On the formal separation between lexical and phonological development: Converging evidence from perception and corpus studies

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Abstract

In this paper, we address relations between lexical and phonological development. We begin with an overview of the literature on infant speech perception relevant to this topic. We then engage in a systematic comparison between the lexical development of two child learners of English and their acquisition of consonants in syllable onsets. After we establish a developmental timeline for each child's onset consonant system, we consider the structure and content of their expressive vocabularies at each relevant phonological milestone. Our study fails to return tangible parallels between the two areas of development. The data instead suggest that patterns of phonological development are best described in terms of the segmental categories they involve, independent of the learners' lexicons.

Acknowledgements

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1. Introduction

Since at least the 1970s, scholars in the area of child language phonology have reported intriguing parallels between lexical and phonological development. One example of this comes from patterns of lexical selection and avoidance, whereby children limit their attempts at producing words to a subset of phonologically-identifiable word shapes, while they appear to explicitly avoid other word shapes, whether they display particular types of syllables, sounds, or sound combinations (Ferguson & Farwell 1975; Leonard et al. 1981; Schwartz & Leonard 1982; see also Stoel-Gammon & Cooper 1984; Stoel-Gammon 2011; Vihman 2014). These patterns appear to be restricted to the earliest stages of phonological development, typically when children have small vocabularies ranging between 50 to 100 words (Stoel-Gammon 2011). This pattern has also been reproduced experimentally, with child learners equipped with similarly-sized vocabularies (Leonard et al. 1981; Schwartz & Leonard 1982).

However, the evidence also suggests that lexical selection and avoidance behaviours are not found in all language learners (e.g. Stoel-Gammon & Cooper 1984; Kehoe 2015). Mentions of selection and avoidance strategies in studies of phonological development based on even slightly more advanced learners are, in comparison, conspicuously missing. This situation may be a matter of focus, as these studies typically concentrate on aspects of children's phonological productions, as opposed to potential relations between phonology and the lexicon (Smith 1973; Fikkert 1994; Levelt 1994; Barlow 1997; Rose 2000; Goad & Rose 2004; Santos 2007; Almeida 2011; Yamaguchi 2012). However, as Stoel-Gammon (2011) points out, the nature of the relationship between the child's lexicon and his/her phonological system remains relatively obscure to this day, as are its implications for related questions, for example concerning the nature of lexical or phonological representations within the mental lexicon, or related implications in the general area of speech processing (see also Sosa & Stoel-Gammon 2012; Ota & Green 2013; Kehoe 2015).

Two main approaches can be identified within the literature to account for relations between lexical and phonological development (see also Saffran & Graf Estes 2006; Curtin & Zamuner 2014 for related discussions). The first focuses primarily on the lexicon as the driver of phonological development draw direct relationships between the content and structure of the child's lexicon and the level of granularity of the phonological representations of the words that make up this lexicon: as more contrasts need to be functionally represented in the lexicon, more detail emerges within phonological representation. This hypothesis is most explicit within the Lexical Restructuring Model (henceforth, LRM), a hypothesis that has been widely applied to first and second language development as well as in the area of phonological awareness and its relationship to literacy development (Charles-Luce & Luce 1990; Walley 1993; Metsala & Walley 1998; Luce & Pisoni 1998; Storkel 2002; Walley, Metsala & Garlock 2003; Storkel 2004; Ballem & Plunkett 2005; Stoel-Gammon 2011; Ainsworth, Welbourne & Hesketh 2015). Competing approaches offer more phonology-centric explanations to behaviours observed in phonological development, in particular from the perspective of production data. These approaches generally acknowledge long-term memory as it applies in the areas of speech perception and lexical development as the primary source of evidence from which the child/learner with develop phonological knowledge (Pierrehumbert 2003; Werker & Curtin 2005; Curtin, Byers-Heinlein & Werker 2011; Munson, Edwards & Beckman 2011). However, they do not necessarily tie the structure of the lexicon with acquisition. Phonological contrastiveness does not act as a necessary trigger of phonological development; only the identification of categories and their distributions by the learner is necessary to trigger development (e.g. Goad & Rose 2004; Lin & Mielke 2008; McAllister Byun 2009; Menn, Schmidt & Nicholas 2009; McAllister Byun, Inkelas & Rose in press).

These approaches also highlight commonly-observed properties of children's early word productions, which tend to display restricted inventories of sounds as well as limitations in sound combinations. These limitations in production must also be explained in light of a growing body of evidence suggesting that early word representations, even at a time when children do not have many contrasts encoded in their lexicons, incorporate a high level of perceptual detail, similar to what is behaviourally observable in adults (e.g. Swingley & Aslin 2002; Coady & Aslin 2003; Swingley 2003; Swingley & Aslin 2007; White & Morgan 2008; Yoshida et al. 2009).

From a methodological standpoint, while cross-sectional studies comparing levels of lexical and phonological development across young learners tend to highlight the general parallel that exists between lexical and phonological development (without, however, demonstrating a causal relation between the two), to our knowledge, relations between lexical and phonological development in individual learners have never been tracked longitudinally. The current study offers a step in this direction, in an attempt to uncover whether patterns of lexical development may in fact offer grounds to predict patterns of phonological development, following the general logic of the LRM.

We first provide additional background concerning this model, which we discuss in light of the relevant literature on the development of speech perception and production abilities. After a brief discussion of methodological and related falsifiability issues, we introduce two longitudinal case studies of the development of North American English by child learners. We summarize each of their patterns of consonantal productions in syllable onsets. We then compare these patterns in light of both the phonological properties of children's expressive vocabularies and usage frequency in their attempted productions. As we will see, the evidence from both the children's expressive vocabularies and usage (in production) fails to provide a reliable basis for predicting patterns of phonological development. In contrast to this, many regularities within each child's phonological system point to phonologically-defined classes of phones. We 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 on properties of the child's lexicon.

2. Background: lexicon-based approaches to phonological development

Studies of phonological development focusing on the shape of the children’s lexicons have their roots in the works by Leopold (1947), Menn (1971) and Waterson (1971), which emphasize the word as a central conditioning domain for phonological behaviours. The word as a unit of analysis is also fundamental to Ferguson & Farwell’s (1975) influential study of child phonology. The intuitions behind these works were later adopted within 'templatic' or 'whole-word' approaches to phonology and phonological development (see Vihman & Croft 2007; Vihman 2014 for a summary of this literature). These approaches focus primarily on word forms produced by young children with typically very small vocabularies, highlighting similarities between these forms, however with limited regard for the extent and composition of the children’s lexicons. This latter topic is better explored in research on how the child's developing lexicon might influence psycholinguistic behaviours, for example in the areas of word recognition and phonological awareness. Charles-Luce & Luce (1990) describe phonological lexicons in terms of similarity, whereby words that share phonological characteristics (e.g. *bit, pit, kit, sit,* ...) cluster together within phonological 'neighbourhoods' (here, the '*-it*' neighbourhood). Charles-Luce & Luce observe that early lexicons generally contain fewer phonological neighbourhoods than the lexicons of adult speakers of the same language, and many of these neighbourhoods can be defined as sparse, as they are often populated by only a single or very few word forms. Charles-Luce & Luce argue that this correlates with low level of representational detail in emerging vocabularies, as only broad distinctions suffice to mark functional distinctions between the words contained within these small-size lexicons. Under this view, lexical development acts as a trigger to phonological development: as children expand their vocabularies, the words stored within their lexicons acquire additional phonological detail, the level of which is governed by the functional requirement to maintain phonological distinctiveness.

Building on a similar line of inquiry, but with a focus on the development of phonological awareness and related alphabetical knowledge in older learners, Metsala (1997) and Metsala & Walley (1998) encapsulated this general hypothesis within the Lexical Restructuring Model: "the representations supporting spoken word recognition become increasingly segmental with spoken vocabulary growth, and this change make possible explicit access to phonemic units" (Metsala & Walley 1998:89).

The LRM offers a simple and plausible explanation from various theoretical perspectives, be they rooted in functionalism or more formal models which embrace the concept of functional contrast. The idea that children's early word forms lack in representational detail is indeed virtually consensual among models of phonological development in production. However, as we discuss below, direct evidence in support of this conceptually simple interpretation of the facts has proven rather elusive, and studies in infant speech perception pose a significant challenge to any such simplification. We review the relevant literature in the next sections.

2.1 Supporting evidence

Central to the LRM is the claim that "young children recognize words in a more holistic manner than do older children and adults" (Metsala & Walley 1998:100). As mentioned above, measures of child and adult vocabularies, which show that child lexicons typically lack in neighbourhood diversity and density, are compatible with this claim.

Evidence from studies of children's developing lexicons has also been brought in support for the LRM. Early lexicons tend to have few neighbourhoods, which also come from frequently-occurring words in the ambient language (Storkel 2003; Stokes 2010). These studies show that words from dense neighbourhoods are typically acquired earlier than words from sparser neighbourhoods (Storkel 2001; Hollich, Jusczyk & Luce 2002). These observations are compatible with the view that high-density neighbourhoods yield increases in representational detail within the learner's lexicon, thereby facilitating the development of frequent phones and phone combinations. Stoel-Gammon (2011) suggests that this may be what underlies selection and avoidance behaviours, as the child may be more inclined to avoid words which are not represented with sufficient phonological detail.

