directly address the claims of the LRM. In order to determine the effect of neighbourhood density on Charlotte's phonological acquisition, Table 29 to Table 33 show specific pairs of consonants to compare and contrast the effect of neighbourhood density on Charlotte's phonological development. Similar to the approach I took in section 2.1, the first three pairs of consonants (reported in Table 29 to Table 31) were selected in order to include a variety of places and manners of articulation. The last two pairs of consonants (in Table 32 and Table 33) were selected in order to include sounds that Charlotte did not acquire during the observation period ([ʧ] and [ð]) and her respectively most frequent substitutions of these sounds ([t] and [d]). A complete list of Charlotte's neighbourhood densities throughout development is provided in the Appendix.

Table 29: Contrasting phonological neighbourhoods of [s] and [t] in Charlotte's lexicon

1;07	**1;08**	**1;09**
A (s=1, t=1)	A (s=1, t=1)	A (s=1, t=1)
		I (s=3, t=1)
	O (s=1, t=1)	O (s=3, t=1)

As shown in Table 28, [s] is mastered at 1;08, and [t] is mastered shortly after, at 1;09. Charlotte's mastery of [s] and [t] is consistent with the claims of the LRM as these two consonants are first contrasted at 1;07 in neighbourhood A, and are contrasted in neighbourhoods A and O one month later at 1;08.

Table 30: Contrasting phonological neighbourhoods of [b] and [m] in Charlotte's lexicon

1;02	**1;03**	**1;04**
	A (b=3, m=1)	A (b=4, m=2)
	U (b=1, m=1)	U (b=1, m=1)

As outlined in Table 28, [b] is mastered at 1;01 and [m] is mastered at 1;03. Charlotte's mastery of [b] and [m] is consistent with the LRM, as both consonants are first contrasted at 1;03 in neighbourhoods A and U, as reported in Table 30. According to the claims of the LRM, [m] was finally acquired when enough contrast was present in Charlotte's lexicon. Thus, in this particular case, Charlotte's mastery of [b] and [m] appears to be consistent with the predictions of the LRM.

Table 31: Contrasting phonological neighbourhoods of [l] and [ɹ] in Charlotte's lexicon

1;10	1;11	2;00	2;01	2;02	2;03	2;04
A (l=1, ɹ=1)	A (l=1, ɹ=1)	A (l=3, ɹ=1)	A (l=3, ɹ=1)	A (l=3, ɹ=3)	A (l=4, ɹ=3)	A (l=4, ɹ=4)
E (l=1, ɹ=2)	E (l=1, ɹ=2)	E (l=1, ɹ=2)	E (l=1, ɹ=3)	E (l=1, ɹ=3)	E (l=1, ɹ=3)	E (l=1, ɹ=6)
	I (l=1, ɹ=1)	I (l=1, ɹ=1)	I (l=1, ɹ=2)	I (l=1, ɹ=2)	I (l=2, ɹ=2)	I (l=3, ɹ=2)
	O (l=1, ɹ=2)	O (l=1, ɹ=2)	O (l=1, ɹ=2)	O (l=1, ɹ=2)	O (l=1, ɹ=3)	O (l=1, ɹ=3)
		U (l=1, ɹ=1)	U (l=1, ɹ=1)	U (l=1, ɹ=1)	U (l=2, ɹ=1)	U (l=2, ɹ=1)

2;05	2;06	2;07	2;08	2;09	2;11
A (l=7, ɹ=4)	A (l=9, ɹ=4)	A (l=9, ɹ=4)	A (l=9, ɹ=5)	A (l=10, ɹ=6)	A (l=11, ɹ=7)
E (l=1, ɹ=6)	E (l=1, ɹ=6)	E (l=4, ɹ=7)	E (l=4, ɹ=7)	E (l=4, ɹ=8)	E (l=4, ɹ=8)
I (l=4, ɹ=2)	I (l=4, ɹ=2)	I (l=5, ɹ=2)	I (l=5, ɹ=3)	I (l=5, ɹ=3)	I (l=6, ɹ=4)
O (l=1, ɹ=3)	O (l=1, ɹ=3)	O (l=1, ɹ=3)	O (l=1, ɹ=3)	O (l=2, ɹ=4)	O (l=2, ɹ=4)
U (l=2, ɹ=1)	U (l=2, ɹ=1)	U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)

Table 28 also shows that [l] is mastered at 2;07 and that [ɹ] was not acquired during the observation period. However, as we can see in Table 31, these consonants are first contrasted much earlier at 1;10 in neighbourhoods A and E, and are contrasted in all five neighbourhoods by 2;00. Despite the very dense neighbourhoods contrasting [l] and [ɹ] relatively early on, Charlotte was unable to master these consonants until much later in her development. Thus, Charlotte's acquisition of the liquids [l] and [ɹ] fails to support the predictions of the LRM.

Table 32: Contrasting phonological neighbourhoods of [ʧ] and [t] in Charlotte's lexicon

1;09	1;10	1;11	2;00	2;01	2;02	2;03
A (ʧ=1, t=1)	A (ʧ=1, t=1)	A (ʧ=2, t=1)	A (ʧ=2, t=2)	A (ʧ=2, t=2)	A (ʧ=2, t=2)	A (ʧ=2, t=2)
E (ʧ=2, t=1)	E (ʧ=2, t=1)	E (ʧ=2, t=3)	E (ʧ=2, t=4)	E (ʧ=2, t=5)	E (ʧ=4, t=5)	E (ʧ=4, t=5)
I (ʧ=1, t=1)	I (ʧ=2, t=1)	I (ʧ=3, t=2)	I (ʧ=4, t=2)	I (ʧ=5, t=3)	I (ʧ=5, t=3)	I (ʧ=5, t=4)
				O (ʧ=1, t=8)	O (ʧ=1, t=8)	O (ʧ=1, t=8)

2;04	2;05	2;06	2;07	2;08	2;09	2;11
A (ʧ=2, t=3)	A (ʧ=2, t=3)	A (ʧ=2, t=3)	A (ʧ=3, t=3)	A (ʧ=3, t=3)	A (ʧ=3, t=4)	A (ʧ=3, t=5)
E (ʧ=4, t=5)	E (ʧ=4, t=5)	E (ʧ=4, t=5)	E (ʧ=5, t=5)	E (ʧ=5, t=7)	E (ʧ=5, t=7)	E (ʧ=5, t=7)
I (ʧ=5, t=4)	I (ʧ=5, t=5)	I (ʧ=5, t=5)	I (ʧ=6, t=5)	I (ʧ=6, t=5)	I (ʧ=6, t=5)	I (ʧ=7, t=6)
O (ʧ=1, t=9)	O (ʧ=1, t=9)	O (ʧ=1, t=9)	O (ʧ=1, t=10)	O (ʧ=2, t=11)	O (ʧ=2, t=11)	O (ʧ=2, t=13)

Returning to Table 28, we can also see that [t] is mastered at 1;09 while [ʧ] is not mastered during the observation period. However, as we can see in Table 32, [ʧ] and [t] are first contrasted at 1;09 in neighbourhoods A, E, and I, and later, at 2;01, these consonants are contrasted in neighbourhoods A, E, I, and O. However, despite the density of these neighbourhoods, Charlotte did not acquire [ʧ] during the observation period. Thus, Charlotte's acquisition of [ʧ] and [t] does not support the LRM.

Table 33: Contrasting phonological neighbourhoods of [ð] and [d] in Charlotte's lexicon

2;00	2;01	2;02	2;03	2;04	2;05	2;06
	E (ð=3, d=1)	E (ð=4, d=1)	E (ð=4, d=2)	E (ð=5, d=2)	E (ð=5, d=2)	E (ð=6, d=2)
I (ð=2, d=1)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)
					O (ð=1, d=11)	O (ð=1, d=11)

2;07	2;08	2;09	2;11
E (ð=6, d=2)	E (ð=6, d=2)	E (ð=6, d=2)	E (ð=6, d=2)
I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=3)
O (ð=1, d=11)	O (ð=1, d=11)	O (ð=1, d=11)	O (ð=1, d=12)

Finally, Table 28 shows that [d] is mastered at 1;03 and that [ð] is not mastered during the period covered by the corpus. However, as reported in Table 33, these consonants are first contrasted at 2;00 in neighbourhood I, and continue to be contrasted across more and more neighbourhoods throughout the remainder of the corpus.

In summary, although Charlotte's acquisition of [s] and [t], and [b] and [m], are consistent with the claims of the LRM, there is an overall lack of correlation between the density of phonological neighbourhoods and Charlotte's phonological development. Thus, these observations corroborate the findings from Georgia's data that neither the appearance nor the density of a phonological neighbourhood can reliably predict a child's path for phonological development. Additionally, as discussed in section 2.1 and addressed in various places above, these findings call into question a central issue of the LRM, concerning the number and density of phonological neighbourhoods required to enable acquisition, an issue which remains unclear both in theory and in practice. Without a consistent metric of neighbourhood density to predict phonological acquisition, assessing the claims of the LRM thus poses a number of methodological challenges.

3. Frequency analysis

In order to incorporate usage frequency into the present investigation, as frequency is a factor highlighted in a number of studies as discussed in Chapter 2, I now turn to an analysis of the two children's consonantal development in light of the total amount of times that each consonant was attested within lexical items (for sake of comparison with usage frequency), attempted forms, and actual productions (including babbles). I report on these data in Table 34 for Georgia, and in Table 35 for Charlotte. The first two columns list (a) the age at which each consonant was first attempted and (b) the age of mastery. The following three columns list (c) the total number of occurrences of each consonant within the children's lexicons, (d) within their attempted forms, and (e) within their actual productions at the time of mastery, the latter also including occurrences of these phones produced in babbles. Keeping with the methodological criteria of the phonological analyses within Chapter 4 and Chapter 5, the following tables incorporate both singleton and branching onsets across all word positions, with the exception of [l], [ɹ], [w], and [j], which are only analyzed within singleton onsets, as these phones behave differently in the second position of a branching onset. However, it is important to note that, within the lexical corpus, targets in flapping environments always appear as the alveolar stops [t] or [d]. Unfortunately, due to the sheer size of the lexical corpus, and also some uncertainty about the actual representation of these phones within the children's lexicons, it was not methodologically practical to adjust the targets within these flapping environments. As a result, the frequency counts for [t] and [d] within the fourth column of Table 34 are overestimated, a fact that I take into account in my discussion below.

Table 34: Frequency of Georgia's onset consonants

Target	First attestation in attempted words	Mastery	Number of attestations in the lexicon at mastery	Number of recorded attempts at mastery	Number of occurrences in actual forms at mastery (including babbles)
b	0;10	1;00	29	23	234
g	1;00	1;00	9	2	87
t	1;00	1;00	20	2	9
m	1;01	1;01	11	2	60
k	1;02	1;02	37	9	59
n	1;02	1;02	19	1	53
p	1;02	1;02	34	2	22
d	1;04	1;04	27	1	543
w	1;05	1;05	16	2	2
ʃ	1;06	1;06	7	1	208
h	1;05	1;06	24	17	432
j	1;05	1;07	7	2	1
s	1;05	1;07	20	19	159
f	1;09	1;09	28	8	48
ʤ	1;09	1;09	12	2	32
ʧ	1;06	1;10	15	4	59
v	1;00	2;00	14	34	67
z	1;09	2;01	19	10	91
l	1;07	2;03	55	138	42
ɹ	1;06	2;10	62	198	53
θ	1;04	N/A	12	(68)	12
ð	1;07	N/A	17	(1317)	336

As we can observe in these data, and similar to the results reported above with regards to the children's phonological neighbourhoods, no clear correlation emerges between the reported data and Georgia's patterns of consonantal development. The number of occurrences of the target consonants, both within the lexicon and in recorded attempts and realizations of these phones, does not predict Georgia's rate of acquisition. There is in fact a high level of disparity across the data and ages of acquisition. Focusing first on lexical data, note for instance that both [h] and [ʃ] are acquired at 1;06, however at this time [h] is represented 24 times in the lexicon whereas [ʃ] is only represented seven times. Additionally, [g] is acquired very early at 1;00, with a lexical total of only nine, whereas neither [θ] nor [ð] is acquired during the observation period, despite being represented 12 and 17 times within lexical items, respectively, by the end of data collection. Thus, it appears that the total number of times that a consonant is attested in the lexicon cannot predict Georgia's phonological acquisition.

