Markedness and implicational relationships in phonological development:

A longitudinal, cross-linguistic investigation

by

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Abstract

This dissertation sets out to evaluate theoretical and empirical issues involved in referring to implicational relationships (i.e., that a *marked* or *complex* sound or phonological process implies the presence of an *unmarked* or *simpler* sound or process) for the treatment of speech sound disorders (e.g., Gierut 2007). Due to the relatively untested and unexplored nature of implicational relationships, and because of their potential relevance to Speech-Language Pathology practice, I investigated the following research questions:

(1) Are implicational relationships warranted cross-linguistically in the description of phonological development?

(2) Can factors outside of universal markedness account for attested patterns of phonological development?

I conducted six detailed longitudinal case studies documenting typical phonological systems in English, French, German, and Portuguese, as well as atypical development in one English-learning child. Based on these studies, I claim that implicational relationships based on universal markedness are theoretically and empirically questionable. The results from my investigation highlight the influence of speech phonetics and phonological distributions in all aspects of development. Additionally, the few implicational relationships that appear to make valid predictions can be described in terms of articulatory complexity: the sounds that the children acquired first are easier to articulate for a number of reasons (e.g., motoric, perceptual, grammatical).

As claims based on universal markedness generally do not account for the data, I investigate whether a phonetically driven view of markedness could apply. This inquiry led me to

advocate for a *markedness-through-mechanism* (Hume 2011) approach to phonological development, which combines perceptual distinctiveness, phonetic variability, and articulatory simplicity; which, in child language, can be rather salient due to anatomical and motor properties of child speech production. I combine this view of phonetically conditioned markedness with the A-map model (McAllister Byun, Inkelas & Rose 2016), which provides a formal link relating perceptual targets and the dimensions involved in the motor-acoustic mappings of these objects on to patterns of speech production.

In a nutshell, combining markedness-through-mechanism with the A-map provides a way to frame the phonological patterns that we observe in child phonological development that is both theoretically consistent and clinically applicable. This approach expands on our understanding of the underpinnings of speech sound disorders and provides a new model that can guide Speech-Language Pathologists in their selection of treatment approaches to speech disorders.

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Chapter 1: Introduction

Within the literature on phonological development and clinical phonology, we sporadically find proposals arguing in favour of implicational relationships as foundational to our understanding and treatment of articulatory and phonological disorders (e.g., Bernthal & Bankson 2004; Gierut 2007). In a nutshell, these proposals are based on the hypothesis that a *marked* or *complex* sound or phonological process implies the presence of an *unmarked* or *simpler* sound or process. In this thesis, I set out to analyze the theoretical and empirical issues involved with using implicational relationships for our understanding of phonological development, as well as for the treatment of speech sound disorders.

During the course of phonological acquisition, the words produced by children exhibit error patterns such as deleting a sound (e.g., *dog* produced as *do_*) and substitution and/or distortion of a speech sound (e.g., *red* produced as *wet*). However, little is known as to why these errors occur, and how they can be accommodated within a comprehensive theory of phonological development. The order and age in which various speech sounds first appear and are later mastered have been extensively studied (e.g., Bernhardt & Stemberger 1998), and developmental normative data have been compiled from multiple studies (e.g., Sander 1972; Prather, Hedrick & Kern 1975; Smit 1993; Tanner, Culbertson & Secord 1997). However, while gaps in young children's phonological inventories and systematic error patterns are well attested in the literature, relatively little research explores whether, or how, these errors might interact with one another.

An exception is Gierut (2007), who proposes that patterns of phonological development can be explained through mainstream phonological theory based on the typological study of adult phonological systems (e.g., Chomsky & Halle 1968). Gierut compiled a list of 22 implicational relationships as observed in phonological development, phonological typology, and the clinical treatment literature. These will be discussed in detail in Chapter 2 below.

These implicational relationships are rooted in universal markedness, following the tradition set by Jakobson (1941) and Trubetzkoy (1969). In my thesis, I engage in a critical discussion of whether the notion of universal markedness should be used to explain aspects of child phonological development. I conduct five detailed longitudinal case studies documenting typical phonological systems in English, French, German, and Portuguese, as well as one case study of atypical English development. Based on these studies, I show that implicational relationships based on universal markedness are theoretically and empirically questionable. Building on this conclusion, I investigate whether alternative views of markedness can capture the data. This inquiry leads me to advocate a *markedness-through-mechanism* approach to phonological development, which combines perceptual distinctiveness, phonetic variability, and articulatory simplicity (Hume 2011). As we will see, due to anatomical and motor differences, these factors are centrally relevant to child language. I combine this view of phonetically conditioned markedness with the A-map model (McAllister Byun, Inkelas & Rose 2016), which provides a formal link between perceptual targets and the dimensions involved in the motor-acoustic mapping of these objects on to patterns of speech production. Building on the tendencies observed in children's production patterns, and on the tenets of the A-map, this work highlights how acoustic-articulatory relationships can serve as a basis to define clinical approaches to clinical speech targets.

The thesis is organized as follows. In the next chapter, I explore the background literature and motivations behind the formulation of specific implicational relationships and discuss a number of theoretical and empirical issues affecting this general approach. I then formulate specific research questions, and introduce the theoretical background required to investigate these questions. Moving on to Chapter 3, I undertake a detailed longitudinal, cross-linguistic study of six children from four different languages. Using this data, in Chapters 4 and 5, I formulate a critical discussion of implicational relationships, and propose alternative ways to describe patterns of phonological development. In Chapter 6, I advocate for a new theoretical approach, the A-map model (McAllister Byun, Inkelas & Rose 2016), which offers a view of development that is both theoretically relevant and clinically applicable. Lastly in Chapter 7, I expand on this view, and discuss how it can improve our understanding and treatment of speech sound disorders.

Chapter 2: Background and methodology

Gierut (2007) proposes 22 implicational relationships, which she defines in terms of sound categories; these include relationships between individual speech sounds as well as relationships between various phonological processes. As described in the left-most column of Table 1, Gierut classifies the relationships into five general categories, each of which corresponds to a specific component of the phonological system. Each relationship is described in detail in the second column, alongside relevant references and examples of potential treatment solutions in the remaining columns.

Table 1: Gierut's (2007: 11) implicational relationships

Hierarchical properties of sound systems	Observed implicational relationships	Acquisition evidence	Examples of complex treatment targets
Phonetic inventory	A stridency and/or laterality distinction implies the phonetic occurrence of a liquid, which implies a fricative and/or affricate, which implies a voice distinction among cognate stops, which implies a nasal and glide.	(Tyler & Figurski 1994)	/s/ in contrast to /θ/ /z/ in contrast to /ð/ /r/ in contrast to /l/
Phonemic inventory	Consonants imply vowels.	(Robb, Bleile & Yee 1999)	Consonant excluded from the child's phonemic inventory.
	Affricates imply fricatives.	(Dinnsen, Chin, & Elbert 1992)	/ʧ ʤ/
	Fricatives imply stops.	(Elbert, Dinnsen & Powell 1984)	/f v θ ð s z ʃ ʒ/
	Voiced obstruents (i.e., stops, fricatives, affricates) imply voiceless obstruents.	(McReynolds & Jetzke 1986)	/b d g/ /v ð z ʒ/
	Liquids imply nasals.	(Gierut, Simmerman & Neumann 1994)	/l r/
	Velars imply coronals.	(Stoel-Gammon 1996)	/k g/
Distributional properties	Fricatives in initial position imply fricatives in final position.	(Ferguson 1977)	Word initial /f v θ ð s z ʃ ʒ/
	Stops in final position imply stops in initial position.	(Dinnsen 1996)	Word-final /p b t d k g/
	Word-initial /r/ implies post-vocalic /r/.	(Smit 1993)	Word-initial /r/

Hierarchical properties of sound systems	**Observed implicational relationships**	**Acquisition evidence**	**Examples of complex treatment targets**
Syllable structure	Clusters imply singletons.	(Gierut & Champion 2001)	Cluster, with the exception of s+obstruent stop sequences.
	Clusters imply affricates.	(Dinnsen, O'Connor & Gierut 2001)	Clusters
	Clusters with a small sonority difference imply clusters with a greater difference.	(Gierut 1999)	/fl- fr- θr- ʃr-/
	Fricative+Liquid clusters imply Stop+Liquid clusters.	(Elbert, Dinnsen & Powell 1984)	/fl- fr- θr- ʃr-/
	Liquid onset clusters imply a liquid in coda position.	(Fikkert 1994) (Baertsch 2002)	/pl- pr- bl- br- tr- dr- kl- kr- gl- gr-/ /fl- fr- θr- ʃr-/
Phonological processes	Stopping (e.g., [b] for /v/) implies liquid gliding (e.g., [w] for /r/).	(Dinnsen & O'Connor 2001a)	/w/ in contrast to /r/ to eliminate liquid gliding.
	Manner assimilation (e.g., [nʌn] *won*) implies liquid gliding (e.g., [w] for /r/).	(Dinnsen & O'Connor 2001a)	/w/ in contrast to /r/ to eliminate liquid gliding.
	Spirantization (e.g., [s] for /t/) implies place assimilation (e.g., [gɔg] *dog*).	(Dinnsen & O'Connor 2001a)	/t d/ in contrast to /k g/ to eliminate place assimilation.
	Progressive place assimilation (e.g., [bop] *boat*) implies regressive place assimilation (e.g., [gɔg] *dog*).	(Stoel-Gammon 1996)	Word-initial /t d/ in contrast to /k g/ to eliminate regressive place assimilation.
	Velar fronting word-finally implies velar fronting word-initially.	(Morrisette, Dinnsen & Gierut 2003)	Word-initial /t d/ in contrast to /k g/ to eliminate velar fronting.

Hierarchical properties of sound systems	Observed implicational relationships	Acquisition evidence	Examples of complex treatment targets
	The absence of a voice contrast in final position implies the absence of a voice contrast in initial position.	(Dinnsen, O'Connor & Gierut 2001)	Word-initial voiced obstruent in contrast to voiceless obstruent to eliminate devoicing.
	Errors of weak syllable deletion in syllables beginning with an obstruent imply like errors in syllables beginning with a sonorant.	(Kehoe & Stoel-Gammon 1997)	Multisyllabic words containing unstressed syllables beginning with a sonorant (e.g., *telephone*, *dinosaur*) to eliminate weak syllable deletion.

Gierut claims that these implicational relationships have applications to the clinical treatment of phonological disorders, the nature of which may be captured in terms of relative complexity or markedness. In brief, Gierut proposes that the more complex (or marked) target segments or phonological structures may stimulate the learning of corresponding less complex objects. It is under this perspective that Gierut proposes possible clinical treatment targets in the right-most column of Table 1.

Gierut credits the robustness of her approach to the fact that the implicational relationships are attested in phonological development, phonological typology, and clinical treatment literature. A logical implication of these observations is that structures appear to be added to the phonology in predictable ways, such that "the end result is a cascading effect on generalization learning" (Gierut 2007: 7). Generalization learning occurs when children apply what they have learned about one category or treatment target to a related non-target phonological item (Elbert, Dinnsen & Powell 1984).

Key to Gierut's proposal is the question of relative complexity, which has been defined in terms of *markedness* across the literature on phonological theory, in the universalist tradition of phonological inquiry set by Jakobson (1941) and Trubetzkoy (1969). While markedness is a widely known concept in linguistics, it can be utilized in a multitude of ways. For example, it can be used to describe a category of constraints in Optimality Theory (McCarthy 2003) or, in the context of theoretical markedness, it can refer to universal principles or laws that govern the functioning of languages. In Chapter 6, I revisit the notion of markedness in depth, and discuss the differences between universal markedness and Hume's (2011) alternative, phonetically-driven *markedness-through-mechanism* approach, focusing on implications for both phonological theory and child phonological development.

Throughout the thesis, I use the term markedness as it applies to descriptive markedness. As such, I will use a subset of markedness descriptors from Hume (2011: 79–81). These descriptors are listed in Table 2 below.

Table 2: Markedness descriptors (adapted from Hume 2011: 79–81)

Unmarked	**Marked**
Simple	Complex
More frequent	Less frequent
Acquired earlier	Acquired later
Articulatorily simple	Articulatorily difficult

Using these markedness descriptors, Gierut (2007) proposes that the acquisition of speech sounds by first language learners follows markedness relationships. A *marked* sound is one that (among other criteria) occurs infrequently in a given language, and is also typically more difficult to produce (e.g., Chomsky & Halle 1968: chap. 9). Gierut posits that if a child has acquired a marked sound, s/he will logically have acquired all *unmarked* sounds that relate to it. For example, affricate consonants (e.g., [ʧ, ʤ]) pattern as marked in English; they are more difficult to articulate because they combine two manners of articulation (stop closure; fricative release) and are typologically disfavoured as they occur less frequently across the world's languages than other stops or fricatives (Żygis, Fuchs & Koenig 2012). Under this view, one would expect the acquisition of the less marked components of affricates (such as /t/ and /ʃ/) to occur before the acquisition of affricates (such as /ʧ/). Expanding on this, Gierut (2007) suggests that knowledge of later acquired sounds (such as the marked affricate /ʧ/) directly predicts the acquisition of earlier, more easily acquired sounds (such as the less marked stop /t/ and fricative /ʃ/).

In addition to markedness, Gierut's (2007) hierarchy of implicational relationships is based on the continuity assumption, and the specific version of learnability theory it implies (Macnamara 1982; Pinker 1984). I turn to these topics in the next section.

1. Motivation for implicational relationships

1.1. Learnability theory and the continuity assumption

According to the continuity assumption, a child's phonological system is a restricted subset of the adult system and is initially composed of unmarked elements. Pinker states:

> The null hypothesis in developmental psychology is that the cognitive mechanisms of children and adults are identical; hence it is a hypothesis that should not be rejected until the data leave us no other choice. […] Let us call this the continuity assumption. […] The continuity assumption should apply not only to the child's cognitive mechanisms but to his or her grammatical mechanisms as well: in the absence of compelling evidence to the contrary, the child's grammatical rules should be drawn from the same basic rule types, and be composed of primitive symbols of the same class, as the grammatical rules attributed to adults in standard linguistic investigations (Pinker 1984: 7).

One interpretation of this hypothesis is that the child's system expands through the addition of increasingly marked elements, itself governed by universal implicational relationships, defined after tendencies observed in linguistic typology, following the tradition of Jakobson (1941) and Trubetzkoy (1969). As previously mentioned, in line with this assumption, Gierut (2007) defines *simple* versus *complex* as unmarked versus marked, with the presence of a marked category implying the presence of an unmarked category. For example, building on previous works on phonological implications (Lleó & Prinz 1996; Lleó & Prinz 1997; Gierut & O'Connor 2002), Gierut states that the presence of clusters in the speech of a given speaker implies the presence of affricates, but not vice versa. This follows a structural logic whereby clusters are more marked than affricates, as the former imply a branching structure within syllable onsets (Lleó & Prinz 1997).

Under this theory, complexity is the key to unlocking the phonological system (Rvachew & Bernhardt 2010), and linear changes (such as the gradual mastery of speech articulation) result from performance factors and learning (e.g., maturation of speech motor control). More sudden, nonlinear changes (such as the first appearance of a new type of syllable structure), are attributed to the response of innate representational constraints to the input of the ambient language (or phonological evidence, as per Pinker 1984).

Gierut also uses evidence from the clinical treatment literature to provide additional support for implicational relationships. Each implicational relationship relies on acquisition evidence as listed in the third column of Table 1. Note that within the context of clinical interventions, treatment progress in Gierut (2007) is determined from the child's baseline level, and therefore the implicational relationships reflect progress and not phonological mastery; this is illustrated in the following section using the Elbert, Dinnsen & Powell (1984) study. Therefore, for an implicational relationship to be validated, the child must simply progress in their production of the speech sound or phonological process.

1.2. Clinical treatment of clusters

Gierut (2007) cites Elbert, Dinnsen & Powell (1984) as evidence for the implicational relationship that fricative+liquid clusters imply stop+liquid clusters. Gierut claims that acquiring a cluster (i.e., a series of two or more consonant sounds, e.g., *spr*) leads to the acquisition of related single consonants (here *s*, *p*, and *r*). In the Elbert, Dinnsen & Powell (1984) study, three pairs of matched participants, ages 4;4 to 6;3, had difficulties in their production of word-initial consonant clusters, for which they substituted sounds (e.g., *tree* produced as *fwee*). These participants underwent phonological intervention focusing on either later developing/more difficult clusters (fricative+liquid, e.g., *sl*, *fr*) or easier/early developing clusters (stop+liquid, e.g., *pl*, *br*). The researchers wanted to see if children would generalize from one type of cluster to the other. Five out of the six subjects made gains in both cluster types, regardless of which cluster type they focused on during therapy. However, one child, who was taught the easier stop+liquid clusters, did not generalize to the later developing category. This child did not produce the fricative+liquid cluster (but did generalize within the stop+liquid category). These findings were taken as support for implicational relationships by Elbert, Dinnsen & Powell (1984), and as support for generalization learning and the possible clinical significance of implicational relationships.

It is important to note that for the final assessment, the clusters had not reached a level of mastery, with only half the subjects scoring above 50% (and only within one cluster type). Therefore, according to generally accepted clinical treatment guidelines, neither the earlier nor the later developing cluster type was mastered (or fully acquired; i.e., reached an accuracy rate of 80% or higher) during the treatment block.

Gierut's implicational relationships rely on marked sounds determining the acquisition of unmarked sounds. However, Elbert, Dinnsen & Powell (1984) found that with the exception of one child, children made gains whether or not their treatment focused on easier or harder cluster types. While this does provide evidence for generalization learning, it does not provide evidence for implicational relationships, where the presence of marked or more difficult sounds implies unmarked or easier sounds, but not vice versa.

This brief discussion of Elbert, Dinnsen & Powell (1984) aimed to highlight the permissive treatment criteria used in support of the notion of implicational relationships. Further exploration into the studies cited by Gierut (2007) follows in section 4. However, first I introduce general criticisms against implicational relationships, from both the perspective of clinical treatment and from that of phonological theory, in the next two sections.

2. Criticism with regards to clinical applications

Other scholars have entertained the inter-related notions of complexity and implicational relationships. Rvachew & Nowak (2001) studied two groups of children who underwent speech therapy. The participants were 48 preschool-age children, age 50 months on average, who had moderately or severely delayed phonological skills. However, the children had age appropriate language comprehension skills. Rvachew & Nowak conducted a randomized controlled trial based on the difficulty of the treatment targets taught to each group. One group of children received treatment for earlier developing sounds for which they had some productive phonological abilities (the children could produce the sounds in some word positions; however, they had not fully mastered the sounds). The second group received treatment that focused on later developing sounds for which the children had the least productive phonological abilities (the children could not produce the sounds even with prompting).

The first group of children, who received treatment on earlier developing stimulable[1] sounds, mastered 38% of their treatment targets. The other group of children, who received treatment for later developing unstimulable sounds, mastered 17% of these more complex targets. This suggests, counter to Gierut's proposal, that it is preferable to focus treatment on less complex sounds.

Another study, Rvachew & Bernhardt (2010), is based on the data collected by Rvachew & Nowak (2001), as previously described. They focused on data from six children who had no phonetic or phonological knowledge of affricates (e.g., producing *jump* as *dump*, or *chip* as *ship*). Three of these children received treatment on sounds considered less complex than affricates (e.g., glides, nasals, stops, fricatives) while the other three children received treatment for sounds considered more complex (e.g., liquids).

The results show that the three children who had treatment focusing on the easier sounds (e.g., [p], [b]) all produced new phonemes after six weeks of therapy, and these new phonemes contained feature contrasts (i.e., voicing, place, or manner of articulation) not previously found in the child's system. Two of the children who had the more complex treatment (e.g., [s], [r]) made no progress at all during the six weeks covered by the study. The third child did not learn the more complex target phonemes but began to produce an untreated fricative during this six week period.

While these later results provide evidence that the treatment of disordered phonological systems may benefit from starting with less complex and less marked options (from the

1 Stimulability refers to the child's ability to correctly produce the target sound when provided with a model. The sound may be tested in various positions (e.g., isolation, syllable or word -initial, -medial, -final) and with various levels of cuing (e.g., auditory model, visual model, tactile cues) (Lof 1996; Miccio, Elbert & Forrest 1999).

perspective of the child's phonological system), they do not provide solid evidence against Gierut's (2007) implicational laws. First, these results do not prescribe to universal markedness (as does Gierut) nor do they offer a general basis to establish a sound's complexity. Note that for Rvachew & Bernhardt's study, sounds were considered marked if absent from the child's inventory and unstimulable, with notions of universal markedness not taken into account.

Yet Rvachew & Bernhardt's results do pose some challenges to Gierut's proposal, as they suggest that children who are taught marked sounds make few to no gains in the accuracy of the marked sounds nor do they learn the other implied sounds. Further, children progressed more in their production of the more complex sounds when treated for the least complex sounds, an observation that may contradict Gierut (2007).

3. Criticisms from the perspective of phonological theory

As mentioned above, Gierut's (2007) theory of implicational relationships predicts that children acquire sounds in a relatively linear manner, following an order dictated by universal markedness. Contrary to this prediction, Bedore, Leonard & Gandour (1994) present a clinical treatment case study of a four year old English-learning girl who substituted a dental click for all target sibilants (i.e., /s, z, ʃ ʒ, ʧ, ʤ/). Clicks are considered marked sounds: they are rare sounds in the world's languages (Ladefoged & Traill 1994), and are not found in English. The clinician chose the sound /s/ as the first treatment target, because it is a frequent sound in English and the child was stimulable for it.

The child showed a rapid and non-linear progression. It took only two treatment sessions over a one week period to remedy the child's substitution pattern, and for her to start using sibilants correctly in spontaneous speech. This suggests that the child had relatively accurate perceptual representations of the sibilant sounds while her articulation of these sounds remained problematic.

This unusual pattern of acquisition, and the quick rate at which the error pattern resolved (and with treatment of the less marked sibilant /s/ instead of the more marked affricates /ʧ/ and /ʤ/), cannot be accounted for using Gierut's (2007) implicational relationships. If the child's phonological system is a restricted subset of the adult system, and if markedness defines the child's grammar, we are left with no explanation for this child's use of dental clicks for target sibilants. Gierut's approach indeed states that if you have acquired the complex sound, you will have acquired the simple sound. This clinical case study also poses a larger problem to markedness approaches to child language acquisition in general.

Other researchers have shown that different phonological error patterns may originate from different sources (e.g., perception, articulation, grammar; e.g., Inkelas & Rose 2003; 2007; Rose 2009). Inkelas & Rose (2003; 2007) investigate a case of Positional Velar Fronting (PVF). Velar Fronting occurs when velar sounds [k, g] are produced as *fronted* coronal sounds [t, d] respectively (e.g., *do* for *go*; see also Dinnsen 2008; Dinnsen et al. 2011). Positional Velar Fronting occurs when velar sounds are produced as fronted coronal sounds only in certain word/syllable positions (initial and/or stressed syllable onsets) but are produced correctly in other word/syllable positions (e.g., syllable codas), as illustrated in (1).

(1) Positional Velar Fronting (from (Inkelas & Rose 2007: 710–711)

a. Fronting of velars in prosodically strong positions

Orthography	IPA Target	IPA Actual	Age
cup	|ˈkʰʌp|	[ˈtʰʌp]	1;09.23
again	|əˈgɛn|	[əˈdɪn]	1;10.25

b. Absence of velar fronting in prosodically weak positions

Orthography	IPA Target	IPA Actual	Age
bagel	|ˈbeɪgəl|	[ˈbejgu]	1;09.23
octopus	|ˈɑktəˌpʊs|	[ˈɑktəpʊs]	2;04.09

Inkelas & Rose (2003; 2007) explore the process of PVF from both motor/articulatory (e.g., jaw and tongue movement) and grammatical perspectives (see also McAllister Byun 2009; 2010). They propose that the process is governed by grammatical conditioning. Inkelas & Rose propose that the phonological grammar conditions the child's articulation of velars. The production of velars in prosodically strong positions causes articulatory reactions: the tongue expands too forcibly and causes the linguopalatal contact that is required for velars to extend too far forward in the mouth (into the coronal region). This results in the coronal release of target velars in strong position. The child is grammatically accurate as his/her production marks the presence of the prosodically strong position. However, the child is unable to produce the velar consonant correctly. While the child's production of velars is segmentally inaccurate in cases of PVF, it maintains grammatical accuracy as the child faithfully attempts to strengthen velars in strong positions but is hindered by articulatory constraints. Additionally, by examining grammatical conditioning and articulatory reactions to this conditioning, Inkelas & Rose (2003; 2007) offer a way to link error patterns that would otherwise appear unrelated.

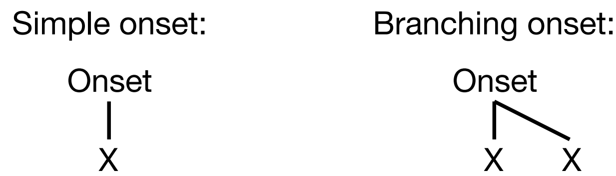
It is however unclear how these types of non-linear relationships could be accounted for by Gierut's (2007) approach, as it focuses almost exclusively on individual speech sound development. From a theoretical standpoint, it is generally accepted that languages are hierarchically organized, such that larger units (e.g., syllables) influence the behaviour of units lower down on the hierarchy (e.g., sounds, features), as represented by the Prosodic Hierarchy shown in Figure 1 (further discussion of the Prosodic Hierarchy and syllable structure is provided in Chapter 2, section 7.1).

Figure 1: Prosodic Hierarchy (Selkirk 1978; 1980; McCarthy & Prince 1986)

Prosodic Word (PWd)
|
Foot (Ft)
|
Syllable (σ)
|
(Syllable subconstituents)
|
Timing unit (X)

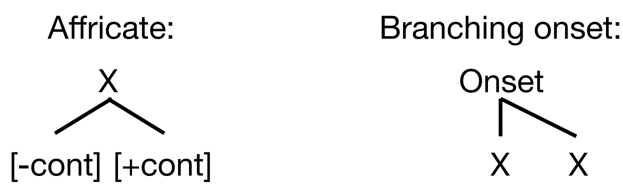
Another challenge concerns the formal relationship that may exist between various marked and unmarked structures as implicated in Gierut's proposal. In Table 1 above, certain implicational relationships relate structurally (e.g., clusters imply singletons) and in terms of markedness from either a typological (i.e., rarer in the world's languages) or articulatory perspective (e.g., affricates are more difficult to produce than stops or fricative consonants). Other implicational relationships, however, lack this type of structural or conceptual comparability. From a theoretical standpoint, one can compare branching onsets to simple onsets due to their structural similarity as shown in Figure 2, where the two structures differ in terms of complexity within a given syllabic constituent (the discussion of onsets and syllable structure will be revisited and expanded in section Chapter 2, section 7.2).

Figure 2: Simple vs. branching onsets



However, comparisons between complex onsets and affricates are formally or representationally unwarranted. As shown in Figure 3, these units involve structures at different levels of representation (syllable-level for the complex onset vs. segmental for the affricate).

Figure 3: Affricate vs. branching onset



While these structures may be compared on independent grounds, for example in terms of frequency or at the level of speech phonetics, the nature of these comparisons remains unexplored in the context of Gierut's original proposal.

4. Criticisms regarding studies used in support of implicational relationships

As already reported in Table 1, for each proposed implicational relationship, Gierut (2007) cites one or more sources of information for the validity of the relationship. However, not all of these sources appear to provide robust evidence for the implicational relationships they are purported to support. For each case where an implication hypothesized by Gierut may be lacking transparent phonetic motivation (e.g., 4.1), going against generally attested patterns of development (e.g., 4.2), or making reference to a theoretical concept with no obvious applicability to clinical treatment (e.g., 4.3), I reviewed the relevant aspects of these original works. The section that follows explores a number of these source articles in the context of their use by Gierut (2007).

4.1. Treatment along a phonological hierarchy (Tyler & Figurski 1994)

Tyler & Figurski (1994) are cited as evidence for the implicational relationship that "a stridency and/or laterality distinction implies the phonetic occurrence of a liquid, which implies a fricative and/or affricate, which implies a voice distinction among cognate stops, which implies a nasal and a glide."

Tyler & Figurski (1994) conducted a treatment study of two children with phonological impairments. Their treatment approach was based on Dinnsen et al.'s (1990) hierarchy of phonetic distinctions, summarized in Table 3. In this hierarchy, a feature from a more complex phonetic level implies the features from less complex levels; the addition of a feature distinction implies the presence of all of the features from the less complex levels.

Table 3: Implicational hierarchy (Dinnsen et al. 1990) as adapted by Tyler & Figurski (1994)

Level	Contrastive Features	Example Inventories
A	[syllabic] [consonantal] [sonorant] [coronal]	b d m n ŋ w j ʔ h
B	[voice]	p b t d k g m n ŋ w j ʔ h
C	[continuant] [delayed release]	p b t d k g f v ʃ ʧ ʤ m n ŋ w j ʔ h
D	[nasal]	p b t d s z ʃ ʧ ʤ m n ŋ l (or) r w j ʔ h
E	[strident] [lateral]	p b t d k g θ ð s z ʃ ʧ ʤ m n ŋ l (or) r w j ʔ h

Dinnsen et al. (1990) hypothesize that teaching higher/more complex targets would result in less complex distinctions being acquired without treatment, while focusing treatment on lower level targets would not trigger acquisition of more complex members of the hierarchy. Tyler & Figurski (1994) evaluated Dinnsen's hierarchy by selecting treatment targets according to the relationships implied by the participants' sound systems. The two participants were children with phonological impairment, aged 2;8 and 2;10, respectively. Both children scored below the 1st percentile on the Goldman-Fristoe Test of Articulation (Goldman & Fristoe 1986) and both children started treatment with Level B inventories according to Dinnsen's hierarchy.

Both children received treatment for 9 weeks, followed by a 5 week withdrawal period. This was followed by another 9 week treatment period and another withdrawal period which was used to evaluate generalization once treatment had ended.

Participant 1 was treated on /l/ to add the level D feature [nasality] that would distinguish nasals from liquids. The hypothesis was that this would cause the acquisition of the Level C distinctions [continuant] and/or [delayed release]. Pre-treatment, Participant 1 could produce /l/ in the nonsense syllable /la/. Participant 2 was treated on /s/ from Level C to establish the [continuant] distinction, which was expected to be acquired next by the child. The hypothesis was that Participant 2 would only add the treated distinction and would not add any more complex distinctions. Participant 2 was stimulable for /s/ in isolation only.

The exact inventories pre- and post-treatment are provided in Table 4 below. New sounds that were added to the participants' inventories are in bold in the right-most column of the table.

Table 4: Pre- and post-treatment inventories (Tyler & Figurski 1994: 98)

Pre-treatment		Post-treatment	
Features	Inventory	Features	Inventory
Participant 1		Participant 1	
(Level B)	(9 sounds)	(Level E)	(21 sounds)
[voice]	b t d g	[voice]	**p** b t d **k** g
		[continuant]	**f v** **s z** **ʃ**
	n ŋ	[delayed release]	**ʧ ʤ**
			m n ŋ
	w j ʔ h	[nasal]	l
			w j h
		[strident]	**ð**
Participant 2		Participant 2	
(Level B)	(10 sounds)	(Level B)	(12 sounds)
[voice]	p b t d g	[voice]	p b t d **k** g
	m n		m n **ŋ**
	w j ʔ h		w j ʔ h

Participant 1, who was treated for the more marked Level D distinction [nasal] using the sound [l], added 12 new sounds to his inventory. This participant did add the less complex feature distinctions ([continuant], [delayed release], [nasal], [strident]) as was hypothesized. Participant 2, who was treated with the less complex Level C distinction, added only two sounds to his consonant inventory ([k, ŋ]). Both of these sounds are at the lower Level B. This participant did not pattern as hypothesized however, as he did not acquire the [continuant] feature of Level C that his treatment focused on.

The sounds that were acquired by both children were taken by Tyler & Figurski as support for Dinnsen's hierarchy and as evidence for the validity of using complex targets during treatment. Participant 2 was not seen as a contradiction, as he added two untrained sounds to his inventory (a level internal change as these sounds were also Level B). Tyler and Figurski claim that level-internal change is also predicted by Dinnsen et al.'s (1990) implicational hierarchy. The fact that Participant 2 did not make as much progress as Participant 1 also supports the hypothesis that treating a less complex sound results in a less robust effect. However, Tyler & Figurski (1994) state that this effect is not clear due to the small sample size.

One of the problems with this analysis is that, if taken to the extreme, Dinnsen et al.'s (1990) hierarchy (and the implicational relationships that Gierut 2007 derives from it) predict that if a child can only make vowel and stop sounds, focusing treatment on /ɹ/ should ultimately result in the child acquiring all of the other sounds without any direct intervention or treatment.

From a more formal perspective, Dinnsen's hierarchy can alternatively be described in terms of natural classes of phonetic elements. For example, level B relates to laryngeal states, while level E relates to manner and place of articulation. Therefore, another way of describing Tyler & Figurski (1994) is to say that Participant 1 (who added 12 sounds) simply learned how to contrast between two types of manners and generalized this new knowledge to the remainder of his consonantal system. Participant 2, on the other hand, was hypothesized to only add the [continuant] distinction and no others due to the treatment target being of lower complexity than Participant 1. However, this latter child did not pattern as predicted, even though the outcome of his treatment does not contradict the hierarchy in Table 3. In the face of these results, it does not seem prudent to establish a treatment hierarchy and implicational relationship based on the treatment progress of a single child, nor to promote a single child's pattern of development as evidence for a universal pattern.

4.2. Acquisition of post-vocalic /ɹ/ (Smit 1993)

Another relationship that warrants further investigation is that according to which "word-initial /r/ implies post-vocalic /r/." Gierut cites Smit (1993) as evidence for this relationship.

Smit (1993) compiled normative data on the errors made by English-learning children when acquiring consonant singletons. The data reported by Smit (1993) come from the Iowa-Nebraska Articulation Norms Project (Smit et al. 1990). This project looked at phonological errors from cross-sectional data from a total of 1049 children. The data come from single word productions that were elicited by the naming of photographs (spontaneously whenever possible).

Of interest to Gierut's proposal is the normative data that was collected for /r/, summarized in Table 5 below. For the following data, the age ranges differ per word position, with each range reflecting a change in the error distribution patterns. The words that are listed next to each word position are the only words elicited to establish the normative data: word-initial [ɹ] is based on the production of the two words *rainbow* and *rope*; post-vocalic [ɹ] is based on the four words *deer, car*, *spider*, *beard*; and intervocalic [ɹ] is based on only one word *earring*. The most common errors are summarized in the errors row of the table.

Table 5: Normative data for [ɹ] (adapted from Smit 1993)

<table>
<tr><td colspan="5">Word-initial (rainbow, rope)</td></tr>
<tr><td>Age</td><td>2-4</td><td>4;6-6</td><td colspan="2">7-9</td></tr>
<tr><td>% estimated accuracy</td><td>22%</td><td>65%</td><td colspan="2">92%</td></tr>
<tr><td>% error frequency of use</td><td>[w] 30-80%
derhoticized 5-15%</td><td>[w] 15-30%
derhoticized 5-15%</td><td colspan="2">[w] 5-15%</td></tr>
<tr><td colspan="5">Post-vocalic (deer, car, spider, beard)</td></tr>
<tr><td>Age</td><td>2-3</td><td>3;6-7</td><td colspan="2">8-9</td></tr>
<tr><td>% estimated accuracy</td><td>43%</td><td>95%</td><td colspan="2">96%</td></tr>
<tr><td>% error frequency of use</td><td>Rounded vowel 15-30%
Ø, [ə] 5-15%</td><td>Rounded vowel 5-15%</td><td colspan="2"></td></tr>
<tr><td colspan="5">Intervocalic (earring)</td></tr>
<tr><td>Age</td><td>2-3</td><td>3;6-5;6</td><td>6-7</td><td>8-9</td></tr>
<tr><td>% estimated accuracy</td><td>25%</td><td>61%</td><td>82%</td><td>96%</td></tr>
<tr><td>% error frequency of use</td><td>[w] 30-80%
Ø 15-30%</td><td>[w] 15-30%
derhoticized 5-15%</td><td>[w] 5-15%</td><td></td></tr>
</table>

As we can see in this table, at the earliest age range, post-vocalic [ɹ] is produced with the greatest accuracy (at 43%). This pattern continues for the following age ranges as well: post-vocalic [ɹ] is produced with the highest level of accuracy at all ages when compared with intervocalic and word-initial [ɹ]. From this data, Gierut infers that post-vocalic [ɹ] implies word-initial [ɹ].

There are a number of concerns with using the normative data described in Smit (1993) to posit an implicational relationship. First, the normative data come from cross-sections and do not look at single systems. It could be, given these data, that some of the children at age 2-3 have [ɹ] in onsets but no [ɹ] in codas. For example, there is no way to tell whether the children who are accurately producing [ɹ] in post-vocalic positions are also accurately producing [ɹ] in the other two phonological contexts. It is therefore impossible to ascertain how the acquisition of these various word positions may be related to each other in a child's grammar; while the general trend may be supporting Gierut's hypothesis, it cannot be taken as an absolute given the data available.

It could also be that some of the differences between the phonological contexts relate more to lexical knowledge than to phonological abilities. For example, it may be that the children participating in Smit's survey were familiar with the lexical item *car* but not *rainbow* at age two. With the child's performance based on such a limited number of specific lexical items, the results may be influenced by lexical knowledge and frequency of usage, or by additional factors such as consonant harmony. *Rainbow* and *rope* were indeed the only two words used to evaluate word-initial [ɹ]. Within this context, the most common error consists of [w] productions across all age ranges. As both target words contain labial consonants, the children's poor performance on these two words may in fact have been influenced by issues outside of [ɹ] pronunciation per se.

4.3. Onset cluster sonority (Gierut 1999)

The evidence for the implicational relationship that "clusters with a small sonority difference imply clusters with a greater difference" comes from Gierut (1999). In this study, Gierut investigated the hypothesis that children follow the Sonority Sequencing Principle (SSP) (as detailed in Chapter 2, section 7.2 below) when acquiring clusters. In a nutshell, Gierut claims that marked clusters, which display smaller sonority differences between the two consonants of a consonant cluster, imply clusters with larger sonority differences between the two consonants (see also Rice 1992; Goad & Rose 2004).

To evaluate the effects of the Sonority Sequencing Principle in cluster acquisition, Gierut investigated the speech of six children with phonological delays. These children ranged in age from 3;2 to 7;8, and none of them had prior speech-language treatment. Each child had to score at or below the 7^{th} percentile on the Goldman-Fristoe Test of Articulation Sounds in Words Subtest

(Goldman & Fristoe 1986) and they had to exclude at least seven singleton consonants from their inventory.

Details of each participant are listed in Table 6 below.

Table 6: Summary of participants (Gierut 1999)

Participant	Age	Phonemes excluded from inventory	Treatment condition	Treated cluster
1	3;2	ŋ, θ, ð, ʃ, ʧ, ʤ, l, ɹ, j	Unmarked	/kl/
2	4;2	t, d, θ, ð, ʃ, ʧ, ʤ, l, ɹ	Unmarked	/kw/
3	6;10	ŋ, θ, ð, ʃ, ʧ, l, ɹ, j	Unmarked	/pɹ/
4	5;11	v, θ, ð, z, ʃ, ʧ, ʤ, l, ɹ	Marked	/fl/
5	7;8	ŋ, θ, ð, s, z, ʃ, l, ɹ	Marked	/fl/
6	3;8	ŋ, k, ɡ, f, v, θ, ð, s, z, ʃ, ʧ, ʤ, l, ɹ, h	Marked	/bl/

In terms of onset clusters, children had to have near 0% accuracy on a picture-naming probe of 146 items that was developed by Gierut. All of the children except Participant 6 produced clusters, however not accurately (e.g., *[fl]y* produced as *[fw]y*). If the child had two instances of such a production, the cluster was counted as permissible in their inventory, and was used to determine which cluster would be focused on in treatment. The children in the unmarked group were taught a cluster with a greater sonority difference than what they produced, whereas the children in the marked group were taught a cluster with a smaller sonority difference than what they produced. In this treatment study, clusters were considered more or less marked relative to the individual child's inventory, however, universal markedness determined that the smaller the sonority difference the more marked the cluster.

Treatment involved onset clusters in 15 non-words, with seven CCVC forms, four CCVCV forms, and four CCVCVC forms. This was designed to allow for open and closed syllables and single and multisyllabic words. The initial CC treatment target clusters were always specific to the cluster being treated for each child. The post-vocalic consonant sounds were limited to /m, n, b, d/.

The non-words were introduced using story books, with each non-word being assigned a noun (n=8) or verb (n=7) category. These non-words were subsequently placed on flashcards for use in treatment. The children received treatment three times a week in one-hour blocks.

Gierut (1999) found that the children who were treated with the less marked clusters made fewer gains in treatment. Participant 2 in the unmarked condition made no gains at all. This is of particular interest as he was the only child with both singleton components of the treated cluster already in his consonant inventory (i.e., he had both /k/ and /w/ in his singleton inventory and was treated with /kw/).