Concerning phonological production, we can also find support for basic relationships between phonological neighbourhood and articulatory abilities. For example, Sosa & Stoel-Gammon (2012) show that words forming dense phonological neighbourhoods tend to be produced by children with lower variability, in comparison to words forming sparser phonological neighbourhoods, while word production accuracy is dependent on age of acquisition. As we discuss below, however, the link between neighbourhood density and variability in word production appears to hold at a certain level of granularity only; as Ota & Green (2013) show, the segmental make-up of the words acquired by children also affects production accuracy in ways that transcend information about the lexicon, a topic we take up again in section 4, in light of our analysis presented in section 3.

Finally, back in the early 1990s, the central tenets of the LRM were compatible with then-current observations suggesting that children often fail to detect mispronunciations in early word forms (Ferguson & Farwell 1975; Benedict 1979; Menyuk & Menn 1986; Walley 1993; Hallé & Boysson-Bardies 1994; Hallé & Boysson-Bardies 1996). For example, Hallé & Boysson-Bardies (1996) suggested that toddlers fail to distinguish between familiar words and modified versions of these words, even when the modifications occur in prominent, word-initial consonants (e.g. *gâteau* [gato] presented as *[kato]). They concluded that initial representations in children's lexicons “have a rather global format” (Hallé & Boysson-Bardies 1996:477). However, this conclusion has not stood the test of time, as we discuss in the next section.

2.2 Contradicting evidence

Coady & Aslin (2003) compared the productive lexicons of two learners of English against properties of child-directed speech and adult lexical data. They showed, in line with Storkel (2001) and Hollich, Jusczyk & Luce (2002), that neighbourhood density effects relate primarily to the set of (frequent) words that children tend to acquire early. These frequent words also tend to incorporate the language's most frequent sounds and sound combinations. In English, this tendency is compounded by the fact that early-acquired words are also typically short and devoid of phonologically complex structures (e.g. consonant clusters). Building on these results, Coady & Aslin (2003), following an earlier line of criticism against Charles-Luce & Luce (1990) by Dollaghan (1994), argued that in order to distinguish between the phonologically similar words that constitute their early lexicons, children's representations must in fact afford a sufficient level of representational detail. Coady & Aslin (2003) also related this argument to a then-emerging body of experimental evidence in the literature on infant speech perception suggesting that young children's early phonological representations are in fact rich in phonetic detail.

At the forefront of this emerging literature were the studies by Swingley & Aslin (2000) and Swingley & Aslin (2002), who showed that 14-month-old toddlers are able to detect subtle mispronunciations in familiar words, and that this ability does not correlate with measures of vocabulary development. These and experimental results obtained since have led to a reinterpretation of the earlier results reported at the end of the preceding section: "[…] more careful measurements and more sensitive experimental paradigms reveal that very young children do show evidence of sensitivity to segmental lexical information in referential speech perception tasks" (Coady & Aslin 2003:443; see also Ballem & Plunkett 2005; Yoshida et al. 2009). The current view is indeed that early lexical representations contain a high level of perceptual detail, except for phonological contexts where distributional factors independently hinder perception (e.g. Vihman et al. 2004; Swingley 2005; Zamuner 2006; Zamuner 2009; Fikkert, Kerkhoff & Zamuner 2006; see also Zamuner 2011 for a recent discussion of this literature).

White & Morgan (2008) conducted a series of experiments during which 19-month-old infants were presented with pairs of known versus unfamiliar (pictures of) objects, and simultaneously exposed to auditory stimuli falling into one of five categories: correct pronunciations (e.g. [ʃuː] for 'shoe'), mispronunciations affecting a single feature (e.g. [fuː], in which only place of articulation deviates from original 'shoe'), two features (e.g. [vuː], with deviant place and voicing) and three features (e.g. [guː], with deviant place, continuancy and voicing) and, finally, a completely novel, unrelated form (e.g. 'dax'). The results show that infants are in fact extremely sensitive to mispronunciations and, furthermore, that this sensitivity co-varies in a linear fashion with the relative degree of phonological deviance between a familiar word and its mispronounced variant, in ways which are qualitatively similar to adult listeners (e.g. Milberg, Blumstein & Dworetzky 1988; Connine et al. 1997 on gradient perceptual effects in adults).

These results were further supported by Swingley (2009), who summarizes a sizeable body of experiments which also found no correlations between young toddlers' vocabulary sizes and their reaction to mispronounced words (e.g. Swingley, Pinto & Fernald 1999; Swingley & Aslin 2000; Swingley & Aslin 2002; Bailey & Plunkett 2002; Swingley 2003). These results are also in line with word learning experiments, which reveal infants' abilities to learn similar-sounding words at relatively young ages (e.g. Ballem & Plunkett 2005; Yoshida et al. 2009).

In a more recent paper, Ota & Green (2013) further question the relationship between lexical neighbourhoods and the development of phonological abilities. Adopting a survival analysis approach to phonological development, they track longitudinal data from three children documented within the English-Providence corpus available through PhonBank, with the aim of uncovering potential correlations between phonological productive abilities and frequency tendencies observed within the language input received by the learner. They show that lexical input frequency is a significant predictor of the age at which target-like productions of onset cluster types are acquired (see also Sosa & Stoel-Gammon 2012 for a similar observation based on cross-sectional data), however with notable variability related to the segmental make-up of specific clusters. As Ota & Green state: "Taken together with the significant main effects of cluster types, these findings underscore the independent role played by phonological structures in the development of sound production" (Ota & Green 2013:561). We build on this observation below, in order to verify whether the development of individual consonants (as opposed to consonant clusters) may itself be influenced by lexical development. As we will see, particular phones appear to defy predictions based on either frequency or contrastiveness. We first expand on this latter consideration in the next section.

2.3 The questionable relevance of minimal pairs

As many of the studies cited above demonstrate, the vocabularies of young children learning languages like English and Dutch show surprisingly few actual minimal pairs: “these results do not support a strong role for minimal pairs in helping to refine children’s knowledge of the words that were tested” (Swingley 2009:265).

Taken more generally, the traditional notion of minimal pair can in fact be considered more as an easy-to-explain instructional shortcut which is arguably more useful for the instructor teaching phonology than for the learner developing a phonological system. A language like English, with an isolating word structure, a relatively small consonant inventory, and a high number of commonly-used CVC forms, naturally lends itself to a contrastiveness analysis by minimal pairs. However, not all languages display full sets of contrastive minimal pairs, which can be rather elusive in polysynthetic or agglutinating languages, where 'words' are often too long to lend themselves to minimal pair analyses, unless we first break them down into individual morphemic units which themselves may not appear in isolation within spoken forms. Contrastiveness diagnoses via minimal pairs of words also yield rather spotty results in languages with large phonological inventories, for example in Kinyarwanda (Kimenyi 1979) or in !Xóõ (Bradfield 2014), both of which display extremely large inventories of consonants, among other properties. Given this, the only reliable approach to phonological contrastiveness is one that relies on phonological distributions, which can be defined relative to prosodic properties such as stress, word and syllable boundaries: excluding cases of phonetic free variation, a phone is contrastive to the extent that its occurrence is not phonologically predictable within a given environment. This logical conclusion is also reinforced by all models of phonological learning based on phone- and/or feature-level distributional evidence (Lin & Mielke 2008; Mielke 2008; Pierrehumbert

2003; Munson, Edwards & Beckman 2011)[1,2] as well as by experimental evidence on categorical development in the absence of minimal pairs (e.g. Maye & Gerken 2000).

Beyond its reliance on contrastive pairs of words and/or part-words, the LRM has also been criticized for the challenges it poses in the area of falsifiability, which we discuss next.

2.4 Falsifiability

Corpus-based assessments of phonological abilities have been made much easier in recent years, in particular given the programs and data available through the PhonBank project (http://childes.talkbank.org/phon). However, assessments of the composition of young children's lexicons remain methodologically extremely difficult to this day. In a nutshell, how can one precisely assess the level of lexical development for any individual, and especially in young learners? In turn, given that the predictions of the LRM must rely on this type of evidence, how can one verify the validity of these predictions?

As reported by Stokes, Kern & Santos (2011), vocabulary development has largely been assessed from various versions and adaptations of the MacArthur-Bates Communicative Development Inventories (henceforth CDI; Fenson et al. 1993; Fenson, Marchman & Thal 2007). These inventories consist of periodic (typically, monthly) caregiver reports on their children's word usage, which can be used to assess lexical and related phonological characteristics of children's lexicons (see also Storkel 2004; Zamuner 2009; Stokes 2010; Zamuner, Morin-Lessard & Bouchat-Laird 2015). As CDI inventories are limited both by children's potentially low rates of communicative behaviours and/or by non-systematic compliance to the protocol on the part of the

1 In fact, as Seidl & Cristia (2012) point out, Pierrehumbert (2003) suggests that learning models do away with minimal pairs altogether and instead concentrate on positional allophones exclusively. This view underlies the approach to data analysis we pursue below.