In fact, the only factor that does appear to predict acquisition is Georgia's rate of actual productions, including within babbles. Focusing on her early acquired sounds, we can see that Georgia's actual productions of these consonants, at mastery, are much more numerous than her recorded attempts, as she tended to produce these sounds regularly within babbles.[4] However this pattern is not as strong concerning her late-acquired and non-acquired sounds. In this case, and following the logic that Georgia acquired these consonants when she was well past the babbling stage, the large majority of her late-acquired and non-acquired sounds are attempted more often than they are produced. For example, [l] is attested in 138 attempts at the time of mastery, with only 42 actual productions recorded. Additionally, [ð] is attempted 1317 times by the end of the observation period, with only 336 actual productions.[5] The only exceptions to this generalization are the voiced fricatives [v] and [z], which were produced slightly more often than the number of attempted forms (e.g., at the age of mastery, [v] was attempted 34 times and was produced 67 times). To further emphasize the influence of production on acquisition, the majority of Georgia's early acquired sounds are mastered as soon as these consonants are first attempted. Thus,

4 Due to the fact that [j] is considered acquired at 1;07, shortly after Georgia's first and only attempt at 1;05, it appears as though she has more attempts than productions at age of mastery. However, this is due to the fact that [j] is acquired so quickly after very few attempts.

5 Note, however, that because the attempted numbers mostly relate to the determiner *the*, which belongs to the category of functional items and also tends to be found within unstressed prosodic environments, these numbers should be taken with a grain of salt.

Georgia's overall speech production patterns, in babbling in particular, are the only observable data that appear to correlate with her path of phonological development. I make similar observations about Charlotte's data, to which I turn now.

Similar to what we saw in Georgia's data is a lack of correlation between Charlotte's lexical data and her phonological development. In fact, as we can see in Table 35, the large majority of Charlotte's early acquired sounds are mastered at a time when the lexical totals are significantly less than the lexical totals of her late-acquired and non-acquired sounds. For example, the majority of Charlotte's early acquired sounds (i.e., sounds acquired before age 2;00) are acquired at a time when lexical totals equal five occurrences or less.

Table 35: Frequency of Charlotte's onset consonants

Target	First attestation in attempted words	Mastery	Number of attestations in the lexicon at mastery	Number of recorded attempts at mastery	Number of occurrences in actual forms at mastery (including babbles)
b	1;01	1;01	1	2	122
p	1;03	1;03	3	3	27
d	1;03	1;03	6	3	348
g	1;03	1;03	2	4	271
m	1;03	1;03	3	8	33
j	1;04	1;04	2	1	1
n	1;05	1;05	5	1	17
w	1;05	1;05	1	1	1
k	1;07	1;07	24	59	90
h	1;07	1;07	5	6	221
s	1;08	1;08	4	4	70
ʃ	1;09	1;09	4	2	21
t	1;07	1;09	24	11	139
f	1;09	1;11	16	9	21
z	1;07	2;05	14	12	181
ʤ	1;08	2;07	14	43	26
l	1;07	2;07	60	186	35
θ	1;03	2;09	10	66	46
v	1;08	2;09	17	26	16
ð	1;07	N/A	12	(746)	93
ʧ	1;09	N/A	27	(59)	32
ɹ	1;07	N/A	58	(193)	16

In contrast, the majority of late-acquired and non-acquired sounds are associated with lexical totals that range from 10 to 60 occurrences. Thus, having more occurrences of a given phone in one's lexicon does not appear to aid in the phonological mastery of that phone.

As we also observed in Georgia's data, Charlotte's actual productions of early acquired sounds, which take babbles into consideration, occur at a much higher rate relative to her attempts. The more occurrences there are of a consonant in her actual productions (also relative to her attempts), the more likely the consonant is to be acquired early. This is especially apparent for the sounds that are mastered at the same age at which they are first attempted (i.e., [b, p, d, g, m, j, n, k, h, s, ʃ]), again something which may be an artefact of Charlotte's relatively sparse CDI data. Thus, once again, productive abilities appear to be the best predictor of phonological acquisition, independent of data about the shape or density of the child's lexicon. However, although [z] is a late-acquired sound, it follows the same pattern observed within the early acquired sounds in that there are more actual productions (181 total productions) than the number of total attempts (12 total attempts) at the time of mastery. Although this observation seems to contradict my argument that a child's productive abilities is the best predictor of phonological acquisition, note that this might in fact be an outcome of my classificatory criteria about early vs. late-acquired sounds. I return to these late-acquired sounds in the discussion below.

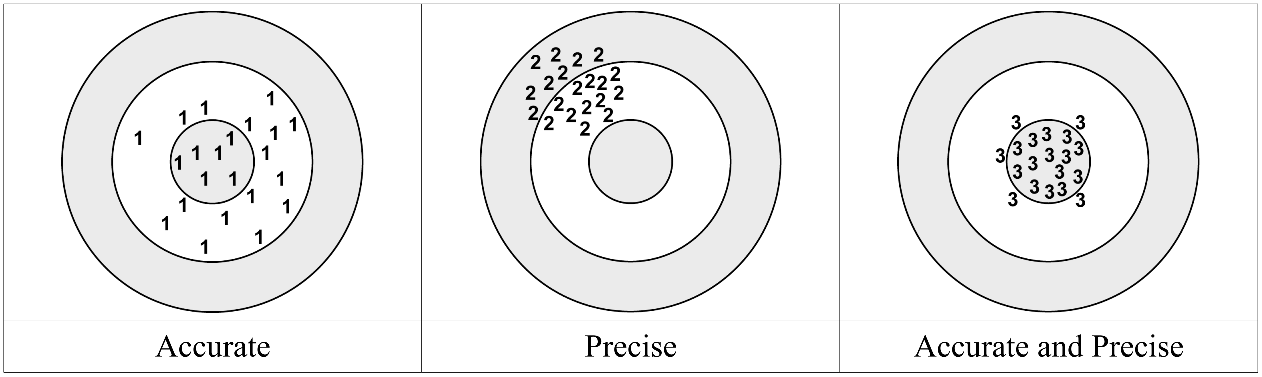
The observations discussed within this chapter offer empirical reasons to minimize the importance of the lexicon in our accounts of children's development of phonological productive abilities. That is not to say that the lexicon is not important: beyond default articulations dictated by bio-mechanical aspects of the vocal tract (MacNeilage & Davis 1990a; MacNeilage & Davis 1990b; MacNeilage & Davis 2000), sounds indeed have to be represented within at least some lexical forms in order to be acquired. Beyond this basic consideration, neither phonological neighbourhoods nor lexical frequency offers developmental predictions regarding the development of productive abilities.

However, if we approach these data from the perspective of segmental phonology, strong generalizations do emerge. For instance, both children exhibit largely similar developmental paths, with difficulties in their productions of [v], [z], [l], [ɹ], [θ], and [ð], each of which can be described in terms of phonological classes (i.e., voiced fricatives; liquids; interdentals). In addition, Charlotte shows difficulty with the target affricates [ʧ] and [ʤ], another developmental pattern that relates to a particular phonological class. These observations provide a basis for the ensuing discussion.

4. An alternative viewpoint

Beyond the presence of a lexicon (which is obviously needed, as noted above), the data above generally support the view that key factors in determining phonological development can be traced to the articulatory properties of the target consonants. This is the view embraced in recent models of phonological development, in particular the A-map model proposed by McAllister Byun, Inkelas & Rose (2016). The A(rticulatory)-map model expands on the multidimensional PRIMIR framework by explicitly incorporating the influence of articulatory factors on phonological development. This additional element of analysis emphasizes the importance of mappings between perceptual and articulatory categories of speech in language acquisition and, in turn, helps us better understand children's developmental behaviours. McAllister Byun, Inkelas & Rose (2016) capture children's patterns of phonological development through a series of grammatically-governed functional pressures, which they define globally as (1) the pressure to be accurate and, in particular, (2) the pressure to be precise, that is to reliably produce similar outputs across multiple attempts at a given target form, even at the expense of phonetic accuracy. Figure 11 below illustrates these concepts using dartboards as a metaphor, where the dartboard's bull's eye represents the target realization for the form that the child is attempting. The first dartboard illustrates a set of accurate productions, as the majority of the individual points (represented by the number 1) centre around the bull's eye; however, these points are not considered precise as they are widely distributed around the centre of the target. Conversely, the second dartboard illustrates a set of precise productions as the individual points (represented by the number 2) compactly occupy a single location; however they are not considered accurate as they are not located within the area of the bull's eye. Lastly, the third dartboard illustrates a set of productions that are both accurate and precise as the individual points are closely distributed within the location of the bull's eye.

Figure 11: A-map model of accuracy and precision (McAllister Byun, Inkelas & Rose 2016:150)



In contexts where a child is unable to reproduce an articulatory target accurately, s/he may instead favour a less accurate but more precise production, especially if the alternative motor plan yields auditory outcomes which are similar to that of the target adult sound (McAllister Byun, Inkelas & Rose 2016:150). For example, if a child struggles to produce the target [θ], s/he may produce [f] as a substitute because it has a similar acoustic outcome. Although this selection is not accurate, the child is able to reliably produce it, which is favourable, from a communicative perspective, to what could instead be random productions. This logic generally accounts for the substitution patterns observed in Georgia's and Charlotte's development, as many of the substitutes used by the children are phonetically close to the corresponding target sounds. To illustrate this point, examples (3) and (4) list Georgia's and Charlotte's systematic patterns of substitution for both the late-acquired sounds and those they acquired after the end of the observation period. Many of the children's substitute sounds only lack one or a few phonetic attributes of the target sounds, while all other aspects of these targets are reproduced faithfully. For example, both Georgia and Charlotte frequently produce the glide [w] as a substitute for the target liquids [l] and [ɹ]. This substitute is fairly similar to the respective target sounds because it satisfies the approximant continuancy of both [l] and [ɹ]; however it lacks the laterality of [l] and the rhoticity of [ɹ]. Similarly, for the voiceless interdental fricative [θ], Georgia produces the voiceless labiodental fricative [f], whereas Charlotte produces the voiced alveolar stop [d]. Although both substitute sounds are inaccurate in some respects, both [f] and [d] are faithful to aspects of target [θ].

(3) Georgia's overall patterns of substitution:

a. Acquired late

i.	[v] → [f]	(2;00 → 2;03)
ii.	[z] → [s]	(2;00 → 2;06)
iii.	[l] → [w]	(1;07 → 2;02)
iv.	[ɹ] → [w]	(1;06 → 2;09)

b. Acquired after

i	[θ] → [f]	(1;10 → 2;10)
ii.	[ð] → [d]	(1;09 → 2;11)

For instance, Georgia's production of [f] satisfies the manner of articulation of [θ] because it is also a voiceless fricative. The place of articulation of [f] is also partly similar to the target [θ] because both involve partial constrictions involving upper teeth, even though [f] substitution represents, from a phonological standpoint, a change in place of articulation (e.g., interdental vs. labiodental). In contrast, Charlotte's substitution by use of [d] does not satisfy the fricative continuancy of the target sound nor does it satisfy the voicelessness of the target sound; however it does retain a coronal place of articulation.