All of the other participants made gains, with some individuals making more gains than others. The acquisition of clusters by all participants is summarized in Table 7 below. Note that all children who acquired new clusters also learned at least three sC clusters.

Table 7: Cluster acquisition for all participants (Gierut 1999)

Participant	Cluster	Post treatment	Follow-up
1	/kl/	/sp, st, sk, bl, gl, fl, sl/	N/A
2	/kw/	None	N/A
3	/pɹ/	/sp, st, sk, tɹ, dɹ/	N/A
4	/fl/	None	6 weeks post: /kw, pl, pɹ, sw, sm, sn, sp, st, sk/ 10 weeks post: /fɹ, bɹ, bl, gɹ/
5	/fl/	/tw, kw, pl, kl, tɹ, bl, gl, dɹ, sw, fl, sm, sn, sp, st, sk/	N/A
6	/bl/	/tw, kw, pl, bl, sw, fl, sm, sn, sp, st/	N/A

Participants 1 and 3 (in the unmarked condition) had their gains attributed to "within-class generalizations," as the clusters they acquired were related segmentally to the treated cluster, with the exception of /sp, st, sk/. Neither of these children learned the cluster that their treatment focused on (i.e., they did not acquire their treated clusters of /kl/ and /pɹ/ respectively). These children also acquired marked clusters in the absence of other unmarked clusters, thereby not following the order of acquisition that is predicted by the SSP.

As for the children who were treated on the more marked clusters, the presence of marked clusters implied the presence of all unmarked clusters that were predicted by the SSP. The children who were taught the more marked clusters even made gains in clusters that would be considered even more marked (e.g., /sm, sn, sp/). For a cluster to be considered acquired, the percentage accuracy could be as low as 20% (e.g., /gl, sk/ for participant 5) (percentages for individual clusters were only provided in graph form for participants 5 and 6).

Participant 4 did not make any gains during treatment despite being treated with a marked cluster type (/fl/). His lack of gains was attributed to a "horizontal learning strategy" whereby a child can only learn unmarked elements despite exposure to marked elements. According to Gierut (Gierut 1999: 716):

> A horizontal strategy of this type is not inconsistent with claims of markedness because, in fact, a child proceeds as would be expected by beginning the acquisition process with an unmarked unit. In these cases, it is thought that treatment sets the necessary foundation for subsequent learning because the linguistic principle has been appropriately introduced.

However, once he was followed at 6 and 10 weeks post-treatment, this child displayed an acquisition pattern similar to the other two children in the marked treatment condition. Ultimately, Gierut concluded that for the children who were treated with unmarked clusters, only within-class generalizations occurred. This is in contrast with the children in the marked condition, where the SSP guided cluster acquisition. Therefore, according to Gierut, the more marked the treatment target, the larger its effects and generalization.

There are multiple problems with using this study to support the claim that clusters with a small sonority difference imply clusters with a greater difference. First, from a speech-language treatment perspective, Gierut implies that the participants acquired sounds in clusters that they did not have in the singleton inventory. It is unclear how singletons were excluded from the treatment targets over the course of intervention. For example, participant 5 was treated on /fl/ but did not have /l/ in their singleton inventory. It is unclear how this cluster would have been treated without directly treating /l/. From a clinician's perspective, during treatment of a sound that a child could not produce (such as /l/) one would typically cue mouth/lip/tongue movement, reinforce correct /l/ productions, model correct /l/ productions, and would initially separate /f/ from /l/ during cluster production practice, eventually speeding up the co-articulation of the sounds until it more closely resembled typical cluster production.

In addition to these concerns about treatment, methodological issues can also be raised. First, the child in the marked condition who made the most gains (Participant 5) was significantly older than the other children. It is indeed unclear whether the gains made by Participant 1 at age 3;2 and Participant 5 at age 7;8 should be comparable. Additionally, most of the cluster gains by Participant 5 can be attributed to the child's acquisition of /l/, /ɹ/, and /s/. Presumably, once these later developing sounds were acquired, this child began to use them in clusters.

Second, the child who made the second highest gains, Participant 6, was the only child with no productions of clusters pre-treatment. All of the other children were making inaccurate cluster productions during the pre-treatment phase, suggesting that they had some phonological representation of consonant clusters. It would in fact seem more likely that his apparently extraordinary gains be credited not to issues in markedness, but to increasing his phonological awareness of clusters: this child presumably learned that consonants can co-occur within clusters and this new knowledge resulted in generalized learning. Furthermore, this child presumably had at least some perceptual representations of the 15 sounds missing from his productive inventory, the role of which remains fully unaccounted for under any analysis focusing on phonological production only.

Finally, when the children who were taught the more marked clusters acquired the sC clusters (sm, sn, sp, st, sk), it was attributed to the treatment of the marked cluster. However, when the children who were taught the unmarked clusters acquired /sp, st, sk/, unlike the children in the marked treatment group, their acquisition of the sC clusters was not considered a byproduct of the complexity of the treated cluster. This points to some inconsistency in data interpretation. Similarly, when Participant 4 did not make any gains during treatment, he was followed post-treatment under the claim that his development would still support markedness in acquisition. It is however unclear why Participant 2, who also did not make any gains during treatment, was not afforded the assumption of the same horizontal learning strategy and was not followed post treatment.

4.4. Stopping, gliding, spirantization, and place assimilation (Dinnsen & O'Connor 2001a)

Gierut (2007) cites Dinnsen & O'Connor (2001a) as support for the implicational relationships that "spirantization implies place assimilation" and "stopping implies liquid gliding." Optimality Theory (OT) provides the basis for both of these implicational relationships. Under Optimality Theory, the grammar consists of a set of universal constraints, and these constraints are ranked in various ways to account for the ways phonological systems might differ (Prince & Smolensky 1993). Dinnsen & O'Connor (2001a) state that OT can show links between otherwise unrelated phonological processes that would go unnoticed under other approaches. Therefore, instead of children simplifying rules or employing processes (e.g., Ingram 1989), and instead of processes operating separately from one another, OT links these patterns together in an implicational relationship. Dinnsen & O'Connor (2001a) go on to state that these relationships supply new avenues for clinical treatment.

Dinnsen and O'Connor analyze spirantization data from Child 126, age 3;11, from the Developmental Phonology Archives at Indiana University. As [t] and [s] share the same features in terms of place and voicing, spirantization relates to a change in manner, where the alveolar stop [t] is produced as the alveolar fricative [s]. They assume that the child's underlying representations are target appropriate (e.g., Smith 1973). The following examples come directly from Dinnsen & O'Connor (2001a: 258):

(2) /t/ replaced by [k] as a result of assimilation:

tiger	[kaɪgoʊ]
ticking	[kɪkɪn]
ticket	[kɪkɪt]

(3) /t/ produced target-appropriately in post-vocalic contexts:

goat	[goʊt]
coat	[koʊt]
cat	[kæt]
paint	[peɪnt]
puppet	[pʌpɪt]

(4) Coronal fricatives resist assimilation:

sick	[sɪk]
sucking	[sʌkin]
sock	[sɑk]
music	[muzɪk]
thank you	[sænkju]

(5) Word-initial /t/ replaced by [s]:

tie	[saɪ]
top	[sɑp]
tape	[seɪp]
toes	[soʊz]
tail	[sɛʊ] tail
teeth	[sis] teeth

As illustrated in the above examples, spirantization occurred for Child 126 for all word-initial [t]s that did not undergo place harmony; all word-initial [t]s underwent spirantization unless the word had a velar which caused word initial [t] to undergo place assimilation. In order to account for this under OT, the processes needed to be ordered as follows (from Dinnsen & O'Connor 2001a: 260):

(6) Correct ordering of rules

Underlying representation	a. /tɪkɪt/ *ticket*	b. /taɪ/ *tie*
Place harmony	kɪkɪt	—
Spirantization	—	saɪ
Phonetic representation	[kɪkɪt]	[saɪ]

As illustrated in example (6), in order to achieve the targets that mirror those provided from Child 126 in example (5) above, place harmony must occur first and then spirantization occurs in the absence of place harmony. It is from this observation that Dinnsen & O'Connor (2001a) extend their findings to create the relationship "stopping implies gliding." This relationship is based solely from the general observation that fricatives are acquired before liquids:

> This might be translated reasonably to two implicationally related error patterns, namely, stopping and gliding. The stopping error pattern would as a general process replace all fricatives with less marked stops, and the gliding error pattern would replace liquid consonants with less marked glides, as we saw earlier. Some children clearly exhibit both error patterns; other children exhibit gliding only, without the stopping error pattern. It appears, however, that no child would exhibit stopping as a general error pattern unless he or she also evidenced the gliding error pattern (Dinnsen & O'Connor 2001a: 266).

The authors propose that as fricatives and liquids, or in this case stopping and gliding, can be formalized using OT, then these two processes must be implicationally related. Dinnsen & O'Connor (2001a) further propose that, based on these OT rankings, clinicians can formulate speech therapy targets: as one of these processes is dependent on the other (in this case, the process(es) of spirantization/stopping), therefore treating the other process will cause the dependent phonological process to disappear without direct treatment (i.e., as spirantization is dependent on place harmony, it cannot exist without place harmony, therefore treatment of place harmony would cause the spirantization to disappear).

Dinnsen & O'Connor (2001a) themselves state that OT allows them to link processes that no other linguistic theory would link, however, they see this as a strength of OT and not as a weakness: OT can offer a theoretical explanation of the error patterns as they are "cast in terms of a fixed universal ranking of constraints..." (Dinnsen & O'Connor 2001a: 267). The authors express that they do not know how commonly these two processes co-occur, however that is not a reason to think that they are not related or uncommon.

Dinnsen & O'Connor's interpretation of the data from Child 126, raises a number of questions. While Dinnsen & O'Connor state that it is a positive reflection on OT that it is the only theory that can create a relationship between two otherwise unrelated processes, this claim may be unwarranted. OT provides a framework that can formalize a coincidence, which can lead to advocating irresponsible clinical treatment that has no basis in the articulatory or grammatical pressures that a child faces in their phonological development. Dinnsen & O'Connor's observations are based on a single child, whose production patterns are then formalized in OT, and then this analysis is promoted to reflect a grammatical universal in the absence of independent evidence.

4.5. Voicing contrast (Dinnsen, O'Connor & Gierut 2001)

Gierut cites Dinnsen, O'Connor & Gierut (2001) as evidence for the implicational relationship whereby "the absence of a voice contrast in final position implies the absence of a voice contrast in initial position." Gierut's motivation for this relationship comes from chain shifts in child Amahl's phonological development.

As described in Smith (1973), at age 2;2, Amahl produced voiced and voiceless obstruents as positionally-determined allophones. Dinnsen, O'Connor & Gierut 2001: (510) state that "obstruents were voiceless unaspirated lenis in word-initial position, voiced unaspirated lenis in word-medial position and voiceless fortis (aspirated or unaspirated) in word-final position." Given these observations, one could state that Amahl devoiced codas and voiced onsets. Dinnsen, O'Connor & Gierut (2001) claim that Amahl's patterning results from two markedness constraints: "avoid voiced obstruents in codas" and "avoid voiceless obstruents in onsets."

Alternatively, and given that the implicational relationships currently being discussed focus on the notion of *contrast*, we must note that while Amahl at age 2;2 was producing obstruents in word-initial, -medial, and -final position in a non-target fashion, he was still maintaining a contrast across different positions. This suggest that he was sensitive to the prosodic properties of his language. Also, as Amahl's errors resolved quickly at 2;5, this further implies that he had relatively accurate, contrastive perceptual representations of the voiced/voiceless distinction while his articulation of these sounds remained problematic. This observation stands in parallel to

Bedore, Leonard & Gandour's (1994) study of rapid resolution for click-substitutions by a four year old girl, as previously discussed in section 3 of this current chapter above. In both cases, we can assume that some type of contrast in phonological representations was already acquired.

Additionally, children, including Amahl (and Eleonora and Wiglaf, who will be discussed in the case studies below), may in fact have been producing a contrast not perceptible by adult listeners. Macken & Barton (1980) found that before the age of two years, some children produce voicing distinctions for onset stops, however this distinction does not match that required to faithfully reproduce the adult targets. Additionally, Imbrie (2005) found that between the ages of 2;6-3;3, children displayed different VOT values than adults, "providing evidence that 2-3 year olds are still developing appropriate time and glottal adjustments for onset voicing distinctions" (Song, Demuth & Shattuck-Hufnagel 2012: 3037). Similarly, in coda position, children have been found to lengthen vowels before voiced codas in comparison to voiceless codas, even when they do not maintain the voicing contrast of the target coda or produce the coda at all (Weismer, Dinnsen & Elbert 1981). Based on this evidence, Amahl may have been preserving the contrast between voiced and voiceless stops, however not in ways perceptible by the adult listener (see Scobbie et al. 1996 for more discussion of covert contrasts in child phonological development).

4.6. Manner assimilation (Dinnsen & O'Connor 2001b)

Manner assimilation is the focus of the implicational relationship that "manner assimilation (e.g., [nʌn] *won*) implies liquid gliding (e.g., [w] for /r/)." While Gierut cites Dinnsen & O'Connor (2001a) as evidence for this relationship, the authors cite another of their works (Dinnsen & O'Connor 2001b), for further discussion of these universal relationships. Dinnsen & O'Connor (2001b) studied various children from the Developmental Phonology Archives at Indiana University, as well as cases in the published literature. The authors discuss two children who displayed consonant harmony, as illustrated below in (7) and (8). Subject 23, aged 4;8, displayed glides undergoing nasal harmony, and gliding of word initial /r/. However, target /r/s that underwent gliding did not undergo nasal harmony.

(7) Subject 23 (Dinnsen & O'Connor 2001b: 600)
- a) Glides underwent nasal harmony
  - *snowing* [nonɪŋ]
  - *blowing* [blonɪŋ]
- b) Word initial /r/ became [w]
  - *read* [wid]
- c) Glides corresponding to target /r/ did not undergo nasal harmony
  - *rain* [weɪn]

(8) Subject 9 Dinnsen & O'Connor (2001b: 600)
- a) Glides underwent fricative harmony
  - *wave* [veɪv]
  - *wolf* [vʊf]
- b) /r/s glided to [w]
  - *read* [wid]
- c) Glides corresponding to target /r/ did not undergo consonant harmony
  - *roof* [wʊf]

It is from these asymmetries that Dinnsen & O'Connor suggest the existence of an implicational relationship. However, upon closer examination of these data, we also note positional asymmetries, which suggest a different interpretation of the facts. Indeed, for Subject 23, in (7), all of the examples of glides undergoing nasal harmony occurred intervocalically, and all cases of /r/s that were glided but resisted nasal assimilation occurred word-initially. Therefore these examples may not be fully comparable, as they involve differences in terms of both syllable position and prosody (weak position versus strong position). Concerning, Subject 9, aged 3;9, who displayed glides that underwent fricative harmony and /r/s glided to [w] while glides corresponding to target /r/s did not undergo consonant harmony, the only examples listed by Dinnsen & O'Connor (2001b) for glides with an underlying /r/ representation that did not undergo consonant harmony are from the word *roof* and the diminutive form *roofy*. It is therefore unclear if this patterning is word specific or relates to systematic conditions.

Dinnsen & O'Connor (2001b) then summarize patterns from various children from the published literature who displayed both gliding and consonant harmony (e.g., Trevor, age 1;3–2;0, from Pater 1997). They also discussed children who displayed gliding only, and state that they could find no instances in the literature where harmony occurred without gliding. However, this appears specific to glides being subject to harmony (a specific manner harmony), and not consonant harmony processes in general. Minimally, we can claim that the evidence in support of their proposal is rather weak and calls for further empirical verification.

4.7. Weak syllable deletion (Kehoe & Stoel-Gammon 1997)

The last relationship to be discussed states that "errors of weak syllable deletion in syllables beginning with an obstruent imply like errors in syllables beginning with a sonorant." The evidence for this relationships comes from Kehoe & Stoel-Gammon (1997). In this article, the authors evaluate various approaches to prosodic development. The authors then evaluate these approaches using data from English-learning children with the goal of being able to account for "the increased preservation of final over non-final unstressed syllables, segmental and prominence effects on truncation rate, and the relative infrequency of epenthesis and stress error patterns" (Kehoe & Stoel-Gammon 1997: 113). Kehoe & Stoel-Gammon find current approaches to be inadequate to account for their data, and advocate for a constraint-based approach such as Optimality Theory.

The authors evaluate data from two studies: Kehoe (1994) and Kehoe (1995). Kehoe (1994) looked at 11 27-month-old children and their ability to produce two-, four-, and five-syllable words, as well as 10 30-month-old children and their ability to make four- and five-syllable words. Kehoe (1995) investigated six children each (for a total of 18) at 22, 28, and 34 months of age, focusing on their ability to produce three- and four-syllable words. In both studies, the words varied in stress patterns. The data are cross-sectional and involve both spontaneous and imitated words. The authors elicited real English words, with the exception of one nonsense word-naming task using three-syllable words to avoid familiarity effects (this task also involved real words). The three syllable words involved a segmental condition which contrasted whether the unstressed syllable had a stop or non-stop consonant.

Kehoe & Stoel-Gammon (1997) observed a number of patterns in the data including that "children preserve stressed syllables and unstressed syllables in word-final position" (Kehoe & Stoel-Gammon 1997: 120). Gierut based the current relationship on their finding that "children preserve unstressed syllables with obstruent onsets more frequently than unstressed syllables with sonorant onsets" (Kehoe & Stoel-Gammon 1997: 114). While Gierut argues that this behaviour is governed by grammatical relationships, Kehoe and Stoel-Gammon suggest that segmental factors may be influenced by resyllabification (when talking about three-syllable words, such as TElePHONE (which has intervocalic sonorants) and CROcoDILE (which has intervocalic obstruents)). Their explanation is supported from studies by Fallows (1981), Treiman & Danis (1988), Wijnen (1988) and Gillis & De Schutter (1997) who showed that sonorants tend to syllabify with the preceding vowel when they occur intervocalically. This causes these sonorants to be syllabified as part of the coda, which results in a medial syllable that lacks an onset. It is this onsetless syllable that undergoes deletion.

Kehoe & Stoel-Gammon (1997) make no claims about universal markedness and do not advocate for an implicational relationship involving the children's deletion patterns. They state:

> Children display a strong tendency to retain unstressed syllables with obstruent onsets and to delete unstressed syllables with sonorant onsets. At the present time we are unsure whether this effect reflects children's varying syllabification strategies (i.e., children syllabify sonorants as codas) or an unwillingness to parse unstressed syllables with sonorant onsets (Kehoe & Stoel-Gammon 1997: 140).

The author's explanation concerns the syllabification and parsing of sonorant sounds. It is unclear why Gierut extrapolates this to be reflective of universal, markedness-driven relationships.

5. Research questions

In an attempt to address Gierut's original proposal in light of the criticisms formulated above, I will pursue the following questions:

(9) Are implicational relationships (as proposed by Gierut 2007) warranted cross-linguistically?

I will address this question by compiling a timeline for six children from four different languages across the span of their development and noting where and at what age each potentially relevant phonological process occurs. I will track the potential manifestation of each of the implicational relationships proposed by Gierut (2007) and see if the patterns these relationships imply are present in the speech outputs of child language learners.

(10) Are the findings true of both typical and atypical phonological development?

Working towards this question, I will examine whether a clinical corpus of English can be accounted for under the theoretical approach (e.g., implicational relationships; universal markedness; structural pressures) as the other corpora. Ideally, any theory should account for both typical and disordered phonology.

(11) What is the source of error patterns in phonological development?

For both the phonological processes and the potential implicational relationships which I uncover in the data, I will investigate their potential origin(s) from the perspectives of both universal markedness and, alternatively, phonetic pressures (e.g., perceptual or articulatory factors).

6. Relevance

Any proposal involving implicational relationships is rooted in phonological and markedness theory. Despite their theoretical and untested nature, implication based treatment approaches have not only gained the attention of the Speech-Language Pathology profession, they have entered mainstream clinical practice. For example, in Bernthal & Bankson's (2004) textbook on Articulation and Phonological Disorders, Chapter 6 of the textbook, titled "Remediation Procedures," cites an implicational relationship based approach (e.g., Gierut 1989) as a valid treatment option. It recommends that treatment focus on sounds that the child has the least phonological knowledge of and, by doing so, treatment will cause system-wide changes. While described alongside a multitude of other treatment approaches, its inclusion highlights the fact that clinical applications of implicational relationships, such as those proposed by Gierut, may influence mainstream Speech-Language Pathology.

Additionally, on the American Speech-Language-Hearing Association (ASHA 2018) website, implication based approaches are listed as both a means of target selection and as a treatment option. The website (http://www.asha.org/PRPSpecificTopic.aspxfolderid=8589935321&section=Treatment) states:

> Approaches used for selecting initial therapy targets for children with articulation and/or phonological disorders include: ... non-developmental/theoretically motivated approaches, including the complexity approach—targets more complex, linguistically marked phonological elements not in the child's phonological system to induce cascading generalization learning of sounds (Gierut 2007).

While the website states that the inclusion of an approach does not equal an endorsement from ASHA, at the very least it establishes that markedness and implicational relationship approaches have made their way into the everyday clinical treatment literature and vernacular.

As previously discussed in Chapter 1, sections 2 and 3, there is literature that provides counter evidence against using implicational relationships in treatment (e.g., Rvachew & Bernhardt 2010), while various phonological processes cannot be accounted for under this kind of markedness based phonology (e.g., Bedore, Leonard & Gandour 1994; Inkelas & Rose 2007). Additionally, the notion of using implicational relationships in clinical treatment is widely untested and, as discussed above, many of the studies used in support of implicational relationships suffer from methodological and empirical challenges.

Therefore, as the topic of implicational relationships is no longer solely theoretical, its validity needs to be tested more systematically. In pursuit of the research questions listed above, I undertake a longitudinal, comparative study of child phonological development. I consider data from six children learning one of the following languages: English (both typical and disordered), German (two children due to relatively smaller datasets), French, and Portuguese. I establish a developmental timeline for each child and look for interactions between production patterns within each developmental period.

Before I begin this study, I provide additional background on the representational concepts that I use throughout this thesis. This is followed by a summary of the methods I use to analyze the acquisition data from each of the four languages.

7. Theoretical background: prosodic structure

In this section, I describe the main theoretical concepts required in the description of prosodic (syllable and stress) structure. I begin with background information about prosodic structure and syllabification.

7.1. Prosodic Hierarchy

From a theoretical standpoint, it is generally accepted that languages are hierarchically organized, as represented by the Prosodic Hierarchy in Figure 1, which I reproduce in Figure 4 for convenience. The internal structure of the syllable itself contains smaller units: sounds are assembled under timing units, which are then organized into syllable constituents (e.g., onset, nucleus, coda; see further below). Syllables combine into feet. Feet exist for purposes of stress assignment and combine to form the prosodic word.

Figure 4: Prosodic Hierarchy (Selkirk 1978; 1980; McCarthy & Prince 1986)

Prosodic Word (PWd)
|
Foot (Ft)
|
Syllable (σ)
|
(Syllable subconstituents)
|
Timing unit (X)

7.2. Sonority and syllable structure

In this section, I describe the formal elements that make up syllable structure across languages. As we will see, sonority is the main factor influencing syllabification (Fudge 1969; Selkirk 1982; 1984; Clements 1990; Rice 1992), so I begin with the Sonority Sequencing Principle (SSP) as defined by Clements (1990) in (12). A few considerations also concern place of articulation; I will mention these whenever relevant.

(12) Sonority Sequencing Principle (SSP; Clements 1990: 285)
Between any member of a syllable and the syllable peak, only sounds of higher sonority rank are permitted.

The SSP states that sonority always decreases as one moves away from the nucleus towards the outside margins of the syllable, in either direction. It requires that sounds be ranked in terms of sonority, as shown in the Sonority Hierarchy in Figure 5. This ranking determines which sounds can occur across syllable positions.

Figure 5: Sonority Hierarchy (Clements 1990)

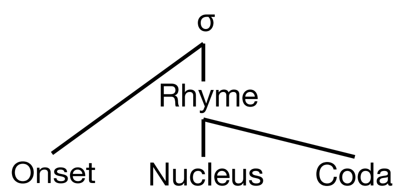
Most sonorous	▲	Vowel
	│	Glide
	│	Liquid
	│	Nasal
Least sonorous	▼	Obstruent

In the subsections that follow, I present a relatively restricted view of syllabification, as proposed by, e.g., Harris (1994). While alternative views of syllabification are available in the literature, the current one offers the types of distinctions that are useful to the ensuing discussions.

7.3. Core syllabification

As shown in Figure 6, the basic syllable is composed of an obligatory rhyme and nucleus, and optionally preceded by an onset and/or followed by a coda (e.g., Pike & Pike 1947; Fudge 1969; Halle & Vergnaud 1978; McCarthy 1979; Selkirk 1982). Core syllables contain any segments that do not violate the SSP.

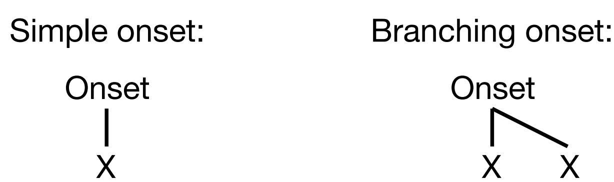
Figure 6: Core syllable structure



The onset is made up of the sounds (consonants or glides) that occur up to the syllable peak (nucleus). The rhyme contains the nucleus, which usually consists of vowels or diphthongs but may also include syllabic consonants.

Languages differ in the syllable positions they allow, as well as in the number of segments they allow in each position. Some languages only allow simple onsets while others allow branching onsets. The onset is a maximally binary constituent (e.g., Harris 1994). Figure 7 (repeated from Figure 2) shows the two possible representations for onsets.

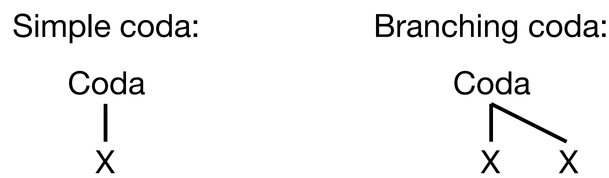
Figure 7: Simple vs. branching onsets



If a language allows branching onsets, the segments must follow the SSP and increase in sonority as they move towards the syllable peak.

The syllable coda is a part of the rhyme and is made up of one or more consonant(s) that occur after the nucleus. Codas pattern differently depending on the language. Some languages do not allow codas at all, and others only allow simple codas but not branching ones. The difference in structure between simple and branching codas is illustrated in Figure 8.

Figure 8: Simple vs. branching codas



Branching codas must also follow the SSP in (12) and decrease in sonority as they move away from the syllable peak towards the word margin.

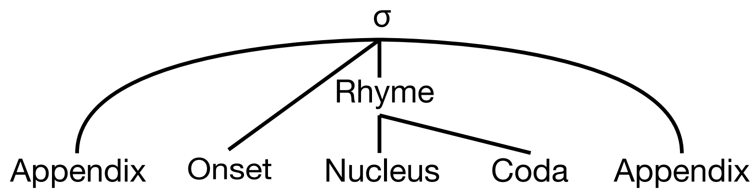
Syllables may also incorporate more elements. I turn to these in the next section.

7.4. Non-core syllabification

As previously mentioned, onset consonants must generally rise in sonority towards the nucleus, and codas fall in sonority following the nucleus, in accordance with the SSP (Clements 1990). Depending on language-specific restrictions, tautosyllabic consonant clusters with flat sonority may or may not be allowed. When they are allowed, these sequences generally involve appendices, which are positions formally considered to exist outside of the syllable.

Figure 9 shows a more complex syllable structure illustrating a maximal syllable, which includes optional left and right appendices. Appendices occur outside of the onset or rhyme and consist of consonants that may violate the SSP.

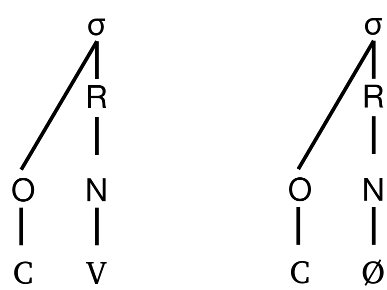
Figure 9: Maximal syllable structure



In the four languages under investigation, /s/ in English and French patterns as an appendix at the left edge of words, as does syllable-initial /ʃ/ in German and Portuguese.[2] Right-edge appendices are only relevant to English and German (e.g., the last three sounds in *sixths* [sɪk<u>sθs</u>]). Syllable appendices, due to their extra-syllabic status, are expected to display peculiar patterns in acquisition as well.

In order to fully describe the syllable structure of the four languages relevant to this study, I must also discuss onsets of empty headed syllables (OEHS). OEHS consist of syllables whose nucleus does not contain any phonetic content. Figure 10 contrasts the difference in structure between a typical onset and an OEHS, for which the empty nucleus is represented by Ø.

Figure 10: Typical onsets vs. onsets of empty headed nuclei



OEHS are particularly relevant to the description of French phonotactics, where word-final consonants must be syllabified as an OEHS. This is described in more detail in section 8.3 below.

2 In European Portuguese, [ʃ] at the left edge of words can also be analyzed as the coda of an empty headed syllable. Under this analysis, the nucleus that precedes these coda consonants is void of any phonetic content. For further explanation refer to Mateus & d'Andrade (2000: 52).

8. Language descriptions

In this section, I provide a descriptive sketch for each of the four languages under investigation, in terms of their phonemic inventory, prosodic properties, and phonotactic constraints. Throughout these descriptions, I focus primarily on consonants, as Gierut's implicational relationships do not consider vocalic development.

8.1. English

English is a member of the West-Germanic language family. The children relevant to this study were learners of American English; I will thus focus on this particular dialect in the following description.

Consonant inventory

General American English has 24 consonant phonemes, listed in Table 8.

Table 8: Consonant phoneme inventory of General American English (Smit 2007)

	Labial	Coronal			Dorsal	Glottal
		dental	alveolar	alveopalatal		
Stops	p, b		t, d		k, g	
Fricatives	f, v	θ, ð	s, z	ʃ, ʒ		h
Affricates				ʧ, ʤ		
Nasals	m		n		ŋ	
Liquids			l, ɹ			
Glides	w			j		

The consonants are divided across four major places of articulation: labial, coronal, dorsal, and glottal. Coronals have the largest consonant inventory and contain three further place distinctions: dental, alveolar, and alveopalatal. The sounds also have varying levels of sonority. Stops have the lowest sonority, followed by fricatives, affricates, nasals, and liquids. Glides have the highest sonority. English also has several common allophones not included in this table; they are described below.

Syllable Structure

Syllables in English can be as small as a single vowel or diphthong (e.g., *I*) and as large as three consonants before and after the vowel ($C_{(0\text{-}3)}VC_{(0\text{-}3)}$) (e.g., *sprints*) (Smit 2007), with words like *sixths* [sɪksθs] a more extreme, rarely occurring case. In terms of internal syllable structure, English allows both vowels and sonorant consonants (such as [ɹ] or [n]) to occur in the nucleus of the syllable. English has both branching onsets and codas, and they adhere to the SSP as described in (12) above: segments decrease in sonority as they move away from the nucleus towards the outside margins. Tautosyllabic consonantal sequences that violate the SSP involve extra-syllabic appendices. English only allows [s] in left-appendix position but can have up to three consonants in word-final appendices. In such cases, all consonants have to be coronal and agree in voicing with the preceding consonant (for example, the final three sounds in *sixths* [sɪksθs]).

Phonotactics

All consonants of English can occur word- and syllable-initially with the exception of /ŋ/. All consonants can occur word- and syllable-finally with the exception of [h]. In addition to the phonemes listed in Table 8, the flap [ɾ] and glottal stop [ʔ] are frequently occurring allophones in English. The flap [ɾ] is an allophone of /t, d/ and occurs in between vowels in onsets of unstressed syllables (e.g., *atom* [æɾəm]); the glottal stop [ʔ] occurs frequently as an allophone of post-vocalic /t/ when it occurs before an alveolar (syllabic) nasal (e.g., *button* [bʌʔən]) (Hammond

1999). Syllable-/word-final /t/ is also commonly expressed as [ʔ] in words such as *department* [dɪpɑʔmənt], *foot* [fʊʔ], and *start* [stɑɹʔ].

English also has two /l/ sounds. /l/ is velarized as [ɫ] when it occurs after a vowel or before a consonant at the end of a word (e.g., *pool* [puɫ] and *help* [hɛɫp]).

In addition, voiceless stops (i.e., /p, t, k/) are aspirated when they are syllable initial and/or precede a stressed vowel (i.e., they are in the onset of a stressed syllable). For example, *pipe* [pʰaɪp], *team* [tʰim], and *kick* [kʰɪk].

Clusters

English allows clusters in word-initial, -medial, and -final positions. Table 9 summarizes the types of consonant clusters allowed in English, as found in Hammond (1999).

Word-initially, /tl/, /dl/, /pw/, and /bw/ are not permitted. Additionally, voiced fricatives cannot occur as the first member of a branching onset.

Table 9: Consonant clusters of English (Hammond 1999: chap. 3)

Cluster type	Generalizations
Word-initial [s]C clusters	[s] clusters with any following consonant except voiced obstruents, affricates, and [ɹ].
Word-initial affricate clusters	Do not occur.
Word-initial obstruent-approximant clusters	No voiced fricatives, alveolar stops [t, d] do not cluster with [l], and labial obstruents [p, b, f, v] do not cluster with a following [w].
Word-initial three consonant clusters	[spr, str, skr, spl, skl, skw, spj, stj, skj]
Word-final nasal-consonant clusters	Voiced obstruents cannot occur.
Word-final [s]+stop clusters	[s] can be followed by any voiceless stop.
Word-final [l]C clusters	[l] can occur with any following obstruent or nasal.
Word-final [ɹ]C clusters	[ɹ] can occur with any following obstruent or nasal or [l].
Word-final C+coronal clusters	Any voiceless stop or fricative can be followed by a voiceless coronal stop or fricative.

For clusters larger than two consonants, the same sequences as those listed in Table 9 above apply: the larger sequences are combinations of the well-formed smaller sequences (also known as the Substring Generalization; Hammond 1999: 54). For example, the word-initial consonant cluster [spl] is composed of the two legal sequences of [sp] and [pl]; the word-final consonant cluster [mpt] is composed of the two legal word-final sequences [mp] and [pt].

Stress

English has lexical stress, which implies that every content word must have one stressed syllable while most multi-syllabic words show alternating stress patterns. As mentioned above, stress is often assigned to the first syllable of words, however a multitude of factors, such as word's grammatical category or the number of affixes present in a word, can affect stress placement (Smit 2007).

8.2. German

German is also a member of the West-Germanic language family. As a member of the same language family as English, its syllable structure and phonotactics are generally similar to those of English, with the few exceptions highlighted below.

Consonant Inventory

German contains 15 uncontroversial consonant phonemes, as detailed in Table 10 (Wiese 1996: 10) (there is debate over the allophonic vs. phonemic status of the sounds listed between parenthesis).

Table 10: German consonant phonemes (Wiese 1996: 10)

	Labial	Coronal		Dorsal	Glottal
		alveolar	alveopalatal		
Stops	p, b	t, d		k, g	(ʔ)
Fricatives	f, v	s, z	ʃ, (ʒ), (ç)	(x)	(h)
Affricates	(p͡f)	(ʦ)	(ʧ), (ʤ)		
Trill				ʁ	
Nasals	m	n		(ŋ)	
Liquids		l			
Glides			(j)		

Similar to English, the coronal place of articulation contains the largest inventory, with the other consonants distributed between labial, dorsal, and glottal places of articulation. However, the two sounds listed as glottal ((ʔ) and (h)) may or may not be phonemes.

German has seven different manners of articulation: stops, fricatives, affricates, trills, nasals, liquids, and glides. The phonemic status of all affricates is debated in the literature, but while the status of the affricates /p͡f/ and /ʦ/ is controversial, for the purpose of this research they will be considered as affricates (Ternes 1987; Fox 2007).

Other controversies involve the alveopalatal and dorsal consonants between parenthesis. These controversies involve the discussion of native vs. loanwords or involve the allophonic status of phone pairs (mainly [ç] and [x]). For example, it is unclear whether the sound /ʒ/ should be considered a phoneme of German as it occurs in a subset of the language comprised of loanwords. For the sounds [ç] and [x], while it is accepted that they are allophones of a single phoneme, there is debate surrounding which sound is the phoneme and which is the allophone. The interested reader can consult (Wiese 1996: 11–16) for more detail.

Syllable Structure

German syllables can be as small as a single vowel and as large as three consonants in prevocalic and postvocalic position in a monosyllabic word (i.e., $C_{(0\text{-}3)}VC_{(0\text{-}3)}$) (e.g., *Sprung* /ʃpʁ/).

Like English, German allows sonorant consonants in nucleus position. German allows both binary branching onsets and codas (Wiese 1996) and these branching structures follow the SSP.

German syllables can have appendices, specifically [ʃ] in syllable-initial position and the extra-syllabic obstruents [t], [s], and [st] in word-final position. There can be a maximum of five consonants following the vowel (e.g., *du schrumpfst* /mpfst/) when appendices follow the coda consonant (Wiese 1996), at least if one considers the /pf/ string in this example to be bi-consonantal as opposed to an affricate.

Phonotactics

German displays several non-optional phonological processes. It has final devoicing which causes all syllable-final fricatives and stops to be realized as voiceless (Fox 2007). For example, *Zug* is pronounced as [ʦuk̲] with the final /g/ devoiced to [k]. Voiceless codas also trigger devoicing of any following obstruents within the same syllable. Finally, in German, the glottal stop /ʔ/ must occur before syllable-initial vowels.

Clusters

German allows for the following phonetic clusters as listed in Table 11. While most of these clusters readily conform to the phonotactics of German described above, others are due to additional rules of phonetic implementation, the details of which are described in Wiese (1996). I am listing the phonetic clusters of German (and French and Portuguese below), because these clusters will be relevant when interpreting the child language data. Children are exposed to these phonetic clusters (which do not always follow the phonological rules of the language) in the input and therefore they may occur in their productions.

Table 11: German phonetic consonant clusters (Wiese 1996)

Onset clusters	**Coda Clusters**	
	Sonorant-obstruent clusters	**Obstruent-obstruent clusters**
pl, pʀ, pn, ps	ʀl, ʀm, ʀn, ʀf, ʀs, ʀʃ, ʀç, ʀp, ʀt, ʀk	sf, sp, st, sk
tʀ, tv	lm, ln, lf, ls, lʃ, lç, lp, lt, lk	fs, ft
kl, kʀ, kn, km, ks, kv	mf, ms, mʃ, mp, mt	χs, χt
bl, bʀ	nf, ns, nʃ, nç, nt, ŋs, ŋʃ, ŋt, ŋk	ʃs, ʃt
dʀ		ts, tʃ
gl, gʀ, gn, gm		ks, kt
fl, fʀ		pf, ps, pʃ, pt
vl, vʀ		
tsv, pfl, pfʀ		
ʃl, ʃʀ, ʃn, ʃm, ʃv		

Stress

Penultimate stress placement is considered the regular stress pattern in German (Kohler 1977; Fox 2007). Similar to English, a number of factors affect stress placement, including morphological affixation. However, one of the last three syllables of the word always receives stress (Wiese 1996).

8.3. French

French belongs to the Romance language family. The description that follows details the sound system and phonotactic constraints of Parisian French, as this is the dialect spoken by the child relevant to this study.

Consonant inventory

French has 20 consonants in its inventory, as detailed in Table 12 below.

Table 12*:* French phonemic inventory (Casagrande 1984)

	Labial	Coronal-Labial	Coronal		Dorsal
			alveolar	alveopalatal	
Stops	p, b		t, d		k, g
Fricatives	f, v		s, z	ʃ, ʒ	
Nasals	m		n	ɲ	
Liquids			l		
Trill					ʁ
Glides	w	ɥ		j	

The consonants have labial, coronal-labial, coronal, and dorsal places of articulation. Similar to English and German described above, the coronal place of articulation displays the largest inventory. The sounds range in sonority from stops, to fricatives, nasals, liquids, trills, and glides. Unlike English and German, French has no phonemic affricates.

The French rhotic [ʁ] differs from the English rhotic [ɹ] in both manner and place of articulation. In regards to manner, the French uvular [ʁ] is phonetically a fricative (i.e., produced with a constriction narrow enough to create turbulent air flow) whereas the English [ɹ] is an approximant (i.e., the articulators approach one another but not narrowly enough to create a constriction or cause turbulent airflow). However, in the data descriptionsiscu below, I include the uvular fricative rhotic [ʁ] under the broad approximant category, on the grounds that uvular fricatives pattern phonologically similar to liquids in French (Rose 2003; Rose & Wauquier-Gravelines 2007:428). The uvular fricative of French (and German and Portuguese) is produced with the tongue dorsum at the uvula, and also differs in place of articulation from the English alveolar rhotic [ɹ], where the tip or blade of the tongue approaches the alveolar ridge.