2 This consensus across various models departs from the tenets of 'templatic' or 'whole-word' phonology, the functioning of which remains ill-defined in all areas of phonological development 'below' the word level.

children's caregivers, these inventories are likely to underestimate the true extent of the child's lexicon (e.g. Paul 2007).

From a more optimistic perspective, CDI data have also been shown to be generally representative of the most prominent phonological properties of children's lexicons (Rescorla et al. 2005; Heilmann et al. 2005). Given the predictions of the LRM, and that of word-based approaches to phonological development more generally, we should expect to observe at least some degree of convergence between children's phonological development and properties of their developing lexicons. However, as we will see next, our results instead align themselves with the contradictory evidence summarized in section 2.2 above; they suggest that the developmental sequence in production is governed by phonetic and phonological factors, in relative independence of the lexical contents of the children's own vocabularies.

3. Current study

We owe the datasets we analyze below to earlier empirical studies by Dr. Barbara Davis, who conducted parallel documentations of the vocabularies (through CDI reports) and phonological productive abilities (through naturalistic data recordings) of typically-developing children learning American English. We selected two of these children for analysis, Georgia and Charlotte, based on the combined availability of both their CDI and production data over a time span during which they acquired most segmental properties of their target language. The corpora documenting their speech productions are publicly available through PhonBank (http://childes.talkbank.org/phon). Original publications based on these data include Davis & MacNeilage (1995) and Davis, MacNeilage & Matyear (2002). The CDI data were most generously provided to us directly by Dr. Davis.

3.1 Methodology

We first summarize the methods employed by Davis and colleagues in the collection and transcription of these data. We then describe how we organized these corpora for the purpose of our study.

3.1.1 Data collection and transcription

The participants were located by informal referral from the surrounding community. Normal development, including absence of hearing disorders, was established through parental report. The CDI data were collected according to the standard protocol for CDI studies: parents were encouraged to record, at monthly intervals, the words they identified from their children's speech productions, using two supporting inventory questionnaires: *CDI-Words and Gestures* and *CDI-Word and Sentences* (Fenson et al. 1993; Fenson, Marchman & Thal 2007).

CDI data were collected on 37 reports documenting Georgia's expressive vocabulary development between the ages of 0;8.26 and 2;11.25, which includes 13 reports based on the *Words and Gestures* questionnaire, collected until the child turned 1;5, and 24 reports based on the *Words and Sentences* questionnaire). The data for Charlotte consist of 32 reports collected between the child's ages of 1;0.26 and 2;7.23, and include two reports from *Words and Gestures* and 30 reports based on *Words and Sentences*, used from the time the child was 1;3.14). In parallel to CDI data collection, actual speech production samples were gathered through naturalistic recordings, collected during the period spanning the children's late (canonical) babbling and early word production stages, until they were approximately 2;11. These recordings took place in the children’s homes, while they were interacting with their parents or other individuals, also with the experimenter taking part in the interaction at times, however in ways which remained natural and observationally as neutral as possible.

The children's babbles and actual word productions were then transcribed using a combination of IPA characters and diacritics. These transcriptions were later converted for use into the Phon software program (Rose et al. 2006; Rose & MacWhinney 2014), and were linked (time-aligned) to the original audio recordings, which we used every time we deemed important to verify aspects of the original transcriptions.

3.1.2 Corpus preparation and data mining

The CDI reports were provide to us in the form of orthographic data transcripts in Phon format. In order to attain a maximally representative vocabulary profile of each child's lexicon, we supplemented the CDI vocabulary data with the words we found in their speech corpora at each relevant age, and which had not been documented within the CDI reports. As we report below in section 3.2.1, this provided a noticeable addition to our dataset.[3] Using a dictionary of pronounced forms (in citation form) built into Phon, we then assigned IPA transcriptions to each orthographic word represented within each dataset, which provided us with an estimate of the phonological content of the children's vocabularies throughout the development period.[4]

Using algorithms built into Phon, we then labelled all the IPA transcriptions for syllable positions and obtained one-to-one phone alignments between IPA Target (model) forms and their corresponding IPA Actual (produced) forms, which we then verified manually for maximal

3 While this effectively broadened our empirical basis for each child, it remains unclear whether this had a significant impact on the overall shape of the children's developing lexical neighbourhoods. As this comparison transcends the goals of the current study, we leave it for further research, which we hope to perform using computer-assisted methods to become available in the foreseeable future (McAllister Byun & Rose to appear).

4 One technical limitation of this method concerns the relative lack of allophonic detail available in the IPA representations of the citation forms, which imposes a certain level of granularity on the results. This is a limitation that affects every similar study in the field. In our analyses below, we limit our focus to singleton consonants located in syllable onsets, thereby controlling for much of the allophonic variation (e.g. avoiding allophonic variation between onset and coda positions, or within complex syllable constituents).

accuracy. We illustrate these aspects of coding in Figure 1, where we can see the screen shot of a Phon record from Georgia's production corpus. Using these alignments, we tracked all patterns of segmental production, substitution, deletion or epenthesis that occur in the data.

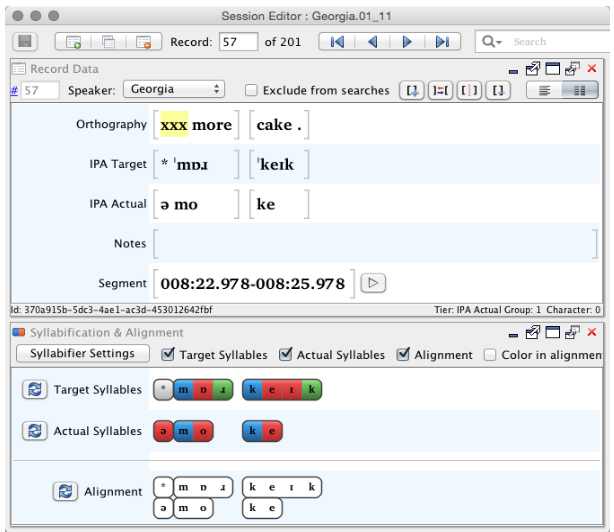

Figure 1: Sample coding within Phon: Syllabification (through colour coding) and phone alignment between target and actual forms

The resulting datasets offer detailed information about the phonological structure and content of the children's developing lexicons as well as representations of their unfolding phonological abilities. Finally, in order to facilitate our comparisons of these two types of longitudinal data, we divided each dataset into one-month periods.

After we completed these preparatory steps, we analyzed the corpora in an attempt to uncover relationships between the lexical and phonological properties of the CDI and production data. From the CDI data we extracted general measures about lexical development and phonological neighbourhoods. From the production data we established the developmental sequence of consonants in syllable onsets. We compare the results of these analyses in the next section.

3.2 Results

We begin with an overview of the two children's general levels of lexical development and overall linguistic productivity. We then continue with more detailed information about both the unfolding of their phonological productive abilities and the content of their developing lexicons.

3.2.1 General measures

As we can see in the next two figures, Georgia was more precocious than Charlotte in the development of her vocabulary. Figure 2 compares the two children based on the CDI data alone, while Figure 3 compares them based on the combined CDI and production data. A closer look at Figure 2 also suggest a jump in vocabulary size for Georgia between 1;09 and 1;10, which however does not appear as salient when all the available data are considered in Figure 3.[5]

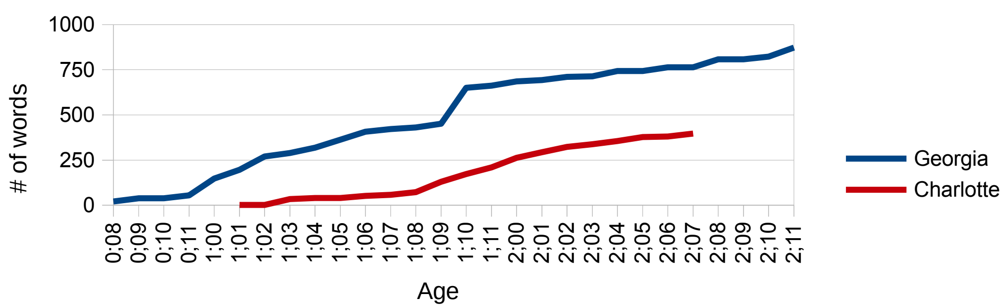

Figure 2: Vocabulary size (CDI data only)

5 Also note that the jump in vocabulary size appears to take place one month earlier in Figure 3; this however is an artifact of data sampling, as CDI reports provide a (monthly-delayed) retrospective assessments of vocabulary development, while production data are associated to the date when they were recorded.