(4) Charlotte's patterns of substitution:

a. Acquired late

i.	[v] → [p]/[b]	(2;01 → 2;08)		
ii.	[z] → [d]	(2;03 → 2;04)		
iii.	[θ] → [d]	(1;03 → 2;02),	[θ] → [s]	(2;03 → 2;09)
iv.	[ʤ] → [d]	(1;09 → 2;06)		
v.	[l] → [w]	(1;09 → 2;06)		

b. Acquired after

i.	[ð] → [d]	(1;07 → 2;11),	[ð] → Ø	(1;11 → 2;03)
ii.	[ʧ] → [t]	(1;09 → 2;08)		
iii.	[ɹ] → [w]	(1;09 → 2;11)		

Moving on to another element central to the A-map model is the notion that children store detailed traces of the phonetic forms they experience in both perception and production. These episodic traces enable children to monitor, through the acoustic-articulatory feedback loop, the accuracy and precision of their motor-acoustic outputs. In fact, McAllister Byun, Inkelas & Rose (2016:156) argue that emergent features are encoded within these phonetic exemplars, which allow children to map an identifiable dimension in the acoustic-perceptual space to the place or manner of articulation necessary for the production of a given target. Thus, these emergent phonetic attributes enable children to attain stable motor-acoustic mappings (McAllister Byun, Inkelas & Rose 2016:156). These improved motor-acoustic mappings in turn provide representational references for the children to further fine-tune their emergent productions, in line with the interactions across various dimensions of speech perception outlined within the PRIMIR framework (see section 2.2 of Chapter 1 for details). This type of interaction can also account for why both Georgia's and Charlotte's early acquired sounds are so frequent in their actual productions in relation to their number of attempts. Because these phones are practiced early in babbles, the children are better able to establish the motor-acoustic mappings of these sounds. Once the connection is made between motor movements and the acoustic outcomes, this connection then provides a basis for further phonological fine-tuning. This interplay between perception and production also offers further insight into the phenomenon of lexical selection and avoidance, whereby children are more likely to attempt words which contain sounds that are present within their babbles, for which they are more likely to have ready and reliable acoustic-articulatory mappings. As discussed in section 3.2 of Chapter 2, the importance of the auditory-articulatory feedback loop, and the key role that babble plays in its establishment, has long been supported within the literature (Fry 1966; Locke 1993; Davis & MacNeilage 1995; Stoel-Gammon 1998; Vihman 2014; Day 2014). Additionally, the importance of articulatory factors also accounts for why Georgia and Charlotte excel in their productions of some phonological classes and struggle in their productions of others. For instance, both children master stops, nasals, and glides early in their development. These sounds are often the first to be acquired by most other children, and are considered easier to produce (Stoel-Gammon 2011:3). In contrast, Georgia and Charlotte both show difficulties in their productions of the arguably more articulatory complex sounds such as the voiced fricatives, interdental fricatives, and liquids. Because these sounds involve more complex, or subtle, articulatory dimensions (e.g., rhoticity; laterality; interdental constriction), these phones are predicted to be less frequent in babbles and to display slower rates of acquisition. Both of these predictions are borne out by the data above.

Chapter 7: Discussion

In this thesis, I have longitudinally compared the lexical and phonological development of two English-learning children, in order to test the predictions of the Lexical Restructuring Model (e.g., Metsala 1997). I began with a definition of lexical profiles for each child based on a combination of CDI and production data, from which I derived the shape and overall density of the children's phonological neighbourhoods during each month of development covered by their respective datasets. I also generated a phonological profile for each child, to systematically compare the children's attempted forms with their actual productions. This enabled me to create a timeline of each child's consonantal development over the period documented by the corpora. I then compared the presence and density of the children's phonological neighbourhoods with their respective phonological production patterns over time. However, I found no reliable correlations between children's phonological neighbourhoods and their individual development of phonological productive abilities. Further, I assessed the total numbers of occurrence of phones within each child's lexicon, attempted forms, and actual productions (including babbles). From this additional analysis, I found that children are more likely to acquire a consonant if this consonant is used often in actual productions.

These findings are in line with other studies described in Chapter 2, namely Swingley, Pinto & Fernald (1999) and Swingley & Aslin (2000), which show that children between 18 and 24 months of age are able to perceive mispronunciations in familiar words regardless of vocabulary size (and the neighbourhood densities it implies). My results corroborate these findings in the area of production, which suggests that the predictions of the LRM are not reflected in production data. Neither the structure nor the size or density of the lexicon has been found to drive children's phonological development. Conversely, children's productivity, especially if assessed in terms of articulatory abilities, appears to best predict patterns of phonological development. In general, the more often a given sound is used during babble, the more likely it is acquired early in the child's development (see, however, Day (2014) and Day (2015) for discussions of exceptions to this broad generalization). These findings are captured in a general fashion by the PRIMIR framework, which encodes relations between multiple dimensions of speech and their interactions in speech perception. However, because PRIMIR focuses on perception rather than production, it cannot by itself explicitly account for the direct influence of speech articulation in children's phonological development. These influences are captured through the recently-proposed A-map model, which formally encodes relations between perceptual and articulatory dimensions of speech. Thus, a combination of both the PRIMIR and the A-map models offers a comprehensive theoretical framework in which we can better understand these results. Combining the PRIMIR and the A-map models is also theoretically consistent in that these models formally supplement one another, and both operate on the basis of multidimensional interactions across different linguistic domains (e.g., perceptual, lexical, and articulatory). Both models also state that phonetic traces are stored early in children's development. As described in section 3.1 of Chapter 2, this claim is supported by Zamuner's (2009) study, which reveals that the context-specific phonetic categories children discover early in development help establish the phonological neighbourhoods within their lexicons. Thus, Zamuner's findings also support the notion that children's early perceptual abilities and phonological knowledge largely influence the nature of their lexicons.

The influence of children's early phonological abilities is also not surprising given the level of phonetic and phonological detail children possess at a very early age. As discussed in section 1 of Chapter 2, children as young as 1;2 demonstrate fine-tuned phonetic sensitivity that is substantial enough to disrupt their recognition of familiar words when a single segment is mispronounced in either onset or coda position (Swingley 2009; White & Morgan 2008). Even in studies that directly focus on the effects of neighbourhood density versus phonological probability, young children benefit from learning non-words with high phonotactic probability, but do not benefit from learning non-words from high-density neighbourhoods (Hollich, Jusczyk & Luce 2002; McKean, Letts & Howard 2013). Thus, these findings undermine a narrow interpretation of the LRM, and instead highlight the importance of children's phonological knowledge. Additional support for the role of children's phonological skills are the longitudinal correlations outlined in example (2) of Chapter 2, repeated here for convenience:

(5) Behavioural correlations between lexical and phonological development (Stoel-Gammon 1992:442–449) [Repeated from Chapter 2, example (2)]

a. The amount of vocalization at age 0;3 and vocabulary size at age 2;3.

b. The age of onset of canonical babble and the age of onset of meaningful speech.

c. The number of CV syllables at age 1;0 and age of first word production.

d. Use of consonants at age 1;0 and phonological skills at age 3;0.

e. Diversity of syllable and sound types at ages 0;6–1;2 and performance on speech and language tests at age 5;0.

With these observations in hand, it is also important to reflect on some of the methodological limitations of the current study. As discussed in section 1.2 of Chapter 3, it would have been ideal if the CDI data of both children assessed the receptive lexicon in addition to the expressive vocabulary. This would have allowed for a more comprehensive analysis of the children's lexical knowledge. However, it seems unlikely that a slightly more comprehensive lexicon would have a significantly different outcome with regards to testing the LRM, as the phonological tendencies observed in the available data are also consistent with the general properties of English phonology. Nonetheless, it would be a compelling addition to this particular type of analysis. Despite this limitation, this study provides methodological grounds for eventual larger studies based on both types of data.

Another potential limitation of the present investigation is the methodological criteria used to assess the children's phonological neighbourhoods. The nature of these neighbourhoods remains theoretically unclear to this day, as other researchers have also pointed out (e.g., Zamuner 2009), suggesting that, from a methodological standpoint, the LRM is difficult to test. This is primarily because the LRM does not explicitly state what is considered a neighbourhood and what is not, in addition to issues with data availability, for example with regard to data on children's expressive lexicons, as mentioned above. In sum, there are no clear criteria available to accurately test the model's claims. Until more defined criteria are established, this will remain a challenge.

Despite its methodological limitations, the current study, as well as several others discussed in this thesis, offer support to both the PRIMIR and the A-map models, both of which situate phonological representation and phonological processing within components of the learner's phonological system, which are themselves relatively independent from (although inter-related to) the lexicon. Together, these models suggest that lexical and phonological development are best understood in terms of the multidimensional interactions that occur across the perceptual, lexical, and articulatory domains of the child's developing system.

In light of these considerations, the bidirectional interaction between lexical and phonological development highlighted by Stoel-Gammon (2011) appears to be best understood through a multidimensional, interactive architecture that is, to a large extent, initiated and driven by children's babbles early in development. Babbles help young children establish an auditory-articulatory feedback loop which enables them to fine-tune both their productive abilities and their phonological representations. Once children possess the perceptual and articulatory units relevant to their phonological knowledge, these units continue to interact with the lexical domain, in a constant fine-tuning of their mental representations at all levels, as stated within both PRIMIR and the A-map frameworks. Not only can these theoretical frameworks predict aspects of children's phonological development, they can also incorporate the variation we observe across children's individual patterns.

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Appendix

Table 36: Georgia's A neighbourhood

0;08		0;09		0;10		0;11		1;00		1;01		1;02		1;03		1;04	
p	0	p	0	p	0	p	0	p	3	p	3	p	3	p	3	p	3
b	1	b	3	b	5	b	5	b	9	b	9	b	10	b	10	b	11
t	0	t	1	t	1	t	1	t	3	t	3	t	3	t	3	t	3
d	2	d	3	d	4	d	4	d	5	d	5	d	5	d	6	d	7
k	0	k	1	k	1	k	1	k	3	k	4	k	4	k	5	k	6
g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	1
f	0	f	0	f	0	f	0	f	1	f	1	f	1	f	1	f	3
v	0	v	0	v	0	v	0	v	1	v	1	v	1	v	1	v	1
θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0
s	0	s	0	s	0	s	0	s	0	s	2	s	2	s	2	s	2
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0
ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	2	h	2	h	2	h	2	h	4	h	5	h	5	h	5	h	7
ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0
ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	1	ʤ	1	ʤ	1
m	1	m	1	m	1	m	1	m	2	m	2	m	4	m	5	m	6
n	2	n	2	n	2	n	2	n	3	n	3	n	5	n	5	n	5
l	0	l	0	l	0	l	0	l	0	l	1	l	2	l	3	l	4
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	3	ɹ	3	ɹ	4
w	0	w	1	w	2	w	2	w	4	w	5	w	6	w	6	w	6
j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0

1;05		1;06		1;07		1;09		1;10		1;11		2;00		2;01		2;02	
p	3	p	3	p	4	p	4	p	9	p	9	p	9	p	11	p	11
b	11	b	11	b	11	b	11	b	19	b	19	b	22	b	24	b	24
t	3	t	3	t	3	t	4	t	6	t	6	t	6	t	7	t	7
d	7	d	7	d	7	d	8	d	10	d	11	d	12	d	13	d	13
k	7	k	7	k	7	k	8	k	10	k	11	k	14	k	14	k	16
g	2	g	2	g	2	g	3	g	5	g	5	g	5	g	5	g	5
f	3	f	3	f	3	f	5	f	5	f	7	f	7	f	7	f	10
v	1	v	1	v	1	v	1	v	2	v	2	v	2	v	2	v	2
θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0
s	3	s	3	s	3	s	3	s	7	s	8	s	8	s	8	s	8
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0
ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	1	ʃ	1	ʃ	1	ʃ	2	ʃ	2
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	8	h	8	h	8	h	9	h	12	h	14	h	15	h	15	h	18
ʧ	0	ʧ	0	ʧ	1	ʧ	1	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2
ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1
m	6	m	7	m	7	m	7	m	7	m	7	m	8	m	11	m	11
n	5	n	5	n	5	n	5	n	7	n	8	n	9	n	10	n	10
l	4	l	4	l	4	l	4	l	6	l	6	l	6	l	6	l	7
ɹ	4	ɹ	4	ɹ	4	ɹ	4	ɹ	5	ɹ	5	ɹ	6	ɹ	9	ɹ	9
w	7	w	7	w	8	w	9	w	10	w	11	w	12	w	13	w	15
j	0	j	0	j	0	j	1	j	1	j	1	j	1	j	1	j	1