Syllable Structure

French displays, at the phonetic level, a syllable structure of $C_{(0\text{-}3)}VC_{(0\text{-}3)}$ (Rose & Wauquier-Gravelines 2007). In syllable nucleus, only vowels are allowed. French allows for branching onsets, which must have rising sonority, as per the SSP.

Codas in French pattern quite differently from English and German, but in part similarly to the other member of the Romance language family under investigation, Portuguese. Codas contain at most one consonant (Bouchard 1980: 20), while right-edge consonants pattern as onsets of empty-headed syllables (Kaye 1990; Kaye, Lowenstamm & Vergnaud 1990; Charette 1991; Harris 1994; 1997; Dell 1995). In words which have only one consonant word-finally, this consonant must be syllabified as an OEHS (see Goad & Brannen 2000 for phonetic evidence in support of empty headed syllables in French). If there are more consonants following the vowel, their syllabification depends on sonority. If word-final consonants have flat or falling sonority towards the right end of the word (e.g., *tact* [tak.t] and *carte* [kaʁ.t], where the period (.)

represents a syllable boundary) then they involve a single consonant coda followed by the onset of an empty-headed syllable. If consonants have rising sonority, then they are syllabified as the branching onset of an empty headed syllable (e.g., *quatre* [ka.tʁ]). If there are three consonants in a row, syllabification is as follows: the first consonant is a coda and the last two have to rise in sonority and pattern as a branching onset (e.g., *arbre* [aʁ.bʁ]).

Phonotactics

A word-initial onset in French can contain any consonant except /ɲ/. Codas can contain any single consonant with the exception of nasals. French does not have nasal codas, however nasals occur in word-final position (e.g., *canne* [ka.n]), where they are syllabified as onsets of empty-headed syllables, similar to all consonants in this position (Piggott 1999; Rose 2000). For sake of comparison below, I will treat all word-final singleton consonants of French as syllable codas, in order to maintain necessary parallels between all datasets.

Clusters

Table 13 details the phonetic consonant clusters and onsets allowed in French in word-initial, -medial, and -final position. Before the vowel, clusters are restricted to /s/ followed by an obstruent and a liquid (e.g., *splendide* [spl̲ɑ̃did]) or they can consist of an obstruent followed by a liquid-glide combination (e.g., *pluie* [plɥi]), where the glide [ɥ] is part of the nucleus (Kaye & Lowenstamm 1984). After the nucleus, French does not allow nasal codas, as already mentioned, but allows obstruent and liquid codas. Adjacent obstruents agree in terms of voicing values (i.e., adjacent obstruents are voiced or voiceless) (e.g., *opter* [ɔpte], but not *[ɔbte]) (Rose 2000).

I am listing the phonetic clusters of French below as they will be relevant when interpreting the child language data.

Table 13: Consonant clusters and onsets in French (Dell 1995)

Word-initial clusters	Word-medial clusters	Word-final clusters
[pl, pr, bl, br, fl, fr, vl, vr, tr, dr, kl, kr, gl, gr]	Most CC clusters except ɲC clusters and clusters of two identical obstruents.	[pl, pr, bl, br, fl, fr, vr, tr, dr, kl, kr, gl, gr]
[sp, st, sk]	[spl, spr, str, skl, skr]	/l/ and /r/ + any consonant (except [lr, ll, rr, lz, lɲ])
[spl, spr, str, skl, skr]	C/l/ [pr, br, fr, vr, tr, dr, kr, gr] C/r/ [pl, pr, bl, br, fl, fr, vl, vr, tr, dr, kl, kr, gl, gr]	[sp, st, sk]
[pn, ps, pf, pt]	[rsp, rst, rstr, lst, lstr]	[pt, kt, ft, ps, ks]
[kn, km, kv, ks, kt]	[ptr, pst, pstr, psk]	[ts, tʃ, dʒ]
[tl, tm, ts, tʃ]	[ktr, kst, kstr, ksk, kskr, kskl, ksp, kspr, kspl]	[nt, nd, ns, nʃ, ms]
[sl, sm, sn, sv, sf]	[rbs, rbt, rks, rkt, rkn, rts, rdz, lpt]	[tm, sm, km, gm, dn, gn, mn]
[ʃl, ʃr, ʃn, ʃv, ʃpr, psk]	[mst, mps, nst, sʃp]	[tl, dl]
[gn, gz]		C/l/ [pr, br, fr, vr, tr, dr, kr, gr] C/r/ [pl, pr, bl, br, fl, fr, vl, vr, tr, dr, kl, kr, gl, gr]
[dz, dʒ]		[spl, spr, str, skl]
[zl, zv, zb, zgr]		[ptr, ktr, kst, kstr]
[mn, ft]		[lpt, rts, rtʃ, rks, rst]
		[ʃtr, nks]

Stress

In French, stress consistently falls on the final syllable of phrases (e.g., Tranel 1981; Kaye & Lowenstamm 1984; Charette 1991). With the exception of schwa, vowels that occur in the last syllable of a phrase (or isolated word) consistently receive stress.

8.4. Portuguese

Portuguese is a Romance language closely linked to Castilian and Catalan (Yavaş & Mota 2007). European Portuguese is the focus of the description below, as it is the dialect relevant to my current research.

Consonant inventory

European Portuguese has 19 consonant phonemes as listed in Table 14.

Table 14: European Portuguese consonant inventory (Yavaş & Mota 2007)

	Labial	Coronal		Dorsal
		alveolar	alveopalatal	
Stops	p, b	t, d		k, g
Fricatives	f, v	s, z	ʃ, ʒ	
Nasals	m	n	ɲ	
Laterals		l	ʎ	
Rhotics		ɾ		ʀ

The consonant phonemes of Portuguese are divided across three major places of articulation: labial, coronal, and dorsal. Similar to the other three languages under investigation, coronal contains the largest inventory. The consonants are spread across the five manners of articulation of stops, fricatives, nasals, laterals, and rhotics. Like French, Portuguese does not have phonemic affricates. Unlike the other three languages, Portuguese also does not have phonemic glides (Yavaş & Mota 2007).

Syllable structure

Portuguese has a syllable structure of $C_{(0-2)}VC_{(0-2)}$ and allows for up to two consonants in prevocalic and postvocalic position. The rhyme always contains a vowel or diphthong within the nucleus; Portuguese does not have syllabic consonants.

Portuguese has singleton and branching onsets that follow the SSP. Like French, Portuguese can only have one consonant in coda position, and any word-final cluster combination includes the onset of an empty headed syllable (e.g., Mateus & d'Andrade 2000; see also Freitas, 1997 and Almeida 2011).

Phonotactics

In European Portuguese, all phonemes can occur word-initially with the exception of /ʎ /, /ɲ/, and /ɾ/. All consonants can occur medially in between vowels and this is the only position where the phonemes /ʎ / and /ɲ/ occur (Mateus & d'Andrade 2000). Portuguese only allows [ɫ], [ɾ] and [ʃ/ʒ] in coda position. Also, [m] and [n] can occur as codas word-medially, with their place of articulation depending on the following consonant (e.g., *lembrar* and "*canto*").

The lateral consonant /l/ displays positional allophones. In onset position, it is generally referred to as "clear" [l]. The "dark" allophone [ɫ] always occurs in syllable- and in word-final positions. Additionally, coda sibilants systematically agree in voicing with the following segment (e.g., *rasca* [ʀáʃkɐ], and *rasga* [ʀáʒgɐ]) (Mateus & d'Andrade 2000). As mentioned above, [ʃ] at the left edge of words can also be analyzed as the coda of an empty headed syllable. Under this analysis, the nucleus that precedes these coda consonants is void of any phonetic content (Mateus & d'Andrade 2000: 52).

Clusters

Portuguese allows a restricted set of consonant combinations. Only plosive/fricative+ liquid consonant clusters can occur in branching onset position. Table 15 details the permissible onset clusters where the first consonant has to be a stop or the voiceless labio-dental fricative /f/ and the second consonant has to be an alveolar liquid /l, ɾ/.

Table 15: European Portuguese onset clusters (Mateus & d'Andrade 2000: 200)

[pɾ, bɾ, tɾ, dɾ, kɾ, gɾ, fɾ]
[pl, bl, fl, kl, gl]

The above clusters can occur in word-initial as well as word-medial position. An additional cluster /vɾ/ is also allowed in word-medial position (e.g., *pala<u>vr</u>a*). In spite of its relatively restricted set of consonants in phonological clusters, Portuguese displays a fairly large rate of vowel deletion (unstressed monophthongs are typically reduced or completely deleted (Mateus & d'Andrade 2000)). This yields a vast series of phonetic consonant clusters. Table 16 lists the phonetic consonant clusters that violate the SSP. These clusters are not branching onsets of a single syllable. Similarly to French, these clusters pattern as the onsets of different syllables with empty headed nuclei.

Additional clusters that violate the SSP occur in colloquial European Portuguese.

Table 16: Portuguese consonant clusters that violate the SSP (Mateus & d'Andrade 2000)

Word-initial	**Word-medial**
[pt], [bd], [kt], [ps], [pn], [tm], [gn], [mn]	[pt], [bt], [bd], [dk], [kt], [bs], bv], [bʒ], [tz], [dv], [ks], [pn], [bn], [tm], [tn], [dm], [dn], [gm], [gn], [mn]

Stress

Similar to English and German, stress assignment in Portuguese is affected by word category and morphological inflection. Stress always falls on one of the last three syllables (i.e, the final, penultimate, or antepenultimate syllable). In general (about 80% of the native vocabulary), stress falls on the final syllable of bare stems and on the penultimate syllable if there is a class marker.

For most nouns, stress occurs on the penultimate syllable (the second syllable from the right-edge of the word) if the word ends in a vowel, and falls on the ultimate (final) syllable when it ends in a consonant. Verbs most often receive penultimate stress; however, this depends on the morphological markers attached to the verb stem. Additionally, unstressed vowels often delete, most commonly following the stressed syllable or in final position (Mateus & d'Andrade 2000).

9. Corpus selection

In order to study how phonological patterns interact, and to track the evolution of production patterns over time, it is necessary to observe these patterns across the relevant span of development (Rose & Inkelas 2011). Working towards this goal, I use data from longitudinal studies, which can provide a detailed look into the developmental logic underlying the types of implicational relationships suggested by Gierut (2007). This longitudinal approach also enables me to focus on potential interactions between the patterns observed in the data.

9.1. Motivating the languages

Working towards my research goals, I studied data from children learning English (both typical and disordered), German, French, and Portuguese. I selected these four languages based on the typological similarities and differences they offer. For example, all of these four languages have /l/ and /r/ in syllable-initial, -medial, and -final positions. As gliding (i.e., the pronunciation of /l/ and /r/ as [j] and [w], respectively) is common in child language productions and features in seven of Gierut's 22 implicational relationships listed in Table 1, the presence of liquids in all four languages is important. These consonants also display phonetic differences, which will allow for a more detailed analysis of how phonetic detail may influence acquisition. For example, in English, the clear [l] of *leaf* is phonetically different from that of the dark (or velarized) [ɫ] in *feel*.

European Portuguese patterns in a similar way, while [l] in German and French does not; these two languages have clear [l] in both syllable-initial and syllable-final positions.

Differences between the languages selected will aid in determining whether Gierut's proposed relationships can be validated cross-linguistically, more specifically across language families as German and English belong to the Germanic language family whereas Portuguese and French are Romance languages. Additional differences, for example in terms of the languages' stress systems, will aid in investigating the cross-linguistic validity of error patterns such as the deletion of weak or unstressed syllables. For example, in French stress is placed on the final syllable of a phrase (or isolated word), whereas in English stress placement is more variable (stress is often assigned to the first syllable of multi-syllabic words; however, this is not a constant and a number of factors, such as morpheme affixation, can affect stress placement).

All of these corpora were obtained through the PhonBank database (http://phonbank.talkbank.org), an online repository of phonological corpora documenting the acquisition of phonetic and phonological properties of acquisition across different languages and populations of learners (Rose & MacWhinney 2014).

9.2. Corpus descriptions

The corpora consists of data from six different children as described in Table 17 below.

Table 17: Participants

Language	Name	Age Range	# of sessions	Sex	Type of Study
English	William	1;04.12 – 3;04.18	44	M	Naturalistic
French	Adrien	1;11.14 – 4;03.27	26	M	Naturalistic
German	Eleonora	1;00.07 – 1;10.25	30	F	Naturalistic
German	Wiglaf	1;03.21 – 2;01.21	24	M	Naturalistic
Portuguese	Inês	0;11 – 4;2	30	F	Naturalistic
English	Ben	3;9.27 – 4;3.5	17	M	Clinical

The typical English data come from the English-Providence Corpus (Demuth, Culbertson & Alter 2006; Song, Sundara & Demuth 2009; Song, Demuth & Shattuck-Hufnagel 2012; Evans & Demuth 2012; Börschinger, Johnson & Demuth 2013; Song et al. 2013). This corpus contains recordings of six monolingual English-learning children collected at their homes during interactions with their parents. I use spontaneous speech data from William from ages 1-3 years, which consists of 44 sessions with audio files available.

The French data come from the French-Yamaguchi corpus (Yamaguchi 2012), which documents one child, Adrien, from ages 1;1 to 4 years, learning Parisian French. The data come from spontaneous speech samples collected during play sessions at his home with his parents. This corpus consists of 31 sessions with audio files available.

The German data come from the German-Grimm corpus (Grimm 2006; 2007).The corpus documents four monolingual learners of German. The data were collected at home during interactions with the children's parents. I use data from Eleonora, which consists of 30 documented sessions from ages 1;0–1;10, and from Wiglaf, who has 24 sessions available from ages 1;03.21–2;01.21.

The Portuguese data come from the Portuguese-CCF corpus (Correia 2009; Costa 2010; Correia & Costa 2010), and consist of the recordings of five monolingual speakers of European Portuguese. The data come from spontaneous speech samples collected at the children's homes with their parents or caretakers. I will use data from Inês, ages 0;11 to 4;2. She has 30 sessions with audio files available.

The clinical English data come from the McAllister-Byun corpus (McAllister Byun 2009; 2011; 2012). This longitudinal corpus was collected through the Neurolinguistics of Language Acquisition and Delay Clinic at Children's Hospital in Boston. The data come from Ben, who has a speech sound disorder with features of Childhood Apraxia of Speech (CAS). The recordings were collected in a clinical setting during the child's speech therapy sessions. McAllister Byun (2009) classified CAS as a phonological delay where articulatory limitations (i.e., limitations on speech motor planning) cause the child to resemble a typically developing child at a much earlier stage of development. At the beginning of the seven month study, Ben's speech was severely unintelligible and he had simplified syllable structure, distorted vowel quality, and inconsistent articulatory errors, all of which are hallmarks of CAS, along with prosodic abnormalities. Ben displayed velar fronting, fricative gliding, prevocalic voicing and final devoicing, cluster simplification, glide epenthesis in onsetless syllables, and gliding/vocalization of liquids.

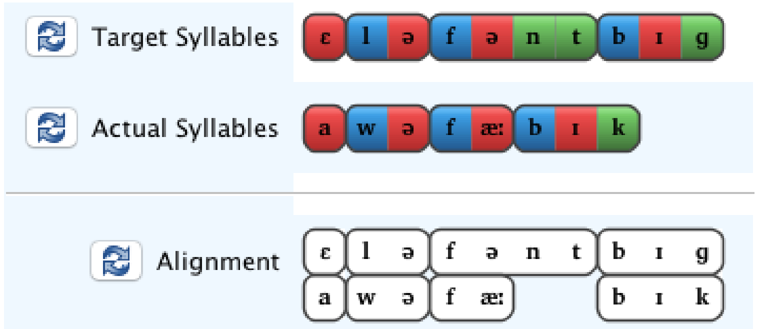
10. Data preparation

Each of these corpora is fully transcribed by their original authors and/or co-members of the teams who worked toward the construction of these corpora. Prior to describing analysis, I will now describe the additional steps I took towards preparing these data for analysis.

To perform the required phonological analyses described in Chapter 3 below, I used the computer software program Phon (Rose et al. 2006; Rose & MacWhinney 2014). Phon is an open-source software program designed to facilitate the building of phonological corpora and their analysis. Phon provides flexible query methods to analyze phonological data and detect the types of phonological patterns described as part of Gierut's original proposal. I used Phon to organize my corpus data and perform the phonological analyses presented below.

Among other functions, Phon automatically labels phonetic transcriptions for syllabification data, with specific algorithms to account for the syllabification properties of each of the languages under analysis. Figure 11 shows the colour-coded syllabification for English.

Figure 11: Syllabification and alignment in Phon



This figure also illustrates phone-by-phone alignments between target and actual word forms. These alignments are at the centre of the analyses proposed, as they enable a systematic compilation of segmental production, substitution, deletion, or epenthesis. While phone alignments are derived through an automatized (best-guess) algorithm within Phon, they also require manual verifications. While performing these verifications, I aligned the phones maximally based on phonetic similarities: vowels aligned with vowels, stops with stops, glides with glides, etc. For example, if [slip] was produced as [wi], the phonetic target and actual production would be matched for the vowel [i], with [s] and [p] deleted, and the [l] would be matched to the glided [w] as these two approximants share the most phonetic features.

Chapter 3: Case studies: a cross-linguistic survey of developmental patterns

1. Introduction

In this chapter, I discuss the phonological development of the five children introduced above in Chapter 2, section 9.2. I describe each child's patterns of segmental development, in order to attain a maximally theory neutral empirical basis to address the current research questions. Also, in order to provide the level of detail required for ensuing discussions, and while Gierut's implicational relationships generally involve broad sound categories such as obstruents, stops, and fricatives, I divided these large categories into the sum of their parts for segmental analysis, thereby looking at the acquisition of each individual sound.

In the descriptions below, I classified a phone or phone category as acquired when the child achieved a majority of accurate productions (i.e., the child has at least 50% phone/category accuracy) within a given session transcript, and the proportion of correct productions continues to increase in consecutive sessions. While this criterion is not as stringent as can be found in other works on child language acquisition (e.g., Santos 2007; Almeida 2011; see Ingram 1981 for an early discussion), the longitudinal data descriptions presented below afford me the opportunity to keep this potential limitation in perspective.

I examined the course of each child's phonological development using a series of query scripts ran on the computer program Phon (Rose et al. 2006; Rose & MacWhinney 2014). I limited my queries to singleton onsets and codas in order to avoid interactions with patterns of cluster reduction (unless I was specifically looking at cluster development). I restricted each singleton onset query to the word-initial position only, irrespective of lexical stress. For all queries, I ignored results from truncated syllables. For example, if *banana* was produced as *nana*, [b] deletion in this case was not reported, as it may relate to an issue in prosodification rather than to the child's actual phonological productive abilities (Gerken 1994; Demuth 1996). For clusters, I queried onset consonant sequences in all word positions (e,g., word-initial, -medial, -final) in order to ensure that my descriptions were based on a minimally valid number of examples. In my descriptions below, I provide detail on whether I observed differences in phonological behaviours across positions.

Investigating coda acquisition, however, also raises several issues such as the differences between word-medial and word-final codas, the differences between coda clusters (e.g., ca<u>rt</u>) and coda-onset clusters (e.g., ca<u>rp</u>et), as well as prosodic issues related to stress. To control for some of these issues, I limited queries to singleton codas in word-final position.

Across all of my descriptions below, I organize the data according to manner of articulation (e.g., obstruents, nasals, approximants), which themselves generally refer to the broad categories referenced in most of the implicational relationships documented above. Within the description of each category, I introduce the data by chronological order of acquisition. Finally, I provide a summary of the child.

2. William

I begin with English-learning William. William had already acquired multiple sounds by the earliest age documented in the corpus (1;04.12), and he acquired an additional two sounds within the first two weeks of recordings.

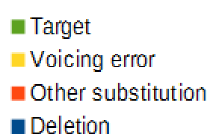
Table 18: William's early consonantal inventory

	Labial	Coronal			Dorsal	Glottal
		dental	alveolar	alveopalatal		
Stops	b		d		k	
Fricatives			s			h
Affricates						
Nasals	m		n			
Liquids			l			
Glides						

As outlined in Table 18, by his first documented session William had already acquired three stops ([b], [d], k]), two fricatives ([s], [h]), and the nasal [m]. By the end of the initial two week period (from 1;04.12–1;04.25), he acquired nasal [n] and the liquid [l] as well. He did not acquire any phones in coda position during this time frame.

In the discussion of William's phonological development below, and for subsequent children's descriptions, the following legend will inform of the child's overall level of phonological performance, unless an alternative one is provided.

Figure 12: Default chart legend



As shown in Figure 12, "Target" describes an accurately produced sound; "Voicing error" describes a sound produced with the correct place and manner of articulation but with incorrect voicing; "Other substitution" encompasses a wide variety of errors that do not fall under the voicing or deletion category; "Deletion" describes when the target sound is deleted from the child's production. When additional patterns are relevant to the discussion (e.g., gliding, stopping, etc.), I provide the relevant legend alongside the figure.

In the next section, I begin my description of William's sound and sound category development from 1;04.12 onward, starting with obstruents in onset position.

2.1. Obstruents in onset position

Stops

As mentioned above, William had already acquired a number of stops in onset position by the earliest corpus session available: [b], [d], and [k] were already acquired at age 1;04.12. During this first developmental session, William accurately produced 15/20 target [b] in syllable onsets, as shown in Figure 13, and [b] continued to be produced with over 50% accuracy in William's subsequent recording sessions.

Figure 13: William's acquisition of [b] in onset

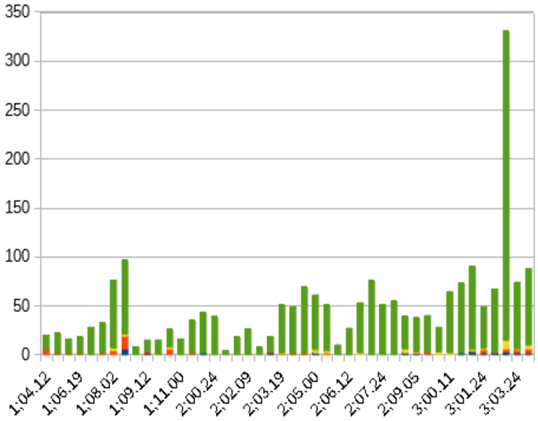


Figure 14: William's acquisition of [d] in onset

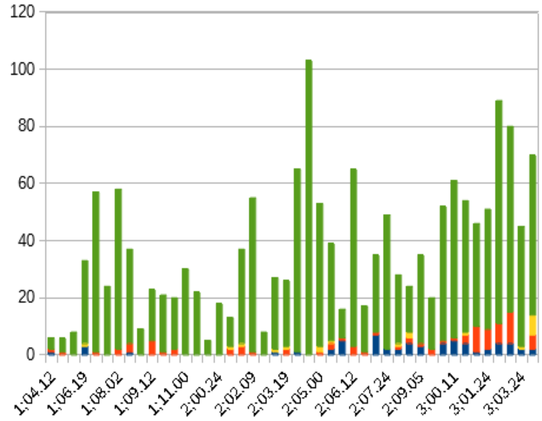
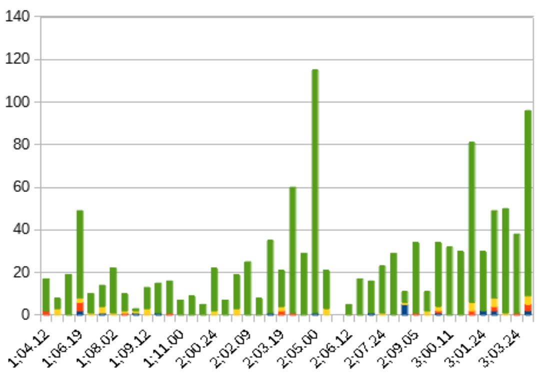


Figure 15: William's acquisition of [k] in onset



William produced [d] in onset with four out of six accurate productions, as shown in Figure 14, and continued to produce [d] with over 50% accuracy throughout his sessions (the two incorrect productions at 1;04.12 resulted from a questionable target word; it is therefore unclear whether these productions truly represent production errors[3]). Lastly, William had also acquired [k] in onset by 1;04.12, with 15/17 sounds produced accurately, and over 50% accuracy across all consecutive sessions, as shown in Figure 15.

Next, William acquired the stops [t], [p], and [g] within the same two-week period.

3 William produced [bʌ] with a possible target of "duck" [dʌk]; however, the target word was marked as questionable by the original transcriber.

Figure 16: William's acquisition of [t] in onset

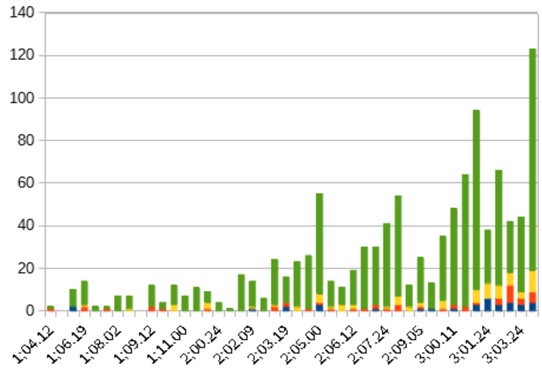


Figure 17: William's acquisition of [p] in onset

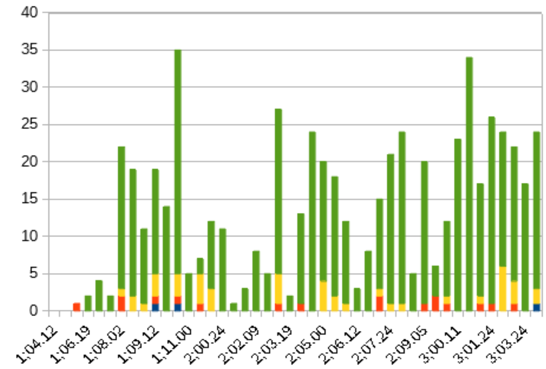
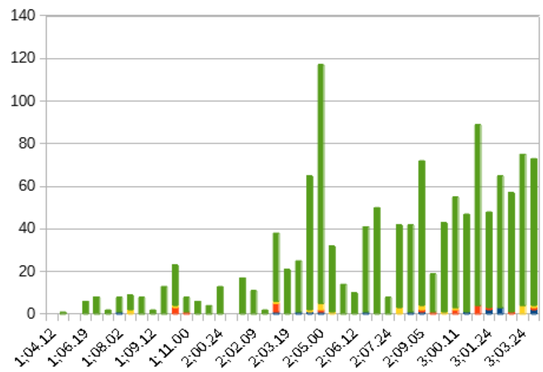


Figure 18: William's acquisition of [g] in onset



As illustrated in the above three figures, William acquired [t] in onset at 1;06.05, with 8/10 correct productions, while both [p] and [g] were both acquired at 1;06.19, with 2/2 and 6/6 accurate productions, respectively.

Fricatives

William had already acquired the fricatives [s] and [h] by the earliest attempts at these sounds recorded in the corpus. As shown in Figure 19, he had acquired [s] in onset by 1;04.12 with eight accurate productions and two other substitutions. [h] in onset was also acquired by 1;04.12, as illustrated in Figure 20, where he produced seven accurate targets (all of the word *h̲ot*) and six deletions (for the words *h̲orsie, h̲ot, h̲ouse*). A noticeably high rate of [h] deletions occurred across the remainder of William's sessions. For example, the last session (3;04.18) records 99 accurate productions and 23 deletions. However, the deletions mostly occurred in connected speech contexts and reflect lenited pronunciations of /h/ in prosodically weak position (e.g., phrases like *give him*, where the [h] generally undergoes deletion), consistent with the properties of the target system.

Figure 19: William's acquisition of [s] in onset

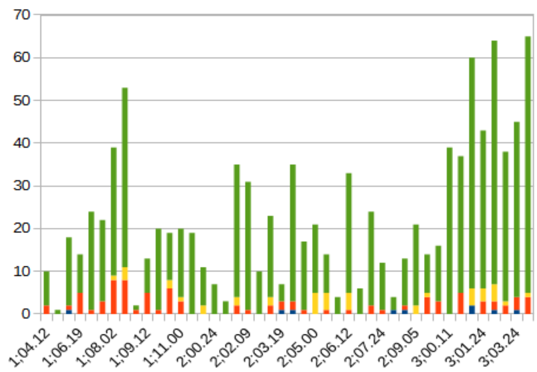
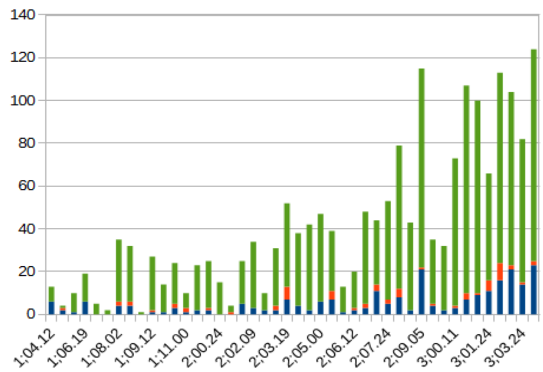


Figure 20: William's acquisition of [h] in onset



William acquired the fricatives [f] and [z] next, however this occurred a few months later. He acquired [f] in onset at 1;07.08, with seven accurate productions (one correct production of *fingers*, six of *fish*) and three other substitutions, as displayed in Figure 21. Before this, William attempted [f] six times, which resulted in a mix of accurate productions and substitutions. At 2;05.00, we observe a drop in performance, with seven accurate productions and nine voicing errors; the voicing errors, however, resulted primarily from the expression *go faster*. William also produced this phrase with the target [f] in the same session, which suggests that he had difficulties with the production of this phrase. William acquired [z] in onset by 1;08.02, as shown in Figure 22, where he produced three accurate targets and one other substitution. Before this, William attempted [z] only once, which underwent deletion. As William did not attempt [z] between 1;04.12 and 1;08.02, I can only state that William had acquired [z] by 1;08.02; however, it may have been acquired earlier.

Figure 21: William's acquisition of [f] in onset

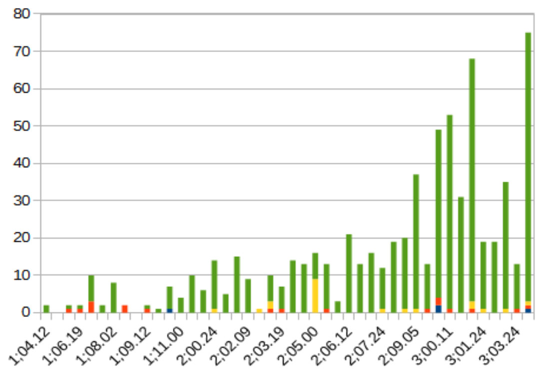
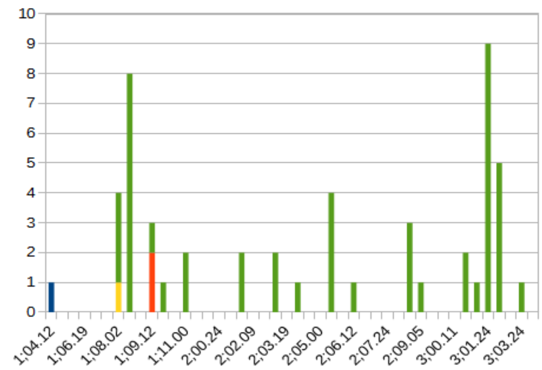


Figure 22: William's acquisition of [z] in onset



The last two fricatives to be acquired in onset position were [ʃ] and [v]. William acquired [ʃ] in onset by 1;08.02, with three accurate productions, as shown in Figure 23. Before this, William attempted [ʃ] only once, which resulted in an accurate production. Due to the lack of recorded attempts, [ʃ] may have been acquired earlier. Similarly, William acquired [v] in onset at 2;04.16 or earlier, with four accurate productions, as displayed in Figure 24. William produced only one correct [v] target out of the three attempted before this session. Similar to [ʃ], William did not attempt many [v] productions in the recordings preceding the session where mastery could be empirically verified.

Figure 23: William's acquisition of [ʃ] in onset

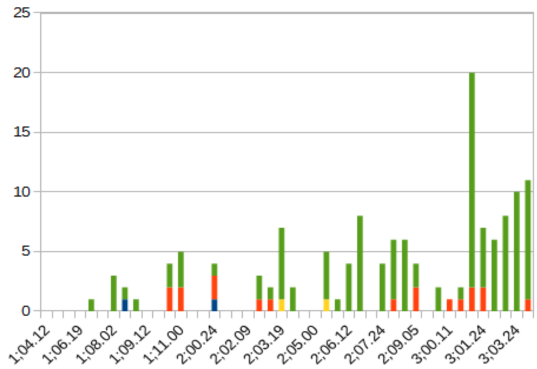
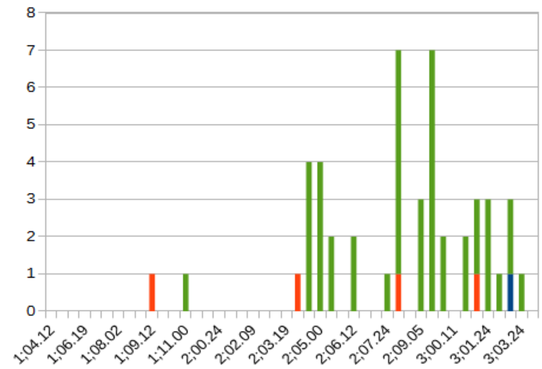


Figure 24: William's acquisition of [v] in onset



William acquired neither of the interdental fricatives by the end of the documented period. Overall, William did not attempt [θ] with much frequency when compared to his other fricative sounds. [θ] briefly looked acquired at 2;09.05, with four accurate productions and three other substitutions (to [f], for the words *<u>Th</u>ursday* and *<u>th</u>irsty*), however William did not maintain a 50% accuracy level in subsequent sessions. His productions dropped below 50% accuracy, and stayed below 50%, after 3;00.11. For example, the last session 3;04.18 shows zero accurate productions, 15 other substitutions (12 to [f] for *<u>th</u>ing(s)* and *<u>th</u>inking*), two instances of stopping, and one deletion.

Figure 25: William's acquisition of [θ] in onset

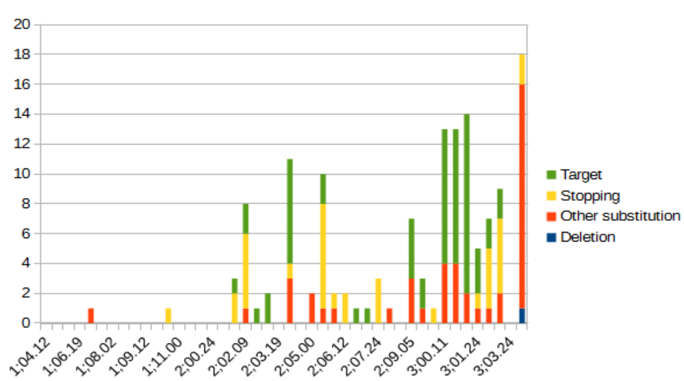
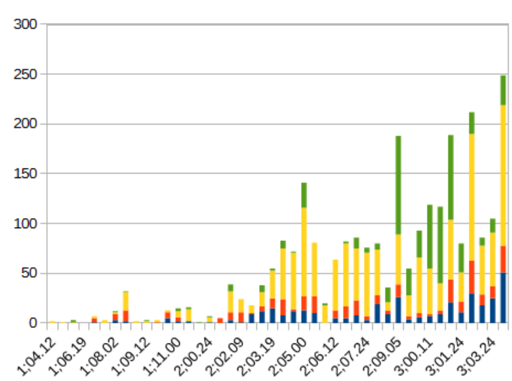


Figure 26: William's acquisition of [ð] in onset



William also did not acquire [ð] in onset by the latest dataset available. As illustrated in Figure 26, in total William made 2613 attempts which resulted in 1304 substitutions to [d], 585 accurate productions, 356 deletions, 94 substitutions to [n], with the remainder of the errors a number of variable substitutions. Due to both connected speech processes and the frequent use of [ð] as part of function words, this consonant patterns variably in the adult input, with phrases such as *in the car* resulting in *the* produced with a lenited or assimilated [ð]. For William, all of the interdentals produced as [d] appear in determiners (e.g., *this, that, there, the* produced as *dis, dat, dere, de*).

Affricates

William acquired [ʧ] in onset at 1;08.02, with five accurate productions and three other substitutions, as displayed in Figure 27. The two most common substitutions consisted of [t] productions, nine times, and [ʃ] productions, six times.

Figure 27: William's acquisition of [ʧ] in onset

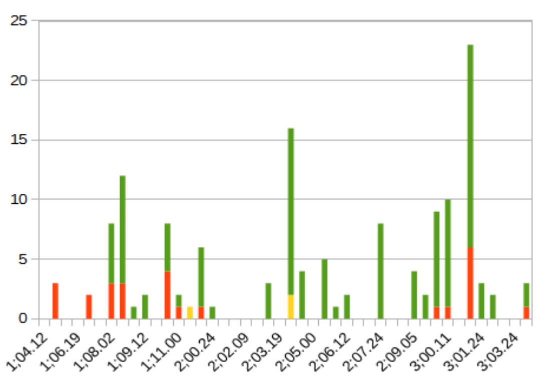
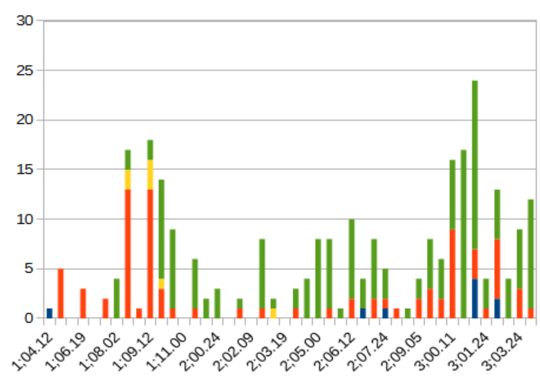


Figure 28: William's acquisition of [ʤ] in onset



William acquired [ʤ] in onset at 1;09.25, as illustrated in Figure 28, with 10 accurate productions, one voicing error, and three other substitutions. The majority of substitutions before this session consisted of [g] productions for the name of the letter *G* [dʒi]. A noticeable rise in substitutions occurred at 3;00.11, where William dipped below 50% accuracy with nine other substitutions ([j] for *juice, job, jive, jump*) and seven accurate productions. At 3;02.21, we observe another dip in accuracy with two deletions, six other substitutions, and five accurate productions. The substitutions here were more variable, with three [ɾ] productions for *just* (e.g., *I just*), two [j] for *juice*, and one [n] production for *just* (*I just*). I could not discern the cause of William's increase in substitutions.

2.2. Nasals in onset position

As reported above in Table 18, William acquired [m] and [n] early, by the end of the first two documented sessions.

Figure 29: William's acquisition of [m] in onset

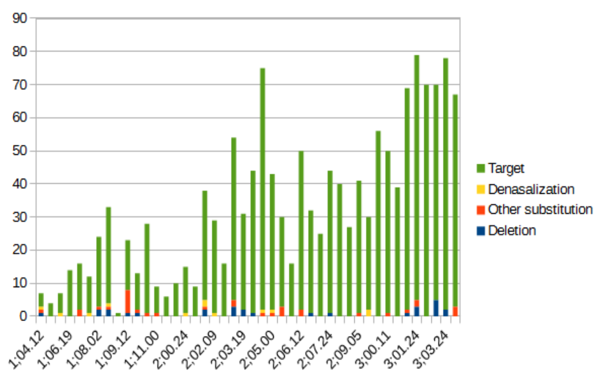
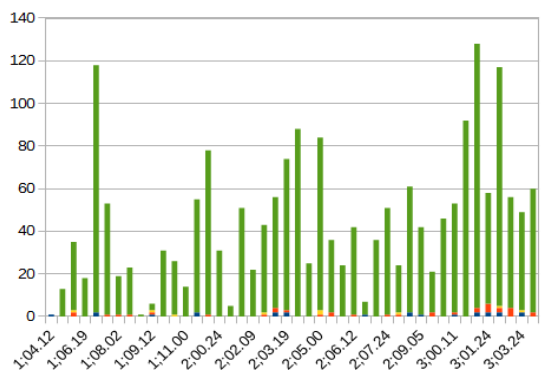


Figure 30: William's acquisition of [n] in onset



As shown in Figure 29, William had acquired [m] in onset by 1;04.12, with four accurate productions, one deletion, one other substitution, and one denasalization (to [b]). [n] in onset was acquired at 1;04.25 with 13 accurate productions, as illustrated in Figure 30. In the one session prior, one attempt occurred resulting in [n] deletion for the word *neigh*.

2.3. Approximants in onset position

William acquired [l] in onset at 1;04.25, with all four attempts at this consonant produced correctly, as displayed in Figure 31. At 1;08.14, we observe a number of substitutions, all of which came from the word *<u>ll</u>ama* pronounced *<u>n</u>ama*. William had no issues producing [l] accurately outside of this specific context.