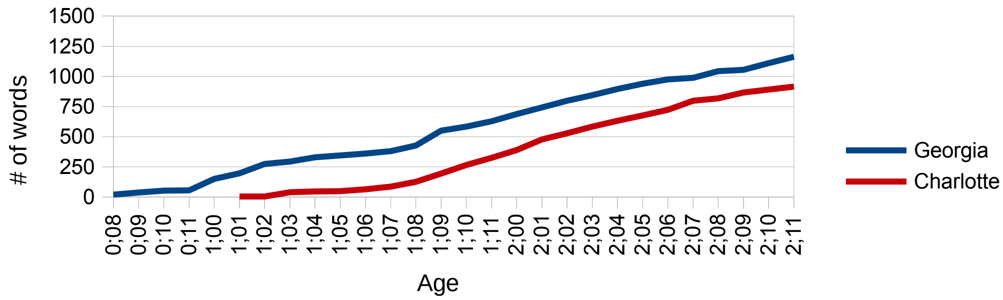

Figure 3: Vocabulary size (number of word types recorded in CDI and production data)

The faster onset and higher rate of vocabulary development displayed by Georgia is also matched by her overall higher level of linguistic productivity, as illustrated in Figure 4 through a comparison between the two children's mean lengths of utterance throughout the period studied.[6]

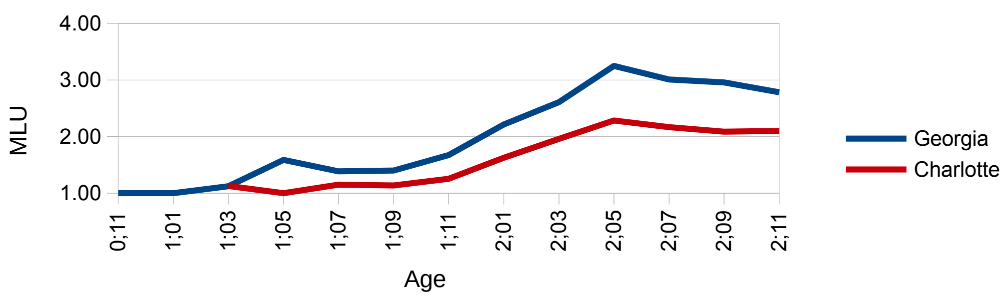

Figure 4: Mean Length of Utterance

In spite of the quantitative differences we observe between the two children, they displayed qualitatively similar developmental curves. As we describe next, the same generally holds true of the development of their articulatory abilities.

6 The relative stabilization of MLU observed in both children's productions at around 30 months of age suggests development in other areas of grammatical development (e.g. MacWhinney 1978; Bowerman 1982 for earlier discussions; McAllister Byun, Inkelas & Rose in press for a recent summary).

3.2.2 Phonological development vs. lexical development

We begin with a summary of Georgia's and Charlotte's patterns in the development of consonants within singleton (i.e. one-consonant) syllable onsets. While other studies focusing on phonological neighbourhood development generally restrict themselves to particular word shapes, for example CVC word forms (e.g. Zamuner 2009), our aim differs in that we are interested in studying the development of phonological productive abilities in light of neighbourhood data. For sake of feasibility, we limited our research to consonants in singleton onsets. We opted for this syllable position based on robust cross-linguistic evidence that onsets typically offer a privileged position for the development of phonological productive abilities, a fact also verified independently in the case of Georgia (Day 2014). Also, while we considered singleton onsets in all word positions (except for /t,d/ in the flapping context), mastery was first attained in word-initial onsets for every consonant where initial vs. medial contexts could be compared at similar ages.

In the interest of clarity, we first report 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. As we can see in Table 1, for both children, early-acquired consonants include all target oral and nasal stops, glides, as well as voiceless, non-dental fricatives. On the other hand, 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.

	Early (prior to 2;00)	**Later** (2;00 or after)	**Not mastered** (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]

Table 1: Georgia's & Charlotte's general phonological development

Keeping these general observations in mind, we now turn to comparisons between consonantal development in production and that of phonological neighbourhoods within each child's lexicon.

Table 2 provides Georgia's phonological neighbourhood data 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 five columns list (a) the relevant target consonants, followed by the child's age when (b) 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, and (e) the number of times each consonant was present in singleton onsets within attempted forms. The remaining columns provide (f) the number of attestations of each consonant within the child's recorded vocabulary at the age of mastery as well as (g) a breakdown of these attestations across five general neighbourhoods, represented by A (low vowels), E (mid front vowels), I (high front vowels), O (mid back vowels) and U (high back vowels).

Target	First attestation in vocabulary	First target-like production	Mastery	Recorded attempts at mastery	Attestations in vocabulary at mastery	Neighbourhoods A	E	I	O	U
b	0;08	0;10	1;00	23	18	9	3	1	3	2
g	0;09	1;00	1;00	2	4	0	1	1	2	0
t	0;08	1;00	1;00	2	9	3	1	2	2	1
m	0;08	1;01	1;01	2	6	2	0	1	3	0
k	0;08	1;02	1;02	9	13	4	1	4	3	1
n	0;08	1;02	1;02	1	9	5	1	0	2	1
p	0;08	1;02	1;02	2	15	3	2	7	2	1
d	0;08	1;04	1;04	1	13	7	0	2	4	0
w	0;08	1;05	1;05	2	13	7	3	1	2	0
ʃ	0;09	1;06	1;06	1	7	0	1	1	4	1
h	0;08	1;05	1;06	17	24	8	5	2	8	1
j	0;08	1;05	1;07	1	4	0	1	0	2	1
s	0;09	1;05	1;07	19	12	3	1	5	3	0
f	0;10	1;09	1;09	8	16	5	1	7	1	2
ʤ	0;08	1;09	1;09	2	8	1	2	2	2	1
ʧ	0;08	1;06	1;10	4	9	2	1	6	0	0
v	1;00	1;00	2;00	25	4	2	2	0	0	0
z	1;02	1;09	2;01	10	2	0	0	2	0	0
l	0;08	1;07	2;03	138	26	10	7	5	2	2
ɹ	0;08	1;06	2;10	609	32	11	9	5	4	3
θ	0;08	1;04	N/A	(39)	(5)	1	0	2	2	0
ð	1;01	1;07	N/A	(1317)	(12)	0	9	2	1	0

Table 2: Georgia's development of consonants in singleton onsets

The first general observation we can draw from this table is that the age at which phones are first attested within the lexicon, irrespective of the neighbourhood data available, 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. 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 we discuss further in section 3.4 below.

Table 3 replicates the same analysis for Charlotte. Again here, and in spite of the sizeable differences in linguistic development observed between the two children in section 3.2.1, the data are no more or less suggestive of a predictive link between lexical and phonological development.

Target	First attestation in vocabulary	First target-like production	Mastery	Recorded attempts at mastery	Attestations in vocabulary at mastery	Neighbourhoods A	E	I	O	U
b	1;01	1;01	1;01	2	1	1	0	0	0	0
p	1;03	1;03	1;03	3	1	0	0	0	1	0
d	1;03	1;03	1;03	3	3	3	0	0	0	0
g	1;03	1;03	1;03	4	1	0	0	0	1	0
m	1;03	1;03	1;03	8	2	1	0	0	0	1
k	1;03	1;03	1;04	8	2	1	0	1	0	0
j	1;04	1;04	1;04	1	1	1	0	0	0	0
n	1;01	1;05	1;05	1	2	1	0	0	1	0
w	1;05	1;05	1;05	1	1	0	0	0	1	0
h	1;03	1;07	1;07	6	6	2	2	0	2	0
s	1;03	1;08	1;08	4	3	1	0	1	1	0
ʃ	1;03	1;09	1;09	2	4	1	1	0	1	1
t	1;03	1;08	1;09	11	7	1	1	1	3	1
f	1;09	1;09	1;11	9	6	1	0	3	1	1
z	1;07	2;03	2;05	12	2	0	0	0	1	1
ʤ	1;08	1;11	2;07	43	10	1	5	0	2	2
l	1;10	1;11	2;07	186	21	9	4	5	1	2
θ	1;03	2;01	2;09	66	6	2	1	2	1	0
v	1;09	2;02	2;09	26	4	2	2	0	0	0
ð	1;07	1;08	N/A	(746)	(9)	0	6	2	1	0
ʧ	1;09	1;09	N/A	(59)	(17)	3	5	7	2	0
ɹ	1;08	2;06	N/A	(361)	(25)	7	8	4	4	2

Table 3: Charlotte's development of consonants in singleton onsets

Charlotte, in line with her lower rate of vocabulary development and mean lengths of utterance observed throughout the observation period, also acquires each target consonant at a slower rate than Georgia. However, as already reported in Table 1 above, aside from more noticeable difficulties with target affricates, the unfolding of her articulatory abilities is very similar to that of Georgia.

The data also generally fail to support the hypothesis that contrastiveness within the developing lexicon drives phonological development. At the time of mastery, some consonants (e.g. [b, h, l, ɹ]) are found in a large number of phonological neighbourhoods in Georgia's vocabulary, while others appear in only a few neighbourhoods [g, j, v, z]. The same holds true of Charlotte's data.