2;03		2;04		2;05		2;06		2;07		2;08		2;09		2;10		2;11	
p	11	p	12	p	12	p	14	p	14	p	14	p	14	p	14	p	14
b	28	b	28	b	28	b	28	b	28	b	28	b	28	b	29	b	30
t	7	t	8	t	11	t	13	t	13	t	13	t	13	t	13	t	13
d	14	d	14	d	15	d	16	d	16	d	16	d	17	d	17	d	18
k	16	k	19	k	19	k	19	k	20	k	21	k	21	k	21	k	22
g	6	g	6	g	6	g	6	g	6	g	7	g	7	g	7	g	10
f	11	f	12	f	13	f	13	f	13	f	13	f	13	f	14	f	15
v	2	v	2	v	3	v	3	v	3	v	3	v	3	v	3	v	3
θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0
s	8	s	8	s	9	s	12	s	12	s	12	s	12	s	13	s	13
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0
ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	3	ʃ	3
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	18	h	20	h	20	h	20	h	21	h	21	h	21	h	21	h	22
ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	3
ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	2
m	11	m	11	m	12	m	13	m	14	m	14	m	14	m	15	m	15
n	10	n	11	n	11	n	11	n	11	n	11	n	11	n	11	n	11
l	10	l	11	l	12	l	12	l	12	l	15	l	15	l	15	l	16
ɹ	9	ɹ	10	ɹ	10	ɹ	10	ɹ	10	ɹ	10	ɹ	11	ɹ	11	ɹ	11
w	15	w	16	w	16	w	16	w	16	w	17	w	17	w	17	w	17
j	1	j	2	j	2	j	2	j	2	j	2	j	2	j	2	j	2

Table 37: Georgia's E neighbourhood

0;08		**0;09**		**0;10**		**0;11**		**1;00**		**1;01**		**1;02**		**1;03**		**1;04**	
p	0	p	0	p	0	p	0	p	2	p	2	p	2	p	3	p	3
b	2	b	2	b	3	b	3	b	3	b	5	b	6	b	6	b	7
t	0	t	0	t	0	t	0	t	1	t	3	t	3	t	4	t	4
d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0
k	0	k	0	k	0	k	0	k	1	k	1	k	1	k	1	k	1
g	0	g	0	g	0	g	0	g	1	g	2	g	2	g	2	g	2
f	0	f	0	f	0	f	0	f	0	f	0	f	1	f	1	f	1
v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0
θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0
ð	0	ð	0	ð	0	ð	0	ð	0	ð	1	ð	1	ð	1	ð	3
s	0	s	0	s	0	s	0	s	0	s	0	s	1	s	1	s	1
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0
ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	0	h	0	h	0	h	0	h	2	h	3	h	3	h	4	h	4
ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	1
ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	1	ʤ	2	ʤ	2	ʤ	2	ʤ	2
m	0	m	0	m	0	m	0	m	0	m	0	m	1	m	1	m	1
n	0	n	0	n	0	n	0	n	0	n	0	n	1	n	1	n	1
l	0	l	0	l	0	l	0	l	0	l	0	l	1	l	1	l	1
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	2
w	0	w	0	w	0	w	0	w	2	w	2	w	3	w	3	w	3
j	0	j	0	j	0	j	0	j	0	j	0	j	1	j	1	j	1

1;05		**1;06**		**1;07**		**1;09**		**1;10**		**1;11**		**2;00**		**2;01**		**2;02**	
p	4	p	4	p	4	p	4	p	10	p	10	p	10	p	10	p	10
b	7	b	8	b	8	b	8	b	10	b	10	b	11	b	12	b	14
t	4	t	4	t	4	t	4	t	5	t	6	t	7	t	7	t	7
d	0	d	0	d	0	d	1	d	1	d	1	d	1	d	1	d	2
k	1	k	2	k	2	k	3	k	4	k	4	k	5	k	5	k	5
g	2	g	2	g	2	g	2	g	3	g	3	g	3	g	3	g	3
f	1	f	1	f	1	f	1	f	1	f	2	f	2	f	3	f	3
v	0	v	1	v	1	v	1	v	2	v	2	v	2	v	2	v	2
θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0
ð	3	ð	3	ð	3	ð	3	ð	4	ð	4	ð	5	ð	5	ð	6
s	1	s	1	s	1	s	2	s	3	s	3	s	3	s	4	s	4
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0
ʃ	0	ʃ	1	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	3	ʃ	3
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	5	h	5	h	5	h	6	h	8	h	8	h	8	h	9	h	9
ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	1
ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	5	ʤ	5	ʤ	5	ʤ	5	ʤ	5
m	1	m	1	m	2	m	2	m	4	m	4	m	4	m	5	m	6
n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	2
l	1	l	1	l	1	l	1	l	2	l	2	l	5	l	6	l	7
ɹ	2	ɹ	4	ɹ	6	ɹ	7	ɹ	7	ɹ	7	ɹ	7	ɹ	7	ɹ	7
w	3	w	3	w	3	w	4	w	4	w	5	w	7	w	10	w	11
j	1	j	1	j	1	j	3	j	3	j	3	j	3	j	3	j	3

2;03		**2;04**		**2;05**		**2;06**		**2;07**		**2;08**		**2;09**		**2;10**		**2;11**	
p	10	p	10	p	11	p	12	p	12	p	13	p	13	p	15	p	16
b	15	b	16	b	17	b	17	b	17	b	19	b	19	b	22	b	24
t	7	t	10	t	11	t	11	t	11	t	12	t	12	t	12	t	15
d	3	d	3	d	3	d	3	d	3	d	3	d	3	d	3	d	4
k	5	k	5	k	6	k	6	k	6	k	6	k	6	k	6	k	6
g	3	g	3	g	3	g	3	g	3	g	3	g	3	g	4	g	4
f	3	f	3	f	4	f	4	f	4	f	5	f	5	f	6	f	6
v	2	v	2	v	2	v	2	v	2	v	2	v	2	v	2	v	2
θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0
ð	7	ð	7	ð	7	ð	7	ð	7	ð	8	ð	8	ð	9	ð	9
s	4	s	5	s	5	s	5	s	5	s	7	s	7	s	7	s	8
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0
ʃ	3	ʃ	3	ʃ	4	ʃ	4	ʃ	5	ʃ	5	ʃ	5	ʃ	5	ʃ	5
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	9	h	9	h	9	h	9	h	9	h	11	h	11	h	12	h	13
ʧ	1	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	3	ʧ	3	ʧ	3	ʧ	3
ʤ	5	ʤ	6	ʤ	6	ʤ	6	ʤ	6	ʤ	6	ʤ	6	ʤ	7	ʤ	7
m	7	m	8	m	8	m	8	m	8	m	8	m	8	m	8	m	8
n	2	n	2	n	3	n	3	n	3	n	3	n	3	n	4	n	5
l	7	l	7	l	7	l	10	l	10	l	11	l	11	l	12	l	13
ɹ	7	ɹ	7	ɹ	7	ɹ	7	ɹ	7	ɹ	9	ɹ	9	ɹ	9	ɹ	9
w	15	w	16	w	16	w	16	w	16	w	17	w	17	w	19	w	20
j	3	j	4	j	4	j	4	j	4	j	4	j	4	j	4	j	5

Table 38: Georgia's I neighbourhood

0;08		**0;09**		**0;10**		**0;11**		**1;00**		**1;01**		**1;02**		**1;03**		**1;04**		**1;05**		**1;06**		**1;07**		**1;09**		**1;10**		**1;11**		**2;00**		**2;01**		**2;02**		**2;03**		**2;04**		**2;05**		**2;06**		**2;07**		**2;08**		**2;09**		**2;10**		**2;11**	
p	0	p	2	p	2	p	2	p	3	p	4	p	7	p	7	p	7	p	7	p	7	p	7	p	9	p	10	p	11	p	12	p	12	p	13	p	13	p	14	p	14	p	15	p	16	p	18	p	19	p	19	p	20
b	0	b	0	b	0	b	0	b	1	b	3	b	5	b	5	b	5	b	5	b	5	b	5	b	6	b	9	b	11	b	11	b	12	b	12	b	12	b	12	b	12	b	13	b	13	b	13	b	13	b	16	b	16
t	0	t	0	t	0	t	0	t	2	t	2	t	2	t	3	t	3	t	3	t	3	t	3	t	3	t	4	t	5	t	6	t	7	t	7	t	7	t	7	t	7	t	7	t	7	t	8	t	8	t	8	t	8
d	0	d	0	d	0	d	0	d	1	d	1	d	2	d	2	d	2	d	2	d	2	d	2	d	2	d	3	d	3	d	3	d	4	d	5	d	6	d	6	d	6	d	6	d	6	d	6	d	6	d	6	d	6
k	0	k	0	k	1	k	1	k	3	k	4	k	4	k	4	k	5	k	5	k	5	k	5	k	5	k	6	k	6	k	6	k	6	k	7	k	7	k	7	k	7	k	7	k	7	k	7	k	7	k	7	k	7
g	0	g	0	g	0	g	0	g	1	g	1	g	1	g	1	g	1	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2	g	2
f	0	f	0	f	1	f	1	f	3	f	3	f	4	f	4	f	4	f	5	f	6	f	6	f	7	f	7	f	8	f	10	f	11	f	11	f	11	f	11	f	11	f	11	f	11	f	11	f	11	f	12	f	12
v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	1	v	1	v	1	v	1	v	1	v	1	v	1	v	1
θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	2	θ	2
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2
s	0	s	0	s	1	s	1	s	1	s	2	s	3	s	4	s	5	s	5	s	5	s	5	s	6	s	10	s	10	s	11	s	11	s	11	s	11	s	11	s	12	s	12	s	12	s	14	s	14	s	15	s	15
z	0	z	0	z	0	z	0	z	0	z	0	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	2	z	2	z	2	z	2	z	2	z	2	z	3	z	3	z	3	z	3	z	3	z	3	z	3	z	3
ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	3	ʃ	4	ʃ	4	ʃ	4
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	0	h	0	h	0	h	0	h	0	h	0	h	1	h	1	h	1	h	2	h	2	h	2	h	2	h	3	h	3	h	3	h	3	h	7	h	8	h	9	h	9	h	9	h	9	h	9	h	9	h	9	h	10
ʧ	1	ʧ	2	ʧ	2	ʧ	2	ʧ	3	ʧ	3	ʧ	4	ʧ	4	ʧ	4	ʧ	4	ʧ	4	ʧ	5	ʧ	5	ʧ	6	ʧ	6	ʧ	7	ʧ	7	ʧ	7	ʧ	7	ʧ	7	ʧ	7	ʧ	7	ʧ	7	ʧ	7	ʧ	7	ʧ	7	ʧ	8
ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	4	ʤ	4	ʤ	5	ʤ	5	ʤ	5	ʤ	5	ʤ	5
m	0	m	0	m	0	m	0	m	1	m	1	m	2	m	2	m	3	m	3	m	3	m	3	m	4	m	5	m	5	m	5	m	5	m	7	m	8	m	9	m	9	m	9	m	10	m	10	m	10	m	10	m	10
n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	2	n	2	n	2	n	3	n	4	n	4	n	4	n	4	n	4	n	4	n	4
l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	2	l	2	l	2	l	2	l	2	l	3	l	3	l	3	l	4	l	4	l	5	l	7	l	8	l	8	l	8	l	9	l	10	l	11	l	11
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	2	ɹ	2	ɹ	3	ɹ	3	ɹ	5	ɹ	5
w	0	w	0	w	0	w	0	w	0	w	1	w	1	w	1	w	1	w	1	w	1	w	1	w	1	w	3	w	4	w	4	w	4	w	4	w	4	w	4	w	4	w	5	w	5	w	5	w	5	w	7	w	8
j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0