Figure 31: William's acquisition of [l] in onset

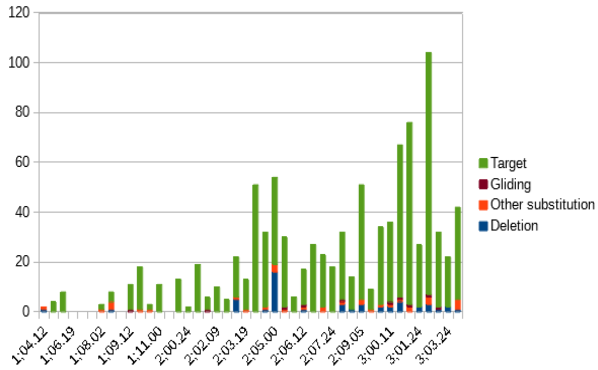
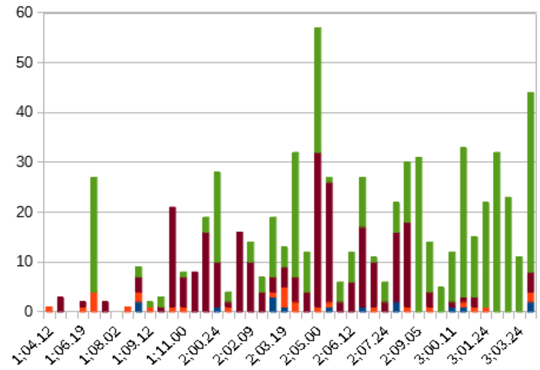


Figure 32: William's acquisition of [ɹ] in onset



William acquired [ɹ] in onset by 1;07.08, as shown in Figure 32, where he produced 23 accurate productions and four other substitutions. He did not produce any target [ɹ]s correctly before this point. However, [ɹ] was prone to gliding to [w] until 2;09.05. For example, at 2;05.00, we observe 25 accurate productions alongside 31 glided productions (and one other substitution). William showed variability with his production of [ɹ], even at the level of individual words; for example, at age 2;05.00, various words such as *<u>r</u>eady*, *<u>r</u>acket*, and *<u>r</u>ide* were sometimes produced correctly with [ɹ] and sometimes glided to [w] (i.e., *<u>w</u>eady, <u>w</u>acket, <u>w</u>ide*).

William acquired the glides [w] and [j] within two weeks of each other. As displayed in Figure 33, he acquired [w] in onset at 1;06.05, with 35 accurate productions and two substitutions. Before this point, William's frequent attempts at [w] most commonly resulted in substitution to [m].

Figure 33: William's acquisition of [w] in onset

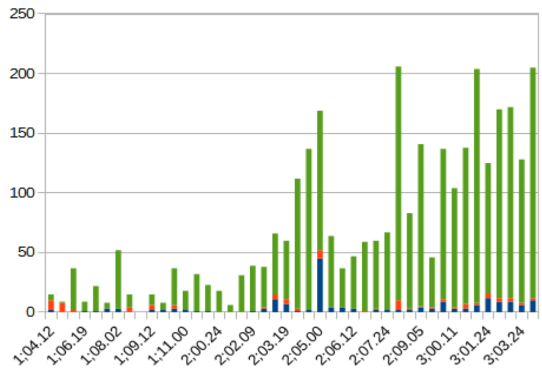
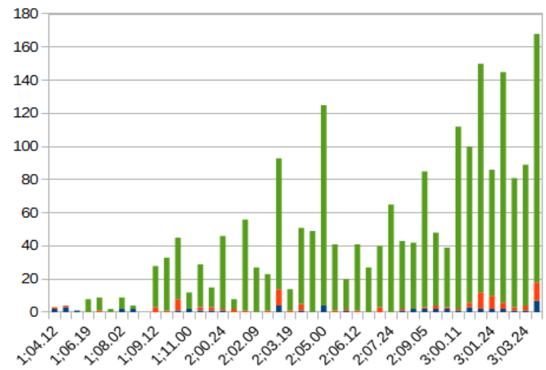


Figure 34: William's acquisition of [j] in onset



Finally, William acquired [j] in onset at 1;06.19, with eight accurate productions, as shown in Figure 34. This is the first session with any correct [j] productions; before this session, [j] most frequently underwent deletion.

2.4. Interim summary

In order to summarize the errors that occurred in onset, onset cluster, and coda development, the legend in Table 19 will be used for all subsequent tables that detail ages of acquisition. Each cell of a table, such as Table 20 to follow, will show the most frequent error pattern(s) for a given session. I used the symbol √ to mark when a sound is acquired, as described in the preceding discussion; X when a sound has not been acquired by the end of the recording sessions; — marks a sound that has not been attempted; D describes when a sound, or entire cluster, undergoes deletion; S marks when a sound, or member of a cluster, undergoes substitution; V marks voicing errors; T describes when the target sound is primarily produced accurately; R is only used for clusters and marks when one member of the cluster undergoes deletion while the other sound is produced accurately; lastly, D+S describes when one member of a cluster undergoes deletion while the other sound undergoes substitution.

Table 19: Legend for chart interpretation

Symbol	Meaning
√	Acquired
X	Not acquired
—	No attempts at target sound
D	Deletion: when describing clusters, this refers to both members of the cluster undergoing deletion.
S	Substitution: when describing clusters, this refers to one or both of the target sounds undergoing substitution in the absence of deletion.
V	Voicing error
T	Target production
R	Reduction: this applies to clusters only and describes when one member of the cluster is deleted.
D+S	Deletion + Substitution: this applies to clusters only and describes when one member of the cluster undergoes deletion and one member undergoes substitution.

Using these conventions, I summarize William's onset development, including the error patterns that occurred during the stages prior to the acquisition of target phones, in Table 20 below.

Table 20: William's onset development

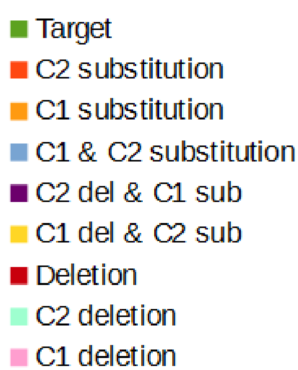
	1;04.12	1;04.25	1;06.05	1;06.19	1;07.08	1;08.02	1;09.12	1;09.25	1;10.12	1;11.00	1;11.15	2;00.12	2;00.24	2;01.26	2;02.09	2;02.21	2;04.03	2;04.16	2;09.05	2;11.14	Not acquired
[b]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[d]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[k]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[s]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[h]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[m]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[n]	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[l]	D/S	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	S/T	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[w]	S	S	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[g]	—	T	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[j]	D	D	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[p]	—	—	S	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[f]	T	—	S/T	S/T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[ɹ]	S	S	—	S	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[z]	D	—	—	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[ʃ]	—	—	—	—	T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[ʧ]	—	S	—	—	S	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[ʤ]	D	S	—	S	—	T	S/T	√	√	√	√	√	√	√	√	√	√	√	√	√	
[v]	—	—	—	—	—	—	S	—	—	T	—	—	—	—	—	—	S	√	√	√	
[θ]	—	—	—	—	S	—	—	—	S	—	—	—	—	S	S	T	S/T	—	S	S	X
[ð]	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	D/S/T	S	X

In summary, William acquired all sounds in onset position by the last session recording, at 2;11.14, with the exception of the interdental fricatives [θ] and [ð]. In general, William acquired fricatives (with the exception of early-acquired [s] and [h]) after all stops had been acquired. He most frequently substituted the affricates [ʧ] and [ʤ] and the rhotic [ɹ], and he acquired all three of these consonants relatively late when compared with most stops, nasals, and the early-acquired fricatives ([s] and [h]). I will now move to discuss William's onset cluster development.

2.5. Consonant clusters in onset position

To accurately describe the development of consonant clusters, a separate legend is required, as provided in Figure 35. A "Target" cluster occurs when the child produces both sounds accurately. "C2 substitution" refers to cases where the first member of the onset cluster is produced accurately and the second sound undergoes substitution (e.g., [kl] produced as [kw]). "C1 substitution" describes when the first sound undergoes substitution and the child produces the second sound correctly (e.g., [kl] produced as [pl]). "C1 & C2 substitution" marks when both sounds undergo substitution (e.g., [kl] produced as [tw]).

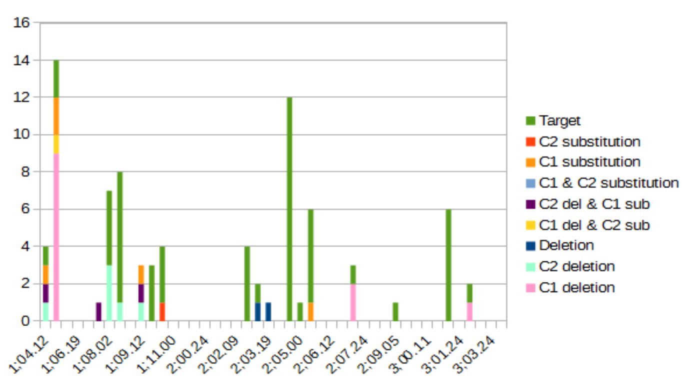
Figure 35: Legend for consonant clusters



Following the same logic, "C2 del & C1 sub" occurs when the second member of the cluster is deleted and the first one undergoes substitution (e.g., [kl] produced as [t]). "C1 del & C2 sub" describes the reverse: it happens when the child deletes the first sound and substitutes the second sound (e.g., [kl] produced as [w]). "Deletion" describes cases where both sounds of the target cluster undergo deletion, whereas "C2 deletion" marks when only the second consonant undergoes deletion with the first sound produced correctly (e.g., [kl] produced as [k]). "C1 deletion" occurs when the first sound undergoes deletion with the second consonant produced accurately (e.g., [kl] produced as [l]).

William acquired the stop-glide cluster type first. To investigate William's acquisition of this type of clusters, I did not include stop-[j] clusters (e.g., [kj], [pj], [bj]) as they pattern differently to stop-[w] clusters; C[w] and C[j] clusters are structurally different from one another in English, with [j] patterning as part of the nucleus (Davis & Hammond 1995). Therefore, I am not including [j] clusters in the descriptions below. Based on William's minimal number of production attempts, C[w] clusters appear to be acquired at 1;09.25, as shown in Figure 36, where William produced three targets accurately. Before this, he went through an earlier stage of C1 deletion at 1;04.25, where all nine deletions consisted of [k] deletions for *quack*. William surpassed a 50% accuracy rate at 1;08.02 and 1;09.12 (all attempts at *quack*), however his performance dropped below 50% in the next session 1;09.12 (again for *quack*), which suggests he still had difficulties with his production of the [kw] cluster. After reaching the acquisition of clusters at 1;09.25, William maintained a 50% accuracy rate with the exception of 2;07.08, where we observe one accurate production (*quiet*) and two C1 deletions (for *twelve*).

Figure 36: William's acquisition of stop-glide onset clusters



As displayed in Figure 37, William acquired the stop-lateral cluster next, at age 1;10.12, with 9/10 accurate productions. Before he acquired this cluster, William most commonly reduced the clusters to C1 (i.e., C2 deletion). The C2 deletions in sessions that followed 1;10.12 affected [bl] clusters specifically. William acquired stop-rhotic clusters two months later, at 2;00.12, as illustrated in Figure 38, with 15 correct productions, 12 C2 substitutions, and one C1 deletion & C2 substitution. Gliding and deletion of [ɹ] were the most common errors from this point onward. Before the mastery stage, both the first and second sound in the cluster frequently underwent substitution, with C1 and C2 substitution and C2 deletion & C1 substitutions comprising the most common errors.

Figure 37: William's acquisition of stop-lateral onset clusters

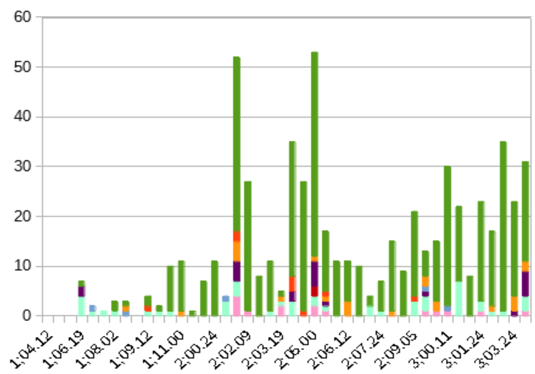
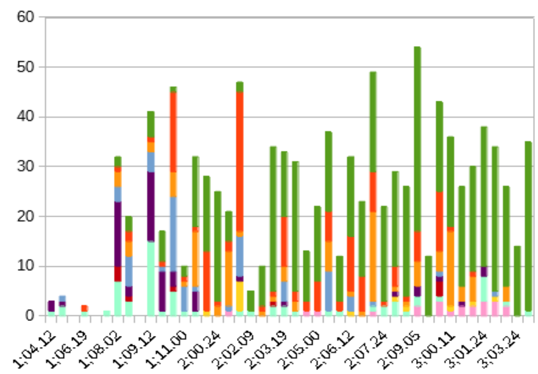


Figure 38: William's acquisition of stop-rhotic onset clusters



Based on the available data, I can claim that William acquired fricative-lateral clusters by age 2;00.12, with five accurate productions, one C2 deletion, and one C1 substitution, as displayed in Figure 39.[4] There is a dearth of data, with no correct productions before this point: William made two previous attempts which resulted in a C2 deletion and a C1 deletion, respectively. Additionally, William did not attempt any fricative-lateral clusters in the six

4 As discussed in Chapter 2, section 7.4, I did not include sC clusters in my investigation of fricative onset clusters as the [s] patterns as an appendix in English.

recording sessions between these attempts and the age of acquisition. As shown in Figure 40, he acquired fricative-rhotic clusters nine months later, at 2;09.05, where he produced five accurate targets and one C2 deletion. However, there is a lack of evidence in earlier sessions as William did not attempt fricative-rhotic clusters with any frequency until age 2;01.26. The five accurate productions that occurred earlier, at 2;03.07, consisted of attempts at the word *three*, but accurate productions did not continue as [ɹ] frequently underwent gliding after this session.

Figure 39: William's acquisition of fricative-lateral onset clusters

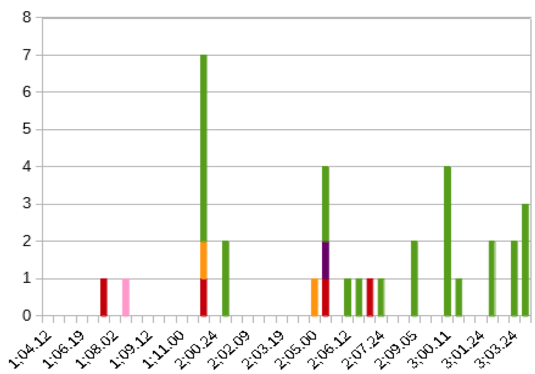
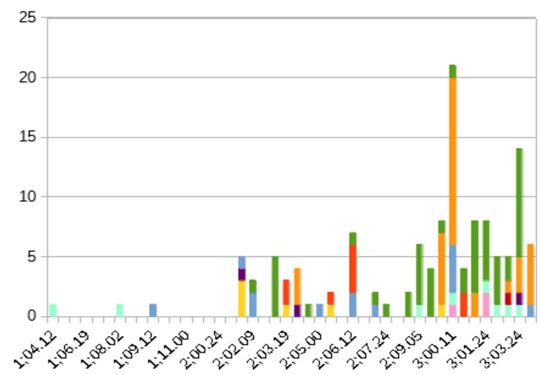


Figure 40: William's acquisition of fricative-rhotic onset clusters



William possibly acquired the fricative-glide cluster next; however, there is a dearth of evidence with only two targets recorded at 2;04.03, and William did not attempt any other forms in this corpus after that age. Nasal-glide clusters appear to be acquired at 2;11.14, with seven accurate productions and one reduction to the nasal consonant.

2.6. Interim summary

William acquired stop-glide clusters first, followed by stop-lateral, stop-rhotic, fricative-lateral, fricative-glide, fricative-rhotic and, lastly, nasal-glide clusters, as summarized in Table 20 below.

Table 21: William's onset cluster development

	1;04.12	1;04.25	1;06.05	1;06.19	1;07.08	1;08.02	1;09.12	1;09.25	1;10.12	1;11.00	1;11.15	2;00.12	2;00.24	2;01.26	2;02.09	2;02.21	2;04.03	2;04.16	2;09.05	2;11.14	Not acquired
Stop-glide	R/S/T	S/T	—	—	—	R/T/D+S	R	√	√	√	√	√	√	√	√	√	√	√	√	√	
Stop-lateral	—	—	—	R	R/D+S	R/T	R/S/T	R/T	√	√	√	√	√	√	√	√	√	√	√	√	
Stop-rhotic	D+S	R/D+S	—	R/S	—	R/D+S	R/D+S	D+S	S	S	S/T	√	√	√	√	√	√	√	√	√	
Fricative-lateral	—	—	—	—	R	—	—	—	—	—	—	√	√	√	√	√	√	√	√	√	
Fricative-glide	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	√	√	√	√	
Fricative-rhotic	R	—	—	—	—	R	D+S	—	—	—	—	—	—	D+S	S	—	S	T	√	√	
Nasal-glide	—	—	—	—	—	—	—	—	—	—	—	—	—	S	—	—	S	—	T	√	

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

William's acquisition of clusters did not correlate with his acquisition of the individual segments that comprise the clusters; he combined both sounds at a significantly later age than when the singleton consonants emerged. For example, he acquired nasals and glides relatively early within the first two months of recordings (by 1;06.19), but nasal-glide clusters were the last cluster type acquired (at 2;11.14).

However, William acquired all stop-clusters before he acquired any fricative-initial clusters, which reflects his general acquisition of stops before fricatives in singleton onsets. Additionally, if we compare William's order of acquisition of singleton laterals and rhotics to their emergence in onset clusters, a pattern emerges: William acquired singleton onset [l] at 1;04.25, and [ɹ] two and a half months later, at 1;07.08. Similarly, William acquired stop-lateral clusters at 1;10.12 and stop-rhotic clusters two months later, at 2;00.12. Fricative-onset clusters follow this emergence pattern as well, with fricative-lateral clusters acquired at 2;00.12 and fricative-rhotic clusters at 2;09.05. Therefore, William mastered laterals before rhotics in both singleton and branching onsets.

As I have at present discussed William's acquisition of onset singletons and onset clusters, I will now turn my focus to William's acquisition of singletons in coda position.

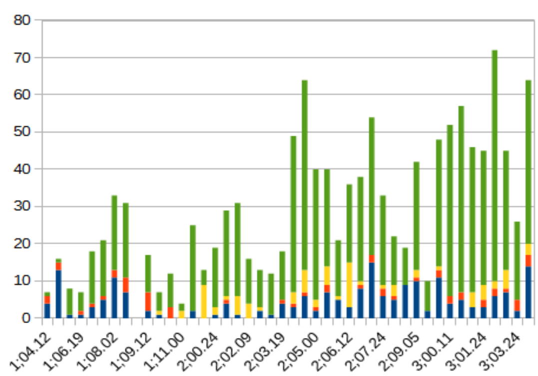
2.7. Obstruents in coda position

As mentioned above, William did not have any coda sounds acquired at the beginning of his recordings. I will now describe William's phonological acquisition of coda stops, fricatives, nasals, and approximants.

Stops

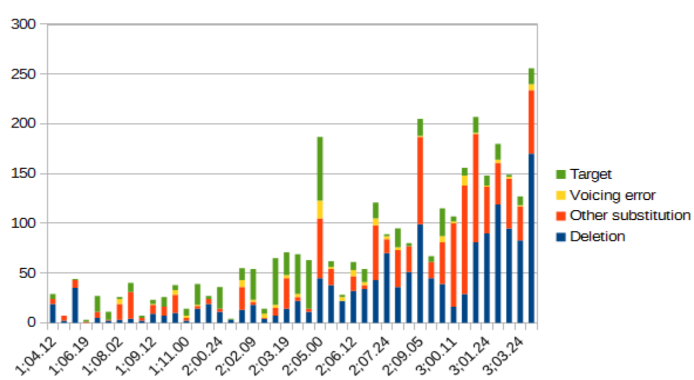
William acquired [k] as his first stop in coda position at 1;06.05, with seven accurate productions and one deletion, as shown in Figure 41. While [k] underwent deletion, final consonant deletion did not affect this sound as drastically as some of the other stops and fricatives that I detail below.

Figure 41: William's acquisition of [k] in coda



William acquired [t] in coda next, at 1;07.08, with 16 accurate productions, six other substitutions, and five deletions. Deletion affected William's production of stops and fricatives as a whole, but affected [t] more severely, as illustrated in Figure 42. Additionally, William commonly substituted [ʔ] for [t]; however, this often occurs in adult speech as well (e.g., *see that*, *see it*), as already discussed in Chapter 2, section 8.1. In total, William made 3286 attempts at coda [t], yielding 1473 deletions, 865 glottal stop productions [ʔ], 591 accurate productions, 164 [ɾ] substitutions, 115 voicing errors, as well as other, more marginal substitutions. Similar to [ʔ], the substitutions to [ɾ] also appeared in phrases such as *get on*, *but I'm*, and *what is*, and reflect substitution patterns that may appear in adult speech. Deletion and glottal stop substitution did not decrease as William aged: the last session, 3;04.18, displays 42 glottal stop substitutions and 170 deletions out of 256 attempts. As final consonant deletion only became a problem for William's target [t] in later sessions (and additionally affected coda [b], [d], [l], [p], and [ɹ] as detailed below), it is possible that this coincided with his acquisition of morphological affixes (e.g., inflectional -ed, -s, -ing, etc). Therefore, William may have been overgeneralizing when certain sounds should and should not occur at the end of words. I will discuss this possible interaction between William's phonological and morphological development further below.

Figure 42: William's acquisition of [t] in coda



William acquired the bilabial stops [b] and [p] within three months of each other, as shown in Figure 43 and Figure 44, respectively. He acquired [b] in coda at 1;11.00 or earlier, with seven accurate productions. No attempts at [b] in coda were recorded before this session. Deletion continued to be a problem, after William reached the acquisition criteria, as he variably produced coda [b] accurately or deleted it. Minimally, the data show that final consonant deletion affected coda [b] quite prominently, similar to coda [t], as described above, with no observable pattern. William acquired [p] in coda at 2;02.09, with three accurate productions and one deletion. Before this, [p] frequently underwent deletion or substitution to a variety of sounds.

Figure 43: William's acquisition of [b] in coda

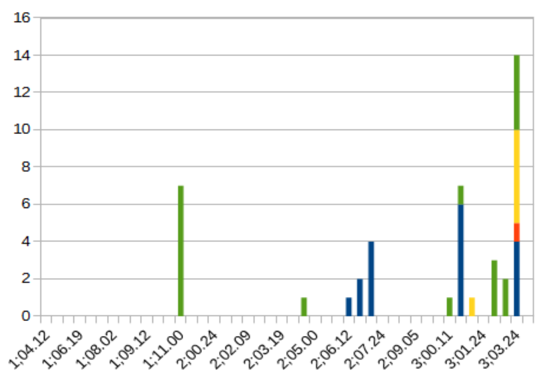
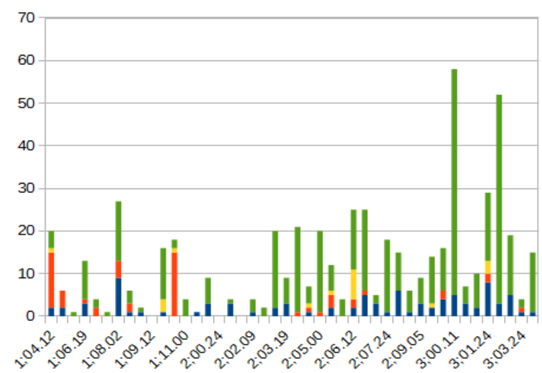


Figure 44: William's acquisition of [p] in coda



William acquired [d] in coda at 1;11.15, with two target productions and two deletions, as displayed in Figure 45. This session marked the first time accurate productions outnumbered other patterns, excluding deletions. Deletions occurred frequently from the first session and grew in number up to, and including, the last session. William made 662 attempts at coda [d] which resulted in 280 deletions, 246 accurate productions, 57 [ɾ] substitutions, 26 voicing errors, and 24 [ʔ] substitutions. The substitutions in the last three sessions consisted primarily of [ɾ] (e.g., *had*, *said*, *bad*, *outside)* in connected speech (e.g., *had a farm*). These substitutions reflect permissible targets in the adult grammar. As we can see in Figure 46 with the flap substitutions removed, William's coda [d] was drastically affected by final consonant deletion, and this occurred across a wide variety of words, both within phrases and in single-word utterances.

Figure 45: William's acquisition of [d] in coda (including [ɾ])

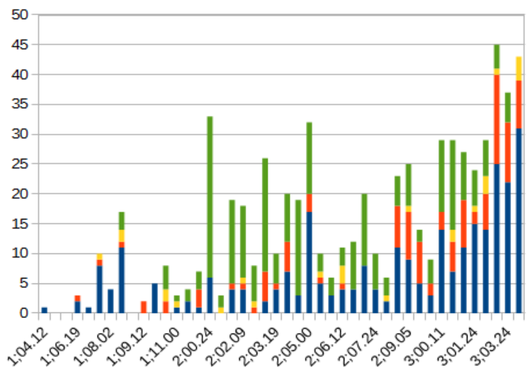
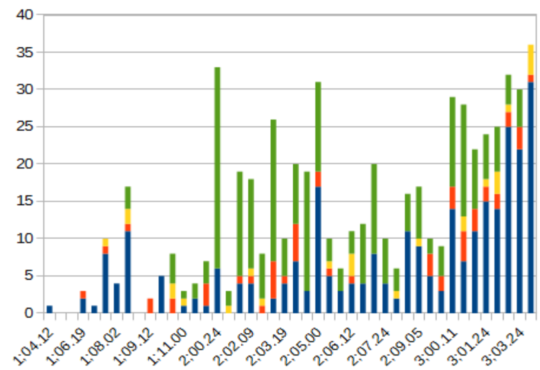
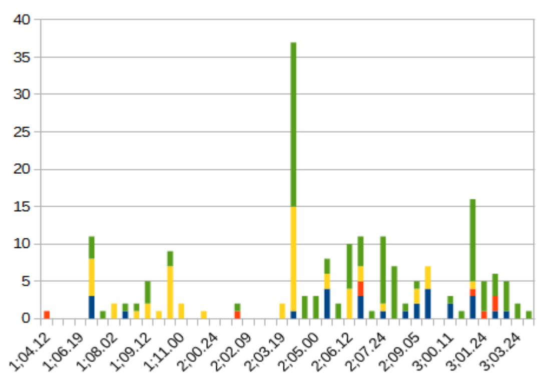


Figure 46: William's acquisition of [d] in coda (minus [ɾ])



As shown in Figure 47, William acquired the other velar obstruent, [g], 10 months after coda [k] at 2;04.03, where he produced 22 accurate targets, one deletion, and 14 voicing errors (all for *big* and *rig*; William also produced these words correctly in this session as well).

Figure 47: William's acquisition of [g] in coda



At 2;04.03, a noticeable spike in production occurred due to William's frequent attempts at producing *big rig* when describing his toy trucks. Before acquiring [g], he most frequently produced [g] as the voicing error [k]; however, William did not make many production attempts in earlier sessions.

Fricatives

William acquired both [ʃ] and [f] in coda position early, at 1;06.05. During this session, William achieved six accurate productions of [ʃ], as displayed in Figure 48. Overall, the two most common substitutions consisted of [s] and [ʧ] productions. William also achieved two accurate productions of [f], as shown in Figure 49. At 2;05.00, we observe a spike in deletions, all of which arose from the word *o<u>ff</u>*. Final consonant deletion was again an issue with coda [f], as with William's other coda stops and fricatives. However, William attempted fewer overall [f] productions, resulting in fewer data from which to observe this process (when compared with coda [t], for example).

Figure 48: William's acquisition of [ʃ] in coda

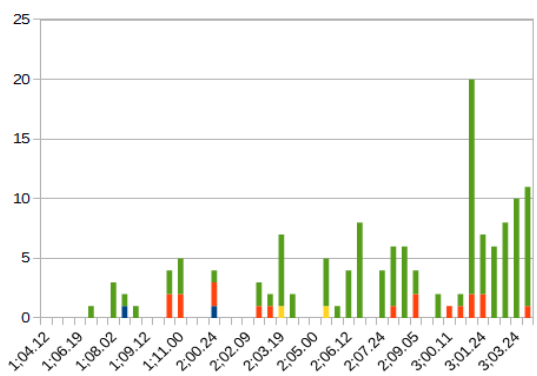
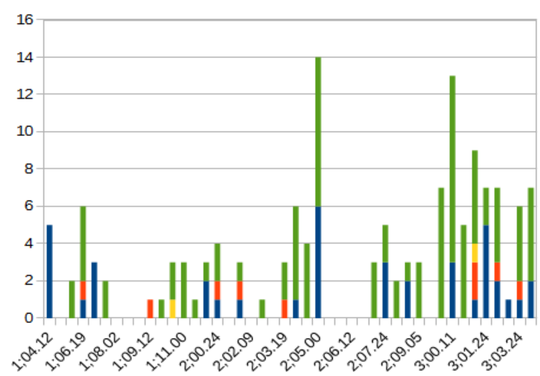


Figure 49: William's acquisition of [f] in coda



As shown in Figure 50, William acquired [s] in coda at 1;08.02, with 13 accurate productions, two deletions, and three other substitutions. Before this, we observe a mix of accurate productions, substitutions, and deletions. At 2;05.00, a noticeable rise in voicing errors occurred (n=24), all of which came from attempts at the function word *thi<u>s</u>*. William acquired [z] in coda at 2;00.24, where he produced 13 accurate targets, six voicing errors, and one other substitution, as displayed in Figure 51. Before this session, attempts most frequently resulted in voicing errors. After this session, [z] became more stable until the last six sessions, where again William frequently produced [z] as its voiceless counterpart [s]. These voicing errors continued up to, and including, the last session. In the final session, at 3;04.18, we observe 23 accurate productions, 11 deletions, six other substitutions, and 50 voicing errors for the words *was*, *nose*, *his*, *is*, *toys*, *terrorize*, *walkie-talkies*, *boys*, *those*, *does*, *these*, and *threes*. This devoicing pattern occurred before both voiced and voiceless sounds (e.g., *his boat*, *is playing*), and did not seem to be influenced by the voicing of the preceding sound. Minimally, as we observed with William's other voiced codas, his performance on obstruent voicing remained fairly variable.

Figure 50: William's acquisition of [s] in coda

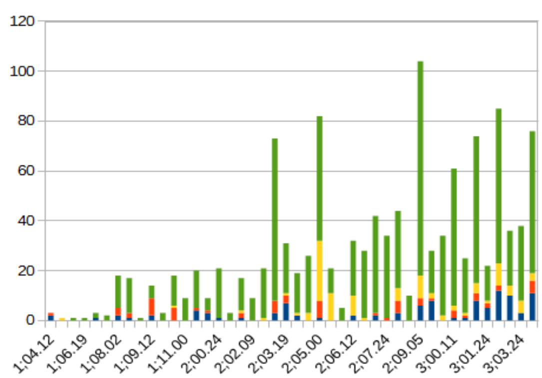
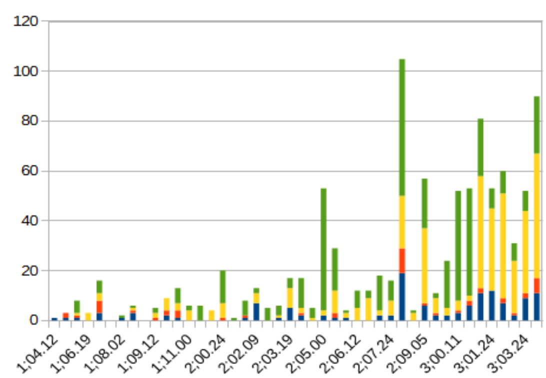
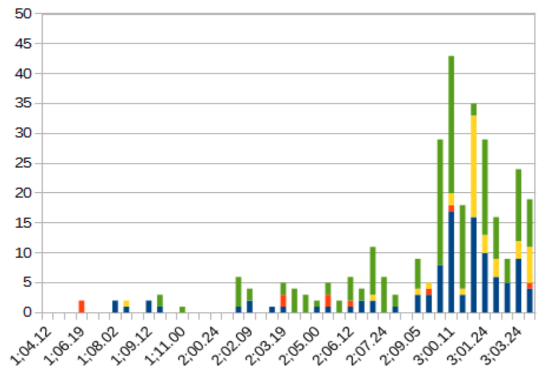


Figure 51: William's acquisition of [z] in coda



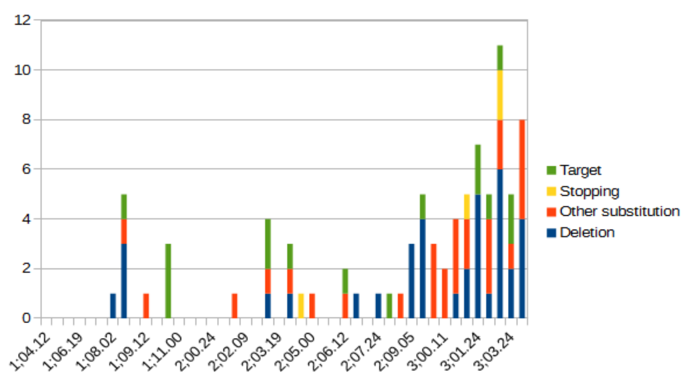
William acquired [v] in coda at 2;01.26, as illustrated in Figure 52, with five accurate productions and one deletion. Before its acquisition, [v] most frequently underwent deletion. Similar to [z] described above, we observe a rise in voicing errors in the last six sessions. The voicing errors did not reflect devoicing that may have been found in adult speech. For example, at 3;01.15, William produced two accurate targets, 17 voicing errors (all for the word *cave*), and 16 deletions; the last session displays eight accurate productions, four deletions, one other substitution, and six voicing errors. For example, devoicing occurred for *fi<u>ve</u> six*, *lo<u>ve</u> trains*, and *ha<u>ve</u> a zipper*. The rise in voicing errors in later sessions parallels what we previously observed with coda [z], described in Figure 51 above.

Figure 52: William's acquisition of [v] in coda



William did not acquire the remainder of the fricative sounds to be discussed by his last available session. He did not acquire [θ] in coda by the latest age documented. As illustrated in Figure 53, in total, William attempted [θ] 86 times, which resulted in 36 deletions, 16 correct targets (not clustered together in the later sessions), and four instances of stopping. The most common substitution consisted of 13 substitutions to [f].

Figure 53: William's acquisition of [θ] in coda

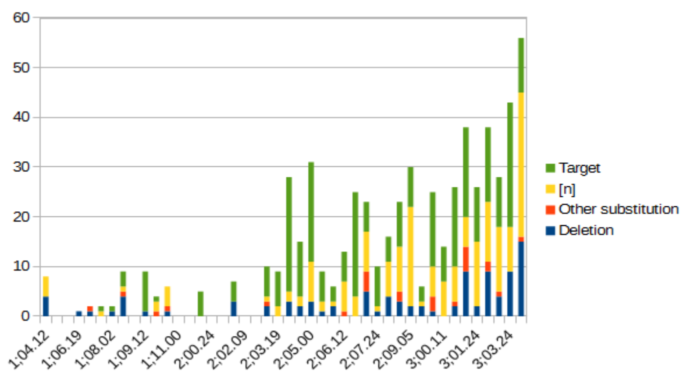


Moving to the last two coda fricatives, William did not attempt enough [ʒ] productions in coda position to assess the development of this consonant; he made only two attempts which resulted in one correct target at 3;00.11 (*garage*) and one [z] substitution (*garage*) at 2;09.05. Lastly, William did not attempt any [ð]s in coda position.

2.8. Nasals in coda position

As displayed in Figure 54, William acquired [ŋ] in coda at 1;09.12, with eight correct productions and one deletion (all attempts at *ding*).

Figure 54: William's acquisition of [ŋ] in coda



In the sessions that follow, William frequently substituted [ŋ] to [n], however these productions reflected permissible targets in the adult language. For example, at 1;10.12, William produced four substitutions to [n], one other substitution, and one deletion. The four words with [n] substitution consisted of two productions each of *sleeping* and *kicking*, which are acceptable in the adult grammar. This differs from earlier sessions, where [n] substitutions occurred for single word utterances such as *sing* and *swing*, which are not acceptable substitutions in the adult grammar. It is thus unclear whether the pronunciations of word-final [ŋ] relate to parental dialects or to an actual phonological process.[5]

2.9. Approximants in coda position

As shown in Figure 55, William acquired the approximant [l] in coda at 2;00.24, where he produced 20 accurate targets, six deletions, one other substitution, and one gliding error. Before this, [l] most frequently underwent deletion or substitution to a variety of sounds. William did not glide [l], but deletion continued to be prevalent with 1273 total attempts resulting in 785 deletions. These deletions occurred frequently throughout all of William's sessions and did not decrease in later sessions.

Figure 55: William's acquisition of [l] in coda

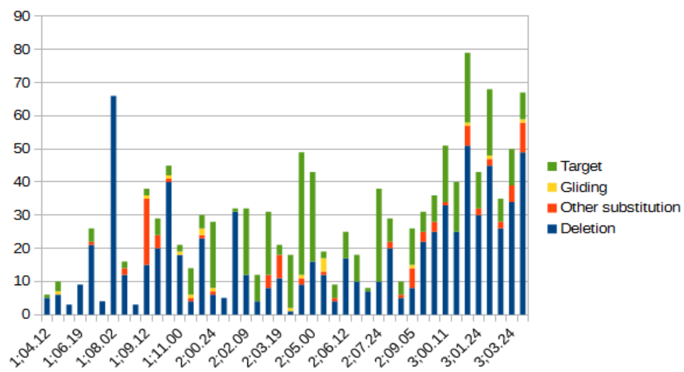
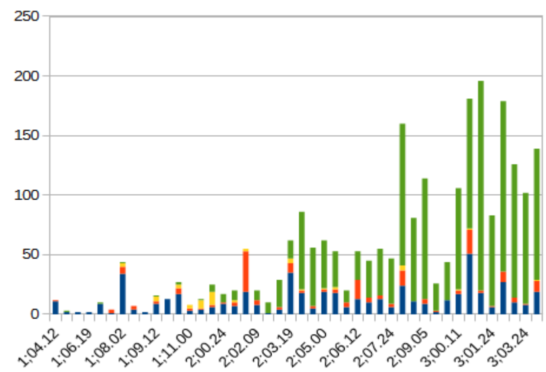


Figure 56: William's acquisition of [ɹ] in coda



William acquired [ɹ] in coda position two months after [l], at 2;02.09, with eight accurate productions, four other substitutions, and eight deletions, as displayed in Figure 56. The most common substitutions consisted of the vocalization of [ɹ] to [ə], 94 times, and to [ɪ], 39 times. Prior to acquisition, [ɹ] most frequently underwent deletion and, occasionally, gliding.

5 This issue, which would require a close study of the child's adult speech environment, transcends the scope of my thesis.

2.10. Interim summary

William acquired all coda consonants under investigation during the observation period, with the exception of the fricatives [θ], [ð], and [ʒ], as summarized in Table 22.

Table 22: William's coda development

	1;04.12	1;04.25	1;06.05	1;06.19	1;07.08	1;08.02	1;09.12	1;09.25	1;10.12	1;11.00	1;11.15	2;00.12	2;00.24	2;01.26	2;02.09	2;02.21	2;04.03	2;04.16	2;09.05	2;11.14	Not acquired
[k]	D	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[ʃ]	—	S	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[f]	D	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	D	S	D	T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[s]	D	V	T	T	D/T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[ŋ]	D/S	—	—	D	D/S	S/T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	—	—	—	—	—	—	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
[d]	D	—	—	D	D	D	D	D	S	D/S/T	√	√	√	√	√	√	√	√	√	√	
[z]	D	S	T	V	S/T	D/T	V/T	V	S/T	V	T	V	√	√	√	√	√	√	√	√	
[l]	D	D	D	D	D	D	D/S	D	D	D	T	D	√	√	√	√	√	√	√	√	
[v]	—	—	—	S	—	D	D	D/T	—	T	—	—	—	√	√	√	√	√	√	√	
[p]	S	S	T	T	S/T	D/T	—	T	S	T	D	T	—	D	√	√	√	√	√	√	
[ɹ]	D	D	D	D	D	D	D	D	D	D/S	D/S	S	D/T	S	√	√	√	√	√	√	
[g]	S	—	—	—	V	V	T	V	V	V	—	V	—	S/T	—	—	√	√	√	√	
[θ]	—	—	—	—	—	D	S	—	T	—	—	—	—	S	—	—	D/S/T	S	D	S	X
[ð]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
[ʒ]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	S	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

Unlike what we observed in William's singleton onset and onset cluster development, his acquisition of stops and fricatives in coda position did not follow the general pattern of stops being acquired before fricatives. While William typically acquired a sound in coda position later than the same sound in onset position, certain asymmetries emerged in terms of voiced-voiceless cognate pairs, as illustrated in Table 23: he acquired [b] in both positions before [p], [d] in both positions before [t], and [k] in both positions before [g]. Similarly, [s] preceded [z], and [f] preceded [v] in terms of acquisition in both positions. Finally, William's acquisition of rhotics and laterals in coda position paralleled his acquisition of these sounds in singleton onsets and onset clusters: [l] emerged first, followed by [ɹ].