3.2.3 Phonological development vs. usage frequency

As usage-based approaches to language development suggest, it is possible that the figures reported above were skewed by frequency pressures, which could have steered developmental patterns away from purely lexical effects (e.g. Tomasello 2003; Vihman & Croft 2007; Lieven 2010; Ambridge & Lieven 2011; Ambridge et al. 2015; Vihman 2014). However, this possibility is also hardly supported by the numbers of attempts available in each corpus: some consonants are acquired in spite of their being seldom recorded in attempted forms, while others show late development in spite of relatively high numbers of occurrence within target forms. In fact, as both Day (2014, 2015) and (Blackmore in preparation) suggest, the only prediction borne out by these datasets is that, by the time a given consonant is mastered, this consonant was already attested in at least *some* actual productions, either within babbles or actual word forms.[7] While this observation may be taken as support for McCune & Vihman's (2001) proposal that productivity predicts development, Day (2014, 2015) shows that this relation is not entirely straightforward: a child may very well produce a phone in babbles without being able to reproduce a similar phone (at least as perceived by human transcribers) in actual word productions. Productivity of a certain phone thus appears to be a condition, rather than a guarantee, for its mastery within word productions (see also Sosa & Stoel-Gammon 2006, 2012; Sosa 2013 and references therein for related discussion). These observations by Day and Blackmore are in line with outcomes of other studies available in the literature, which generally fail to support usage frequency as the driving force behind phonological development in

7 We do not report on these data here as they transcend the scope of the current analysis.

production, even though frequency pressures may at times yank development patterns in particular directions (Kehoe & Lleó 2003; Demuth 2007; Edwards & Beckman 2008; Rose 2009; Ota & Green 2013; see also Brown 1973 for an early criticism of frequency-based explanations, and Rose & Inkelas 2011 for additional discussion). For example, back to the data reported above in Table 2 and Table 3, we can hypothesize that the slow development of the voiced fricatives [z, v], relative to their voiceless counterparts, is at least in part influenced by the low frequency of these consonants in the language. These results for Georgia and Charlotte suggest a role for practice in phonological development, a factor highlighted in many recent analyses of phonological development (e.g. Inkelas & Rose 2007; Stoel-Gammon 2011; Vihman & Keren-Portnoy 2011; Menn, Schmidt & Nicholas 2013; Vihman 2014; McAllister Byun, Inkelas & Rose in press). However, the way and extent to which practice actually influences phonological development remains to be explored in more detail, for example in terms of how it can help the child shape stable production patterns for different perceptual categories, a point we take up again in our general discussion below.

3.3 Interim summary

Together, the results we report above conspire against views which attribute a central role for the lexicon and lexical neighbourhoods in children's phonological development. That is not to say that the lexicon is not important: beyond default articulations dictated by bio-mechanical aspects of the vocal tract (e.g. MacNeilage & Davis 1990a,b; MacNeilage & Davis 2000), the commonly-held view that sounds must be represented within lexical forms in order to be acquired remains central. However, trajectories of phonological development appear to transcend information about both phonological neighbourhoods and usage frequency. As we discuss further below, these factors might instead be reflected in processing measures of production, as opposed to articulatory measures, for example in terms of reaction times across various stages of development or concerning the emergence of phonological awareness.

3.4 The emergence of phonology as an independent system

The observations in section 3.2 more convincingly point at the relative independence of phonology as an emergent component within the children's developing systems. Within the literature on infant speech perception, the existence of separate domains within the child's system has recently been formalized within the PRIMIR framework (Processing Rich Information from Multi-dimensional Interactive Representations; Werker & Curtin 2005; Curtin, Byers-Heinlein & Werker 2011; see also Zamuner 2009 for additional discussion). Within PRIMIR, the input signal is processed along formally independent yet inter-related levels, called 'planes'. While the original proposal focuses on the 'General-Perceptual', 'Word', and 'Phoneme' planes, Werker, Curtin and colleagues suggest that the system can accommodate as many planes as needed to encode relevant properties of the ambient language, as they are identified by the learner. Unavoidably, this must include representations for the types of motor-acoustic pairings central to the reproduction of perceptual phonological categories in spoken forms. This is the locus of the A-map model (McAllister Byun, Inkelas & Rose in press), a novel proposal which supplements PRIMIR in the area of phonological production. Building on many of the assumptions behind the Linked-Attractor model (Menn, Schmidt & Nicholas 2009), one of the aims of the A-map is to formally capture the development of abstract associations between the perceptual categories identified by the child and the articulatory dimensions involved in their reproduction within speech forms (e.g. Halle & Stevens 1959; Halle & Stevens 1962; Halle & Stevens 1979; Keyser & Stevens 2006; Stevens & Keyser 2010).

Recall from Table 1 that both Georgia and Charlotte acquired all target oral and nasal stops as well as glides relatively early, and also mastered non-dental voiceless fricatives before dental and/or voiced ones. Recall as well that Charlotte showed difficulties mastering the production of target [ʧ] and [ʤ]. As we shift our focus away from the lexicon and consider these data from a phonological standpoint, it is striking that all of these observations point to natural classes effects which are firmly established within the literature on phonological theory (Clements & Ridouane 2006; Mielke 2008; Mielke 2011; Lin & Mielke 2008). In spite of potential effects from frequency such as those noted above concerning [z] and [v], the general developmental patterns observed in both children's data are generally in line with expectations about consonantal development, namely that obstruent stops, nasal, and glides be mastered early, and that fricatives, affricates, and liquids be acquired at later stages, also including the contrast between alveolar and dental fricatives (e.g. Smit 1993; Bernhardt & Stemberger 1998; Sosa 2013). The same logic applies to the main patterns of substitution displayed by each child during pre-mastery stages, listed in Table 4. As we can see from these data, most substitutions involve simple phonetic attributes, for example with regard to obstruent voicing, liquid rhoticity and laterality, or, specific to Charlotte, the fricative release required in the production of affricates.

Substitution pattern	Georgia	Charlotte
Devoicing	|v| → [f]	
	|z| → [s]	
Stopping		|v| → [p/b]
		|z| → [d]
		|θ| → [d]
		|ð| → [d]
De-dentalization	|θ| → [f]	|θ| → [s]
	|ð| → [d]	
Gliding	|l| → [w]	|l| → [w]
	|ɹ| → [w]	|ɹ| → [w]
De-affrication		|ʤ| → [d]
		|ʧ| → [t]

Table 4: Georgia's and Charlotte's main substitution patterns prior to mastery

The categorical nature of these patterns supports a view of phonology as an independent system. While the lexicon supplies the child with target word forms, including the sounds and sound combinations contained within these forms, the data suggests that the articulatory mastery of these phonological units is not crucially dependent on the structure of the child's developing lexicon.

4. Discussion

These results in fact nicely converge with those from infant speech perception studies reported in section 2.2, which suggest that the content of the child's lexicon cannot be taken as the main driver of phonological productive abilities. Instead, the degree of phonetic detail memorized for each word form, and also across different phonological positions within these words, appears to supply the relevant information, independent of functional contrastiveness. While sparse lexicons cannot supply the learner with all of the information relevant to building an abstract system of contrasts, it does provide perceptual targets which children must attempt to reproduce through their own speech-motor articulations. As McAllister Byun, Inkelas & Rose (in press) argue, articulatory productivity depends on the stability of these sensory-motor mappings across word productions, even in case these mappings are inaccurate and result in phonological substitutions. Together, these observations also suggest that functional contrastiveness, and its relation to phonological awareness, arguably emerge at a later stage, as the child's gradually climbs the phonological 'ladder of abstraction' (Munson, Edwards & Beckman 2011; see also Pierrehumbert 2003).

Returning briefly to the phenomenon of selection and avoidance discussed in introduction, the results and discussion above suggest that the child's awareness of his/her own phonological articulatory abilities, rather than the actual content of their lexicons, might be at the source of these behaviours (Ferguson & Farwell 1975; Menn, Schmidt & Nicholas 2009).[8] A formal separation between the lexical and phonological components of the child's developing system is also compatible with the observation we made in introduction that children appear to stop employing selection and avoidance strategies relatively early: as soon as they have developed reliable sensory-motor mappings for the speech sounds present in the word forms contained in their lexicon, they no longer need to avoid these forms in production. As the development of these mappings does not need to rely on lexical development per se, assuming the presence of a basic lexicon, selection and avoidance behaviours can be resolved relatively early.

Importantly, however, our argument is not to dismiss the theoretical or practical relevance of the lexicon and phonological neighbourhoods in other areas of phonological representation and processing. Rich phonological neighbourhoods such as those which characterize the lexicons of more advanced child learners or adult speakers indeed constitute powerful networks for the processing of phonological representations, whose effects have been noted in tasks such as word learning, lexical retrieval, and the detection of speech errors (e.g. Storkel 2006; Storkel,

8 Of course, as noted in the relevant literature, these behaviours are arguably governed by a number of non-linguistic, personality-related traits which may also yield different degrees of self-censorship on the part of different children.

Armbruster & Hogan 2006; Storkel 2011; White & Morgan 2008; see also Stamer & Vitevitch 2012; Chan & Vitevitch 2015 for similar observations in second language development). Behavioural differences in phonological processing observed across different age groups may also be tied to the relative degree of inter-connectedness within lexicons, for which lexicon size does matter, as suggested in much of the literature summarized in section 2.2 (see also Pierrehumbert 2003, Munson, Kurtz & Windsor 2005, and references therein for additional discussion).