Table 39: Georgia's O neighbourhood

0;08		**0;09**		**0;10**		**0;11**		**1;00**		**1;01**		**1;02**		**1;03**		**1;04**		**1;05**		**1;06**		**1;07**		**1;09**		**1;10**		**1;11**		**2;00**		**2;01**		**2;02**		**2;03**		**2;04**		**2;05**		**2;06**		**2;07**		**2;08**		**2;09**		**2;10**		**2;11**	
p	0	p	0	p	0	p	0	p	1	p	2	p	2	p	2	p	2	p	2	p	2	p	2	p	3	p	7	p	7	p	8	p	8	p	10	p	10	p	10	p	10	p	10	p	10	p	11	p	11	p	11	p	11
b	0	b	0	b	2	b	2	b	3	b	3	b	6	b	7	b	9	b	9	b	10	b	11	b	11	b	14	b	15	b	16	b	17	b	17	b	17	b	17	b	18	b	18	b	19	b	20	b	20	b	21	b	23
t	0	t	0	t	0	t	0	t	2	t	6	t	8	t	8	t	8	t	9	t	9	t	10	t	10	t	11	t	12	t	12	t	12	t	12	t	13	t	13	t	14	t	14	t	15	t	15	t	15	t	16	t	17
d	0	d	1	d	1	d	1	d	3	d	4	d	4	d	4	d	4	d	4	d	4	d	4	d	5	d	8	d	8	d	8	d	8	d	9	d	10	d	10	d	10	d	10	d	11	d	12	d	12	d	12	d	13
k	0	k	0	k	1	k	1	k	2	k	2	k	3	k	4	k	4	k	4	k	4	k	4	k	4	k	6	k	7	k	8	k	9	k	10	k	11	k	12	k	13	k	14	k	14	k	14	k	15	k	15	k	16
g	0	g	0	g	1	g	1	g	2	g	2	g	2	g	2	g	2	g	2	g	3	g	3	g	3	g	6	g	7	g	7	g	8	g	9	g	9	g	9	g	11	g	11	g	11	g	11	g	11	g	11	g	12
f	0	f	0	f	1	f	1	f	1	f	1	f	1	f	1	f	1	f	1	f	1	f	1	f	1	f	1	f	2	f	3	f	4	f	4	f	5	f	6	f	6	f	7	f	7	f	7	f	8	f	8	f	8
v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0
θ	0	θ	0	θ	0	θ	0	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	1	ð	1	ð	1	ð	1	ð	1	ð	1	ð	1	ð	1	ð	1	ð	1	ð	1	ð	1
s	0	s	0	s	0	s	0	s	1	s	1	s	2	s	2	s	2	s	3	s	3	s	3	s	4	s	6	s	6	s	6	s	7	s	8	s	8	s	9	s	9	s	9	s	10	s	10	s	10	s	10	s	12
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0
ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	2	ʃ	2	ʃ	3	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	5	ʃ	5	ʃ	5	ʃ	5	ʃ	5	ʃ	5	ʃ	5	ʃ	6
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	0	h	0	h	0	h	0	h	2	h	5	h	7	h	7	h	7	h	8	h	8	h	9	h	10	h	11	h	11	h	11	h	12	h	12	h	15	h	16	h	17	h	17	h	17	h	17	h	17	h	17	h	17
ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	1
ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	3	ʤ	4	ʤ	4	ʤ	4	ʤ	6	ʤ	6	ʤ	6	ʤ	6	ʤ	6	ʤ	6	ʤ	6	ʤ	6	ʤ	6	ʤ	6
m	0	m	0	m	1	m	1	m	3	m	3	m	3	m	3	m	3	m	3	m	3	m	3	m	3	m	5	m	6	m	7	m	7	m	7	m	7	m	7	m	8	m	8	m	8	m	8	m	8	m	8	m	9
n	1	n	1	n	1	n	1	n	2	n	2	n	2	n	2	n	2	n	2	n	2	n	3	n	3	n	4	n	4	n	5	n	5	n	5	n	5	n	6	n	6	n	6	n	6	n	7	n	7	n	10	n	10
l	0	l	0	l	0	l	0	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	3	l	4	l	4	l	4	l	4	l	4	l	4	l	4
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	3	ɹ	3	ɹ	4	ɹ	4	ɹ	4	ɹ	4	ɹ	4	ɹ	4	ɹ	4	ɹ	5
w	1	w	1	w	1	w	1	w	1	w	1	w	1	w	2	w	2	w	2	w	2	w	2	w	3	w	4	w	4	w	4	w	6	w	6	w	6	w	8	w	8	w	8	w	8	w	8	w	8	w	8	w	8
j	0	j	0	j	0	j	0	j	0	j	1	j	2	j	2	j	2	j	2	j	2	j	2	j	3	j	6	j	6	j	6	j	6	j	6	j	7	j	7	j	7	j	7	j	7	j	7	j	7	j	7	j	7

Table 40: Georgia's U neighbourhood

0;08		0;09		0;10		0;11		1;00		1;01		1;02		1;03		1;04		1;05		1;06		1;07		1;09		1;10		1;11		2;00		2;01		2;02		2;03		2;04		2;05		2;06		2;07		2;08		2;09		2;10		2;11	
p	0	p	0	p	0	p	0	p	0	p	1	p	1	p	1	p	3	p	3	p	3	p	3	p	3	p	5	p	6	p	7	p	7	p	8	p	8	p	8	p	8	p	8	p	8	p	12	p	12	p	14	p	15
b	0	b	1	b	1	b	1	b	2	b	3	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4	b	4
t	0	t	0	t	0	t	0	t	1	t	1	t	2	t	2	t	3	t	3	t	3	t	4	t	4	t	6	t	6	t	7	t	7	t	7	t	7	t	7	t	7	t	7	t	7	t	8	t	8	t	8	t	8
d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	1	d	1	d	2	d	2	d	2	d	2	d	2	d	2	d	2	d	2	d	2	d	2	d	2
k	1	k	1	k	1	k	1	k	1	k	1	k	1	k	1	k	1	k	1	k	1	k	1	k	1	k	4	k	6	k	6	k	6	k	6	k	6	k	6	k	6	k	6	k	6	k	6	k	6	k	7	k	7
g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	1	g	1	g	3	g	3	g	3	g	3	g	3	g	3	g	3	g	3	g	3	g	3	g	3	g	3
f	0	f	0	f	0	f	0	f	1	f	1	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	3	f	3	f	3	f	3	f	3	f	3
v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0
θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0
s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	1	z	1
ʃ	0	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	3	ʃ	3	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	1	h	2	h	3	h	3	h	3	h	3	h	3	h	3	h	3	h	3	h	3
ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0
ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1
m	0	m	0	m	0	m	0	m	0	m	0	m	0	m	1	m	1	m	1	m	1	m	1	m	1	m	4	m	5	m	5	m	5	m	6	m	6	m	6	m	6	m	6	m	6	m	6	m	6	m	6	m	6
n	0	n	0	n	0	n	0	n	0	n	0	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1
l	0	l	0	l	0	l	0	l	0	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	3	l	3
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	3	ɹ	3	ɹ	3	ɹ	3
w	0	w	0	w	0	w	0	w	0	w	0	w	0	w	0	w	0	w	0	w	0	w	0	w	1	w	2	w	2	w	2	w	2	w	2	w	2	w	2	w	2	w	2	w	2	w	2	w	2	w	2	w	3
j	0	j	0	j	0	j	0	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	2	j	2	j	3	j	3

Table 41: Charlotte's A neighbourhood

1;01		1;02		1;03		1;04		1;05		1;06		1;07		1;08		1;09		1;10		1;11		2;00		2;01		2;02		2;03		2;04		2;05		2;06		2;07		2;08		2;09		2;11	
p	0	p	0	p	0	p	0	p	0	p	0	p	0	p	2	p	4	p	4	p	5	p	6	p	7	p	10	p	11	p	11	p	13	p	14	p	15	p	16	p	19	p	19
b	1	b	1	b	3	b	4	b	4	b	4	b	4	b	5	b	6	b	10	b	14	b	17	b	19	b	21	b	21	b	21	b	22	b	23	b	24	b	24	b	25	b	25
t	0	t	0	t	0	t	0	t	0	t	0	t	1	t	1	t	1	t	1	t	1	t	2	t	2	t	2	t	2	t	3	t	3	t	3	t	3	t	3	t	4	t	5
d	0	d	0	d	3	d	3	d	3	d	3	d	4	d	5	d	7	d	8	d	8	d	9	d	9	d	10	d	10	d	10	d	11	d	12	d	14	d	14	d	15	d	16
k	0	k	0	k	1	k	1	k	1	k	1	k	1	k	2	k	2	k	4	k	7	k	11	k	14	k	14	k	14	k	14	k	15	k	16	k	19	k	20	k	20	k	22
g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	1	g	2	g	3	g	3	g	3	g	3	g	3	g	3	g	6	g	6	g	6	g	6	g	6	g	6	g	6
f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	1	f	3	f	6	f	6	f	8	f	8	f	8	f	10	f	11	f	11	f	11	f	11
v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	2	v	2	v	2	v	2	v	2	v	2	v	2	v	2	v	2	v	2	v	2	v	2	v	2	v	2
θ	0	θ	0	θ	1	θ	1	θ	1	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2	θ	2
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0
s	0	s	0	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	3	s	5	s	7	s	8	s	9	s	11	s	15	s	15	s	16	s	17
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0
ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	1	ʃ	2	ʃ	2	ʃ	3	ʃ	3	ʃ	3	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	4	ʃ	5	ʃ	5
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	0	h	0	h	1	h	1	h	1	h	2	h	2	h	3	h	4	h	6	h	6	h	7	h	10	h	12	h	14	h	15	h	16	h	16	h	16	h	17	h	17	h	18
ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	1	ʧ	1	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	3	ʧ	3	ʧ	3	ʧ	3
ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1
m	0	m	0	m	1	m	2	m	2	m	3	m	3	m	4	m	5	m	6	m	6	m	7	m	8	m	9	m	9	m	11	m	12	m	12	m	18	m	18	m	20	m	21
n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	2	n	2	n	2	n	3	n	5	n	8	n	8	n	9	n	9	n	9	n	11	n	11	n	11	n	11
l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	1	l	1	l	3	l	3	l	3	l	4	l	4	l	7	l	9	l	9	l	9	l	10	l	11
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	3	ɹ	3	ɹ	4	ɹ	4	ɹ	4	ɹ	4	ɹ	5	ɹ	6	ɹ	7
w	0	w	0	w	0	w	0	w	0	w	3	w	3	w	3	w	5	w	5	w	7	w	9	w	11	w	11	w	11	w	12	w	13	w	13	w	14	w	14	w	15	w	17
j	0	j	0	j	0	j	1	j	1	j	1	j	1	j	1	j	1	j	1	j	2	j	2	j	2	j	3	j	3	j	3	j	3	j	3	j	3	j	3	j	3	j	3