Table 23: Summary of William's phonological development

1;04.12	1;04.25	1;06.05	1;06.19	1;07.08	1;08.02	1;09.12	1;09.25	1;10.12	1;11.00	1;11.15	2;00.12	2;00.24	2;01.20	2;02.09	2;04.03	2;04.16	2;09.05	2;11.14	Not acquired
ONSET																			
[b] [d] [k] [s] [h] [m]	[n] [l]	[t] [w]	[p] [g] [j]	[f] [ɹ]	[z] [ʃ] [ʧ]		[ʤ]									[v]			[θ] [ð]
ONSET CLUSTER																			
							Stop-glide	Stop-lateral			Stop-rhotic Fricative-lateral				Fricative-glide		Fricative-rhotic	Nasal-glide	
CODA																			
		[k] [f] [ʃ]		[t] [s]		[ŋ]			[b]	[d]		[z] [l]	[v]	[p] [ɹ]	[g]				[θ] [ð] [ʒ]

As observed above, the phonological process of final consonant deletion (FCD) significantly affected William's acquisition of coda consonants. As previously described, FCD most notably affected [t], [d], and [l], but also [p], [b], and [ɹ]. As mentioned above, final consonant deletion only became a problem for William around age 2;03.19. Therefore, it is possible that this coincided with his acquisition of morphological affixes (e.g., inflectional -*ed*, -*s*, -*ing*, etc) which caused William to overgeneralize when certain sounds should and should not occur at the end of words. Table 24 illustrates William's use of inflectional morphology up to age 2;05.16. As we can see from this table, it is indeed around 2;3 that William began to productively use inflectional suffix markers beyond the earlier-acquired plural [-s] suffix, making morphology a potential confound in his use of word-final stops more generally.

Table 24: William's inflectional morphology usage

	1;04.12	1;04.25	1;06.05	1;06.19	1;07.08	1;07.18	1;08.02	1;08.14	1;08.28	1;09.12	1;09.25	2;01.26	2;02.09	2;02.21	2;03.07	2;03.19	2;04.03	2;04.16	2;05.00	2;05.16
3rd person -s												3					1	1	13	
possessive -s															1	1			4	
possessive -s deletion												1							2	
possessive -s substitution												[θ]								
plural -s		1	1	1	8	7		8	2	7	4	1	3	4	13	2	14	8	14	36
plural -s deletion	1							2							2					1
plural -s substitution			[ʃ]							3 [ʃ]	2 [θ]			[t]					[d]	[ʔ]
-ing					1		1					3	1		2	7	20	3	16	4
-ing deletion					1		1					1				2	1	1	2	1
-ing substitution							1 [g]								1 [n]	2 [n]	2 [n]		12 [n]	2 [n]
-ed	No attempts														1		2	1	Inc	?
-ed deletion														1	6	2	6		2	
-ed substitution															1 [ɪt] 1 [d]		2 [v]			
comparative -er															6		7	10	9	

Indeed, William did not have difficulty with his acquisition of plural and possessive *-s*, nor did he produce many errors during his acquisition of the progressive marker *-ing*. The rise in final consonant deletion at age 2;03.19 most closely corresponds with William's acquisition of past tense *-ed*, his first inflectional marker that contains a word final-stop. This may have triggered a re-analysis of his word-final stops (or perhaps a re-analysis of all word-final sounds with the exception of [s] and [ŋ] for which he had already established inflection markers). It appears that the emergence of the past tense morpheme, not inflectional morphology in general, triggered William's final consonant deletion. This issue, which persisted until the end of the documented period, calls for additional considerations that transcend the scope of this thesis.

I now turn to discussing German-learner Eleonora's phonological development.

3. Eleonora

German speaker Eleonora had only one consonant sound, [h], acquired at the beginning of her recorded sessions. However, she acquired six additional sounds within the first two months of recordings, from 1;00.07-1;02.07, as shown in Table 25.

Table 25: Eleonora's early consonantal inventory

	Labial	Coronal		Dorsal	Glottal
		alveolar	alveopalatal		
Stops	p, b	t, d			
Fricatives					h
Affricates					
Trill					
Nasals	m	n			
Liquids					
Glides					

Within this two month period, Eleonora acquired bilabial stops [p] and [b], alveolar stops [t] and [d], and nasals [m] and [n] in onset position. She did not acquire any coda sounds during this time.

In the descriptions below, I detail Eleonora's phonological development. Similar to the other case studies, I group sounds into broad phonetic categories and arrange the sounds in chronological order within these categories. As we will see, Eleonora did not make as many production attempts as the other children, which resulted in an overall scarcity of data for most of the sounds under investigation. In order to remedy this, I describe the phonological development of a second German-learner, Wiglaf, in the next section.

3.1. Obstruents in onset position

Stops

As mentioned above, Eleonora acquired both [b] and [t] in onset at 1;01.11. She acquired [b] with 10 accurate productions, as shown in Figure 57. Eleonora maintained a level of 50% accuracy with her productions of [b] in subsequent sessions; however, voicing errors commonly occurred. Her productions displayed inconsistencies across the same words and within the same session: for example, at 1;04.08, *buch* [ˈbuːx], *baby* [ˈbeːbiː], and *baum* [ˈbaʊm] were produced correctly with target [b], and a total of five voicing errors also occurred for *baby* and *baum*. It is unclear why Eleonora had difficulty with the voicing contrast during certain sessions (a similar pattern emerged with the voiced stops [d] and [g], discussed below). Eleonora also acquired [t] in onset at 1;01.11, as illustrated in Figure 58, with eight accurate productions. While [t] exhibited some voicing errors, as a group, the voiceless stops did not undergo voicing errors as frequently as the voiced stops.

Figure 57: Eleonora's acquisition of [b] in onset

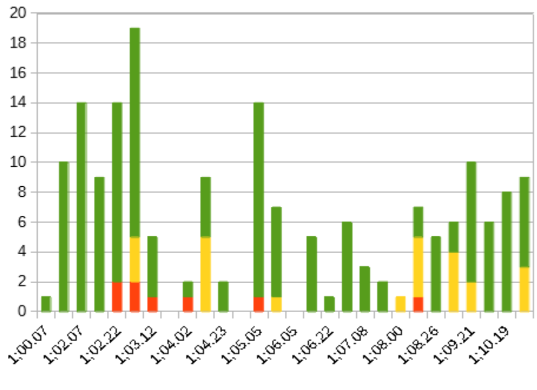
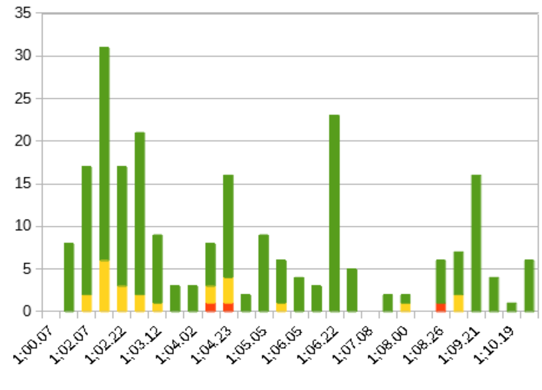


Figure 58: Eleonora's acquisition of [t] in onset



Eleonora acquired [p] and [d] in onset next at 1;02.07. She acquired [p], as shown in Figure 59, with two accurate productions, which reached the 50% accuracy criterion. As displayed in Figure 60, she acquired [d] in onset with eight accurate productions. Eleonora did not maintain a level of 50% accuracy with [d] due to voicing errors. However, her voicing errors in later sessions were restricted mostly to productions of *d̲a* [ˈd̲aː] and *d̲as* [ˈdas] (although Eleonora sometimes produced these words accurately with target [d], suggesting she had difficulty with these two particular function words). Due to her overall lack of attempts at other words with [d] in onset position, sessions that only contain attempts at *da* and *das* caused onset [d] to look unacquired.

Figure 59: Eleonora's acquisition of [p] in onset

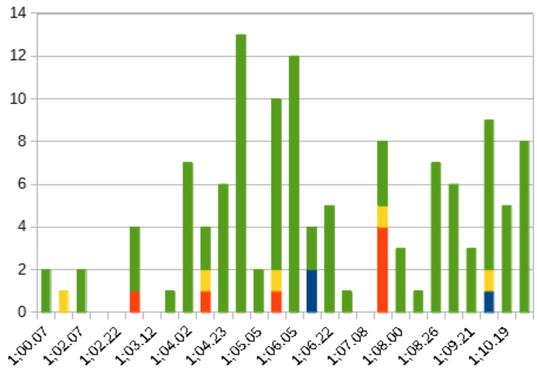
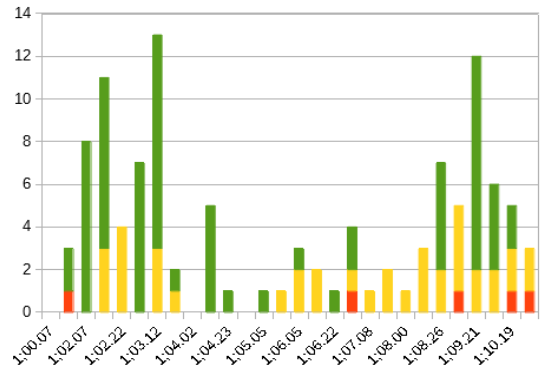


Figure 60: Eleonora's acquisition of [d] in onset



Eleonora acquired [k] in onset at 1;06.05, where she produced nine accurate targets, as shown in Figure 61. Before this, Eleonora attempted [k] eight times and it underwent a variety of substitutions. After this point, variable substitutions for [k] occurred across different words (e.g., at 1;06.15, [k] was substituted by [h] for the word *cornflakes* [ˈkɔʀnflɛɪks], [s] for *Karussel* [kaʀʊˈsɛl], and [p] for *Kamel* [kaˈmeːl]).

Figure 61: Eleonora's acquisition of [k] in onset

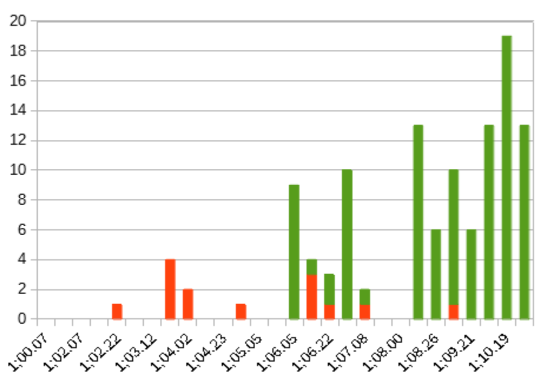
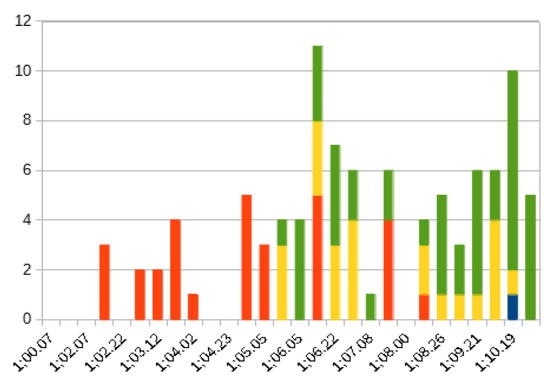


Figure 62: Eleonora's acquisition of [g] in onset

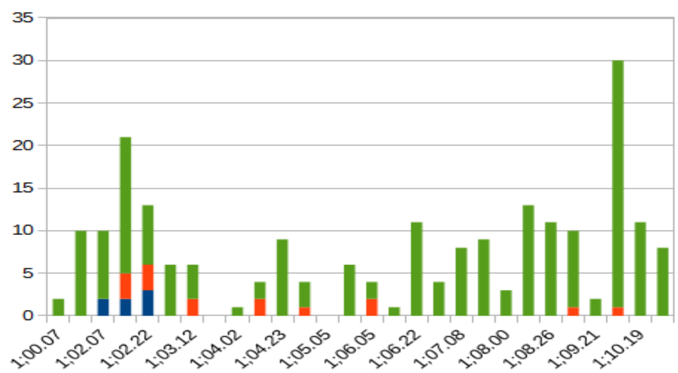


As displayed in Figure 62, Eleonora acquired [g] in onset two months later, at 1;08.26, with four accurate productions and one voicing error. Prior to this, [g] primarily underwent substitution to [t]; in later sessions, Eleonora's primary error changed from substitution to voicing errors, similar to the other voiced obstruents described above. Voicing errors remained common after acquisition, as Eleonora continued to optionally produce devoiced [g] across a range of different words.

Fricatives

As mentioned above, [h] was the only sound already acquired at the beginning of Eleonora's corpus documentation. As illustrated in Figure 63, she had acquired [h] in onset by 1;00.07 and she maintained a greater than 50% accuracy level in this consonant across all sessions.

Figure 63: Eleonora's acquisition of [h] in onset



Eleonora acquired [v] in onset next, six months later, at 1;06.15. She produced six accurate productions and two deletions, as shown in Figure 64. Prior to this, Eleonora frequently substituted [v] to [β]. After this, we observe a noticeable spike in substitutions at 1;07.15, which yielded eight substitutions and two accurate productions. Seven of those substitutions consist of <u>*w*</u>*urm* [ˈ<u>v</u>ʊʀm] produced with the labiodental approximant [ʋ]. This was the only session with [ʋ] substitution, and it only affected the word <u>*w*</u>*urm*. Eleonora acquired [f] in onset one month later, at 1;08.15, as illustrated in Figure 65, with two accurate productions. Prior to this, Eleonora most commonly substituted to [ʔ] (five times), and then to [β] (three times).

Figure 64: Eleonora's acquisition of [v] in onset

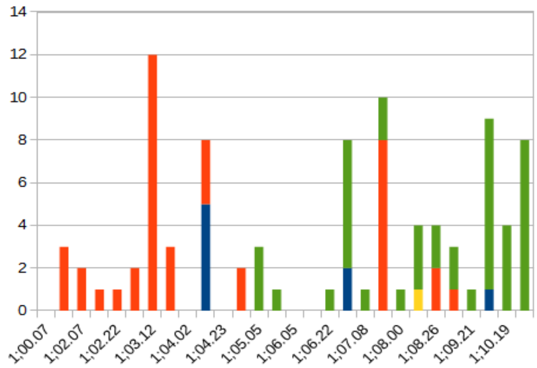
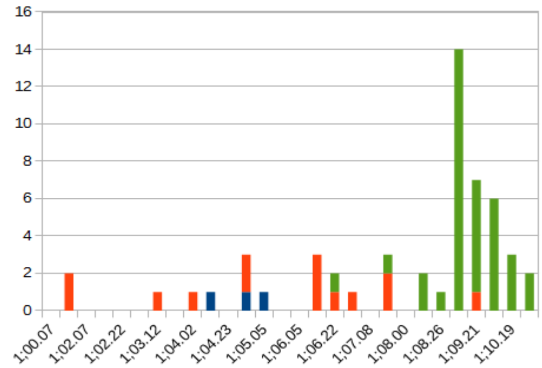


Figure 65: Eleonora's acquisition of [f] in onset



Eleonora did not acquire the remainder of the target fricative sounds by her latest documented session. Based on the minimal data available, she did not acquire [z] in onset, as shown in Figure 66. She made only 15 attempts in total which resulted in six accurate productions and six voicing errors, as well as substitutions to [t], [d], and [θ].

Figure 66: Eleonora's acquisition of [z] in onset

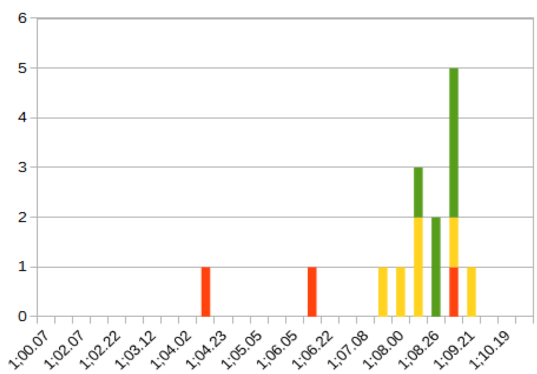
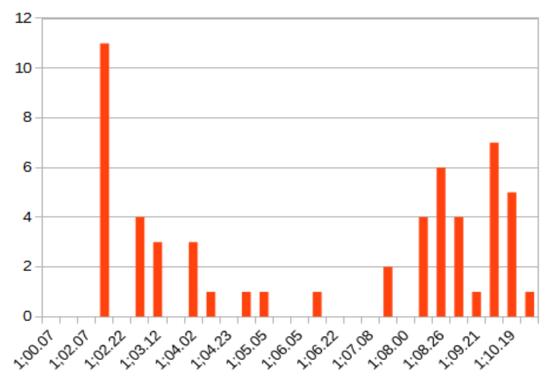


Figure 67: Eleonora's acquisition of [ʃ] in onset

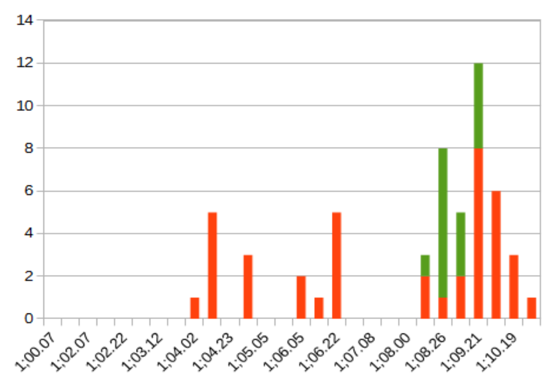


Eleonora also did not acquire [ʃ]. As illustrated in Figure 67, out of 55 total [ʃ] attempts, 21 resulted in substitution to [t], seven in substitution to [ʦ], five to [ɕ], five to [ç], along with a variety of other, less frequent substitutions. She did not produce any correct targets. No specific sound substitution was particularly prominent towards the later sessions, and I cannot observe a leading substitution pattern, outside of her producing [ʃ] generally too far back within the palatal area.

Affricates

Eleonora did not acquire any affricates in onset position during the period documented by the corpus. Eleonora attempted [p͡f] only six times, which she reduced to [p^h] for *pferdchen* [p͡feːʀtçən] at 1;06.22, and substituted to [p], [f], and [ʔ] at 1;06.29 for the same word. The corpus also documents one substitution to [f] at 1;07.15 and 1;08.26, both for the word *pferd* [ˈp͡feːʀt]. Eleonora attempted [ʦ] 55 times, which resulted in 15 accurate productions, 14 substitutions to [p], 11 to [t], five to [s], five to [θ], in addition to other, more variable substitutions, as shown in Figure 68.

Figure 68: Eleonora's acquisition of [ʦ] in onset



Lastly, Eleonora also did not acquire [ʧ] during the documented period. She attempted [ʧ] six times, all for the word *tschüss* [ˈʧʏs]. All attempts underwent substitution to [z] or [ç].

3.2. Nasals in onset position

As mentioned above, Eleonora acquired both nasals within the first two months of recordings. As shown in Figure 69, she acquired [n] in onset at 1;01.11, with 10 accurate productions and two denasalizations to [d]. She acquired [m] in onset one month later, at 1;02.07, where she produced 12 accurate productions, as displayed in Figure 70. All deletions that occurred up to 1;08.26 were for a single word, *mandarine* [manda'ʀiːnə].

Figure 69: Eleonora's acquisition of [n] in onset

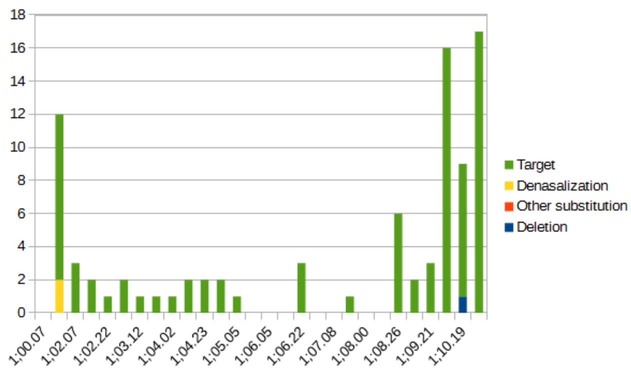
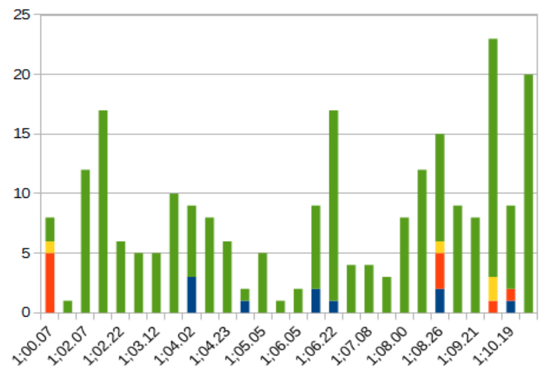


Figure 70: Eleonora's acquisition of [m] in onset



At 1;08.26, we observe a rise in substitutions. Eleonora produced [m] as both [k] and [t] for the word *mikrofon* [mikʀo'foːn]. The two deletions observed in this session also occurred during attempts at *mikrofon* [mikʀo'foːn]. Eleonora also produced [m] as [b] for ['gʊk 'maːl]. More generally, Eleonora could produce *mal* in isolation, and only pronounced it incorrectly when paired with *guck*, suggesting that she had difficulty with this phrase in particular.

3.3. Approximants in onset position

As shown in Figure 71, based on the minimal number of attempts available, Eleonora acquired [l] in onset at 1;06.29, where she produced two accurate targets and one other substitution. [l] did not undergo gliding, and substitutions to [t] and [d] occurred only for the target word *l̲icht* [ˈl̲ɪçt]. Eleonora acquired rhotics in onset position three months later, at 1;10.02, as illustrated in Figure 72, with 15 accurate productions and three other substitutions. Prior to this, [ʀ] most frequently underwent substitution to [h].

Figure 71: Eleonora's acquisition of [l] in onset

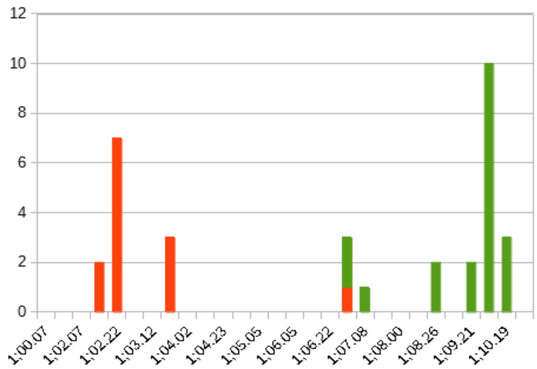
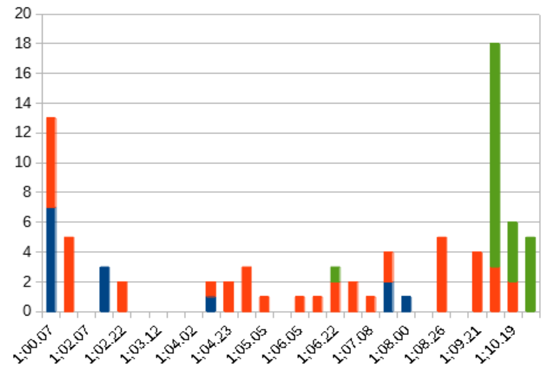
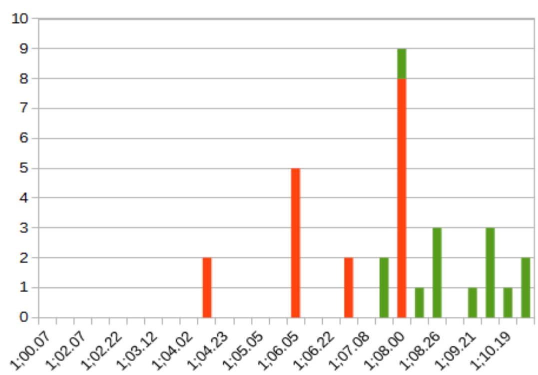


Figure 72: Eleonora's acquisition of [ʀ] in onset



Eleonora acquired [j] in onset at 1;08.15, as displayed in Figure 73, with one accurate production.

Figure 73: Eleonora's acquisition of [j] in onset



In the preceding session, 1;08.00, Eleonora produced one target for *j̲a* [j̲aː] and eight substitutions to [n] for *J̲ona* [ˈj̲oːnaː] and *J̲oni* [ˈj̲oːniː]. Eleonora never produced *J̲ona* and *J̲oni* accurately during her recorded sessions. Out of 31 attempts, 14 resulted in accurate productions, 13 in substitutions to [n] (all for *Jona* and *Joni*), and for the word *Joghurt* [ˈj̞oːgʊʀt] at 1;06.05, Eleonora produced three substitutions to [k] and one to [h].

3.4. Interim summary

Eleonora had only one sound, [h], acquired at the beginning of her corpus sessions. She went on to acquire all sounds in onset position by the last session available, 1;10.02, except for the fricatives [z] and [ʃ], and the affricates [p͡f], [ʦ], and [ʧ]. Her acquisition of onset consonants is summarized in Table 26 below.

Table 26: Eleonora's onset development

	1;00.07	1;01.11	1;02.07	1;02.14	1;04.02	1;04.08	1;04.23	1;05.23	1;06.05	1;06.15	1;06.29	1;08.15	1;08.26	1;10.02	Not acquired
[h]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	T	√	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[n]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[p]	T	V	√	√	√	√	√	√	√	√	√	√	√	√	
[d]	—	S/T	√	√	√	√	√	√	√	√	√	√	√	√	
[m]	S	T	√	√	√	√	√	√	√	√	√	√	√	√	
[k]	—	—	—	—	S	—	—	—	√	√	√	√	√	√	
[v]	—	S	S	S	—	D	—	T	—	√	√	√	√	√	
[l]	—	—	—	S	—	—	—	—	—	—	√	√	√	√	
[f]	—	S	—	—	S	D	—	—	—	S	S	√	√	√	
[j]	—	—	—	—	—	S	—	—	S	—	S	√	√	√	
[g]	—	—	—	S	S	—	—	S	T	S	V	V	√	√	
[ʀ]	D/S	S	—	D	—	D/S	S	—	S	S	S	—	S	√	
[z]	—	—	—	—	—	S	—	—	—	—	—	S	T	—	X
[ʃ]	—	—	—	S	S	S	—	—	—	S	—	S	S	S	X
[p͡f]	—	—	—	—	—	—	—	—	—	—	S	—	S	—	X
[ʦ]	—	—	—	—	S	S	—	—	S	S	—	S	T	S	X
[ʧ]	—	—	—	—	—	—	—	—	—	S	—	—	—	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

Overall, Eleonora acquired nasals and most stops before she acquired the majority of fricatives, with two exceptions: her early acquisition of [h] and late acquisition of [g]. Voicing errors were especially prominent with [g], which may have influenced its late acquisition.

In general, voicing errors occurred frequently both before and after the acquisition of the voiced stops [b], [d], and [g]. Eleonora did not have difficulty producing the voiceless stops, nor did she struggle with voicing distinctions for fricatives. As discussed above in Chapter 2, section 8.2, German has syllable-final devoicing which causes all syllable-final fricatives and stops to be realized as voiceless. From the child's perspective, producing stops in onset position presents added complexities when compared to coda position, as they have to produce a contrast between voiced and voiceless stops. Therefore, establishing this contrast may have influenced Eleonora's voicing errors in onset position. While Eleonora also had difficulty with the contrast between voiced and voiceless fricatives, she did not do so as systematically as she did with onset stops.

In regards to approximants, Eleonora acquired [l] at 1;06.29, a little over three months earlier than she acquired [ʀ] at 1;10.02. She also acquired the glide [j] relatively late, at 1;08.15. Lastly, Eleonora, did not acquire any affricate sounds during the documented sessions.

I now move on to describe her acquisition of onset clusters.

3.5. Consonant clusters in onset position

Eleonora only acquired one cluster type over the course of the documented period. If we consider only the [tʀ] cluster, we can claim that Eleonora acquired stop-rhotic clusters at 1;10.02. As illustrated in Figure 74, Eleonora produced [tʀ] with the most accuracy. She produced 12 correct targets out of 22 attempts, and these occurred in the last three sessions. However, Eleonora also made one incorrect attempt at [pʀ], and 41 attempts at [bʀ], which resulted in only four accurate productions. She also made 16 attempts at [dʀ], which yielded no correct productions, 19 attempts at [kʀ] with one accurate production, and two incorrect attempts at [gʀ].

Eleonora did not acquire stop-lateral clusters, as summarized in Figure 75. Specifically, Eleonora did not acquire [pl] as she made no correct productions for this cluster. Out of 23 attempts at [bl], nine resulted in accurate productions; however, these cases were scattered across different recording sessions, such that Eleonora never reached the criterion for mastery. [kl] had four attempts resulting in three accurate productions, and all three targets occurred in the last four sessions (while the error occurred in an earlier session). Therefore, [kl] may have been acquired at the end of the recorded period; however, more evidence would be required to establish this. Eleonora also did not acquire [gl]: she made five attempts which resulted in one accurate production.

Figure 74: Eleonora's acquisition of stop-rhotic onset clusters

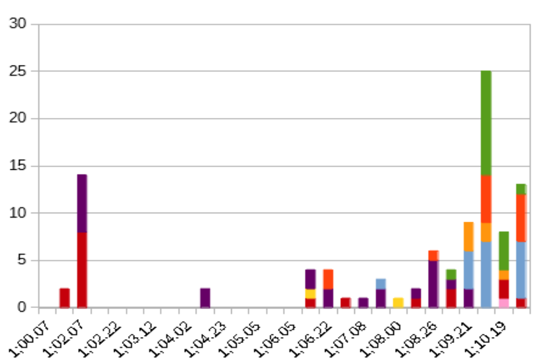
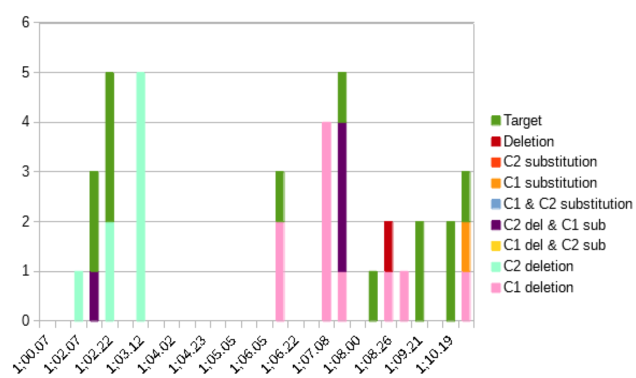


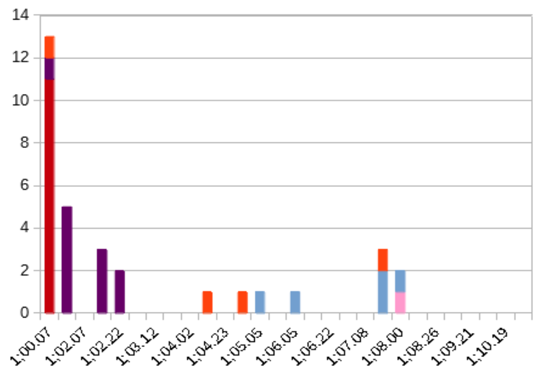
Figure 75: Eleonora's acquisition of stop-lateral onset clusters



Eleonora did not acquire fricative-lateral clusters, with only four attempts and no correct productions. As for fricative-rhotic clusters, there was not enough evidence to state whether they were acquired as Eleonora only made one attempt, which resulted in an accurate production at age 1;10.19.

Eleonora also did not acquire stop-glide clusters. As illustrated in Figure 76, out of 32 attempts, Eleonora most commonly reduced [dj] to [d] 11 times, and to [t] 11 times.

Figure 76: Eleonora's acquisition of stop-glide onset clusters



Eleonora also did not acquire nasal-glide clusters. She made six attempts at [nj], all of which were produced as [ŋ]. Lastly, Eleonora made no attempts at producing a fricative-glide cluster.

3.6. Interim summary

Eleonora acquired only one cluster type during her documented sessions; however, an overall lack of recorded attempts at clusters may have underestimated her productive abilities. Based on the available evidence, Eleonora only acquired stop-rhotic clusters during the period documented by the corpus, as summarized in Table 27. Stop-lateral clusters most frequently underwent C2 deletion, whereas stop-rhotic clusters displayed more variability and underwent a variety of deletion and substitution patterns before acquisition at 1;10.02. Eleonora did not attempt many fricative-rhotic and fricative-lateral clusters, only three and one respectively, from which we cannot draw any firm conclusion.

Table 27: Eleonora's onset cluster development

	1;00.07	1;01.11	1;02.07	1;02.14	1;04.02	1;04.08	1;04.23	1;05.23	1;06.05	1;06.15	1;06.29	1;08.15	1;08.26	1;10.02	Not acquired
Stop-rhotic clusters	—	R	R	—	—	D+S	—	—	—	R/D +S	R	R/D +S	D+S	√	X
Stop-lateral clusters	—	—	R	D+S	—	—	—	—	—	R	—	T	R/D	—	X
Stop-glide clusters	R	D+S	—	D+S	—	S	—	—	S	—	—	—	—	—	X
Fricative -rhotic clusters	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
Fricative -lateral	—	—	—	—	—	—	—	—	—	R	—	—	—	S	X
Nasal-glide	—	—	—	—	—	—	—	—	—	—	—	—	D+S	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

Similar to the other stop-onset clusters, stop-glide and nasal-glide clusters most frequently underwent reduction to the first consonant. Eleonora did not attempt any fricative-glide clusters; based on the lack of attempts, combined with the information above regarding the other fricative-onset clusters, the data minimally suggest that fricative-onset clusters emerged later when compared to stop- and nasal-initial clusters.

I now move on to describe Eleonora's singleton coda development.

3.7. Obstruents in coda position

Stops

Based on the minimal recorded evidence available, Eleonora acquired [p] in coda position at 1;04.02, with five accurate productions, as shown in Figure 77. She acquired [t] in coda six days later, at 1;04.08, as displayed in Figure 78, where she produced one accurate target (*s̲alat* [z̲aˈla:t]).[6]

Figure 77: Eleonora's acquisition of [p] in coda

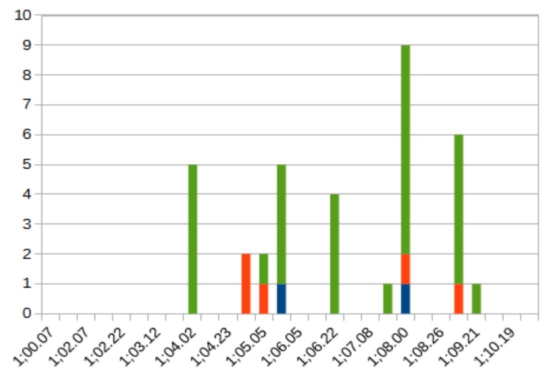
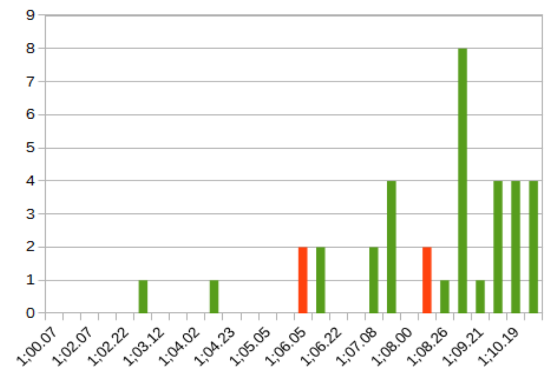
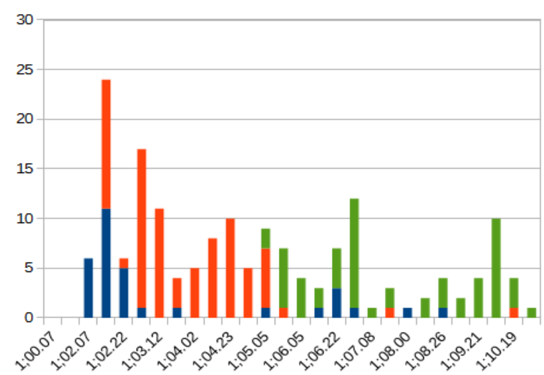


Figure 78: Eleonora's acquisition of [t] in coda



Eleonora acquired [k] in coda at 1;05.23, as illustrated in Figure 79, with six accurate productions and one other substitution.

Figure 79: Eleonora's acquisition of [k] in coda



Prior to this, [k] most frequently underwent substitution. Eleonora attempted [k] 78 times before acquisition at 1;05.23, which resulted primarily in 55 substitutions to [t].

6 I did not count [t] as acquired for the previous session, with one accurate production, because Eleonora produced a single syllable word as a two-syllable word, causing the final [t] to be preserved but as an onset of a second syllable (e.g., [ˈty:t] produced as [ˈtɯˈtɯ]).

Fricatives

While there is an overall dearth of data concerning fricatives in coda, Eleonora appears to have acquired [ç] in coda position at 1;02.14, with two accurate productions, as shown in Figure 80. She acquired [f] in coda next at 1;05.23, where she produced five accurate targets. As shown in Figure 81, Eleonora did not attempt [f] before 1;03.22. Prior to acquisition at 1;05.23, attempts resulted in a mix of variable substitutions and accurate productions. After this, the four substitutions at 1;06.15 consisted of three substitutions to [ɸ] (which is very close to [f] phonetically), and one to [l] for *auf* [ʔaʊf] (Eleonora correctly produced this word 16 other times in this session as well).

Figure 80: Eleonora's acquisition of [ç] in coda

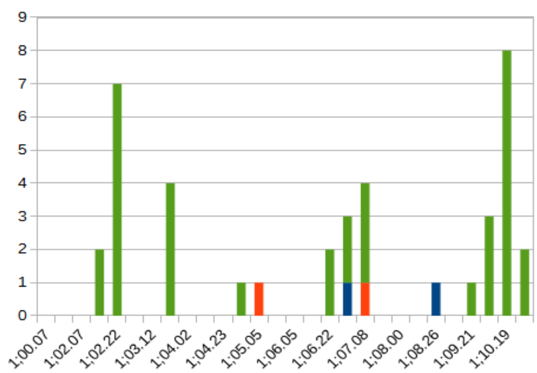
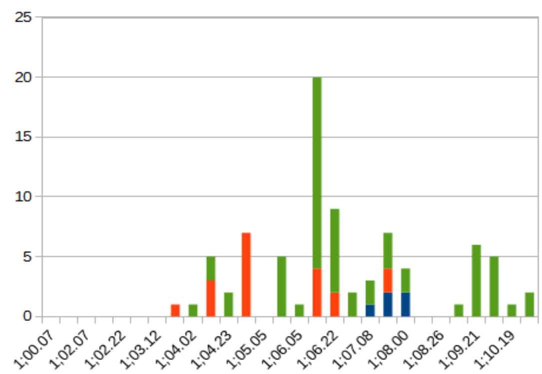


Figure 81: Eleonora's acquisition of [f] in coda



Based on the minimal number of recorded production attempts, Eleonora acquired [x] in coda at 1;05.23, with two accurate productions, as shown in Figure 82. Before this, Eleonora attempted [x] five times, all of which underwent substitution. The two substitutions that occurred at 1;09.21, consisted of assimilation to [n] for *noch* [ˈnɔx] and substitution to [s] for *auch* [ˈʔaʊx]. Eleonora produced both words correctly in earlier sessions. The two deletions at 1;10.19 occurred for *noch* [ˈnɔx] as well. As displayed in Figure 83, Eleonora acquired [s] in coda two weeks later, at 1;06.05, where she produced three accurate targets and one other substitution ([t] for *das*

[ˈdas̱]). She produced *das* twice correctly in this session as well. Prior to this, Eleonora's scarce attempts at [s] in coda position were met with varying levels of success, and resulted in a mix of substitutions and correct productions.

Figure 82: Eleonora's acquisition of [x] in coda

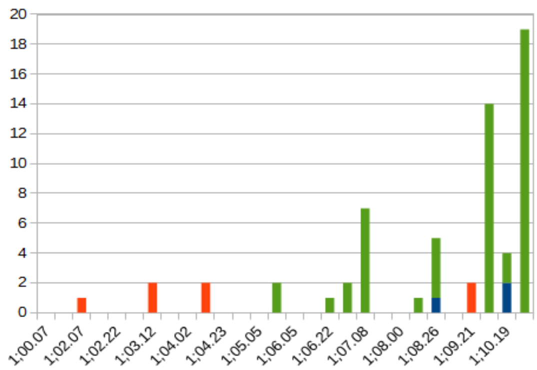
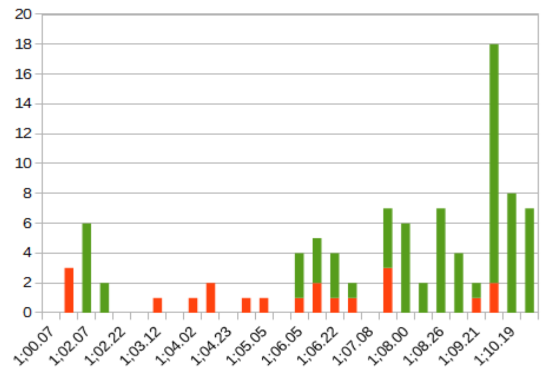


Figure 83: Eleonora's acquisition of [s] in coda



The last fricative to be discussed, [ʃ] in coda, was not acquired during the recorded period. Out of a total of 10 attempts for the whole corpus, Eleonora produced two as target, and eight as substitutions (four to [s], two to [ç], and one each to [ɕ] and [ɸ]).