Finally, our argument is compatible with the view recently expressed by Sosa & Stoel-Gammon (2012) that "[i]t may be that in young children, both metrics [vocabulary size and phonological knowledge] assess the same construct: the degree of abstract phonemic knowledge" (p. 605). We contend, however, that while this must be true if the productive lexicon is used as a metric of vocabulary size, it remains unclear whether this claim can be extended to the receptive lexicon, the size of which is arguably larger across all developmental stages. This question, as well as further explorations of the relationships between lexical knowledge and phonological development, call for the incorporation of additional measures of the children's productive and receptive lexicons, which we hope to consider in future research.

References

Ainsworth, Stephanie, Stephen Welbourne & Anne Hesketh. 2015. Lexical Restructuring in Preliterate Children: Evidence from Novel Measures of Phonological Representation. *Applied Psycholinguistics*. 1–27. doi:10.1017/S0142716415000338.

Almeida, Letícia. 2011. Acquisition de la structure syllabique en contexte de bilinguisme simultané portugais-français. Lisbon: Universidade de Lisboa Ph.D. Dissertation.

Ambridge, Ben, Evan Kidd, Caroline F. Rowland & Anna L. Theakston. 2015. The Ubiquity of Frequency Effects in First Language Acquisition. *Journal of Child Language* 42(02). 239–273. doi:10.1017/S030500091400049X.

Ambridge, Ben & Elena V.M. Lieven. 2011. *Child Language Acquisition: Contrasting Theoretical Approaches*. Cambridge: Cambridge University Press.

Bailey, Todd M. & Kim Plunkett. 2002. Phonological Specificity in Early Words. *Cognitive Development* 17. 1267–1284.
Ballem, Kate D. & Kim Plunkett. 2005. Phonological Specificity in Children at 1;2. *Journal of Child Language* 32(1). 159–173. doi:10.1017/S0305000904006567.
Barlow, Jessica A. 1997. A Constraint-Based Account of Syllable Onsets: Evidence from Developing Systems. Indiana University Ph.D. Dissertation.
Benedict, Helen. 1979. Early Lexical Development: Comprehension and Production. *Journal of Child Language* 6(2). 183–200.
Bernhardt, Barbara H. & Joseph P. Stemberger. 1998. *Handbook of Phonological Development from the Perspective of Constraint-Based Nonlinear Phonology*. San Diego: Academic Press.
Blackmore, Sarah. in preparation. Exploring Formal Relationships Between Lexical and Phonological Development. Memorial University of Newfoundland M.A. Thesis.
Bowerman, Melissa. 1982. Starting to Talk Worse: Clues to Language Acquisition from Children's Late Speech Errors. In Sidney Strauss (ed.), *U-shaped Behavioral Growth*. New York: Academic Press.
Bradfield, Julian. 2014. Clicks, Concurrency and Khoisan. *Phonology* 31(1). 1–49. doi:10.1017/S0952675714000025.
Brown, Roger. 1973. *A First Language: The Early Stages*. Cambridge, MA: Harvard University Press.
Chan, Kit Ying & Michael S. Vitevitch. 2015. The influence of neighborhood density on the recognition of Spanish-accented words. *Journal of Experimental Psychology: Human Perception and Performance* 41(1). 69–85. doi:10.1037/a0038347.
Charles-Luce, Jan & Paul A. Luce. 1990. Similarity Neighbourhoods of Words in Young Children's Lexicons. *Journal of Child Language* 17(1). 205–215.
Clements, George N. & Rachid Ridouane. 2006. Quantal Phonetics and Distinctive Features: a Review. In Antonis Botinis (ed.), *Proceedings of the ISCA Tutorial and Research Workshop on Experimental Linguistics*, 17–24. Athens: University of Athens.
Coady, Jeffry A. & Richard N. Aslin. 2003. Phonological Neighbourhoods in the Developing Lexicon. *Journal of Child Language* 30(2). 441–469. doi:10.1017/S0305000903005579.
Connine, Cynthia M., Debra Titone, Thomas Deelman & Dawn Blasko. 1997. Similarity Mapping in Spoken Word Recognition. *Journal of Memory and Language* 37(4). 463–480.
Curtin, Suzanne, Krista Byers-Heinlein & Janet F. Werker. 2011. Bilingual Beginnings as a Lens for Theory Development: PRIMIR in Focus. *Journal of Phonetics* 39(4). 492–504.
Curtin, Suzanne & Tania S. Zamuner. 2014. Understanding the Developing Sound System: Interactions Between Sounds and Words. *Wiley Interdisciplinary Reviews: Cognitive Science* 5(5). 589–602. doi:10.1002/wcs.1307.
Davis, Barbara L. & Peter F. MacNeilage. 1995. The Articulatory Basis of Babbling. *Journal of Speech and Hearing Research* 38(6). 1199–1211.
Davis, B. L., P. F. MacNeilage & C. L. Matyear. 2002. Acquisition of serial complexity in speech production: a comparison of phonetic and phonological approaches to first word production. *Phonetica* 59(2-3). 75–107.
Day, Kayla. 2014. Exploring Phonological Relationships between Babbling and Early Word Productions. Memorial University of Newfoundland M.A. Thesis.
Day, Kayla. 2015. Babbling as a Potential Predictor of Difficulty in Segmental Acquisition. Poster. Paper presented at the International Child Phonology Conference, St. John's, Canada.

Demuth, Katherine. 2007. The Role of Frequency in Language Acquisition. In Insa Gülzow & Natalia Gagarina (eds.), *Frequency Effects in Language Acquisition*, 528–538. Berlin: Mouton de Gruyter.

Dollaghan, Christine A. 1994. Children's Phonological Neighbourhoods: Half Empty or Half Full? *Journal of Child Language* 21(2). 257–271.

Edwards, Jan & Mary E. Beckman. 2008. Some Cross-Linguistic Evidence for Modulation of Implicational Universals by Language-Specific Frequency Effects in Phonological Development. *Language Learning and Development* 4(2). 122–156. doi:10.1080/15475440801922115.

Fenson, Larry, Philip S. Dale, J. Stephen Reznick & Elizabeth Bates. 1993. *MacArthur Communicative Development Inventories: User's Guide and Technical Manual W/Test Forms*. Singular Publishing Group.

Fenson, Larry, Virginia A. Marchman & Donna Thal. 2007. *MacArthur-Bates Communicative Development Inventories: User's Guide and Technical Manual*. Paul H. Brookes Publishing Company.

Ferguson, Charles A. & Carol B. Farwell. 1975. Words and Sounds in Early Language Acquisition. *Language* 51. 419–439.

Fikkert, Paula. 1994. *On the Acquisition of Prosodic Structure*. (HIL Dissertations in Linguistics 6). The Hague: Holland Academic Graphics.

Fikkert, Paula, Annemarie Kerkhoff & Tania S. Zamuner. 2006. Acquisition of Voicing Neutralization and Alternations in Dutch.

Goad, Heather & Yvan Rose. 2004. Input Elaboration, Head Faithfulness and Evidence for Representation in the Acquisition of Left-edge Clusters in West Germanic. In René Kager, Joe Pater & Wim Zonneveld (eds.), *Constraints in Phonological Acquisition*, 109–157. Cambridge: Cambridge University Press.

Halle, Morris & Kenneth N. Stevens. 1959. Analysis by Synthesis. In W. Wathen-Dunn & L.E. Woods (eds.), *Proceedings of the Seminar on Speech Compression and Processing*, D7. USAF Cambridge Resource Center.

Halle, Morris & Kenneth N. Stevens. 1962. Speech Recognition: A Model and a Program for Research. *IRA Transactions of the PGIT, IT-8*. 155–159.

Halle, Morris & Kenneth N. Stevens. 1979. Some Reflexions on the Theoretical Bases of Phonetics. In Björn Lindblom, Sven E. G. Öhman & Gunnar Fant (eds.), *Frontiers of Speech Communication Research*, 335–349. New York: Academic Press.

Hallé, Pierre A. & Bénédicte de Boysson-Bardies. 1994. Emergence of an Early Receptive Lexicon: Infants' Recognition of Words. *Infant Behavior and Development* 17. 119–129.

Hallé, Pierre A. & Bénédicte de Boysson-Bardies. 1996. The Format of Representation of Recognized Words in Infants' Early Receptive Lexicon. *Infant Behavior and Development* 19. 463–481.

Heilmann, John, Susan Ellis Weismer, Julia Evans & Christine Hollar. 2005. Utility of the MacArthur-Bates Communicative Development Inventory in Identifying Language Abilities of Late-Talking and Typically Developing Toddlers. *American Journal of Speech-Language Pathology* 14(1). 40–51.

Hollich, George, Peter W. Jusczyk & Paul A. Luce. 2002. Lexical Neighborhood Effects in 17-Month-Old Word Learning. *Proceedings of the Annual Boston University Conference on Language Development* 26(1). 314–323.

Inkelas, Sharon & Yvan Rose. 2007. Positional Neutralization: A Case Study from Child Language. *Language* 83(4). 707–736.