Table 42: Charlotte's E neighbourhood

1;01		1;02		1;03		1;04		1;05		1;06		1;07		1;08		1;09		1;10		1;11		2;00		2;01		2;02		2;03		2;04		2;05		2;06		2;07		2;08		2;09		2;11	
p	0	p	0	p	0	p	0	p	0	p	0	p	0	p	0	p	2	p	4	p	5	p	5	p	8	p	9	p	11	p	11	p	12	p	13	p	15	p	15	p	15	p	15
b	0	b	0	b	1	b	1	b	1	b	1	b	4	b	5	b	7	b	7	b	7	b	9	b	9	b	12	b	12	b	13	b	13	b	15	b	16	b	17	b	17	b	18
t	0	t	0	t	1	t	1	t	1	t	1	t	1	t	1	t	1	t	1	t	3	t	4	t	5	t	5	t	5	t	5	t	5	t	5	t	5	t	7	t	7	t	7
d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	1	d	1	d	2	d	2	d	2	d	2	d	2	d	2	d	2	d	2
k	0	k	0	k	0	k	0	k	0	k	0	k	0	k	0	k	2	k	3	k	3	k	3	k	3	k	3	k	3	k	4	k	5	k	5	k	5	k	5	k	5	k	5
g	0	g	0	g	0	g	1	g	1	g	1	g	1	g	1	g	1	g	3	g	3	g	4	g	4	g	4	g	4	g	4	g	4	g	4	g	5	g	5	g	7	g	7
f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	1	f	1	f	1	f	1	f	2	f	3	f	3	f	3	f	3	f	3	f	6
v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	1	v	1	v	1	v	1	v	1	v	1	v	1	v	2	v	2	v	2	v	2
θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	1	θ	1
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	1	ð	1	ð	1	ð	3	ð	3	ð	3	ð	3	ð	4	ð	4	ð	5	ð	5	ð	6	ð	6	ð	6	ð	6	ð	6
s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0
ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	0	h	0	h	0	h	0	h	0	h	1	h	2	h	2	h	2	h	3	h	4	h	4	h	6	h	6	h	7	h	7	h	7	h	7	h	8	h	8	h	8	h	8
ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	2	ʧ	4	ʧ	4	ʧ	4	ʧ	4	ʧ	4	ʧ	5	ʧ	5	ʧ	5	ʧ	5
ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	1	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	3	ʤ	3	ʤ	5	ʤ	5	ʤ	5	ʤ	5
m	0	m	0	m	0	m	0	m	0	m	0	m	0	m	0	m	0	m	0	m	1	m	1	m	1	m	1	m	1	m	2	m	3	m	3	m	3	m	3	m	3	m	4
n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0
l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	4	l	4	l	4	l	4
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	1	ɹ	2	ɹ	2	ɹ	2	ɹ	3	ɹ	3	ɹ	3	ɹ	6	ɹ	6	ɹ	6	ɹ	7	ɹ	7	ɹ	8	ɹ	8
w	0	w	0	w	0	w	0	w	0	w	0	w	1	w	1	w	2	w	2	w	3	w	5	w	6	w	6	w	8	w	8	w	8	w	10	w	11	w	12	w	12	w	13
j	0	j	0	j	0	j	0	j	0	j	1	j	1	j	1	j	2	j	2	j	2	j	2	j	2	j	2	j	3	j	3	j	3	j	3	j	3	j	3	j	3	j	3

Table 43: Charlotte's I neighbourhood

1;01		**1;02**		**1;03**		**1;04**		**1;05**		**1;06**		**1;07**		**1;08**		**1;09**		**1;10**		**1;11**		**2;00**		**2;01**		**2;02**		**2;03**		**2;04**		**2;05**		**2;06**		**2;07**		**2;08**		**2;09**		**2;11**	
p	0	p	0	p	0	p	0	p	0	p	0	p	0	p	1	p	3	p	5	p	6	p	7	p	12	p	13	p	14	p	15	p	17	p	18	p	19	p	19	p	21	p	21
b	0	b	0	b	2	b	2	b	2	b	3	b	4	b	4	b	4	b	4	b	5	b	6	b	7	b	8	b	8	b	8	b	8	b	9	b	12	b	12	b	13	b	13
t	0	t	0	t	0	t	0	t	0	t	0	t	0	t	0	t	1	t	1	t	2	t	2	t	3	t	3	t	4	t	4	t	5	t	5	t	5	t	5	t	5	t	6
d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	1	d	2	d	2	d	2	d	2	d	2	d	2	d	2	d	2	d	2	d	3
k	0	k	0	k	1	k	1	k	1	k	1	k	1	k	1	k	1	k	1	k	2	k	3	k	3	k	4	k	4	k	4	k	5	k	5	k	6	k	6	k	7	k	8
g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	1	g	1	g	3	g	3	g	3	g	3	g	3	g	3	g	3	g	3
f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	1	f	2	f	3	f	4	f	6	f	6	f	6	f	8	f	9	f	10	f	10	f	10	f	10	f	10
v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0
θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	1	θ	2	θ	2
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	1	ð	1	ð	1	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2	ð	2
s	0	s	0	s	1	s	1	s	1	s	1	s	1	s	1	s	3	s	3	s	4	s	6	s	8	s	9	s	10	s	10	s	11	s	11	s	11	s	11	s	13	s	14
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	1	z	1	z	1	z	1	z	1
ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	0	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	2	ʃ	2
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	1	h	3	h	4	h	5	h	6	h	7	h	7	h	7	h	7	h	7	h	8	h	8
ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	1	ʧ	2	ʧ	3	ʧ	4	ʧ	5	ʧ	5	ʧ	5	ʧ	5	ʧ	5	ʧ	5	ʧ	6	ʧ	6	ʧ	6	ʧ	7
ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0
m	0	m	0	m	0	m	0	m	0	m	0	m	1	m	2	m	2	m	2	m	2	m	2	m	2	m	3	m	3	m	3	m	3	m	5	m	5	m	5	m	6	m	7
n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	1	n	1	n	2	n	2	n	2	n	2	n	2	n	2	n	2	n	2	n	2	n	2
l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	1	l	1	l	1	l	1	l	2	l	3	l	4	l	4	l	5	l	5	l	5	l	6
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	1	ɹ	1	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	3	ɹ	3	ɹ	4
w	0	w	0	w	0	w	0	w	0	w	0	w	0	w	0	w	1	w	1	w	1	w	1	w	3	w	3	w	3	w	3	w	3	w	3	w	4	w	4	w	5	w	5
j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0

Table 44: Charlotte's O neighbourhood

1;01		1;02		1;03		1;04		1;05		1;06		1;07		1;08		1;09		1;10		1;11		2;00		2;01		2;02		2;03		2;04		2;05		2;06		2;07		2;08		2;09		2;11	
p	0	p	0	p	1	p	1	p	1	p	1	p	1	p	1	p	1	p	2	p	3	p	3	p	4	p	4	p	5	p	5	p	6	p	7	p	8	p	8	p	9	p	10
b	0	b	0	b	0	b	0	b	0	b	0	b	0	b	4	b	8	b	13	b	13	b	14	b	15	b	15	b	15	b	17	b	17	b	19	b	21	b	22	b	23	b	23
t	0	t	0	t	0	t	0	t	1	t	1	t	1	t	1	t	3	t	4	t	6	t	6	t	8	t	8	t	8	t	9	t	9	t	9	t	10	t	11	t	11	t	12
d	0	d	0	d	0	d	0	d	0	d	2	d	3	d	5	d	5	d	7	d	8	d	8	d	9	d	9	d	10	d	11	d	11	d	11	d	11	d	11	d	11	d	12
k	0	k	0	k	0	k	0	k	0	k	0	k	0	k	1	k	1	k	2	k	3	k	5	k	7	k	8	k	10	k	12	k	13	k	13	k	13	k	13	k	13	k	15
g	0	g	0	g	1	g	1	g	1	g	1	g	1	g	1	g	2	g	2	g	3	g	5	g	5	g	5	g	5	g	5	g	5	g	7	g	7	g	7	g	7	g	8
f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	1	f	1	f	1	f	1	f	2	f	2	f	2	f	3	f	3	f	5	f	6	f	7	f	7	f	7
v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0
θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	1	θ	1	θ	1	θ	1
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	1	ð	1	ð	1	ð	1	ð	1	ð	1
s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	1	s	2	s	4	s	5	s	6	s	6	s	7	s	8	s	8	s	10	s	10	s	11	s	12	s	13	s	13
z	0	z	0	z	0	z	0	z	0	z	0	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	1	z	1
ʃ	0	ʃ	0	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	2	ʃ	2	ʃ	2	ʃ	3	ʃ	3	ʃ	3	ʃ	3	ʃ	3	ʃ	3	ʃ	3
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	0	h	0	h	0	h	0	h	0	h	1	h	2	h	2	h	3	h	4	h	5	h	5	h	5	h	5	h	6	h	6	h	7	h	7	h	7	h	7	h	8	h	8
ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	1	ʧ	2	ʧ	2	ʧ	2
ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	1	ʤ	1	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	2
m	0	m	0	m	0	m	0	m	0	m	0	m	0	m	2	m	2	m	3	m	4	m	4	m	5	m	5	m	6	m	7	m	7	m	7	m	9	m	9	m	10	m	10
n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	3	n	3	n	3	n	4	n	6	n	6	n	6	n	6	n	7	n	7	n	7	n	7	n	7	n	7
l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	1	l	2	l	2
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	2	ɹ	3	ɹ	3	ɹ	3	ɹ	3	ɹ	3	ɹ	3	ɹ	4	ɹ	4
w	0	w	0	w	0	w	0	w	1	w	1	w	1	w	2	w	2	w	3	w	3	w	4	w	4	w	5	w	5	w	5	w	5	w	5	w	5	w	6	w	6	w	6
j	0	j	0	j	0	j	0	j	0	j	1	j	1	j	1	j	1	j	1	j	2	j	2	j	3	j	3	j	3	j	3	j	3	j	3	j	3	j	3	j	4	j	4

Table 45: Charlotte's U neighbourhoods

1;01		**1;02**		**1;03**		**1;04**		**1;05**		**1;06**		**1;07**		**1;08**		**1;09**		**1;10**		**1;11**		**2;00**		**2;01**		**2;02**		**2;03**		**2;04**		**2;05**		**2;06**		**2;07**		**2;08**		**2;09**		**2;11**	
p	0	p	0	p	0	p	0	p	0	p	0	p	0	p	0	p	0	p	1	p	2	p	2	p	3	p	3	p	3	p	4	p	4	p	7	p	7	p	7	p	7	p	7
b	0	b	0	b	1	b	1	b	1	b	1	b	1	b	2	b	2	b	3	b	3	b	3	b	4	b	4	b	4	b	5	b	5	b	6	b	6	b	6	b	6	b	8
t	0	t	0	t	0	t	0	t	0	t	0	t	0	t	0	t	1	t	3	t	3	t	3	t	5	t	5	t	5	t	5	t	5	t	5	t	5	t	5	t	5	t	5
d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	0	d	1	d	1	d	1	d	1	d	1	d	1	d	1	d	1	d	1	d	1
k	0	k	0	k	0	k	0	k	0	k	0	k	2	k	2	k	2	k	2	k	2	k	2	k	2	k	2	k	2	k	2	k	2	k	2	k	3	k	3	k	3	k	3
g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	0	g	1	g	1	g	1	g	1	g	1
f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	0	f	1	f	1	f	1	f	1	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2	f	2
v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0	v	0
θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0	θ	0
ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0	ð	0
s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	0	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1	s	1
z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	0	z	1	z	1	z	1	z	1	z	1	z	1	z	1
ʃ	0	ʃ	0	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	1	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	2	ʃ	3
ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0	ʒ	0
h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0	h	0
ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0	ʧ	0
ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	0	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	1	ʤ	2	ʤ	2	ʤ	2	ʤ	2	ʤ	3	ʤ	3
m	0	m	0	m	1	m	1	m	1	m	1	m	1	m	1	m	1	m	1	m	2	m	3	m	3	m	3	m	3	m	3	m	3	m	3	m	4	m	4	m	4	m	4
n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	0	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1	n	1
l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	0	l	1	l	1	l	1	l	1	l	2	l	2	l	2	l	2	l	2	l	2	l	2	l	2
ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	0	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	1	ɹ	2	ɹ	2	ɹ	2	ɹ	2
w	0	w	0	w	0	w	0	w	0	w	0	w	0	w	1	w	1	w	3	w	3	w	3	w	3	w	3	w	4	w	4	w	4	w	4	w	4	w	4	w	4	w	4
j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	0	j	1	j	1	j	1	j	1	j	1	j	2	j	2	j	2	j	2	j	2