Affricates

The corpus shows no evidence that Eleonora acquired [p͡f] in coda. She made only three attempts at [p͡f] for the word *knopf* [ˈknɔp͡f] at 1;02.07, all of which underwent deletion.

3.8. Nasals in coda position

Eleonora did not acquire [ŋ] in coda position by the latest session available. Eleonora made only 13 attempts which resulted in five accurate productions, four substitutions to [n], and four deletions.

3.9. Approximants in coda position

Both target approximants, [l] and [ʀ], were affected by deletion in coda position before and after acquisition, as illustrated in Figure 84 and Figure 85, respectively. Eleonora acquired [l] in coda at 1;04.23, with 12 accurate productions. In the next session, 1;04.30, we observe a spike in substitutions which yielded two accurate productions for *apfel* [ˈʔap͡fəl], two gliding substitutions to [j] for *krokodil* [kʀokoˈdiːl] and *kamel* [kaˈmeːl], and one vocalization to [a] for *kamel*. The other rise in substitution, at 1;07.15, consisted of [m] substitutions for *guck+mal* [ˈgʊkˌmaːl]. This phrase was also problematic for [m] in onset position, as already discussed in section 3.2.

Figure 84: Eleonora's acquisition of [l] in coda

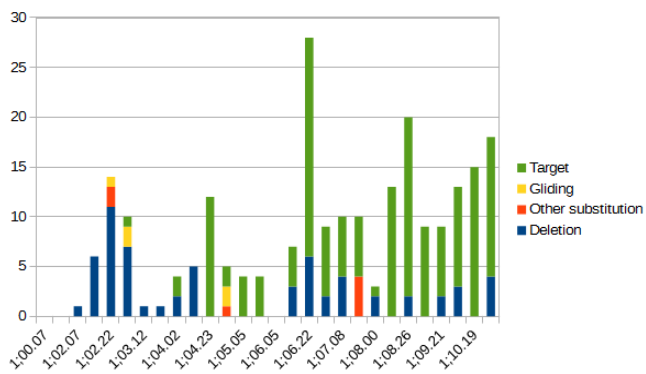
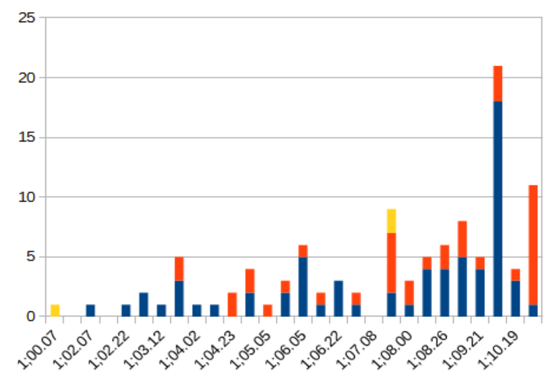


Figure 85: Eleonora's acquisition of [ʀ] in coda



As we can see in Figure 85, Eleonora did not acquire [ʀ] in coda position. Out of 108 total attempts, 66 underwent deletion, and the number of deletions increased in later sessions proportionally to the number of Eleonora's attempts. Aside from deletion, the most common substitutions consisted of 27 vocalizations to [ɐ] and five to [a], three substitutions to [j], and a variety of other, more marginal substitutions. The vocalizations to [ɐ] may reflect allophonic variation: [ɐ] is a common and widespread allophone of post-vocalic [ʀ] (Wiese 1996). However, even if Eleonora's productions resulted from this allophonic pronunciation, her deletions of [ʀ] remained too frequent and prevented her from attaining the 50% accuracy criterion across consecutive sessions.

3.10. Interim summary

At the beginning of her documented sessions, Eleonora had not acquired any sounds in coda position. During her recordings, from 1;00.07 to 1;10.02, Eleonora acquired all voiceless stops and fricatives (with the exception of [ʃ]) in coda, as summarized in Table 28. However, she did not acquire [ʃ], [p͡f], [ʀ], or [ŋ] in this position.

Table 28: Eleonora's coda development

	1;00.07	1;01.11	1;02.07	1;02.14	1;04.02	1;04.08	1;04.23	1;05.23	1;06.05	1;06.15	1;06.29	1;08.15	1;08.26	1;10.02	Not acquired
[ç]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
[p]	—	—	—	—	√	√	√	√	√	√	√	√	√	√	
[t]	—	—	—	—	—	√	√	√	√	√	√	√	√	√	
[l]	—	—	D	D	D/T	D	√	√	√	√	√	√	√	√	
[k]	—	—	D	D/S	S	S	S	√	√	√	√	√	√	√	
[f]	—	—	—	—	T	S	T	√	√	√	√	√	√	√	
[x]	—	—	S	—	—	S	—	√	√	√	√	√	√	√	
[s]	—	S	T	T	S	S	—	—	√	√	√	√	√	√	
[ʃ]	—	S	—	—	—	—	—	—	—	—	—	S	—	S	X
[p͡f]	—	—	D	—	—	—	—	—	—	—	—	—	—	—	X
[ʀ]	S	—	D	—	D	D	S	D	D	D/S	D/S	D	D	D	X
[ŋ]	—	—	—	—	—	—	—	—	—	S	—	D/T	—	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

As discussed above in Chapter 2, section 8.2, German has syllable-final devoicing which causes all syllable-final fricatives and stops to be realized as voiceless (Fox 2007). Eleonora did not have difficulty with coda stops in the same way that she did onset stops, suggesting that the voicing contrast in onset position is more difficult to master than the unambiguous voiceless stops that occur word-finally.

A general overview of Eleonora's phonological development, including singleton onsets, onset clusters, and singleton codas, is summarized in Table 29.

Table 29: Summary of Eleonora's phonological development

1;00.07	1;01.11	1;02.07	1;02.14	1;04.02	1;04.08	1;04.23	1;05.23	1;06.05	1;06.15	1;06.29	1;08.15	1;08.26	1;10.02	Not acquired
ONSET														
[h]	[b] [t] [n]	[p] [d] [m]						[k]	[v]	[l]	[f] [j]	[g]	[ʀ]	[z] [ʃ] [p͡f] [t͡s] [t͡ʃ]
ONSET CLUSTER														
													Stop-rhotic	Stop-lateral Stop-glide Fricative-rhotic Fricative-lateral Nasal-glide
CODA														
			[ç]	[p]	[t]	[l]	[k] [f] [x]	[s]						[ʃ] [p͡f] [ʀ] [ŋ]

In onset position, Eleonora generally acquired nasals and non-velar stops earlier than she acquired fricatives, glides, and approximants. Eleonora acquired velar stops later in both onset and coda position, and she did not acquire the velar nasal [ŋ] during the documented period. Eleonora only acquired one cluster type, stop-rhotic clusters, however she made minimal attempts at producing the other clusters.

While Eleonora displayed a sizable number of voicing errors during her acquisition of stops in onset position, voicing errors did not influence her acquisition of stops and fricatives in coda position. The unambiguous nature of the voiceless stops that occur syllable-finally appeared to help her acquire stops in coda position without voicing errors.

Also, similar to onset development, Eleonora acquired [l] significantly before [ʀ]. Lastly, similar again to her onset acquisition, Eleonora did not acquire [ʃ] or [p͡f] in coda position.

As discussed above, Eleonora did not make many production attempts during her recordings. Due to the overall dearth of data, I examined the phonological development of another German-learner, Wiglaf.

4. Wiglaf

I investigated the phonological acquisition of another German speaker from the same corpus as Eleonora (Grimm 2006; 2007) due to Eleonora's overall lack of production attempts. Wiglaf has 24 documented sessions, from ages 1;03.21 to 2;01.21. He had already acquired the sound [p] in onset position by the beginning of his documented sessions. During his first two months of recordings, from 1;03.21 to 1;05.26, Wiglaf acquired an additional four sounds in onset position.

Table 30: Wiglaf's early consonantal inventory (onset)

	Labial	Coronal		Dorsal	Glottal
		alveolar	alveopalatal		
Stops	p				
Fricatives					h
Affricates					
Trill					
Nasals	m	n			
Liquids					
Glides			j		

As summarized in Table 30, Wiglaf acquired the fricative [h], the nasals [m] and [n], and the glide [j] during this early period. In addition to these sounds, he also acquired [p] and [f] in coda position during this period.

4.1. Obstruents in onset position

Stops

As mentioned above, Wiglaf had already acquired [p] in onset by 1;03.21, where he made one accurate production, as shown in Figure 86. He slipped below 50% accuracy on two occasions due to voicing errors: 1;10.13 displays three voicing errors (*Pilze* [ˈp̱ɪltsə] produced as [ˈḇiːlːtsə]) and one accurate production (*Papagei* [p̱apaˈgaɪ]; 1;11.23 has four voicing errors (*papa* [ˈp̱apa]→[ˈbapa], *packen* [ˈp̱akən]→[ˈḇak], *Polizeiauto* [p̱oliˈtsaɪˌʔaʊtoː]→[ˌḇoliˈsaɪˌʔaʊtɤ]) and three accurate productions (*Papagei* [p̱apaˈgaɪ]). As we will see below, voicing errors commonly affected Wiglaf's onset stops, however it is his voiced stops that displayed the most voicing errors (which is in parallel with Eleonora's acquisition of onset stops discussed above).

Wiglaf acquired [b] in onset next at 1;06.12, as illustrated in Figure 87, where he made six accurate productions and three voicing errors. Prior to this, attempts resulted in a mix of voicing errors and accurate productions. Voicing errors remained common until 1;11.23, and caused his accuracy to dip below 50% at 1;09.02, 1;09.19, 1;09.26, 1;10.13, and 1;11.13. These voicing errors occurred across a variety of words, with no observable pattern.

Figure 86: Wiglaf's acquisition of [p] in onset

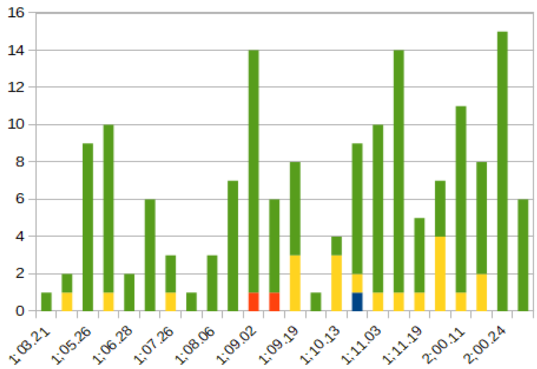
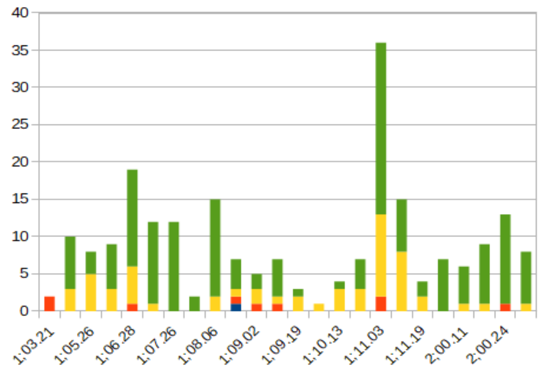


Figure 87: Wiglaf's acquisition of [b] in onset



As shown in Figure 88, Wiglaf acquired [t] at 1;07.11, where he made two accurate productions. He maintained a level of 50% accuracy or more in subsequent sessions. Prior to this, Wiglaf made only two attempts at [t] at 1;03.21, for the expression *tut tut*, which I did not consider in my assessment of his phonological abilities due to the onomatopoetic nature of the word. Wiglaf acquired [d] at 2;00.17, as illustrated in Figure 89, with 57 accurate productions, 37 voicing errors, one other substitution, and nine deletions. Prior to this, Wiglaf did not exceed the 50% accuracy threshold in any single session. His most common error consisted of voicing errors, and this continued after acquisition.

Figure 88: Wiglaf's acquisition of [t] in onset

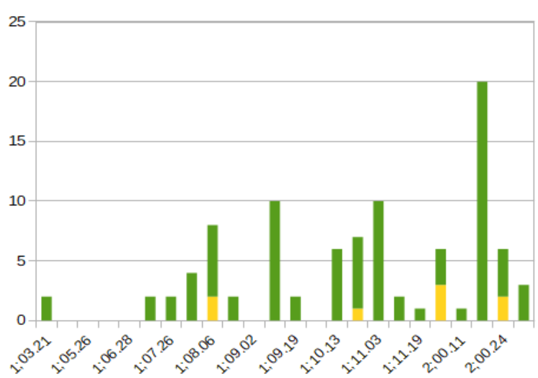
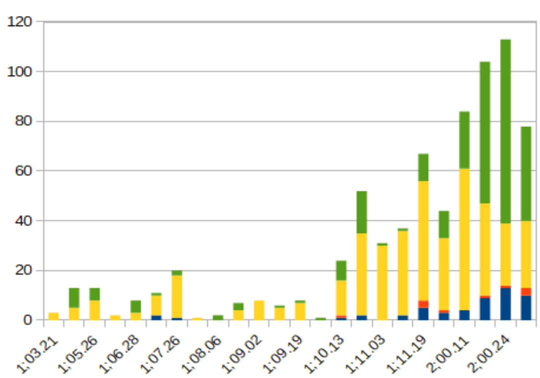


Figure 89: Wiglaf's acquisition of [d] in onset



Wiglaf acquired both [k] and [g] in onset at 1;11.13. He acquired [k] with 12 accurate productions, two voicing errors, and one deletion, as shown in Figure 90. He did not attempt [k] during the first six sessions. From 1;07.26 to acquisition at 1;11.13, the most common error consisted of substitution to the glottal stop [ʔ] (n=33) across a variety of words.

Figure 90: Wiglaf’s acquisition of [k] in onset

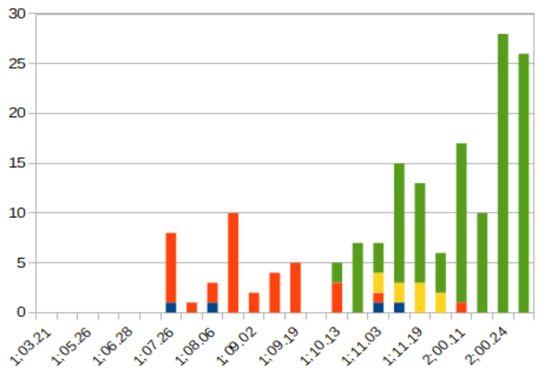
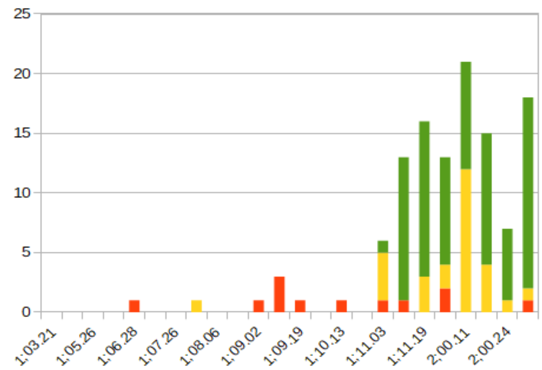


Figure 91: Wiglaf’s acquisition of [g] in onset

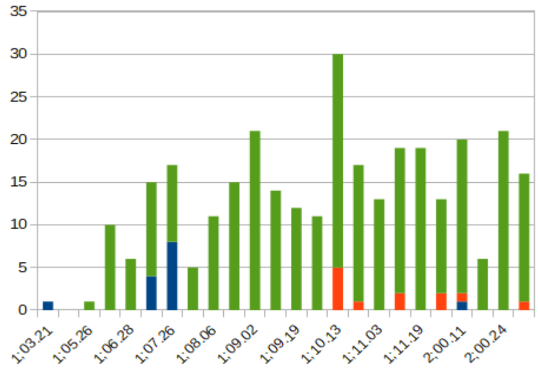


As displayed in Figure 91, Wiglaf acquired [g] at 1;11.13, with 12 accurate productions and one other substitution. He made minimal attempts prior to that which resulted primarily in [ʔ] substitution, similar to [k]. Voicing errors became common after acquisition, with target accuracy falling below 50% at 2;00.11, where he produced 12 voicing errors out of 21 attempts at [g]. I could not observe a pattern to the voicing errors, as the same word could be produced correctly or with a voicing error within the same session, e.g., *gela* [g̥əˈlaː], and *gute* [ˈg̥uːtə] at 2;00.11, both produced with target [g] and devoiced [k].

Fricatives

As mentioned above, Wiglaf acquired [h] early, during the first two months of recordings. As illustrated in Figure 92, he acquired [h] in onset at 1;05.26. Prior to this, Wiglaf made only one attempt at [h], which underwent deletion.

Figure 92: Wiglaf's acquisition of [h] in onset



Wiglaf acquired [v] in onset next, three months later, at 1;08.13. He made two accurate productions, as shown in Figure 93. Prior to this, Wiglaf made minimal attempts at this consonant, which primarily resulted in substitution to [β]. Wiglaf maintained a level of 50% accuracy, except at 1;11.03, where he produced seven voicing errors (for a variety of words) out of 13 attempts. Wiglaf acquired [f] in onset three months later, at 1;11.03, as illustrated in Figure 94, with 12 accurate productions and one other substitution. Prior to this, Wiglaf frequently made voicing errors, which persisted until the following session at 1;11.13. However, he did not make any attempts at [f] until age 1;09.02.

Figure 93: Wiglaf's acquisition of [v] in onset

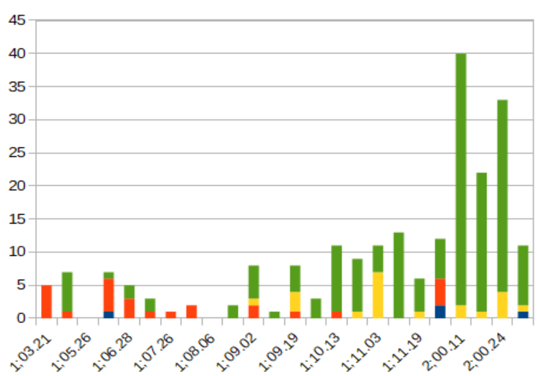
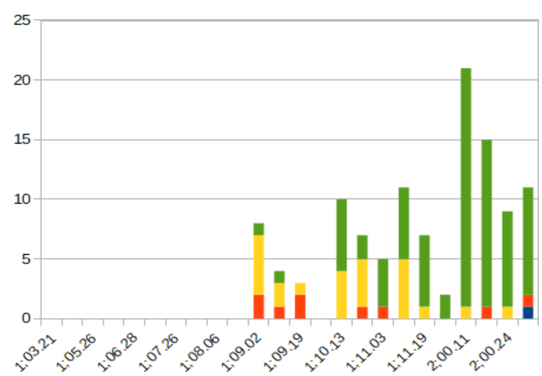


Figure 94: Wiglaf's acquisition of [f] in onset



Wiglaf did not acquire the remainder of the target fricative sounds to be discussed by his latest documented session. He did not acquire [z] in onset, as shown in Figure 95, where no session exceeds 50% accuracy. In the first six sessions where he attempted [z] (he made no recorded attempts before age 1;08.06), Wiglaf most frequently substituted [z] with [v], however this only occurred a total of 14 times scattered across six different sessions. In later sessions, his attempts resulted primarily in voicing errors (n=39) and a mix of infrequent substitutions and accurate productions.

Figure 95: Wiglaf's acquisition of [z] in onset

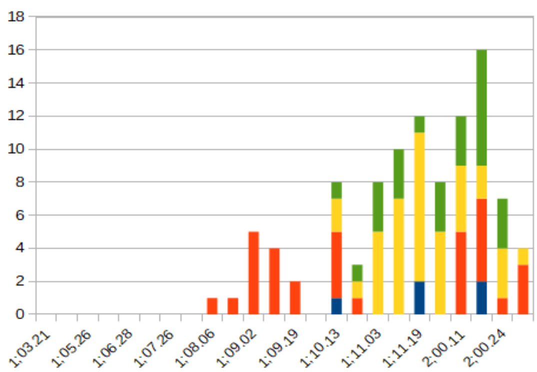
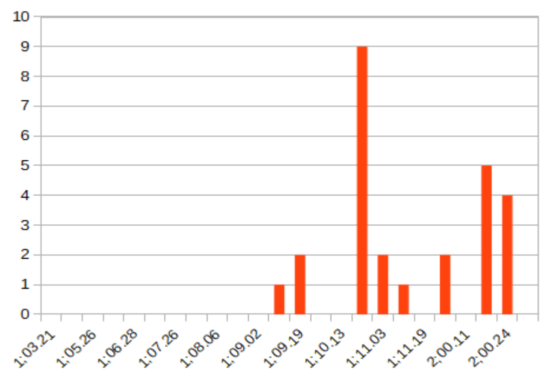


Figure 96: Wiglaf's acquisition of [ʃ] in onset



Based on the minimal evidence available, Wiglaf also did not acquire [ʃ], as illustrated in Figure 96. He made only 26 attempts, which yielded no correct productions. The most common error was substitution to [s], which occurred 16 times.

Affricates

Wiglaf acquired one affricate over the course of his documented sessions. He acquired [ʦ] in onset at 2;01.07, with eight accurate productions and one substitution, as shown in Figure 97. Prior to this, Wiglaf did not attempt [ʦ] until 1;08.13, and then [ʦ] underwent substitution primarily to [s] (n=18) and [v] (n=7), along with other, more marginal substitutions. While target accuracy was improving in the later sessions, a longer period of documentation would have been useful to verify whether Wiglaf maintained his level of accuracy.

Figure 97: Wiglaf's acquisition of [t͡s] in onset

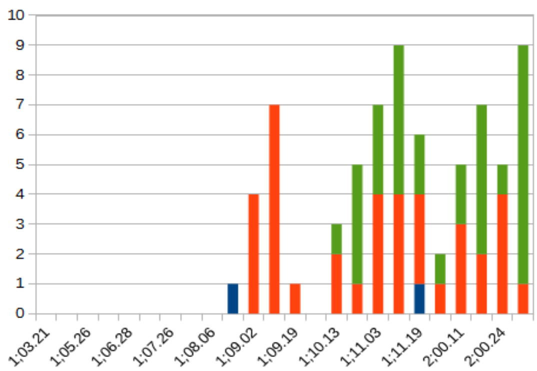
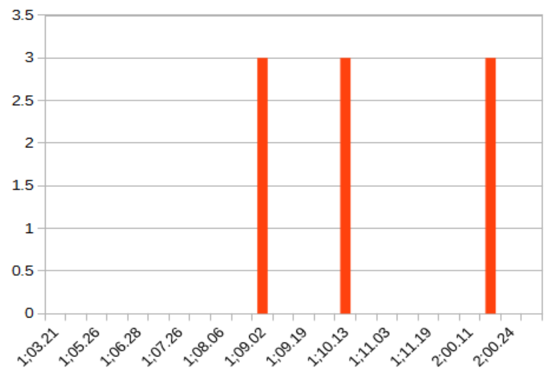


Figure 98: Wiglaf's acquisition of [p͡f] in onset



While there is a dearth of data, as displayed in Figure 98, it appears that Wiglaf did not acquire the affricate [p͡f] in onset position, as he made no correct productions out of nine attempts; he substituted [p͡f] to [f] (n=4), [v] (n=3), and [p] (n=2). Wiglaf also did not acquire [ʧ] in onset, with only two attempts at 1;11.13. Both attempts resulted in substitution to [t] for the word *tschüss* [ˈʧʏs].

4.2. Nasals in onset position

As mentioned above, Wiglaf acquired both nasals within the first two months of recordings. As shown in Figure 99, he acquired [n] at 1;05.03 with two accurate productions. Prior to this, Wiglaf did not make any attempts at this consonant. We observe a rise in substitutions at 2;00.17, which yielded six substitutions to [l], exclusively for the word *nämlich* [ˈn̲ɛːmlɪç], which was produced as [l̲eːmɪç]. This suggests idiosyncratic assimilation caused by the [l] in the second syllable of the target form, as [n] did not undergo assimilation in other words or in other phonetic environments.

Figure 99: Wiglaf's acquisition of [n] in onset

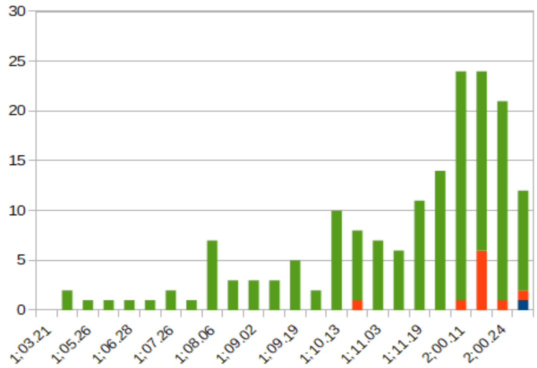
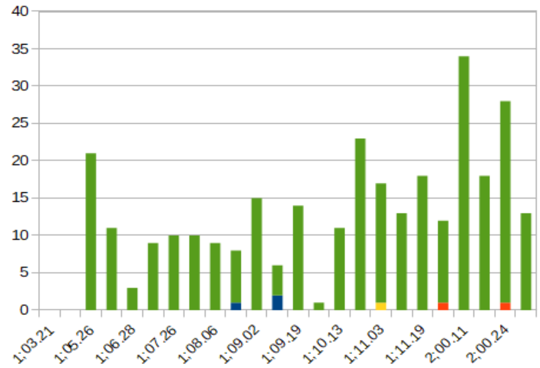


Figure 100: Wiglaf's acquisition of [m] in onset

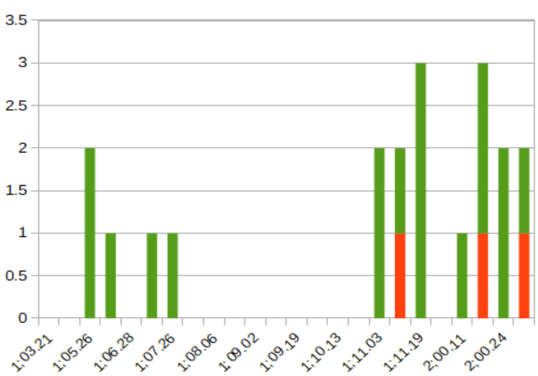


As displayed in Figure 100, Wiglaf acquired [m] in onset three weeks later, at 1;05.26, with 21 accurate productions. He did not make any attempts at this consonant in the two earlier sessions.

4.3. Approximants in onset position

Based on his minimal number of attempts, as illustrated in Figure 101, Wiglaf acquired [j] in onset at 1;05.26, with two accurate productions. Out of 20 total attempts, Wiglaf produced 17 correctly.

Figure 101: Wiglaf's acquisition of [j] in onset



As displayed in Figure 102, Wiglaf acquired [l] in onset at 1;10.28, where he made four accurate productions. Prior to this, his attempts resulted in substitution to [v] across a variety of words (22 times out of 88 attempts), with no observable influence from surrounding consonants. Wiglaf did not attempt [l] in onset position until 1;08.13. While Wiglaf also substituted other voiced sounds to [v], he did not do so frequently with the exception of [l], which suggests that this substitution is not representative of a larger phonological process.

Figure 102: Wiglaf's acquisition of [l] in onset

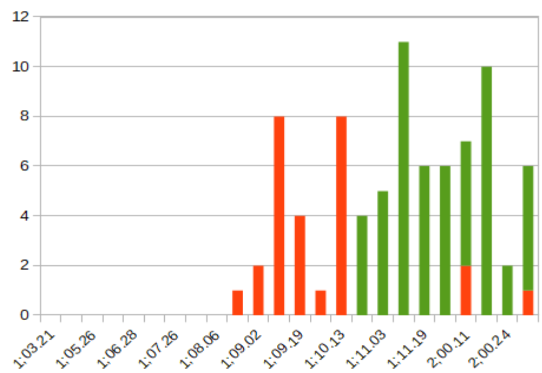
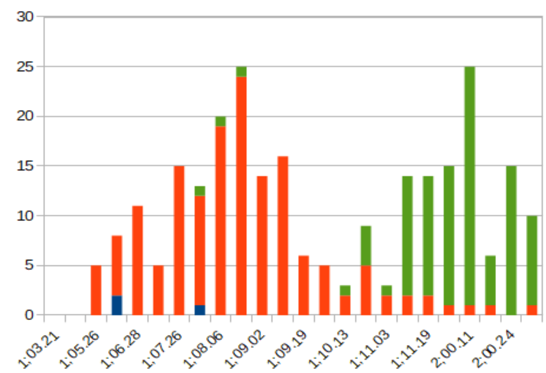


Figure 103: Wiglaf's acquisition of [ʀ] in onset



Wiglaf acquired [ʀ] a few weeks later, at 1;11.13, as illustrated in Figure 103, with 12 accurate productions and two other substitutions. Prior to this, [ʀ] underwent substitution, primarily to [h].

4.4. Interim summary

Wiglaf had only one sound in onset position, [p], acquired at the beginning of his documented sessions. He acquired a variety of onset sounds by his last recorded session, at 2;01.07. However, he did not acquire the fricatives [z] and [ʃ], nor the affricates [p͡f] and [ʧ]. Wiglaf's acquisition of onset consonants is summarized in Table 31 below.

Table 31: Wiglaf's onset development

	1;03.21	1;05.03	1;05.26	1;06.12	1;07.11	1;08.02	1;08.13	1;09.02	1;09.09	1;09.19	1;10.28	1;11.03	1;11.13	2;00.17	2;01.07	Not acquired
[p]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[n]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[j]	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[m]	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[h]	D	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	S	T	V	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	T	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
[v]	S	T	—	S	S	S	√	√	√	√	√	√	√	√	√	
[l]	—	—	—	—	—	—	S	S	S	S	√	√	√	√	√	
[f]	—	—	—	—	—	—	—	V	V	S	V	√	√	√	√	
[k]	—	—	—	—	—	S	S	S	S	S	T	S/T	√	√	√	
[g]	—	—	—	—	—	V	—	S	S	S	—	V	√	√	√	
[ʀ]	—	—	S	S	S	S	S	S	S	S	S	S	√	√	√	
[d]	V	T	V	V	V	V	V	V	V	V	V	V	V	√	√	
[ʦ]	—	—	—	—	—	—	D	S	S	S	T	S/T	S/T	S/T	√	
[z]	—	—	—	—	—	—	S	S	S	S	S/T	V	V	S/T	S	X
[ʃ]	—	—	—	—	—	—	—	—	S	S	S	S	S	S	—	X
[ʧ]	—	—	—	—	—	—	—	—	—	—	—	—	S	—	—	X
[p͡f]	—	—	—	—	—	—	—	S	—	—	—	—	—	S	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

Wiglaf's acquisition of onsets mirrored Eleonora's in several ways: voicing errors affected voiced stops; [h] was acquired early, with all other fricatives acquired months later; and neither child acquired [z] or [ʃ], nor the affricates [p͡f] or [ʧ]. Interestingly, while Eleonora produced voicing errors for voiced stops (and minimally for voiced fricatives), Wiglaf had difficulty with the voicing contrast for both voiced and voiceless stops and fricatives. As discussed in Chapter 2, section 8.2, above for Eleonora, German has syllable-final devoicing, which causes all syllable-final fricatives and stops to be realized as voiceless. From the child's perspective, this adds a certain degree of complexity to syllable onsets when compared to codas, as they have to produce a contrast between voiced and voiceless obstruents in onsets.

Wiglaf acquired [l] at 1;10.28, and [ʀ] only a few weeks later, at 1;11.13. While this fits with Eleonora's development in that [l] was acquired first, the time frame differs as Eleonora acquired [l] three months earlier than [ʀ], and her [l] was acquired at 1;06.29, four months earlier than Wiglaf's. Lastly, while Eleonora, did not acquire any affricate sounds during the documented sessions, Wiglaf acquired the affricate [ʦ] during his last recorded session.

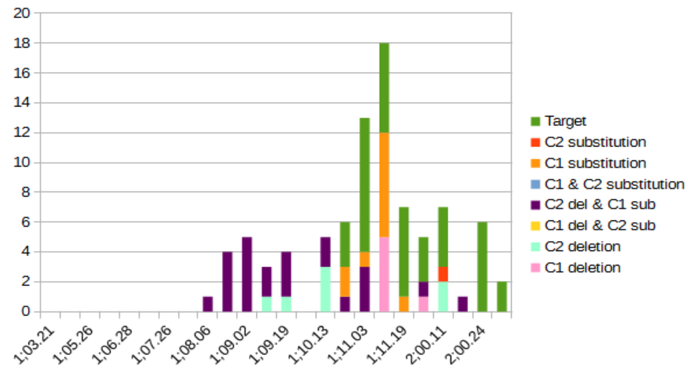
I now move on to describe Wiglaf's acquisition of onset clusters.

4.5. Consonant clusters in onset position

Wiglaf acquired three cluster types over the course of his documented sessions. Based on the minimal evidence available, Wiglaf acquired fricative-rhotic clusters at 1;10.28. While he only attempted this cluster type 13 times, Wiglaf produced 11 accurate targets for a variety of words. His two incorrect attempts resulted in reductions to [ʁ].

Wiglaf acquired stop-lateral clusters immediately after, at 1;11.03, as illustrated in Figure 104, where he made nine accurate productions (four [bl] and five [kl]), one C1 substitution error, and three C2 deletion & C1 substitution errors. The errors occurred on the same words that he also produced correctly in this session (e.g., *blaulichter* [<u>bl</u>aʊˌlɪçtəʀ] and *kleinen* [<u>kl</u>aɪnən]). Wiglaf did not attempt this cluster type until 1;08.06. Specifically, over the course of his sessions, Wiglaf made 48 attempts at [bl], which resulted in 21 correct targets. The most common errors consisted of reduction to [b], attested 11 times, and reduction with substitution to [p], six times.

Figure 104: Wiglaf's acquisition of stop-lateral clusters



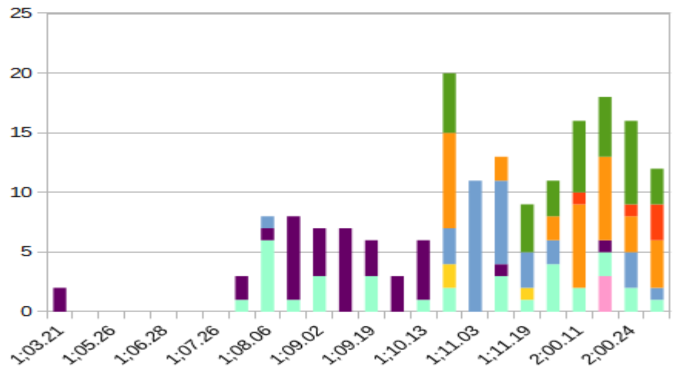
Wiglaf also attempted [pl] twice, which resulted in one accurate production and one substitution to [bl]. He attempted [tl] twice with one accurate production and one substitution to [kl], and attempted [gl] four times, which yielded one accurate production and one [tl], [v], and [l] substitution. Finally, Wiglaf attempted [kl] 32 times, which resulted in 15 accurate productions, 15 reductions to [t], and a variety of less frequent errors.

If looking solely at [fl] clusters, Wiglaf acquired fricative-lateral clusters at 1;11.13, where he made two accurate productions.[7] In total, Wiglaf made six attempts at [fl] resulting in five accurate productions and one reduction to [f].

Wiglaf did not acquire any other cluster types. Stop-glide clusters were not acquired by his last recorded session, 2;01.07, with seven attempts and no accurate productions. Wiglaf also did not acquire stop-rhotic clusters in his documented sessions, as displayed in Figure 105. He made 27 attempts at [bʁ] which resulted in three accurate productions, 10 reductions to [b], and reduction with substitution to [p] five times. He also made 103 attempts at [dʁ], which resulted in 18 accurate productions. 15 of these productions occurred in the last five sessions; therefore Wiglaf showed progress towards the acquisition of [dʁ].

7 As discussed in Chapter 2, section 8.2 above, [ʃ] patterns as a left-edge appendix in German. Therefore, I did not include it in my investigation of fricative-lateral clusters.

Figure 105: Wiglaf's acquisition of stop-rhotic clusters



The most common errors consisted of 28 substitutions to [t] (none in the last five sessions), and 22 voicing substitutions to [tʁ] (13 in the last five sessions). Wiglaf also attempted [kʁ] 14 times, which resulted in three accurate productions, [tʁ] 12 times, with five accurate productions, and [gʁ] 23 times, with four accurate productions. The most common errors for [gʁ] consisted of the voicing errors [kʁ] eight times and [kχ] five times.

Lastly, Wiglaf did not acquire nasal-glide clusters during his documented sessions. He made only three attempts which yielded two C1 deletions and one accurate production.

4.6. Interim summary

Wiglaf acquired fricative-rhotic, fricative-lateral, and stop-lateral clusters over the course of his recorded sessions, as summarized in Table 32. In his corpus data, he did not acquire stop-glide, stop-rhotic, and nasal-glide clusters.

Table 32: Wiglaf's onset cluster development

	1;03.21	1;05.03	1;05.26	1;06.12	1;07.11	1;08.02	1;08.13	1;09.02	1;09.09	1;09.19	1;10.28	1;11.03	1;11.13	2;00.17	2;01.07	Not acquired
Fricative-rhotic clusters	—	—	—	—	—	—	—	—	—	—	√	√	√	√	√	
Stop-lateral clusters	—	—	—	—	—	D+S	D+S	D+S	D+S	D+S	S/T	√	√	√	√	
Fricative-lateral clusters	—	—	—	—	—	—	—	—	—	—	—	—	√	√	√	
Stop-glide clusters	—	—	—	—	—	—	—	—	—	—	S	—	R	—	—	X
Stop-rhotic clusters	—	—	—	—	—	R	D+S	R/D +S	D+S	R/D +S	S	S	S	S	S	X
Nasal-glide clusters	—	—	—	—	—	—	—	R	D	—	—	—	T	—	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

Wiglaf's acquisition of onset clusters did not mirror his acquisition of singleton onsets: he acquired [l] in onset before [ʀ] in singleton onsets, however he acquired fricative-rhotic clusters before any consonant-lateral clusters. Interestingly, Wiglaf acquired fricative-rhotic clusters at 1;10.28, two weeks earlier than he acquired [ʀ] in singleton onset position. During these two weeks, [ʀ] in onset was produced as a mix of accurate productions and various fricatives (e.g., [x], [h], [ɣ]). While not a large gap in acquisition, the fricative nature of [ʀ] in German may lend itself to co-articulation in fricative-rhotic clusters, which could have facilitated the learning of this cluster type. Eleonora did not acquire these clusters during her recorded sessions, however she only made three attempts at this type of cluster. Eleonora did acquire stop-rhotic clusters during her recorded sessions, and she acquired both stop-rhotic clusters and singleton [ʀ] simultaneously in her last session, 1;10.02. For both children, [l] and [ʀ] patterned differently in their singleton onset and onset cluster acquisition.

4.7. Obstruents in coda position

Stops

As mentioned above, Wiglaf acquired two sounds in coda position within the first two months of recordings. Based on the available evidence, Wiglaf acquired [p] in coda at 1;05.03, as illustrated in Figure 106, with four accurate productions. In the one session prior, he made one attempt at [p] which underwent deletion.

Figure 106: Wiglaf's acquisition of [p] in coda

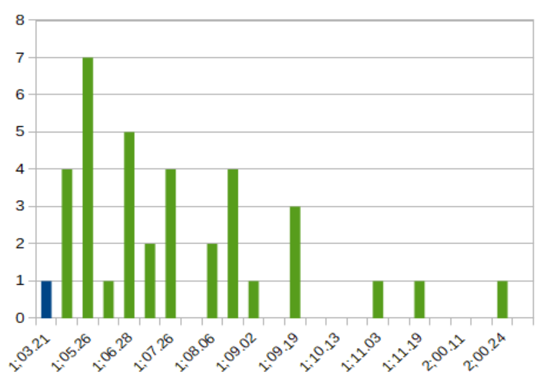
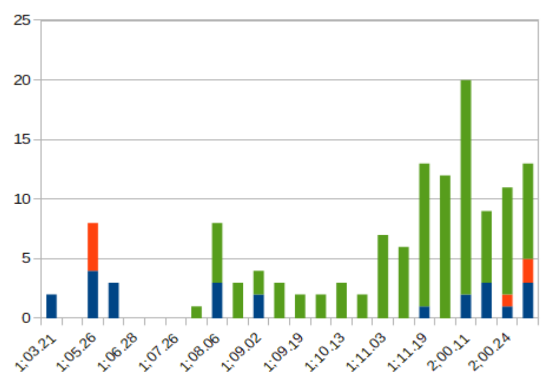


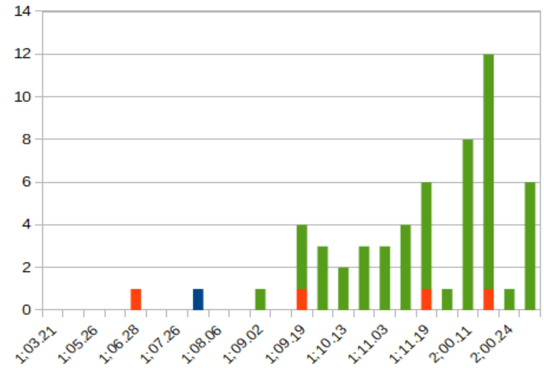
Figure 107: Wiglaf's acquisition of [t] in coda



Wiglaf acquired [t] in coda three months later, at 1;08.02, as displayed in Figure 107, with one accurate production. In total, he made 132 attempts, which yielded 101 accurate productions. We observe a rise in errors in later sessions, which resulted from a mix of deletion and substitution to glottal stop [ʔ] and [s] across a variety of words.