Kehoe, Margaret. 2015. Lexical-Phonological Interactions in Bilingual Children. *First Language* 35(2). 93–125. doi:10.1177/0142723715574398.
Kehoe, Margaret & Conxita Lleó. 2003. A Phonological Analysis of Schwa in German First Language Acquisition. *The Canadian Journal of Linguistics / La revue canadienne de linguistique* 48(3/4). 289–327.
Keyser, Samuel Jay & Kenneth N. Stevens. 2006. Enhancement and Overlap in the Speech Chain. *Language* 82(1). 33–63. doi:10.1353/lan.2006.0051.
Kimenyi, Alexandre. 1979. *Studies in Kinyarwanda and Bantu Phonology*. . Vol. 33. (Current Inquiry into Language and Linguistics). Edmonton, Canada: Linguistic Research.
Leonard, Laurence B., Richard G. Schwartz, Barbara Morris & Kathy Chapman. 1981. Factors Influencing Early Lexical Acquisition: Lexical Orientation and Phonological Composition. *Child Development* 52(3). 882–887.
Leopold, Werner F. 1947. *Speech Development of a Bilingual Child: A Linguist's Record, Vol. 2: Sound-learning in the First Two Years*. Evantson, IL: Northwest University Press.
Levelt, Clara. 1994. *On the Acquisition of Place*. (HIL Dissertations in Linguistics 8). The Hague: Holland Academic Graphics.
Lieven, Elena. 2010. Input and First Language Acquisition: Evaluating the Role of Frequency. *Lingua* 120(11). 2546–2556.
Lin, Ying & Jeff Mielke. 2008. Discovering Place and Manner Features: What can be Learned from Acoustic and Articulatory Data. *University of Pennsylvania Working Papers in Linguistics* 14(1). 19.
Luce, Paul A. & David B. Pisoni. 1998. Recognizing Spoken Words: The Neighborhood Activation Model. *Ear and Hearing* 19(1). 1–36.
MacNeilage, Peter F. & Barbara L. Davis. 1990a. Acquisition of Speech Production: Frames, then Content. In Marc Jeannerod (ed.), *Attention and Performance XIII: Motor Representation and Control*, 453–476. Hillsdale, NJ: Lawrence Erlbaum.
MacNeilage, Peter F. & Barbara L. Davis. 1990b. Acquisition of Speech Production: The Achievement of Segmental Independence. In William J. Hardcastle & Alain Marchal (eds.), *Speech Production and Modeling*, 55–68. Dordrecht: Kluwer Academic Publishers.
MacNeilage, Peter F. & Barbara L. Davis. 2000. On the Origin of Internal Structure of Word Forms. *Science* 288. 527–531.
MacWhinney, Brian. 1978. *The Acquisition of Morphophonology*. Chicago: University of Chicago Press.
Maye, Jessica & LouAnn Gerken. 2000. Learning Phonemes without Minimal Pairs. In S. Catherine Howell, Sarah A. Fish & Thea Keith-Lucas (eds.), *Proceedings of the 24th Annual Boston University Conference on Language Development*, 522–533.
McAllister Byun, Tara. 2009. The Articulatory Basis of Positional Asymmetries in Phonological Acquisition. Massachusetts Institute of Technology Ph.D. Dissertation.
McAllister Byun, Tara, Sharon Inkelas & Yvan Rose. in press. The A-map Model: Articulatory Reliability in Child-specific Phonology. *Language*.
McAllister Byun, Tara & Yvan Rose. to appear. Analyzing Clinical Phonological Data Using Phon. *Seminars in Speech and Language*.
McCune, Lorraine & Marilyn M. Vihman. 2001. Early Phonetic and Lexical Development: A Productivity Approach. *Journal of Speech, Language, and Hearing Research* 44(3). 670–684.
Menn, Lise. 1971. Phonotactic Rules in Beginning Speech: A Study in the Development of English Discourse. *Lingua* 26. 225–251.

Menn, Lise, Ellen Schmidt & Brent Nicholas. 2009. Conspiracy and Sabotage in the Acquisition of Phonology: Dense Data Undermine Existing Theories, Provide Scaffolding for a New One. *Language Sciences* 31(2-3). (Data and Theory: Papers in Phonology in Celebration of Charles W. Kisseberth). 285–304.

Menn, Lise, Ellen Schmidt & Brent Nicholas. 2013. Challenges to Theories, Charges to a Model: The Linked-Attractor Model of Phonological Development. In Marilyn M. Vihman & Tamar Keren-Portnoy (eds.), *The Emergence of Phonology: Whole-word Approaches and Cross-linguistic Evidence*, 460–502. Cambridge: Cambridge University Press.

Menyuk, Paula & Lise Menn. 1986. Early Strategies for the Perception and Production of Words and Sounds. In Paul Fletcher & Michael Garman (eds.), *Language Acquisition: Studies in First Language Development*, 198–222. 2nd Edition. Cambridge: Cambridge University Press.

Metsala, Jamie L. 1997. An Examination of Word Frequency and Neighborhood Density in the Development of Spoken-Word Recognition. *Memory & Cognition* 25(1). 47–56. doi:10.3758/BF03197284.

Metsala, Jamie L. & Amanda C. Walley. 1998. Spoken Vocabulary Growth and the Segmental Restructuring of Lexical Representations: Precursors to Phonemic Awareness and Early Reading Ability. In Jamie L. Metsala & Linnea C. Ehri (eds.), *Word Recognition in Beginning Literacy*, 89–120. Mahwah, NJ: Lawrence Erlbaum Associates.

Mielke, Jeff. 2008. *The Emergence of Distinctive Features*. Oxford: Oxford University Press.

Mielke, Jeff. 2011. Distinctive Features. In Colin J. Ewen, Elizabeth Hume, Marc van Oostendorp & Keren Rice (eds.), *The Blackwell Companion to Phonology*, 391–415. Malden, MA: Wiley-Blackwell.

Milberg, William, Sheila Blumstein & Barbara Dworetzky. 1988. Phonological Factors in Lexical Access: Evidence from an Auditory Lexical Decision Task. *The Bulletin of the Psychonomic Society* 26(4). 305–308.

Munson, Benjamin, Jan Edwards & Mary E. Beckman. 2011. Phonological Representations in Language Acquisition: Climbing The Ladder of Abstraction. In Abigail C. Cohn, Cécile Fougeron & Marie K. Huffman (eds.), *The Oxford Handbook of Laboratory Phonology*, 288–309. Oxford University Press.

Munson, Benjamin, Beth A. Kurtz & Jennifer Windsor. 2005. The Influence of Vocabulary Size, Phonotactic Probability, and Wordlikeness on Nonword Repetitions of Children with and without Specific Language Impairment. *Journal of Speech, Language, and Hearing Research* 48(5). 1033–1047.

Ota, Mitsuhiko & Sam J. Green. 2013. Input Frequency and Lexical Variability in Phonological Development: A Survival Analysis of Word-initial Cluster Production. *Journal of Child Language* 40(03). 539–566.

Paul, Rhea. 2007. *Language Disorders from Infancy Through Adolescence: Assessment & Intervention*. Elsevier Health Sciences.

Pierrehumbert, Janet B. 2003. Phonetic Diversity, Statistical Learning, and Acquisition of Phonology. *Language and Speech* 46(2-3). 115–154.

Rescorla, Leslie, Nan Bernstein Ratner, Peter Jusczyk & Anne Marie Jusczyk. 2005. Concurrent Validity of the Language Development Survey: Associations with the MacArthur-Bates Communicative Development Inventories: Words and Sentences. *American Journal of Speech-Language Pathology* 14(2). 156–163.

Rose, Yvan. 2000. Headedness and Prosodic Licensing in the L1 Acquisition of Phonology. McGill University Ph.D. Dissertation.

Rose, Yvan. 2009. Internal and External Influences on Child Language Productions. In François Pellegrino, Egidio Marsico, Ioana Chitoran & Christophe Coupé (eds.), *Approaches to Phonological Complexity*, 329–351. Berlin: Mouton de Gruyter.

Rose, Yvan & Sharon Inkelas. 2011. The Interpretation of Phonological Patterns in First Language Acquisition. In Colin J. Ewen, Elizabeth Hume, Marc van Oostendorp & Keren Rice (eds.), *The Blackwell Companion to Phonology*, 2414–2438. Malden, MA: Wiley-Blackwell.

Rose, Yvan & Brian MacWhinney. 2014. The PhonBank Project: Data and Software-Assisted Methods for the Study of Phonology and Phonological Development. In Jacques Durand, Ulrike Gut & Gjert Kristoffersen (eds.), *The Oxford Handbook of Corpus Phonology*, 380–401. Oxford: Oxford University Press.

Rose, Yvan, Brian MacWhinney, Rodrigue Byrne, Gregory Hedlund, Keith Maddocks, Philip O'Brien & Todd Wareham. 2006. Introducing Phon: A Software Solution for the Study of Phonological Acquisition. In David Bamman, Tatiana Magnitskaia & Colleen Zaller (eds.), *Proceedings of the 30th Annual Boston University Conference on Language Development*, 489–500. Somerville, MA: Cascadilla Press.

Saffran, Jenny R. & Katharine Graf Estes. 2006. Mapping Sound to Meaning: Connections Between Learning About Sounds and Learning About Words. In Robert V. Kail (ed.), *Advances in Child Development and Behavior*, 1–38. New York: Elsevier.