Table 46: Contrasting phonological neighbourhoods of [s] and [t] in Georgia's lexicon

0;11	**1;00**	**1;01**	**1;02**	**1;03**	**1;04**	**1;05**	**1;06**	**1;07**	**1;09**
		A (s=2, t=3)	A (s=2, t=3)	A (s=2, t=3)	A (s=2, t=3)	A (s=3, t=3)	A (s=3, t=3)	A (s=3, t=3)	A (s=3, t=4)
			E (s=1, t=3)	E (s=1, t=4)	E (s=1, t=4)	E (s=1, t=4)	E (s=1, t=4)	E (s=1, t=4)	E (s=2, t=4)
	I (s=1, t=2)	I (s=2, t=2)	I (s=3, t=2)	I (s=4, t=3)	I (s=5, t=3)	I (s=5, t=3)	I (s=5, t=3)	I (s=5, t=3)	I (s=6, t=3)
	O (s=1, t=2)	O (s=1, t=6)	O (s=2, t=8)	O (s=2, t=8)	O (s=2, t=8)	O (s=3, t=9)	O (s=3, t=9)	O (s=3, t=10)	O (s=4, t=10)

1;10	**1;11**	**2;00**	**2;01**	**2;02**	**2;03**	**2;04**	**2;05**	**2;06**	**2;07**
A (s=7, t=6)	A (s=8, t=6)	A (s=8, t=6)	A (s=8, t=7)	A (s=8, t=7)	A (s=8, t=7)	A (s=8, t=8)	A (s=9, t=11)	A (s=12, t=13)	A (s=12, t=13)
E (s=3, t=5)	E (s=3, t=6)	E (s=3, t=7)	E (s=4, t=7)	E (s=4, t=7)	E (s=4, t=7)	E (s=5, t=10)	E (s=5, t=11)	E (s=5, t=11)	E (s=5, t=11)
I (s=10, t=4)	I (s=10, t=5)	I (s=11, t=6)	I (s=11, t=7)	I (s=11, t=7)	I (s=11, t=7)	I (s=11, t=7)	I (s=12, t=7)	I (s=12, t=7)	I (s=12, t=7)
O (s=6, t=11)	O (s=6, t=12)	O (s=6, t=12)	O (s=7, t=12)	O (s=8, t=12)	O (s=8, t=13)	O (s=9, t=13)	O (s=9, t=14)	O (s=9, t=14)	O (s=10, t=15)
U (s=1, t=6)	U (s=1, t=6)	U (s=1, t=7)	U (s=1, t=7)	U (s=1, t=7)	U (s=1, t=7)	U (s=1, t=7)	U (s=1, t=7)	U (s=1, t=7)	U (s=1, t=7)

2;08	**2;09**	**2;10**	**2;11**
A (s=12, t=13)	A (s=12, t=13)	A (s=13, t=13)	A (s=13, t=13)
E (s=7, t=12)	E (s=7, t=12)	E (s=7, t=12)	E (s=8, t=15)
I (s=14, t=8)	I (s=14, t=8)	I (s=15, t=8)	I (s=15, t=8)
O (s=10, t=15)	O (s=10, t=15)	O (s=10, t=16)	O (s=12, t=17)
U (s=1, t=8)	U (s=1, t=8)	U (s=1, t=8)	U (s=1, t=8)

Table 47: Contrasting phonological neighbourhoods of [b] and [m] in Georgia's lexicon

0;08	**0;09**	**0;10**	**0;11**	**1;00**	**1;01**	**1;02**	**1;03**	**1;04**	**1;05**
A (b=1, m=1)	A (b=3, m=1)	A (b=5, m=1)	A (b=5, m=1)	A (b=9, m=2)	A (b=9, m=2)	A (b=10, m=4)	A (b=10, m=5)	A (b=11, m=6)	A (b=11, m=6)
						E (b=6, m=1)	E (b=6, m=1)	E (b=7, m=1)	E (b=7, m=1)
				I (b=1, m=1)	I (b=3, m=1)	I (b=5, m=2)	I (b=5, m=2)	I (b=5, m=3)	I (b=5, m=3)
		O (b=2, m=1)	O (b=2, m=1)	O (b=3, m=3)	O (b=3, m=3)	O (b=6, m=3)	O (b=7, m=3)	O (b=9, m=3)	O (b=9, m=3)
							U (b=4, m=1)	U (b=4, m=1)	U (b=4, m=1)

1;06	**1;07**	**1;09**	**1;10**	**1;11**	**2;00**	**2;01**	**2;02**	**2;03**	**2;04**
A (b=11, m=7)	A (b=11, m=7)	A (b=11, m=7)	A (b=19, m=7)	A (b=19, m=7)	A (b=22, m=8)	A (b=24, m=11)	A (b=24, m=11)	A (b=28, m=11)	A (b=28, m=11)
E (b=8, m=1)	E (b=8, m=2)	E (b=8, m=2)	E (b=10, m=4)	E (b=10, m=4)	E (b=11, m=4)	E (b=12, m=5)	E (b=14, m=6)	E (b=15, m=7)	E (b=16, m=8)
I (b=5, m=3)	I (b=5, m=3)	I (b=6, m=4)	I (b=9, m=5)	I (b=11, m=5)	I (b=11, m=5)	I (b=12, m=5)	I (b=12, m=7)	I (b=12, m=8)	I (b=12, m=9)
O (b=10, m=3)	O (b=11, m=3)	O (b=11, m=3)	O (b=14, m=5)	O (b=15, m=6)	O (b=16, m=7)	O (b=17, m=7)	O (b=17, m=7)	O (b=17, m=7)	O (b=17, m=7)
U (b=4, m=1)	U (b=4, m=1)	U (b=4, m=1)	U (b=4, m=4)	U (b=4, m=5)	U (b=4, m=5)	U (b=4, m=5)	U (b=4, m=6)	U (b=4, m=6)	U (b=4, m=6)

2;05	**2;06**	**2;07**	**2;08**	**2;09**	**2;10**	**2;11**
A (b=28, m=12)	A (b=28, m=13)	A (b=28, m=14)	A (b=28, m=14)	A (b=28, m=14)	A (b=29, m=15)	A (b=30, m=15)
E (b=17, m=8)	E (b=17, m=8)	E (b=17, m=8)	E (b=19, m=8)	E (b=19, m=8)	E (b=22, m=8)	E (b=24, m=8)
I (b=12, m=9)	I (b=13, m=9)	I (b=13, m=10)	I (b=13, m=10)	I (b=13, m=10)	I (b=16, m=10)	I (b=16, m=10)
O (b=18, m=8)	O (b=18, m=8)	O (b=19, m=8)	O (b=20, m=8)	O (b=20, m=8)	O (b=21, m=8)	O (b=23, m=9)
U (b=4, m=6)	U (b=4, m=6)	U (b=4, m=6)	U (b=4, m=6)	U (b=4, m=6)	U (b=4, m=6)	U (b=4, m=6)

Table 48: Contrasting phonological neighbourhoods of [l] and [ɹ] in Georgia's lexicon

1;00	**1;01**	**1;02**	**1;03**	**1;04**	**1;05**	**1;06**	**1;07**	**1;09**	**1;10**
	A (l=1, r=1)	A (l=2, r=3)	A (l=3, r=3)	A (l=4, r=4)	A (l=4, r=4)	A (l=4, r=4)	A (l=4, r=4)	A (l=4, r=4)	A (l=6, r=5)
		E (l=1, r=1)	E (l=1, r=1)	E (l=1, r=2)	E (l=1, r=2)	E (l=1, r=4)	E (l=1, r=6)	E (l=1, r=7)	E (l=2, r=7)
				I (l=2, r=1)	I (l=2, r=1)	I (l=2, r=1)	I (l=2, r=1)	I (l=2, r=1)	I (l=3, r=1)
	O (l=2, r=1)	O (l=2, r=1)	O (l=2, r=1)	O (l=2, r=1)	O (l=2, r=1)	O (l=2, r=1)	O (l=2, r=1)	O (l=2, r=1)	O (l=2, r=2)
								U (l=1, r=1)	U (l=1, r=2)

1;11	**2;00**	**2;01**	**2;02**	**2;03**	**2;04**	**2;05**	**2;06**	**2;07**	**2;08**
A (l=6, r=5)	A (l=6, r=6)	A (l=6, r=9)	A (l=7, r=9)	A (l=10, r=9)	A (l=11, r=10)	A (l=12, r=10)	A (l=12, r=10)	A (l=12, r=10)	A (l=15, r=10)
E (l=2, r=7)	E (l=5, r=7)	E (l=6, r=7)	E (l=7, r=7)	E (l=7, r=7)	E (l=7, r=7)	E (l=7, r=7)	E (l=10, r=7)	E (l=10, r=7)	E (l=11, r=9)
I (l=3, r=1)	I (l=3, r=1)	I (l=4, r=1)	I (l=4, r=1)	I (l=5, r=1)	I (l=7, r=1)	I (l=8, r=1)	I (l=8, r=2)	I (l=8, r=2)	I (l=9, r=3)
O (l=2, r=2)	O (l=2, r=2)	O (l=2, r=2)	O (l=2, r=3)	O (l=2, r=3)	O (l=3, r=4)	O (l=4, r=4)	O (l=4, r=4)	O (l=4, r=4)	O (l=4, r=4)
U (l=2, r=2)	U (l=2, r=2)	U (l=2, r=2)	U (l=2, r=2)	U (l=2, r=2)	U (l=2, r=2)	U (l=2, r=2)	U (l=2, r=2)	U (l=2, r=2)	U (l=2, r=3)

2;09	**2;10**	**2;11**
A (l=15, r=11)	A (l=15, r=11)	A (l=16, r=11)
E (l=11, r=9)	E (l=12, r=9)	E (l=13, r=9)
I (l=10, r=3)	I (l=11, r=5)	I (l=11, r=5)
O (l=4, r=4)	O (l=4, r=4)	O (l=4, r=5)
U (l=2, r=3)	U (l=3, r=3)	U (l=3, r=3)

Table 49: Contrasting phonological neighbourhoods of [θ] and [f] in Georgia's lexicon

0;11	**1;00**	**1;01**	**1;02**	**1;03**	**1;04**	**1;05**	**1;06**	**1;07**	**1;09**
	A (θ=1, f=1)	A (θ=1, f=1)	A (θ=1, f=1)	A (θ=1, f=1)	A (θ=1, f=3)	A (θ=1, f=3)	A (θ=1, f=3)	A (θ=1, f=3)	A (θ=1, f=5)
	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)	O (θ=1, f=1)

1;10	**1;11**	**2;00**	**2;01**	**2;02**	**2;03**	**2;04**	**2;05**	**2;06**	**2;07**
A (θ=1, f=5)	A (θ=1, f=7)	A (θ=1, f=7)	A (θ=1, f=7)	A (θ=1, f=10)	A (θ=1, f=11)	A (θ=1, f=12)	A (θ=1, f=13)	A (θ=1, f=13)	A (θ=1, f=13)
			I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)	I (θ=1, f=11)
O (θ=1, f=1)	O (θ=2, f=2)	O (θ=2, f=3)	O (θ=2, f=4)	O (θ=2, f=4)	O (θ=2, f=5)	O (θ=2, f=6)	O (θ=2, f=6)	O (θ=2, f=7)	O (θ=2, f=7)