As shown in Figure 108, Wiglaf acquired [k] in coda position at 1;09.02, where he made one accurate production. Prior to this, he made only two attempts, which yielded one substitution to [p] and one deletion.

Figure 108: Wiglaf's acquisition of [k] in coda



Fricatives

While Wiglaf did not make many attempts at [f] in coda, it appears that he acquired this consonant at 1;05.03, with nine accurate productions. As shown in Figure 109, he did not make any attempts in the one previous session. We observe a substitution blip at 1;07.26, which resulted in three accurate productions and five substitutions to [ɸ], which is phonetically very similar to [f] (all for attempts at *auf* [ʔaʊf̲]). Wiglaf acquired [s] next, at 1;06.12, as illustrated in Figure 110, where he made three accurate productions. We observe a rise in substitution at 1;07.26, which resulted from one deletion, four substitutions to [θ] (for different words), and five accurate productions.

Figure 109: Wiglaf's acquisition of [f] in coda

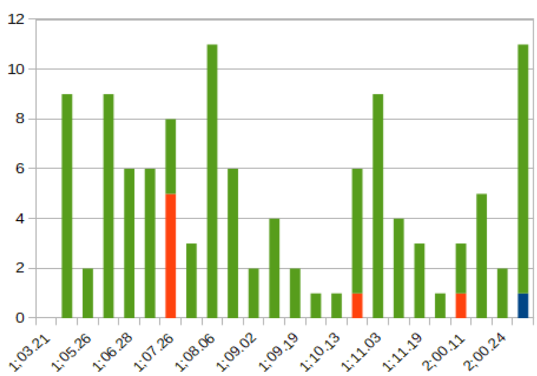
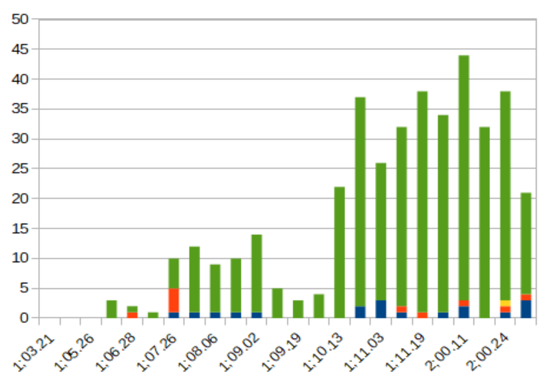


Figure 110: Wiglaf's acquisition of [s] in coda



As displayed in Figure 111, Wiglaf acquired [x] in coda at 1;09.09, with five accurate productions. He made only one attempt in the sessions prior to this, which resulted in a substitution to [f]. We observe a rise in deletions at 2;00.24, where Wiglaf made 24 accurate productions, one substitution to [f], and six deletions (all for *auch* [ˈʔaʊx̠]; *auch* was also produced correctly 15 times in this session). Based on the minimal amount of data available, Wiglaf acquired [ç] at 1;10.28. As illustrated in Figure 112, he produced 24 out of 24 attempts correctly. Wiglaf did not attempt [ç] until age 1;09.02.

Figure 111: Wiglaf's acquisition of [x] in coda

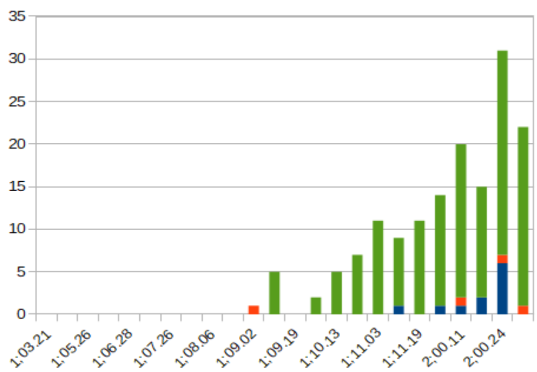
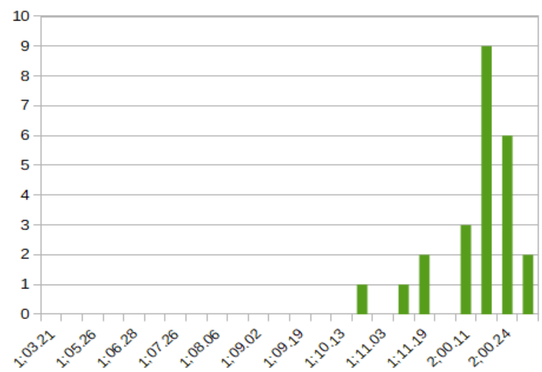


Figure 112: Wiglaf's acquisition of [ç] in coda



Wiglaf did not acquire the last fricative to be discussed, [ʃ] in coda, during the documented period. Wiglaf displayed a similar pattern to his acquisition of [ʃ] in singleton onsets: he made only six attempts, all of which resulted in substitution to [s].

Affricates

Wiglaf did not attempt any affricate sounds in coda position during his recorded sessions.

4.8. Nasals in coda position

Based on the available data, Wiglaf had acquired [ŋ] in coda by 1;11.13. He made only eight attempts in total, which all resulted in accurate productions.

4.9. Approximants in coda position

Wiglaf acquired [l] in coda at 1;09.19, with four accurate productions and two deletions, as shown in Figure 113. In earlier sessions, [l] looked acquired. However, in these sessions, all of the data produced came from the same two words, *heil* [ˈhaɪl̠] and *ball* [ˈbal̠], which appears to have overestimated his productive abilities. Once Wiglaf started attempting coda [l] in other words, his accuracy slipped below 50% consistently until 1;09.19, where he started maintaining productions with over 50% accuracy.

Figure 113: Wiglaf's acquisition of [l] in coda

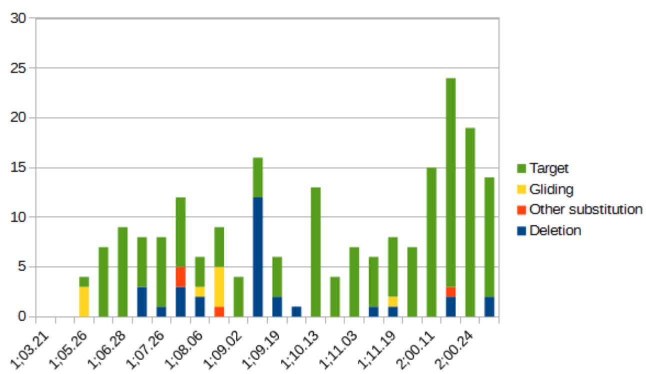
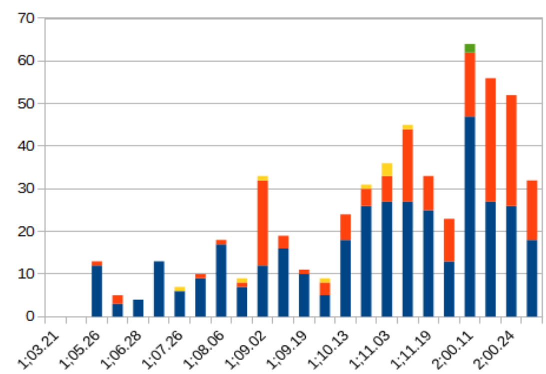


Figure 114: Wiglaf's acquisition of [ʀ] in coda



Wiglaf did not acquire [ʀ] in coda by the last documented session. As illustrated in Figure 114, in total, he made 547 attempts, which yielded 368 deletions. In terms of substitutions, Wiglaf most commonly produced [ʀ] as the vocalization [ɐ] (n=154). As discussed in Eleonora's section above, the vocalizations to [ɐ] may reflect allophonic variation: [ɐ] is a common and widespread allophone of post-vocalic [ʁ] (Wiese 1996). However, even with these vocalizations coded as correct productions, Wiglaf's deletion of [ʁ] remains too frequent and would prevent him from surpassing the 50% accuracy criterion across consecutive sessions.

4.10. Interim summary

At the beginning of his documented sessions, Wiglaf had not acquired any sounds in coda position. During the period covered by his recordings, Wiglaf acquired all coda sounds with the exceptions of [ʃ] and [ʁ], as summarized in Table 33.

Table 33: Wiglaf's coda development

	1;03.21	1;05.03	1;05.26	1;06.12	1;07.11	1;08.02	1;08.13	1;09.02	1;09.09	1;09.19	1;10.28	1;11.03	1;11.13	2;00.17	2;01.07	Not acquired
[p]	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[f]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[s]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	D	—	D/S	D	—	√	√	√	√	√	√	√	√	√	√	
[k]	—	—	—	S	—	D	—	√	√	√	√	√	√	√	√	
[x]	—	—	—	—	—	—	S	S	√	√	√	√	√	√	√	
[l]	—	—	S	T	D/T	D/T	S/T	D/T	D	√	√	√	√	√	√	
[ç]	—	—	—	—	—	—	—	—	—	—	√	√	√	√	√	
[ŋ]	—	—	—	—	—	—	—	—	—	—	—	—	√	√	√	
[ʃ]	—	—	—	—	—	—	S	—	—	—	S	—	—	—	S	X
[ʁ]	—	—	D	D/S	D	D	D	D/S	D	D	D	D	D/S	D/S	D/S	X
[p͡f]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

As discussed above in Chapter 2, section 8.2, German has syllable-final devoicing, which causes all syllable-final fricatives and stops to be realized as voiceless (Fox 2007). Similar to Eleonora discussed above, Wiglaf did not make voicing errors with voiceless stops and fricatives in coda position. Similar to Eleonora, this suggests that the unambiguous voiceless stops that occur syllable-finally are easier to master in comparison to the voicing contrast that must be reproduced in onset position.

Table 34 summarizes Wiglaf’s phonological development, including singleton onsets, onset clusters, and singleton codas.

Table 34: Summary of Wiglaf’s phonological development

1;03.21	1;05.03	1;05.26	1;06.12	1;07.11	1;08.02	1;08.13	1;09.02	1;09.09	1;09.19	1;10.28	1;11.03	1;11.13	2;00.17	2;01.07	Not acquired
ONSET															
[p]	[n]	[j] [m] [h]	[b]	[t]		[v]				[l]	[f]	[k] [g] [ʀ]	[d]	[ʦ]	[z] [ʃ] [ʧ] [p͡f]
ONSET CLUSTER															
										Fricative-rhotic	Stop-lateral	Fricative-lateral			Stop-glide Stop-rhotic Nasal-glide
CODA															
	[p] [f]		[s]		[t]		[k]	[x]	[l]	[ç]		[ŋ]			[ʃ] [ʀ] [p͡f]

In onset position, Wiglaf acquired bilabial and alveolar stops before fricatives, with the exception of the early-acquired [h]. He also generally acquired the voiceless member of cognate stops first, with [k] and [g] the exception as they were acquired at the same age. In both onset and coda positions, Wiglaf acquired laterals before rhotics, however consonant-rhotic onset clusters emerged before consonant-lateral clusters.

As already mentioned, Wiglaf and Eleonora followed a similar pattern of acquisition in several ways: the fricative [h] was acquired considerably earlier than all other fricatives; both children had difficulty with the voicing contrast for onset stops; both acquired a consonant-rhotic cluster before a consonant-lateral cluster (fricative-rhotic for Wiglaf, stop-rhotic for Eleonora); neither acquired [z], [ʃ], [ʧ], or [p͡f] in onset position; neither acquired [ʃ], [p͡f] (Wiglaf made no attempts), or [ʀ] in coda position, which suggests that these are later acquired sounds in the language. The two children also displayed many differences such as Wiglaf's late acquisition of [d] at 2;00.17 (his last stop acquired), as opposed to Eleonora's early acquisition of [d] at 1;02.07; and Eleonora's early acquisition of [k] at 1;06.05 and late acquisition of [g] at 1;08.06, compared to Wiglaf's simultaneous acquisition of both [k] and [g] at 1;11.13.

Next, I describe the phonological acquisition of French-learner Adrien.

5. Adrien

French-learning Adrien had only one phone, [m], acquired by the earliest documented session, at 1;11.14. As summarized in Table 35, by the end of the first two months of recordings (from age 1;11.14 to 2;01.13), Adrien had acquired an additional three sounds: the alveolar stops [t] and [d], and the nasal [n]. The table below represents his onset inventory only, as he did not acquire any coda consonants during that time.

Table 35: Adrien's early consonantal inventory

	Labial	Coronal-Labial	Coronal		Dorsal
			alveolar	alveopalatal	
Stops			t, d		
Fricatives					
Nasals	m		n		
Liquids					
Trill					
Glides					

In the sections below, I describe Adrien's onset, onset cluster, and coda consonant development. As with the other children's phonological acquisition detailed above, sounds are grouped into the larger phonological categories of obstruents, nasals, and approximants, and within each category, I list the descriptions in chronological order of acquisition. In general, Adrien made minimal production attempts before 2;00.16; however, the graphs below include all sessions to allow comparisons between all datasets.

5.1. Obstruents in onset position

Stops

Adrien acquired the alveolar stops [t] and [d] within one month of each other. As shown in Figure 115 and Figure 116, he acquired [t] in onset at 2;00.16, with five accurate productions, and [d] in onset at 2;01.13 with seven accurate productions. Adrien consistently maintained 50% production accuracy across his sessions with both sounds. A rise in voicing errors affecting [d] can be observed at 3;02.11, which yielded 42 accurate productions, 37 voicing errors, five deletions, and one other substitution. These voicing errors occurred primarily for the word *dessine* [desin] produced as *tessine*. However, Adrien pronounced this word with target [d] ten times in this session as well, suggesting variability with this word in particular.

Figure 115: Adrien's acquisition of [t] in onset

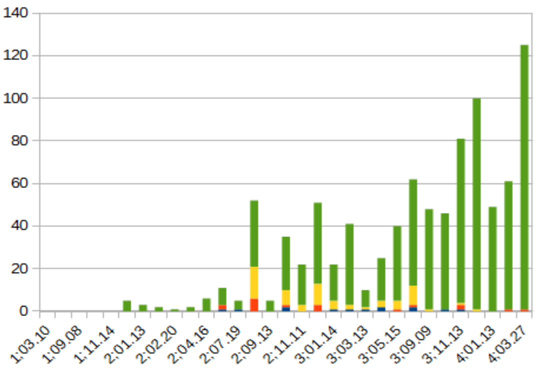
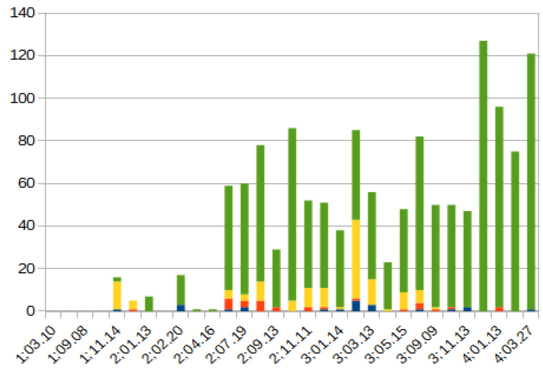


Figure 116: Adrien's acquisition of [d] in onset



Adrien acquired the bilabial stops [p] and [b] at the same age, as displayed in Figure 117 and Figure 118, respectively. He acquired [p] in onset at age 2;02.20, where he produced 39 accurate targets, one deletion, and two voicing errors, and [b] in onset at 2;02.20, with 14 accurate productions, one other substitution, and six deletions. In the few sessions prior to this, Adrien produced [p] as its voiced counterpart [b], whereas target [b] underwent deletion. Adrien continued to produce both sounds with greater than 50% accuracy in subsequent sessions.

Figure 117: Adrien's acquisition of [p] in onset

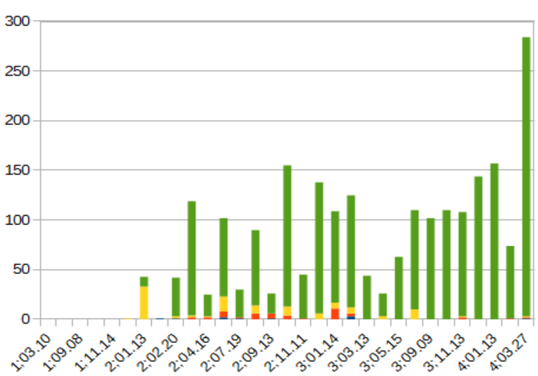
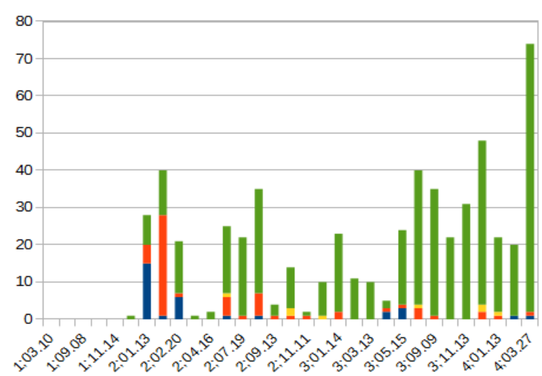


Figure 118: Adrien's acquisition of [b] in onset



Adrien acquired the velar stops [k] and [g] within two months of each other. As shown in Figure 119, he acquired [k] in onset at 2;05.23, with 12 accurate productions and six other substitutions, and he maintained a level of 50% accuracy across consecutive sessions. Before this, he primarily substituted [k] to [t] (e.g., *carton* [kaʁtɔ̃] as [taʁtɔ̃]). Similarly, after reaching the acquisition stage, Adrien still frequently substituted [t] for [k]. The most noticeable spike for this substitution occurred at age 2;02.20, with [k] produced as [t] 56 times during Adrien's first recorded attempts at *carton*, as Adrien produced [kaʁtɔ̃] as [tato]. We observe another spike in substitutions at 2;10.15, where 21 occurrences of [k] were substituted to [d]; most commonly, Adrien produced *comment* [komɑ̃] as [domɑ̃] 18 times in this session.

Figure 119: Adrien's acquisition of [k] in onset

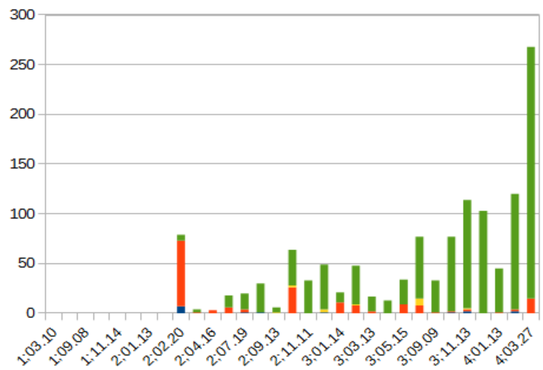
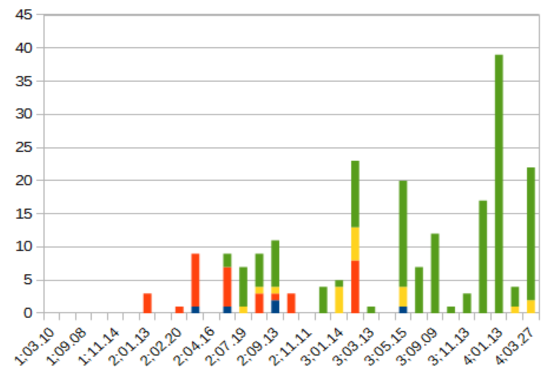


Figure 120: Adrien's acquisition of [g] in onset



Adrien acquired [g] in onset at 2;07.19, as illustrated in Figure 120, with five accurate productions and one voicing error. Prior to this, he commonly substituted to [t] and [d]. Variable errors occurred up until age 3;05.15 when [g] started to stabilize. The most common errors consisted of *gâteau* pronounced as [tato] and *gardé* [gaʁd] produced as [dad]. With the exception of the later occurring errors affecting *comment* ([komɑ̃] produced as [domɑ̃]), we observe that Adrien's errors for both [k] and [g] resulted from the process of consonant harmony, where the velar sounds adopted the coronal place feature from sounds that occurred elsewhere in the target word.

Fricatives

Adrien made minimal attempts at [v] and [f] until midway through the documented period. Adrien acquired [v] in onset at 2;02.20, as illustrated in Figure 121, with eight accurate productions and one other substitution. In the three sessions prior to this, Adrien did not attempt [v]. He acquired [f] in onset nearly nine months later, at 2;11.11, with three accurate productions and two other substitutions, as displayed in Figure 122. The other substitutions in this session (and most of the substitutions in the sessions preceding) consisted of substitutions to [t] and [d] for the phrase *c'est fermé* [sɛ fɛʁme], where consonant harmony again affected Adrien's productions. For example, in session 2;10.15, the [f] of *c'est fermé* was produced as [d] six times [di dame]; it however agreed with Adrien's [d] substitution for *c'est*. Adrien indeed had difficulty with *c'est* production in general, as discussed next.

Figure 121: Adrien's acquisition of [v] in onset

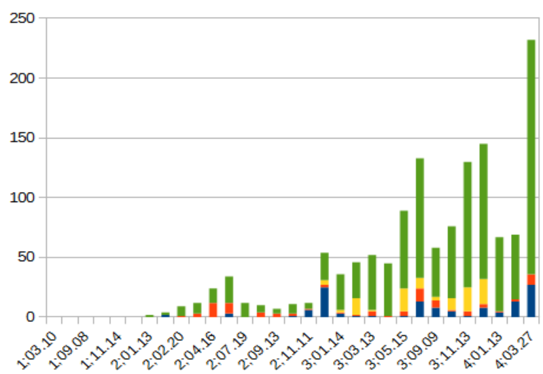
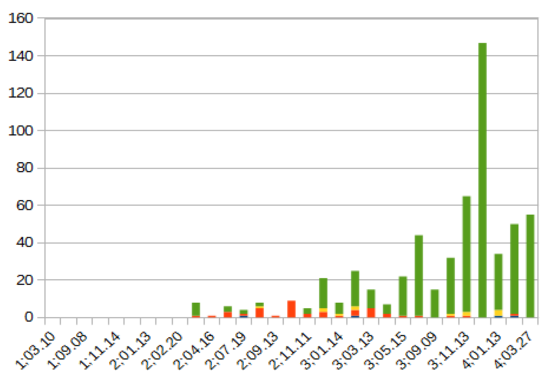
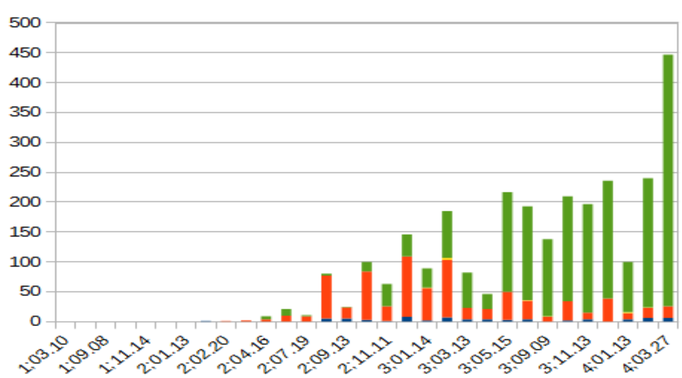


Figure 122: Adrien's acquisition of [f] in onset



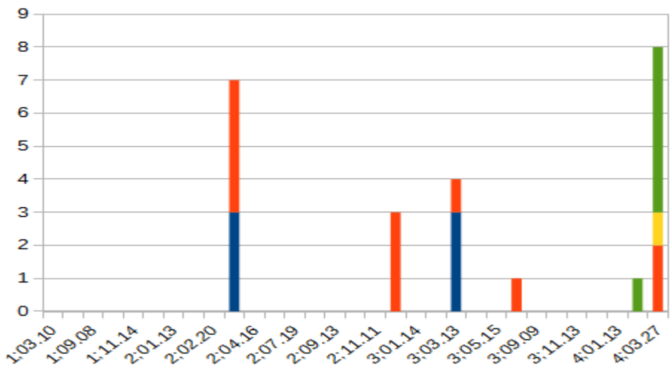
As shown in Figure 123, Adrien acquired [s] in onset at 3;03.13, with 59 accurate productions, 19 other substitutions, and four deletions. Before this, [s] frequently underwent substitution, most commonly to [t] (e.g., *c'est* [sɛ], *ça* [sa], *si* [si], *soeur* [sœʁ], *sucette* [sysɛt], *sait* [sɛ]), to [ɕ] (most frequently *ça*, also *c'est*), and to [d] (all for *c'est*). Adrien had difficulty in particular with [s] production for this form *c'est* [sɛ], which included [s] substitution to [t], [d], [ɕ], [j], and [ʒ], as well as deletion, all within individual sessions (e.g., 2;08.13). However, this may again reflect consonant harmony, as many of these productions for [s] assimilated to the place feature of the following word, or adopted the place feature that Adrien had substituted for other sounds within the word. For example, at 2;08.13, Adrien produced *c'est tombé* [sɛ tɔ̃be] as [de tome] where the [s] harmonized to the following [t], *c'est jaune* [sɛ ʒon] as [je jon] where the [s] became [j] in harmony with Adrien substituting [j] for [ʒ], *c'est fermé* [sɛ fɛʁme] as [te tɛme] where again the consonant harmony occurred for an incorrect substitution of [t] for [f] on the second word, and *c'est chaud* [sɛ ʃo] as [çe ço] where the [s] harmonized to match in place with the incorrect substitution again. While these examples illustrate consonant harmony, note that many of Adrien's production errors did not. For example, in the same session 2;08.13, Adrien produced *c'est vert* [sɛ vɛʁ] as [de va], *c'est papa* [sɛ papa] as [je papa] and [te papa], and *ça pue* [sa py] as [ta py]. While the [s] underwent substitution in all of these examples, it did not assimilate to the place of the following consonant.

Figure 123: Adrien's acquisition of [s] in onset



Adrien did not acquire the remainder of the fricatives to be discussed by the last recording available. Based on the minimal production attempts, he did not acquire [z] in onset. As displayed in Figure 124, Adrien made 24 attempts, which resulted in six accurate productions, five of which occurred in the last session (where it may have been emerging; however, more evidence is required). In the last session, Adrien made two substitutions to [d] (for *xylophone* [zilofɔn]), one voicing error to [s] (for *zorro* [zoʁo]), and five accurate productions (for *zed* [zɛd], *xylophone* [zilofɔn], and *zorro* [zoʁo]).

Figure 124: Adrien's acquisition of [z] in onset



As illustrated in Figure 125 and Figure 126, Adrien did not acquire [ʃ] or [ʒ] in onset by the latest documented session. [ʃ] most frequently underwent substitution to [s] and [t], whereas [ʒ] was substituted to [d], [z], and [j].

Figure 125: Adrien's acquisition of [ʃ] in onset

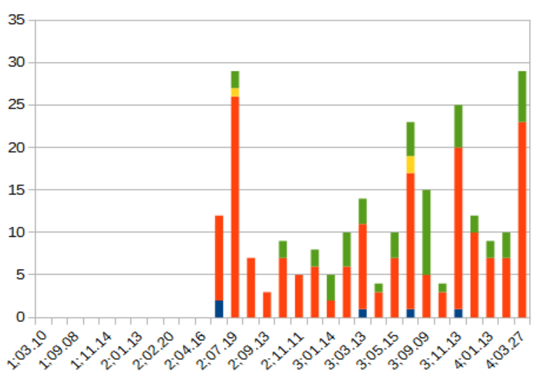
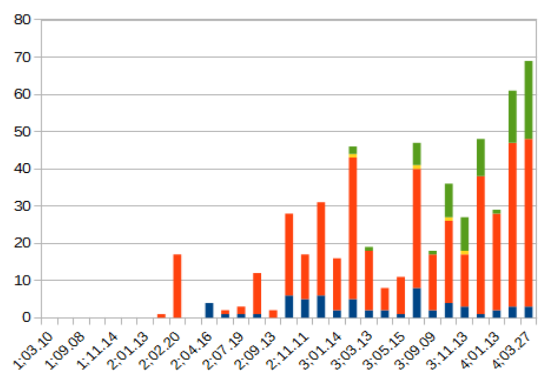


Figure 126: Adrien's acquisition of [ʒ] in onset



A wide range of other, more marginal substitutions also occurred for both sounds. While Adrien produced more accurate targets in the later sessions for both sounds, he did not reach the 50% criterion for either.

5.2. Nasals in onset position

As mentioned above, Adrien acquired [m] and [n] within the first two months of recordings. He had acquired [m] in onset by 1;11;14, with six accurate productions, as shown in Figure 127. We observe a spike in deletions at 2;01.13, which yielded seven deletions and only one accurate production. However, these deletions occurred solely for the word *merci* [mɛʁsi], which Adrien first attempted in this session.

Figure 127: Adrien's acquisition of [m] in onset

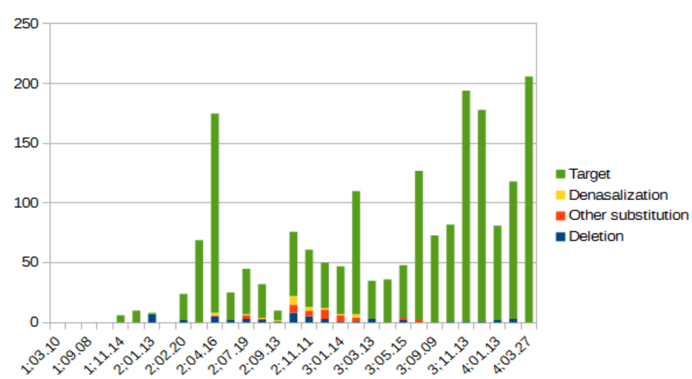
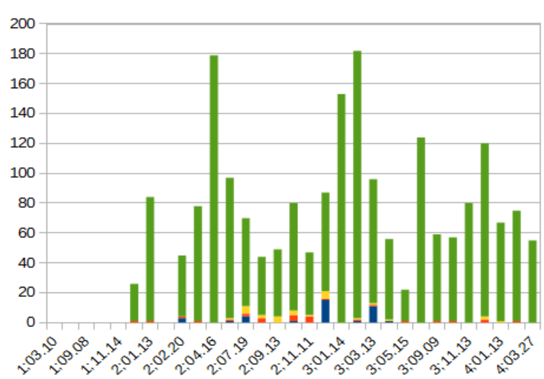


Figure 128: Adrien's acquisition of [n] in onset

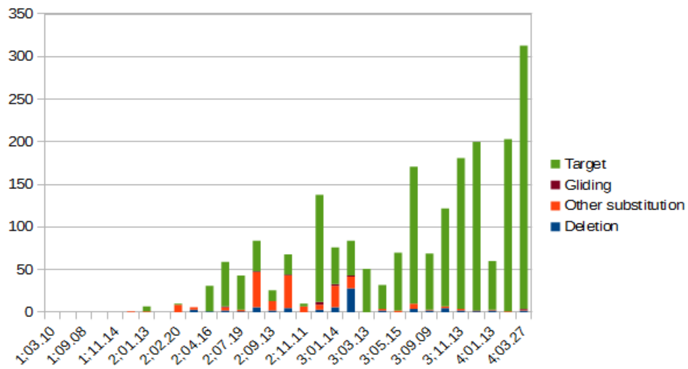


Adrien acquired [n] in onset next at 2;00.16, as illustrated in Figure 128, with 25 accurate productions and one substitution to [ɲ] (all of which occurred for *non* [nɔ̃]).

5.3. Approximants in onset position

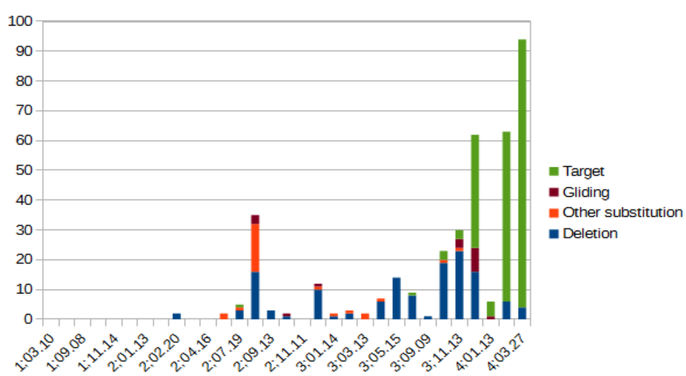
As displayed in Figure 129, Adrien acquired the lateral [l] in onset position at 2;04.16, with 30 accurate productions and one deletion. Prior to this, Adrien frequently substituted [l] to [p], specifically for the word *l̲apin* [lapɛ̃], which suggests place harmony with the word-medial [p].

Figure 129: Adrien's acquisition of [l] in onset



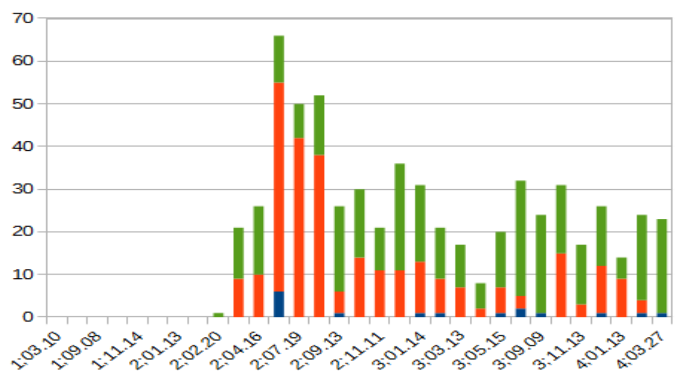
The uvular fricative [ʁ] was the last approximant acquired. Adrien acquired [ʁ] in onset at 4;00.16, where he made 38 accurate productions, eight glide substitutions, and 16 deletions, as shown in Figure 130. Even at this late age, Adrien produced [ʁ] variably, with [ʁ] deleted, glided, or produced accurately for the same word (e.g., *r̲egarde* [ʁ̲əgaʁd] was produced all three ways in session 4;00.16). Prior to acquisition, [ʁ] most frequently underwent deletion.

Figure 130: Adrien's acquisition of [ʁ] in onset



Adrien acquired [w] in onset at 2;09.13, as illustrated in Figure 131, with 20 accurate productions, five substitutions, and one deletion. The most common error consisted of 215 substitutions to [v]. The substitutions to [v] occurred for *oui* [wi] (with no observable interference from [v] elsewhere within the attempted forms, and often in single-word utterances). However, Adrien produced *oui* correctly in these sessions as well, suggesting he had difficulty producing this word.

Figure 131: Adrien's acquisition of [w] in onset



Adrien did not make many attempts at the other two glides. He may have acquired [j] in onset at 2;09.13, where he produced one accurate target, as shown in Figure 132. However, Adrien made only 12 attempts at this glide in total, which resulted in eight accurate productions and four deletions.

Figure 132: Adrien's acquisition of [j] in onset

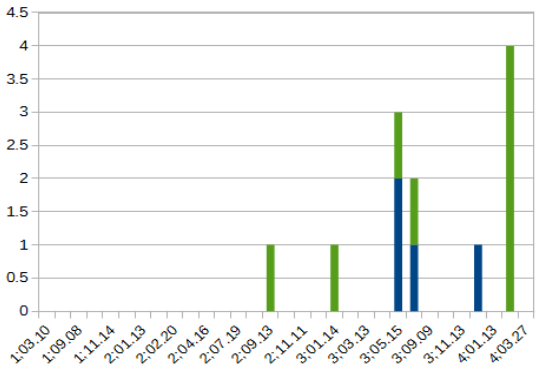
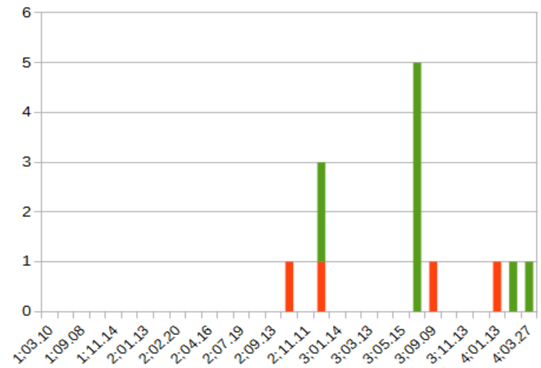


Figure 133: Adrien's acquisition of [ɥ] in onset



Based on the available evidence, Adrien acquired [ɥ] in onset at 3;00.16, with two accurate productions and one substitution to [w] (all for the word *h̲uit* [ɥ̲it]), as shown in Figure 133. The two substitutions at 3;09.09 and 4;01.13 consisted of substitution to [v] for the word *h̲uit* [ɥ̲it].

5.4. Interim summary

Starting with the sounds [m], [n], [t], and [d] at the beginning of his sessions, Adrien acquired all sounds in onset position by the end of the documented period, with the exception of the fricatives [z], [ʃ], and [ʒ]. As summarized in Table 36, Adrien acquired stops and nasals noticeably earlier than he acquired fricatives, with [v] the only fricative acquired during the same time frame as all of the stop sounds. Similarly, Adrien acquired glides in onset position after all stops. Finally, he also acquired the lateral [l] over a year and a half earlier than the rhotic uvular fricative [ʁ], which was the last sound Adrien acquired during the observation period.

Table 36: Adrien's onset development

	1;11.14	2;00.16	2;01.13	2;02.20	2;04.16	2;05.23	2;07.19	2;09.13	2;10.15	2;11.11	3;00.16	3;02.11	3;03.13	3;05.15	3;10.14	3;11.13	4;00.16	4;01.13	Not acquired
[m]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[n]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[d]	V	V	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[p]	—	V	V	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	—	T	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[v]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[l]	—	S	T	S	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[k]	—	—	—	S	S	√	√	√	√	√	√	√	√	√	√	√	√	√	
[g]	—	—	S	S	—	S	√	√	√	√	√	√	√	√	√	√	√	√	
[w]	—	—	—	T	S/T	S	S	√	√	√	√	√	√	√	√	√	√	√	
[j]	—	—	—	—	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
[f]	—	—	—	—	—	S/T	T	S	S	√	√	√	√	√	√	√	√	√	
[ɥ]	—	—	—	—	—	—	—	—	S	—	√	√	√	√	√	√	√	√	
[s]	—	—	—	S	S/T	S/T	S	S	S	S/T	S	S/T	√	√	√	√	√	√	
[ʁ]	—	—	—	D	—	S	D	D	D/S	—	D	D	S	D	D	D	√	√	
[z]	—	—	—	—	—	—	—	—	—	—	S	—	D	—	—	—	—	T	X
[ʃ]	—	—	—	—	—	S	S	S	S	S	S	S	S	S	S	S	S	S	X
[ʒ]	—	—	—	S	D	D/S	S	S	S	S	S	S	S	S	S	S	S	S	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

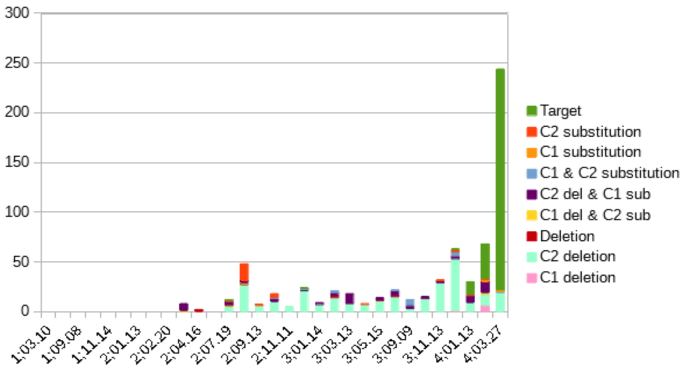
Adrien's productions frequently displayed the process of consonant harmony, more specifically place assimilation. As discussed above, [k], [g], [s], and [w] underwent place assimilation to sounds that occurred further along within the word or in the next phrase. [f] may have been affected by place assimilation; however, this remains unclear due to its frequent co-occurrence with [s] (which did undergo place assimilation).

I now move on to discuss Adrien's onset cluster development. I will compare his acquisition of singleton onsets to his acquisition of onset clusters below. As we will see, Adrien's acquisition of onset clusters did not correlate with the development of his singleton consonants.