Santos, Christophe dos. 2007. Développement phonologique en français langue maternelle: une étude de cas. Université Lumière Lyon 2 Ph.D. Dissertation.

Schwartz, Richard G. & Larry B. Leonard. 1982. Do Children Pick and Choose? An Examination of Phonological Selection and Avoidance. *Journal of Child Language* 9. 319–336.

Seidl, Amanda & Alejandrina Cristia. 2012. Infants' Learning of Phonological Status. *Frontiers in Psychology* 3. doi:10.3389/fpsyg.2012.00448. http://journal.frontiersin.org/article/10.3389/fpsyg.2012.00448/abstract.

Smit, Ann Bosma. 1993. Phonologic Error Distribution in the Iowa-Nebraska Articulation Norms Project: Consonant Singletons. *Journal of Speech and Hearing Research* 36. 533–547.

Smith, Neilson V. 1973. *The Acquisition of Phonology: A Case Study*. Cambridge: Cambridge University Press.

Sosa, Anna V. 2013. Transitions to First Words. In Beate Peter & Andrea MacLeod (eds.), *Comprehensive Perspectives on Speech Sound Development and Disorders: Pathways from Linguistic Theory to Clinical Practice*, 135–149. New York: Nova Publishers. http://site.ebrary.com/id/10704287.

Sosa, Anna Vogel & Carol Stoel-Gammon. 2006. Patterns of Intra-word Phonological Variability during the Second Year of Life. *Journal of Child Language* 33(01). 31. doi:10.1017/S0305000905007166.

Sosa, Anna V. & Carol Stoel-Gammon. 2012. Lexical and Phonological Effects in Early Word Production. *Journal of Speech, Language, and Hearing Research* 55(2). 596–608.

Stamer, Melissa K. & Michael S. Vitevitch. 2012. Phonological Similarity Influences Word Learning in Adults Learning Spanish as a Foreign Language. *Bilingualism* 15(3). 490–502. doi:10.1017/S1366728911000216.

Stevens, Kenneth N. & Samuel J. Keyser. 2010. Quantal Theory, Enhancement and Overlap. *Journal of Phonetics* 38(1). 10–19.

Stoel-Gammon, Carol. 2011. Relationships between Lexical and Phonological Development in Young Children. *Journal of Child Language* 38(1). 1–34.

Stoel-Gammon, Carol & Judith A. Cooper. 1984. Patterns of Early Lexical and Phonological Development. *Journal of Child Language* 11. 247–271.
Stokes, Stephanie F. 2010. Neighborhood Density and Word Frequency Predict Vocabulary Size in Toddlers. *Journal of Speech, Language, and Hearing Research* 53(3). 670–683.
Stokes, Stephanie F., Sophie Kern & Christophe Dos Santos. 2011. Extended Statistical Learning as an Account for Slow Vocabulary Growth. *Journal of Child Language* 39(1). 105–129.
Storkel, Holly L. 2001. Learning New Words: Phonotactic Probability in Language Development. *Journal of Speech, Language, and Hearing Research* 44(6). 1321–1337.
Storkel, Holly L. 2002. Restructuring of Similarity Neighbourhoods in the Developing Mental Lexicon. *Journal of Child Language* 29(2). 251–274.
Storkel, Holly L. 2003. Learning New Words II: Phonotactic Probability in Verb Learning. *Journal of Speech, Language, and Hearing Research* 46(6). 1312–1323.
Storkel, Holly L. 2004. Do Children Acquire Dense Neighborhoods? An Investigation of Similarity Neighborhoods in Lexical Acquisition. *Applied Psycholinguistics* 25(2). 201–221. doi:10.1017.S0142716404001109.
Storkel, Holly L. 2006. Do Children Still Pick and Choose? The Relationship between Phonological Knowledge and Lexical Acquisition Beyond 50 Words. *Clinical Linguistics & Phonetics* 20(7-8). 523–529.
Storkel, Holly L. 2011. Differentiating Word Learning Processes May Yield New Insights – a Commentary on Stoel-Gammon's "Relationships Between Lexical and Phonological Development in Young Children." *Journal of Child Language* 38(1). 51–55. doi:10.1017/S0305000910000486.
Storkel, Holly L., Jonna Armbruster & Tiffany P. Hogan. 2006. Differentiating Phonotactic Probability and Neighborhood Density in Adult Word Learning. *Journal of Speech, Language, and Hearing Research* 49(6). 1175–1192.
Swingley, Daniel. 2003. Phonetic Detail in the Developing Lexicon. *Language and Speech* 46(2-3). 265–294.
Swingley, Daniel. 2005. 11-Month-Olds' Knowledge of How Familiar Words Sound. *Developmental science* 8(5). 432–443.
Swingley, Daniel. 2009. Onsets and Codas in 1.5-Year-Olds' Word Recognition. *Journal of Memory and Language* 60. 252–269.
Swingley, Daniel & Richard N. Aslin. 2000. Spoken Word Recognition and Lexical Representation in Very Young Children. *Cognition* 76(2). 147–166.
Swingley, Daniel & Richard N. Aslin. 2002. Lexical Neighborhoods and the Word-form Representations of 14-month-olds. *Psychological Science* 13(5). 480–484.
Swingley, Daniel & Richard N. Aslin. 2007. Lexical Competition in Young Children's Word Learning. *Cognitive Psychology* 54(2). 99–132. doi:10.1016/j.cogpsych.2006.05.001.
Swingley, Daniel, John P. Pinto & Anne Fernald. 1999. Continuous Processing in Word Recognition at 24 Months. *Cognition* 71(2). 73–108.
Tomasello, Michael. 2003. *Constructing a Language: A Usage-based Theory of Language Acquisition*. Cambridge: Harvard University Press.
Vihman, Marilyn & Tamar Keren-Portnoy. 2011. The Role of Production Practice in Lexical and Phonological Development – a Commentary on Stoel-Gammon's "Relationships Between Lexical and Phonological Development in Young Children." *Journal of Child Language* 38(1). 41–45. doi:10.1017/S0305000910000504.
Vihman, Marilyn M. 2014. *Phonological Development: The First Two Years*. Second Edition. Hoboken: Wiley-Blackwell.

Vihman, Marilyn M. & William Croft. 2007. Phonological Development: Toward a “Radical” Templatic Phonology. *Linguistics* 45(4). 683–725.
Vihman, Marilyn, Satsuki Nakai, Rory A. DePaolis & Pierre Hallé. 2004. The Role of Accentual Pattern in Early Lexical Representation. *Journal of Memory and Language* 50(3). 336–353. doi:10.1016/j.jml.2003.11.004.
Walley, Amanda C. 1993. The Role of Vocabulary Development in Children′s Spoken Word Recognition and Segmentation Ability. *Developmental Review* 13(3). 286–350. doi:10.1006/drev.1993.1015.
Walley, Amanda C., Jamie L. Metsala & Victoria M. Garlock. 2003. Spoken Vocabulary Growth: Its Role in the Development of Phoneme Awareness and Early Reading Ability. *Reading and Writing* 16(1-2). 5–20.
Waterson, Natalie. 1971. Child Phonology: A Prosodic Review. *Journal of Linguistics* 7. 179–211.
Werker, Janet F. & Suzanne Curtin. 2005. PRIMIR: A Developmental Framework of Infant Speech Processing. *Language Learning and Development* 1(2). 197–234.
White, Katherine S. & James L. Morgan. 2008. Sub-Segmental Detail in Early Lexical Representations. *Journal of Memory and Language* 59(1). 114–132. doi:10.1016/j.jml.2008.03.001.
Yamaguchi, Naomi. 2012. Détermination des parcours d’acquisition des sons du langage chez des enfants francophones à développement typique. Université Sorbonne Nouvelle Paris 3 Ph.D. Dissertation.
Yoshida, Katherine A., Christopher T. Fennell, Daniel Swingley & Janet F. Werker. 2009. 14-month-old Infants Learn Similar Sounding Words. *Developmental Science* 12. 412–418.
Zamuner, Tania S. 2006. Sensitivity to Word-Final Phonotactics in 9-to 16-month-old Infants. *Infancy* 10(1). 77–95. doi:10.1207/s15327078in1001_5.
Zamuner, Tania S. 2009. The Structure and Nature of Phonological Neighbourhoods in Children’s Early Lexicons. *Journal of Child Language* 36(1). 3–21.
Zamuner, Tania S. 2011. Stepping Backwards in Development: Integrating Developmental Speech Perception with Lexical and Phonological Development – a Commentary on Stoel-Gammon’s “Relationships Between Lexical and Phonological Development in Young Children.” *Journal of Child Language* 38(1). 56–60. doi:10.1017/S0305000910000516.
Zamuner, Tania S., Elizabeth Morin-Lessard & Natasha Bouchat-Laird. 2015. Phonological Patterns in the Lexical Development of Canadian French. In Mehmet Yavaş (ed.), *Unusual Productions in Phonology: Universals and Language-Specific Considerations*, 28–48. New York: Taylor & Francis.