2;08	**2;09**	**2;10**	**2;11**
A (θ=1, f=13)	A (θ=1, f=13)	A (θ=1, f=14)	A (θ=1, f=15)
I (θ=1, f=11)	I (θ=1, f=11)	I (θ=2, f=12)	I (θ=2, f=12)
O (θ=2, f=7)	O (θ=2, f=8)	O (θ=2, f=8)	O (θ=2, f=8)

Table 50: Contrasting phonological neighbourhoods of [ð] and [d] in Georgia's lexicon

1;07	**1;09**	**1;10**	**1;11**	**2;00**	**2;01**	**2;02**	**2;03**	**2;04**	**2;05**
	E (ð=3, d=1)	E (ð=4, d=1)	E (ð=4, d=1)	E (ð=5, d=1)	E (ð=5, d=1)	E (ð=6, d=2)	E (ð=7, d=3)	E (ð=7, d=3)	E (ð=7, d=3)
	I (ð=2, d=2)	I (ð=2, d=3)	I (ð=2, d=3)	I (ð=2, d=3)	I (ð=2, d=4)	I (ð=2, d=5)	I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)
				O (ð=1, d=8)	O (ð=1, d=8)	O (ð=1, d=9)	O (ð=1, d=10)	O (ð=1, d=10)	O (ð=1, d=10)

2;06	**2;07**	**2;08**	**2;09**	**2;10**	**2;11**
E (ð=7, d=3)	E (ð=7, d=3)	E (ð=8, d=3)	E (ð=8, d=3)	E (ð=9, d=3)	E (ð=9, d=4)
I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)	I (ð=2, d=6)
O (ð=1, d=10)	O (ð=1, d=11)	O (ð=1, d=12)	O (ð=1, d=12)	O (ð=1, d=12)	O (ð=1, d=13)

Table 51: Contrasting phonological neighbourhoods of [s] and [t] in Charlotte's lexicon

1;06	**1;07**	**1;08**	**1;09**	**1;10**	**1;11**	**2;00**	**2;01**	**2;02**	**2;03**
	A (s=1, t=1)	A (s=1, t=1)	A (s=1, t=1)	A (s=1, t=1)	A (s=1, t=1)	A (s=1, t=2)	A (s=3, t=2)	A (s=5, t=2)	A (s=7, t=2)
							E (s=1, t=5)	E (s=1, t=5)	E (s=1, t=5)
			I (s=3, t=1)	I (s=3, t=1)	I (s=4, t=2)	I (s=6, t=2)	I (s=8, t=3)	I (s=9, t=3)	I (s=10, t=4)
		O (s=1, t=1)	O (s=3, t=1)	O (s=3, t=1)	O (s=4, t=2)	O (s=6, t=2)	O (s=8, t=3)	O (s=9, t=3)	O (s=10, t=4)
							U (s=1, t=5)	U (s=1, t=5)	U (s=1, t=5)

2;04	**2;05**	**2;06**	**2;07**	**2;08**	**2;09**	**2;11**
A (s=8, t=3)	A (s=9, t=3)	A (s=11, t=3)	A (s=15, t=3)	A (s=15, t=3)	A (s=16, t=4)	A (s=17, t=5)
E (s=1, t=5)	E (s=1, t=5)	E (s=1, t=5)	E (s=1, t=5)	E (s=1, t=7)	E (s=1, t=7)	E (s=1, t=7)
I (s=10, t=4)	I (s=11, t=5)	I (s=11, t=5)	I (s=11, t=5)	I (s=11, t=5)	I (s=13, t=5)	I (s=14, t=6)
O (s=10, t=4)	O (s=11, t=5)	O (s=11, t=5)	O (s=11, t=5)	O (s=11, t=5)	O (s=13, t=5)	O (s=14, t=6)
U (s=1, t=5)	U (s=1, t=5)	U (s=1, t=5)	U (s=1, t=5)	U (s=1, t=5)	U (s=1, t=5)	U (s=1, t=5)

Table 52: Contrasting phonological neighbourhoods of [b] and [m] in Charlotte's lexicon

1;02	**1;03**	**1;04**	**1;05**	**1;06**	**1;07**	**1;08**	**1;09**
	A (b=3, m=1)	A (b=4, m=2)	A (b=4, m=2)	A (b=4, m=3)	A (b=4, m=3)	A (b=5, m=4)	A (b=6, m=5)
					I (b=4, m=1)	I (b=4, m=2)	I (b=4, m=2)
						O (b=4, m=2)	O (b=8, m=2)
	U (b=1, m=1)	U (b=1, m=1)	U (b=1, m=1)	U (b=1, m=1)	U (b=1, m=1)	U (b=2, m=1)	U (b=2, m=1)

1;10	**1;11**	**2;00**	**2;01**	**2;02**	**2;03**	**2;04**	**2;05**
A (b=10, m=6)	A (b=14, m=6)	A (b=17, m=7)	A (b=19, m=8)	A (b=21, m=9)	A (b=21, m=9)	A (b=21, m=11)	A (b=22, m=12)
	E (b=7, m=1)	E (b=9, m=1)	E (b=9, m=1)	E (b=12, m=1)	E (b=12, m=1)	E (b=13, m=2)	E (b=13, m=3)
I (b=4, m=2)	I (b=5, m=2)	I (b=6, m=2)	I (b=7, m=2)	I (b=8, m=3)	I (b=8, m=3)	I (b=8, m=3)	I (b=8, m=3)
O (b=13, m=3)	O (b=13, m=4)	O (b=14, m=4)	O (b=15, m=5)	O (b=15, m=5)	O (b=15, m=6)	O (b=17, m=7)	O (b=17, m=7)
U (b=3, m=1)	U (b=3, m=2)	U (b=3, m=3)	U (b=4, m=3)	U (b=4, m=3)	U (b=4, m=3)	U (b=5, m=3)	U (b=5, m=3)

2;06	**2;07**	**2;08**	**2;09**	**2;11**
A (b=23, m=12)	A (b=24, m=18)	A (b=24, m=18)	A (s=25, t=20)	A (s=25, t=21)
E (b=15, m=3)	E (b=16, m=3)	E (b=17, m=3)	E (b=17, m=3)	E (b=18, m=4)
I (b=9, m=5)	I (b=12, m=5)	I (b=12, m=5)	I (b=13, m=6)	I (b=13, m=7)
O (b=19, m=7)	O (b=21, m=9)	O (b=22, m=9)	O (b=23, m=10)	O (b=23, m=10)
U (b=6, m=3)	U (b=6, m=4)	U (b=6, m=4)	U (b=6, m=4)	U (b=8, m=4)

Table 53: Contrasting phonological neighbourhoods of [l] and [ɹ] in Charlotte's lexicon

1;09	**1;10**	**1;11**	**2;00**	**2;01**	**2;02**	**2;03**
	A (l=1, ɹ=1)	A (l=1, ɹ=1)	A (l=3, ɹ=1)	A (l=3, ɹ=1)	A (l=3, ɹ=3)	A (l=4, ɹ=3)
	E (l=1, ɹ=2)	E (l=1, ɹ=2)	E (l=1, ɹ=2)	E (l=1, ɹ=3)	E (l=1, ɹ=3)	E (l=1, ɹ=3)
		I (l=1, ɹ=1)	I (l=1, ɹ=1)	I (l=1, ɹ=2)	I (l=1, ɹ=2)	I (l=2, ɹ=2)
		O (l=1, ɹ=2)	O (l=1, ɹ=2)	O (l=1, ɹ=2)	O (l=1, ɹ=2)	O (l=1, ɹ=3)
			U (l=1, ɹ=1)	U (l=1, ɹ=1)	U (l=1, ɹ=1)	U (l=2, ɹ=1)

2;04	**2;05**	**2;06**	**2;07**	**2;08**	**2;09**	**2;11**
A (l=4, ɹ=4)	A (l=7, ɹ=4)	A (l=9, ɹ=4)	A (l=9, ɹ=4)	A (l=9, ɹ=5)	A (l=10, ɹ=6)	A (l=11, ɹ=7)
E (l=1, ɹ=6)	E (l=1, ɹ=6)	E (l=1, ɹ=6)	E (l=4, ɹ=7)	E (l=4, ɹ=7)	E (l=4, ɹ=8)	E (l=4, ɹ=8)
I (l=3, ɹ=2)	I (l=4, ɹ=2)	I (l=4, ɹ=2)	I (l=5, ɹ=2)	I (l=5, ɹ=3)	I (l=5, ɹ=3)	I (l=6, ɹ=4)
O (l=1, ɹ=3)	O (l=1, ɹ=3)	O (l=1, ɹ=3)	O (l=1, ɹ=3)	O (l=1, ɹ=3)	O (l=2, ɹ=4)	O (l=2, ɹ=4)
U (l=2, ɹ=1)	U (l=2, ɹ=1)	U (l=2, ɹ=1)	U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)	U (l=2, ɹ=2)

Table 54: Contrasting phonological neighbourhoods of [ʧ] and [t] in Charlotte's lexicon

1;08	**1;09**	**1;10**	**1;11**	**2;00**	**2;01**	**2;02**	**2;03**
	A (ʧ=1, t=1)	A (ʧ=1, t=1)	A (ʧ=2, t=1)	A (ʧ=2, t=2)	A (ʧ=2, t=2)	A (ʧ=2, t=2)	A (ʧ=2, t=2)
	E (ʧ=2, t=1)	E (ʧ=2, t=1)	E (ʧ=2, t=3)	E (ʧ=2, t=4)	E (ʧ=2, t=5)	E (ʧ=4, t=5)	E (ʧ=4, t=5)
	I (ʧ=1, t=1)	I (ʧ=2, t=1)	I (ʧ=3, t=2)	I (ʧ=4, t=2)	I (ʧ=5, t=3)	I (ʧ=5, t=3)	I (ʧ=5, t=4)
					O (ʧ=1, t=8)	O (ʧ=1, t=8)	O (ʧ=1, t=8)

2;04	**2;05**	**2;06**	**2;07**	**2;08**	**2;09**	**2;11**
A (ʧ=2, t=3)	A (ʧ=2, t=3)	A (ʧ=2, t=3)	A (ʧ=3, t=3)	A (ʧ=3, t=3)	A (ʧ=3, t=4)	A (ʧ=3, t=5)
E (ʧ=4, t=5)	E (ʧ=4, t=5)	E (ʧ=4, t=5)	E (ʧ=5, t=5)	E (ʧ=5, t=7)	E (ʧ=5, t=7)	E (ʧ=5, t=7)
I (ʧ=5, t=4)	I (ʧ=5, t=5)	I (ʧ=5, t=5)	I (ʧ=6, t=5)	I (ʧ=6, t=5)	I (ʧ=6, t=5)	I (ʧ=7, t=6)
O (ʧ=1, t=9)	O (ʧ=1, t=9)	O (ʧ=1, t=9)	O (ʧ=1, t=10)	O (ʧ=2, t=11)	O (ʧ=2, t=11)	O (ʧ=2, t=13)

Table 55: Contrasting phonological neighbourhoods of [ð] and [d] in Charlotte's lexicon

1;11	**2;00**	**2;01**	**2;02**	**2;03**	**2;04**
		E (ð=3, d=1)	E (ð=4, d=1)	E (ð=4, d=2)	E (ð=5, d=2)
	I (ð=2, d=1)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)

2;05	**2;06**	**2;07**	**2;08**	**2;09**	**2;11**
E (ð=5, d=2)	E (ð=6, d=2)	E (ð=6, d=2)	E (ð=6, d=2)	E (ð=6, d=2)	E (ð=6, d=2)
I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=2)	I (ð=2, d=3)
O (ð=1, d=11)	O (ð=1, d=11)	O (ð=1, d=11)	O (ð=1, d=11)	O (ð=1, d=11)	O (ð=1, d=12)