5.5. Consonant clusters in onset position

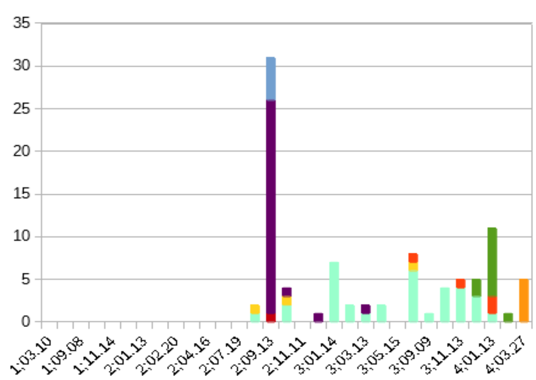
Adrien acquired stop-rhotic clusters at 4;01.13, as illustrated in Figure 134, with 13 accurate productions, one C2 substitution, seven C2 deletion & C1 substitutions, and nine C2 deletions. Prior to this, C2 deletion was the most common error across all stop-rhotic clusters; however, Adrien did not attempt this cluster type until 2;03.29. Specifically, Adrien acquired [kʁ] at 4;01.13: he produced [kʁ] accurately 100 times in total (out of 153 attempts), and all correct productions occurred in the last three sessions. He also acquired [gʁ] at 4;01.13, where he made 51 accurate productions in the last three sessions (out of 122 total attempts). Adrien acquired [pʁ] one month later, at 4;02.13, with [pʁ] reduced to [p] 40 times out of 78 attempts. He produced [pʁ] correctly 28 times in the last two sessions, where it reached the 50% accuracy criterion. He also acquired [tʁ] at 4;02.13, where he reduced [tʁ] to [t] 70 times, and produced [tʁ] correctly 92 times (all correct productions occurred in the last two sessions). Adrien did not acquire [bʁ] by the last recorded session, as he made only one correct production out of 18 attempts. He also did not acquire [dʁ], with only one correct attempt as well.

Figure 134: Adrien's acquisition of stop-rhotic onset clusters



Fricative-rhotic clusters, shown in Figure 135, consist of [fʁ] and [vʁ]. Adrien did not attempt any fricative-rhotic clusters before 2;09.13. He acquired the cluster [fʁ] at 4;01.13; however, [vʁ] does not appear to be acquired with only two accurate productions, attested at 4;00.16. The most common error consisted of [vʁ] reduction to [v]. Prior to acquisition, [fʁ] was most frequently reduced and substituted to [d], or reduced to [f]. Of the nine accurate productions of [fʁ] (out of 56 attempts in total), eight occur at 4;01.13, and one at 4;02.13.

Figure 135: Adrien's acquisition of fricative-rhotic onset clusters



Based on the available evidence recorded in the corpus, Adrien did not acquire stop-lateral and fricative-lateral clusters during the documented sessions, as displayed in Figure 136 and Figure 137, respectively.

Figure 136: Adrien's acquisition of stop-lateral onset clusters

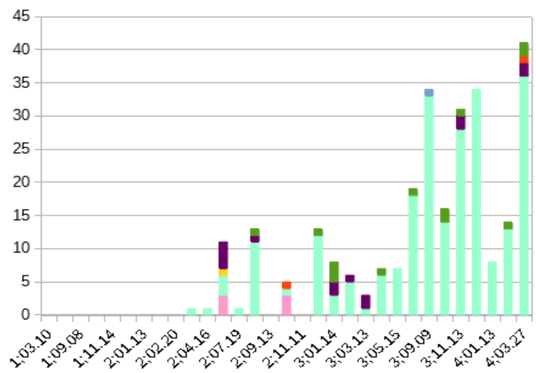
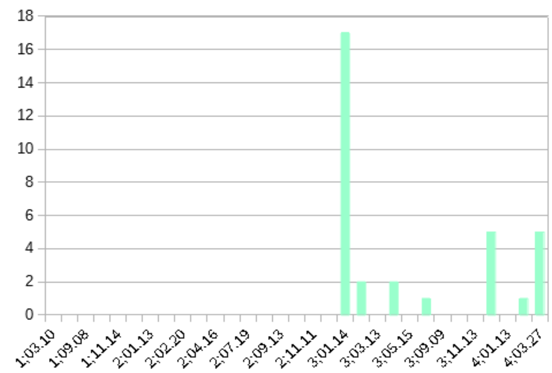


Figure 137: Adrien's acquisition of fricative-lateral onset clusters



The most frequent error for both onset clusters consisted of C2 deletion. Adrien did not attempt any stop-lateral clusters before 2;03.19, and he made minimal attempts at fricative-lateral clusters in general.

5.6. Interim summary

Adrien's onset cluster development is summarized in Table 37 below. Adrien acquired stop-rhotic and fricative-rhotic clusters at 4;01.13. He did not acquire stop-lateral or fricative-lateral clusters. His acquisition of clusters did not parallel his acquisition of laterals and rhotics: he acquired [l] at 2;04.16, and [ʁ] much later at 4;00.16; however, he did not acquire any lateral clusters despite acquiring both rhotic clusters. Adrien also acquired all singleton stops before singleton fricatives (with the exception of [v]), however, this does not appear to have influenced his onset cluster development with stop-rhotic and fricative-rhotic clusters acquired at the same age.

Table 37: Adrien's onset cluster development

	1;11.14	2;00.16	2;01.13	2;02.20	2;04.16	2;05.23	2;07.19	2;09.13	2;10.15	2;11.11	3;00.16	3;02.11	3;03.13	3;05.15	3;10.14	3;11.13	4;00.16	4;01.13	Not acquired
Stop-rhotic	—	—	—	—	D	—	D/ D+ S	R	R	R	R	R	R/D +S	R	R	R	R	√	
Fricative-rhotic	—	—	—	—	—	—	—	D+ S	R/D +S	—	D+ S	R	R/D +S	—	R	R	R	√	
Stop-lateral	—	—	—	—	R	R/D +S	R	—	R	—	R	R	D+ S	R	R	R	R	R	X
Fricative-lateral	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—	—	R	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

I now move to discuss Adrien's singleton coda development. In line with the descriptions above for onset development, I have grouped coda consonants into structurally similar stop, fricative, and approximant categories, the latter including the uvular [ʁ]. As we will see, a different pattern emerges in Adrien's singleton coda development when compared to his singleton onset development.

5.7. Obstruents in coda position

Stops

As shown in Figure 138, Adrien acquired [t] in coda at 2;04.16, with two accurate productions. However, Adrien did not attempt coda [t] in previous recordings, and thus may have acquired [t] earlier. A noticeable spike in deletions occurred at 3;00.16, which resulted in seven deletions and no accurate productions. The deletions occurred for the phrases *autre côté* [ot̲ kote] and *petite roue* [pətit̲ ʁu]; it is unclear as to why Adrien had difficulty with coda [t] in these particular phrases in this session, as he had produced coda [t] in phrases with a similar phonetic environment (i.e., coda [t] followed by a consonant in the next word) in previous sessions.

Figure 138: Adrien's acquisition of [t] in coda

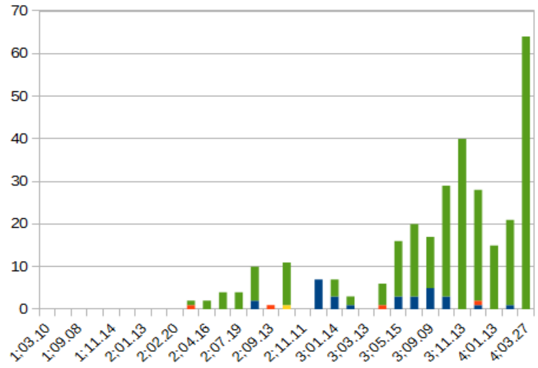
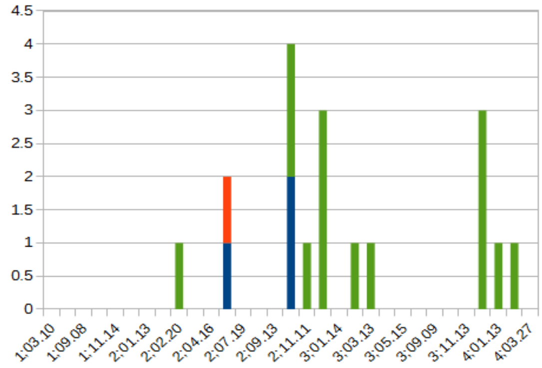


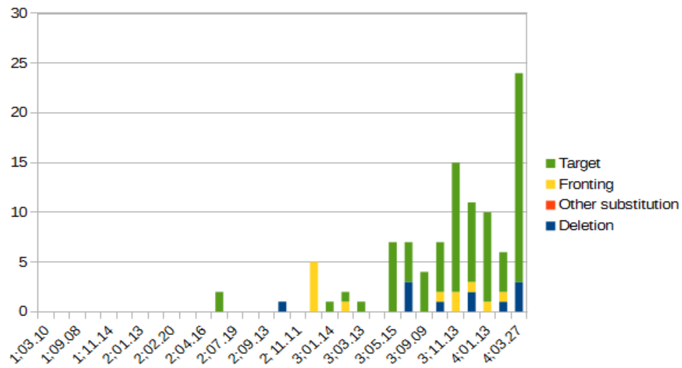
Figure 139: Adrien's acquisition of [p] in coda



Based on the minimal available evidence, Adrien acquired [p] in coda six months later, at 2;10.15, where he produced two accurate targets and two deletions, as displayed in Figure 139. Prior to this, only three attempts were recorded. Overall, Adrien attempted coda [p] only 18 times in total, which resulted in 14 accurate productions, one other substitution to [t], and three deletions.

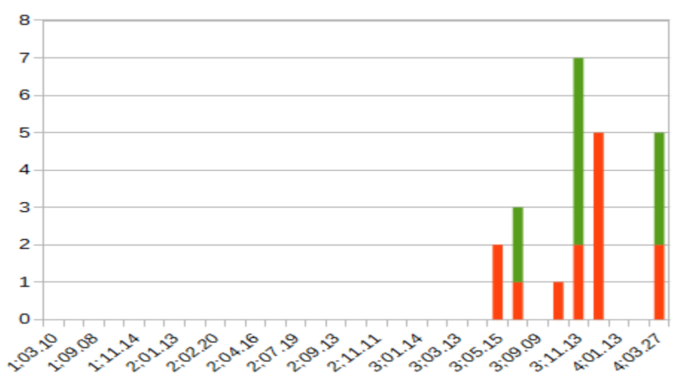
Adrien acquired [k] in coda next, at 3;05.15, as illustrated in Figure 140, with seven accurate productions. Prior to this, he made infrequent attempts at [k], resulting in both fronting to [t] and accurate productions. The deletions that occurred for coda [k] after 2;05.15 displayed inconsistencies within the same record, for the same word. For example, Adrien produced *avec* [avɛk] at 3;08.06 with both accurate coda [k] and with [k] deleted. The deletions occurred in various phonetic environments, when the coda was both followed by a vowel or by a consonant. However, Adrien did not appear to display a phonological deletion process (as opposed to William described in section 2 of this chapter above) as he did not delete coda consonants frequently or predictably.

Figure 140: Adrien's acquisition of [k] in coda



Based on the minimal recorded evidence available for both sounds, Adrien had not acquired [d] or [b] in coda position by the last session at 4;03.27. He did not acquire [d], as shown in Figure 141, with 23 total attempts that resulted in 10 accurate productions (for *demande* [dəmɑ̃d], *commande* [komɑ̃d]), two substitutions to [m] (for *commande* [komɑ̃d]), and 11 substitutions to [n] (for *grande* [gʁɑ̃d], *commande* [komɑ̃d]). The substitutions to [m] and [n] suggest that the presence of preceding nasals affected Adrien's production of coda [d].

Figure 141: Adrien's acquisition of [d] in coda



Lastly, there was not enough evidence to establish the acquisition of [b] in coda position. Adrien made only seven attempts in total, which resulted in four accurate productions (*tombe* [tɔ̃b] three times, and *cubes* [kyb] once) and three substitutions to [m] (for *tombe* [tɔ̃b] as [tɔ̃m]).

Fricatives

Based on the available evidence, Adrien had acquired [f] in coda by 3;00.16, where he made two accurate productions. He did not attempt [f] before 3;00.16. Adrien made no incorrect productions of [f] in coda position, as he accurately produced a variety of words such as *kof* [kɔf], *patapouf* [patapuf], *pouf* [puf], *neuf* [nœf], and *oeuf* [œf].

Adrien acquired [s] in coda at 3;05.15, with three accurate productions and one deletion, as shown in Figure 142. Prior to this, he made minimal attempts at this phonological context, which resulted in a mix of deletions, substitutions (most commonly to [t]), and some accurate productions. Based on the available evidence, Adrien acquired [z] in coda six months later, at 3;11.13, as illustrated in Figure 143, with two accurate productions. In total, he made 23 attempts, resulting in 11 accurate productions. Prior to acquisition, [z] underwent deletion or substitution to a variety of sounds.

Figure 142: Adrien's acquisition of [s] in coda

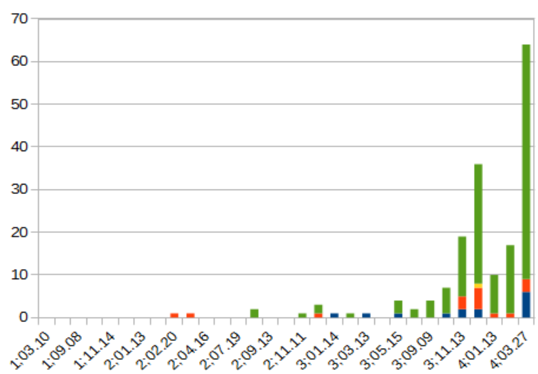
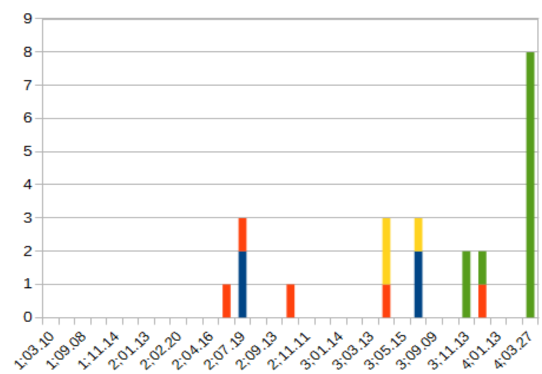
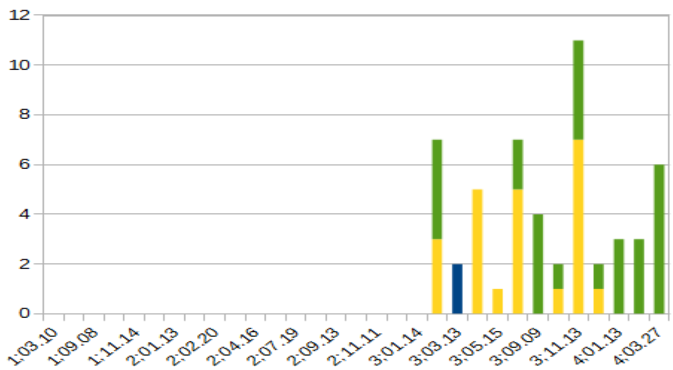


Figure 143: Adrien's acquisition of [z] in coda



As displayed in Figure 144, based on minimal attempts, Adrien also acquired [v] in coda at 4;01.13, where he produced three accurate targets; this session marks where previous voicing errors resolved. Adrien did not attempt [v] in coda until 3;02.11 and frequently produced it as its voiceless counterpart [f] until acquisition at 4;01.13. Adrien's difficulty with mastering the voicing contrast appears specific to [v] in coda and did not affect other sounds.

Figure 144: Adrien's acquisition of [v] in coda



Adrien did not acquire [ʃ] or [ʒ] in coda by the latest session available (4;03.27). He made minimal attempts at words containing either sound, which resulted in a scarcity of recorded data for analysis.

Figure 145: Adrien's acquisition of [ʃ] in coda

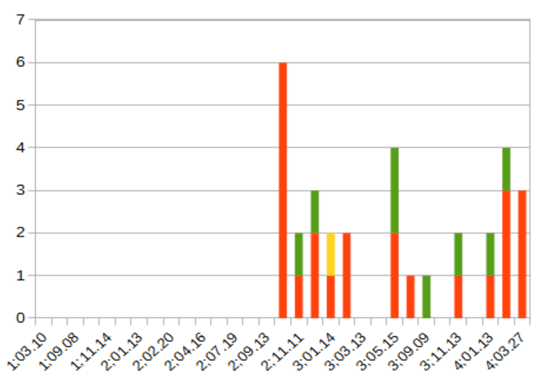
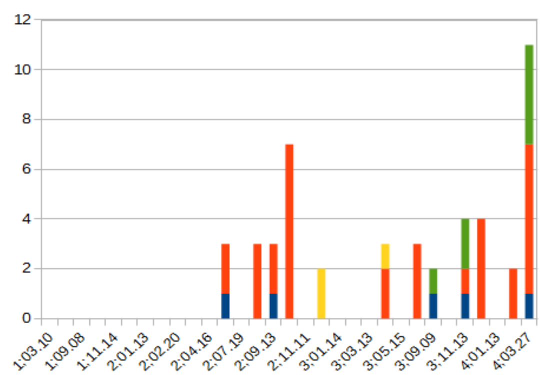


Figure 146: Adrien's acquisition of [ʒ] in coda

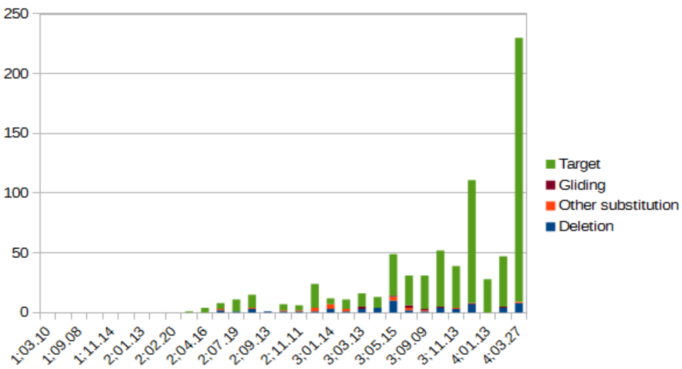


As illustrated in Figure 145 and Figure 146, he most frequently substituted [ʃ] to [s] and [ʒ] to [z]. While Adrien maintained a voicing distinction between the two sounds, he produced both with the wrong place of articulation, similar to his error pattern in syllable onsets.

5.8. Approximants in coda position

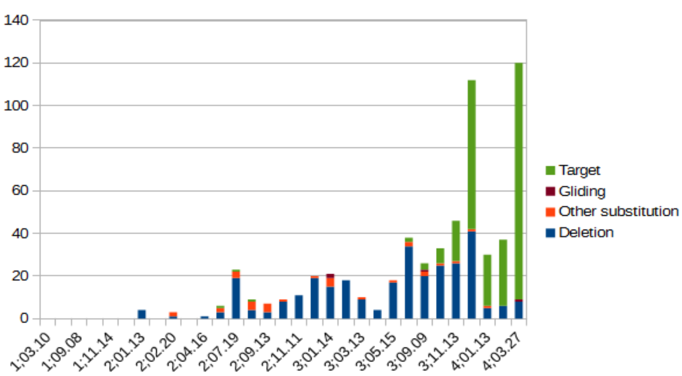
Adrien acquired the approximant [l] in coda position at 2;04.16, with four accurate productions, as shown in Figure 147. This also marks where Adrien began to produce [l] more frequently, and his productions increased in number in subsequent sessions.

Figure 147: Adrien's acquisition of [l] in coda



As displayed in Figure 148, Adrien acquired [ʁ] in coda over one and a half years later, at 4;00.16, where he produced 70 accurate targets, one substitution, and 41 deletions. Overall, [ʁ] most frequently underwent deletion: across his 606 attempts, Adrien produced 270 accurately, while 301 underwent deletion. This deletion pattern in coda position was specific to [ʁ].

Figure 148: Adrien's acquisition of [ʁ] in coda



Adrien showed inconsistency in producing coda [ʁ] up to, and including, the last session. For example, in the last session, the [ʁ] of *pour* [puʁ̲] underwent deletion four times, while Adrien produced this word correctly 32 times. Various other words displayed inconsistency across the recorded sessions as well. For example, at 4;00.16, Adrien produced *faire* [fɛʁ̲], *pour* [puʁ̲], *sur* [syʁ̲], *encore* [ɑ̃kɔʁ̲], *voiture* [vwatyʁ̲], *abord* [abɔʁ̲], and others, both correctly and with [ʁ] deleted, with no observable pattern.

5.9. Interim summary

At the beginning of his documented sessions, Adrien had no sounds acquired in coda position. By the end of his sessions, Adrien had acquired all sounds in coda position with the exception of [ʃ], [ʒ], [b], [d], and [g], as summarized in Table 38 below. In general, in coda position, Adrien acquired voiceless stops and fricatives before voiced ones, and he acquired [l] earlier than [ʁ].

Table 38: Adrien's coda development

	1;11.14	2;00.16	2;01.13	2;02.20	2;04.16	2;05.23	2;07.19	2;09.13	2;10.15	2;11.11	3;00.16	3;02.11	3;03.13	3;05.15	3;10.14	3;11.13	4;00.16	4;01.13	Not acquired
[t]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[l]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[p]	—	—	—	T	—	D/S	—	—	√	√	√	√	√	√	√	√	√	√	
[f]	—	—	—	—	—	—	—	—	—	—	√	√	√	√	√	√	√	√	
[k]	—	—	—	—	—	T	—	—	D	—	S	D/S	T	√	√	√	√	√	
[s]	—	—	—	S	—	—		—	—	T	S/T	T	D	√	√	√	√	√	
[z]	—	—	—	—	—	S	D	—	S	—	—	—	—	—	—	√	√	√	
[ʁ]	—	—	D	S	D	D/S	D	D/S	D	D	D	D	D	D	D	D	√	√	
[v]	—	—	—	—	—	—	—	—	—	—	—	V/T	D	V	V/T	V	V/T	√	
[d]	—	—	—	—	—	—	—	—	—	—	—	—	—	S	S	S/T	S	—	X
[ʃ]	—	—	—	—	—	—	—	—	S	S/T	S	S	—	S/T	—	S/T	—	S/T	X
[ʒ]	—	—	—	—	—	S	—	S	S	—	V	—	—	—	—	T	S	—	X
[b]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	T	S	—	X
[g]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	S/T	—	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

As we can observe in Table 39, a different pattern emerged in Adrien's acquisition of singleton codas when compared to his acquisition of singleton onsets. Adrien did not acquire coda stops before coda fricatives as he did with onsets; this is especially noticeable as he did not acquire the stops [b], [d], and [g] by the end of his sessions.

Table 39: Summary of Adrien's phonological development

1;11.14	2;00.16	2;01.13	2;02.20	2;04.16	2;05.23	2;07.19	2;09.13	2;10.15	2;11.11	3;00.16	3;02.11	3;03.13	3;05.15	3;10.14	3;11.13	4;00.16	4;01.13	Not acquired
ONSET																		
[m]	[n] [t]	[d]	[p] [b] [v]	[l]	[k]	[g]	[j] [w]		[f]	[ɥ]		[s]				[ʁ]		[z] [ʃ] [ʒ]
ONSET CLUSTER																		
																	Stop-rhotic Fricative-rhotic	Stop-lateral Fricative-lateral
CODA																		
			[t] [l]					[p]		[f]			[k] [s]		[z]	[ʁ]	[v]	[b] [d] [g] [ʃ] [ʒ]

However, Adrien acquired voiceless members of both fricatives and stops first in coda position; he acquired voiceless [t], [p], [f], [k], [s], before any voiced obstruent sounds. This pattern did not emerge in his development of onset consonants, where Adrien acquired both voiced and voiceless stops at similar ages. Additionally, in parallel to his acquisition of [l] and [ʁ] in onset position, Adrien acquired coda [l] over a year and a half earlier than he acquired coda [ʁ], with both sounds emerging a month earlier in coda position when compared to onset position.

I now move on to discuss Inês, a learner of European Portuguese.

6. Inês

At the beginning of the data collection period, Inês, a learner of European Portuguese, had only one consonant firmly established in her phonological productive inventory, the bilabial nasal [m].

In the first two months of recordings, from 0;11.14 to 1;01.30, she acquired three additional sounds, [d], [p], and [n], as summarized in Table 40.

Table 40: Inês's early consonantal inventory

	Labial	Coronal		Dorsal
		alveolar	alveopalatal	
Stops	p	d		
Fricatives				
Nasals	m	n		
Laterals				
Rhotics				

In the sections that follow, I describe Inês's phonological development (for additional discussion, see Burkinshaw 2014; Rose 2014). In line with the case studies detailed above, sounds are grouped into larger manner categories and then arranged according to their chronological order of acquisition.

As discussed with French speaker Adrien above, I include the uvular fricative rhotic [ʁ] under the broad approximant category, on the grounds that uvular fricatives pattern phonologically similar to liquids (Mateus & d'Andrade 2000: 28). Portuguese, however, adds an extra element to liquid development, as it displays two rhotic consonants in its consonantal inventory, and these rhotics differ both in their phonetic nature and distribution. The alveolar flap [ɾ] (produced with the tongue tip briefly making contact with the alveolar ridge) occurs in non-initial singleton onsets, syllable codas, and branching onsets, while the uvular fricative rhotic [ʁ] occurs in singleton onset position (both word-initial and -medial) (Mateus & d'Andrade 2000).

Additionally, European Portuguese allows the voiced stops /b, d, ɡ/ to be produced as the fricatives /β, ð, ɣ/ in most syllable positions (Mateus & d'Andrade 2000). Consonant codas are also subject to the *sandhi* phenomenon whereby word-final [ʃ/ʒ] are treated as part of the next word in connected speech contexts: if the following word begins with a voiceless sound then the final fricative is produced as voiceless [s/ʃ]; if the following word begins with a voiced sound then the final fricative is also voiced [z/ʒ]; lastly, if the following word begins with a vowel, the final consonant surfaces as intervocalic [z] (Mateus & d'Andrade 2000). This phenomenon will be observed in the discussion of Inês's coda consonants below.

I begin with Inês's singleton onset development, starting with her acquisition of obstruent consonants.

6.1. Obstruents in onset position

Stops

As previously mentioned, Inês acquired onset [d] and [p] within her first two months of recordings. She acquired [d] at 1;00.25, with 15 accurate productions, one voicing error, and one substitution, as shown in Figure 149. Inês acquired [p] one month later, at 1;01.30, with six accurate productions and two voicing errors, as displayed in Figure 150. Inês maintained over 50% accuracy for both sounds in subsequent sessions.

Figure 149: Inês's acquisition of [d] in onset

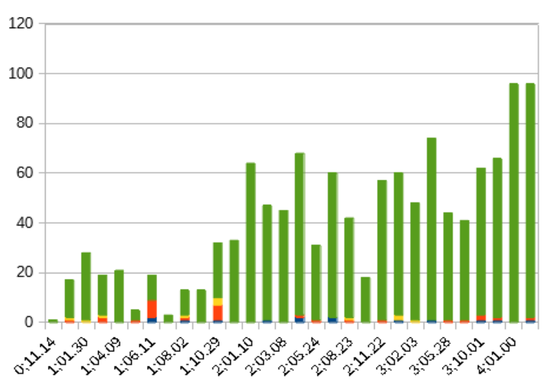
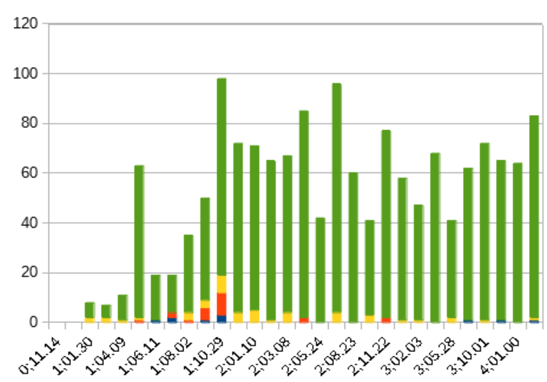


Figure 150: Inês's acquisition of [p] in onset



As illustrated in Figure 151 and Figure 152, Inês acquired [t] and [k] in onset at 1;03.06. She acquired [t] with four accurate productions and one voicing error at 1;03.06, and she maintained a level of 50% accuracy in consecutive sessions, with the exception of 1;08.02. Inês also acquired [k] in onset at 1;03.06, with 11 accurate productions and two other substitutions. Coming back to [t], we note a rise in substitutions at age 1;08.02, which yielded 12 accurate productions, one voicing error, and 17 other substitutions. All of the substitutions at 1;08.02, however, resulted from consonant harmony: the substitutions consisted of six instances of [t] produced as [k] (all for the word *t̲alco* [t̲aɫku]), one instance of [t] substituted to [g] (also for the word *t̲alco*), and 10 instances of [t] substituted to [p] (all for the word *t̲ampa* [ˈt̲ɐ̃pɐ]).

Figure 151: Inês's acquisition of [t] in onset

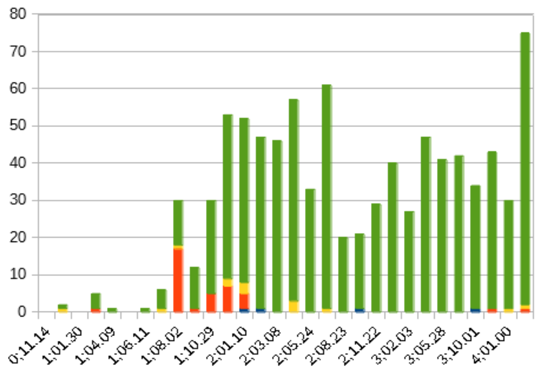
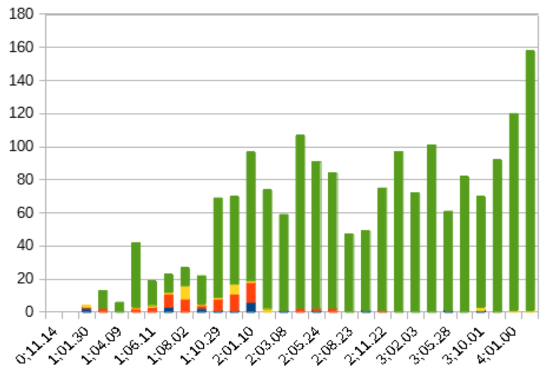
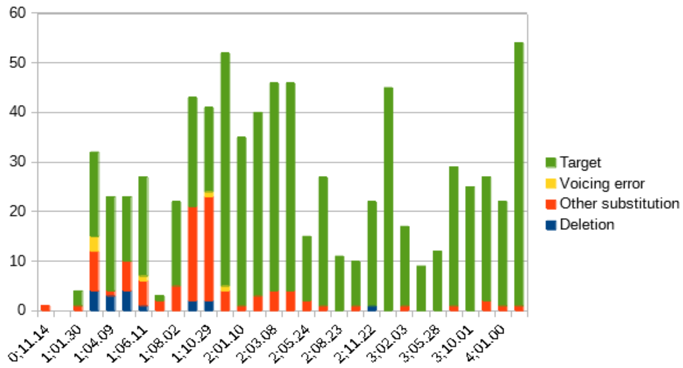


Figure 152: Inês's acquisition of [k] in onset



Inês acquired [b] in onset at 1;04.09, as illustrated in Figure 153, with three deletions, one other substitution, and 19 accurate productions. She continued to produce [b] with greater than 50% accuracy over subsequent sessions. Prior to 1;04.09, attempts at [b] resulted in a mix of accurate productions and variable substitutions.

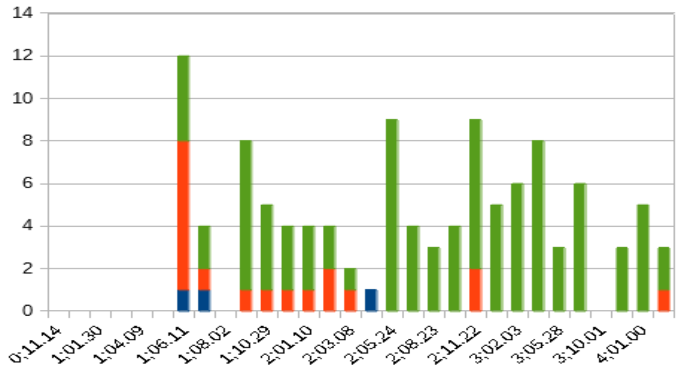
Figure 153: Inês's acquisition of [b] in onset



A spike in substitutions for [b] occurred at 1;09.19, when 19 substitutions and 22 accurate productions were recorded. During this session, Inês produced [b] as [m] for the word *b̲onecas* [b̲u ˈnɛkɐʃ] 14 times. This suggests nasal assimilation as target [b] was produced as the bilabial nasal [m]. In this session, Inês also produced [b] as [β] once for *b̲óia* [ˈb̲ɔjɐ], three times for *b̲oneca* [b̲u ˈnɛkɐ], and once for the word *b̲anho* [ˈb̲ɐɲu]; however, [β] is an acceptable allophone of [b] in Portuguese as mentioned above. [b] also underwent deletion twice for *b̲oneca*. Another rise in substitutions occurred at 1;10.29. Inês again substituted [b] to [m] 19 times for the word *b̲oneca* and once for *b̲anana*. The pronunciation of *b̲oneca* stabilized in the next session, 2;00.11, as Inês produced nine target *b̲onecas* and one target *b̲anana* [b̲ɐˈnɐnɐ] correctly. This provides evidence that nasal assimilation resolved after 2;00.11.

As illustrated in Figure 154, Inês acquired [g] in onset at 1;09.19, with seven accurate productions and one other substitution.

Figure 154: Inês's acquisition of [g] in onset



During the two preceding sessions, her attempts at [g] resulted in a mix of accurate productions, substitutions, and a few deletions.

Fricatives

Stopping, the phonological process of substituting target fricatives with stops, severely affected the acquisition of Inês's fricatives. In the data below, Inês displayed the stopping of fricatives up to age 2;07.16 for some fricatives, and to age 2;11.22 for others.

While Inês had acquired labial stops by her earliest documented session as described above, we observe that she did not stop labial [f/v] to labial [p/b], but instead produced them with the wrong place of articulation (as alveolar [t/d]) until age 2;01 (Burkinshaw 2014). After 2;01, she produced fricative targets with the right place of articulation but continued to stop them. Inês then acquired the fricatives at different ages based on their place of articulation. At 2;03.08 six substitutions to [t] (for *faz* [ˈf̲aʃ]→[ˈt̲ɐ], *favor* [f̲ɐˈvoɾ]→[t̲ɐˈdɔli], *fotografia* [f̲utugɾɐˈfiɐ]→ [t̲utɨˈtʲiɐ]) and eight substitutions to [p] occurred (for *fazer* [f̲ɐˈzeɾ]→[p̲ɨˈdelɨ], *feliz* [f̲ɨˈliz]→ [p̲i ˈlid], *fazia* [f̲ɐˈziɐ]→[p̲ɐˈdiɐ], *fita* [ˈf̲itɐ]→[ˈp̲itʲɐ], *fica* [ˈf̲ikɐ]→[ˈp̲ikɐ]). Two substitutions to [b] also occurred for *faz* [ˈf̲aʃ]→[ˈb̲a].

Inês acquired both labiodental fricatives at 2;07.16. As shown in Figure 155, she acquired [f] with 27 accurate productions and five other substitutions (all substitutions to [p] for words produced correctly elsewhere in the session).

Figure 155: Inês's acquisition of [f] in onset

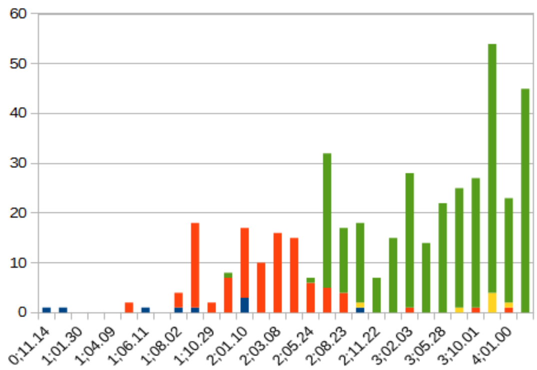
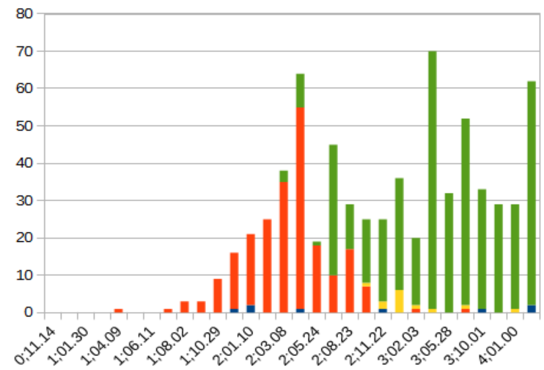


Figure 156: Inês's acquisition of [v] in onset



Inês also acquired [v] in onset at 2;07.16, as illustrated in Figure 156. She produced 35 targets and 10 other substitutions (all [b] for *vamos* [ˈvɐmuʃ]→[ˈbɐwmʃ], *vai* [ˈvaj]→[ˈbaj], and *vou* [ˈvo]→[ˈbo]; Inês produced these words with target [v] in this session as well). Before this session, Inês most commonly substituted [v] to the stop [b] 79 times and to [d] 71 times. While both of these stops occurred frequently, they appeared at distinctly different ages: at 2;03.08, [d] errors ended and [b] errors emerged. This marks the point where Inês persisted in stopping fricatives, but started to produce them with the accurate place of articulation (Burkinshaw 2014; Rose 2014: 49).

Inês acquired [s] in onset at 2;10.20, as displayed in Figure 157, with 11 accurate productions and four other substitutions. Prior to this, Inês most frequently stopped [s] to [t]. Out of the 225 substitutions to [t], 215 of these occurred before acquisition at 2;10.20. At 2;07.17, the age at which Inês acquired [f] and [v], she began to produce [s] with greater accuracy. While the stopping of [f] and [v] in onset resolved at 2;07.17 as described above, [s] and the remaining fricatives did not reach a level of 50% accuracy until four months later. [z] in onset, as illustrated in Figure 158, was not acquired until the process of stopping had already resolved. Therefore, I can make no claims regarding stopping and [z] in onset position. Based on the minimal evidence available, Inês acquired [z] at 2;11.22, with 10 accurate productions, four other substitutions, and one deletion. Prior to acquisition, Inês attempted [z] five times, which resulted primarily in substitution.

Figure 157: Inês's acquisition of [s] in onset

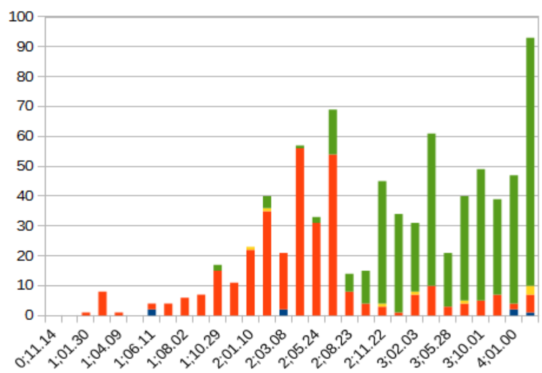
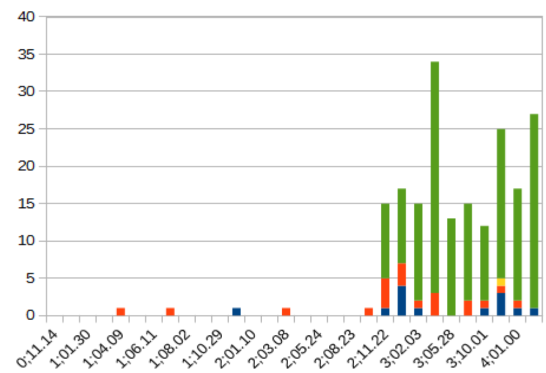


Figure 158: Inês's acquisition of [z] in onset



Inês acquired [ʃ] and [ʒ] in onset at 2;11.22, as shown in Figure 159 and Figure 160, respectively. As with Inês's other fricatives, [ʃ/ʒ] underwent stopping, and surfaced as [t/d] prior to acquisition. In total, Inês made 164 attempts at [ʃ], which resulted in 69 produced accurately, 61 substitutions to [t], and other, more variable substitutions. All 61 of the [t] substitutions occurred prior to the date of acquisition at 2;11.22.

Figure 159: Inês's acquisition of [ʃ] in onset

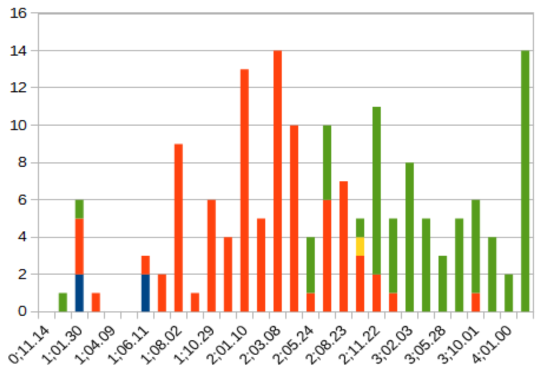
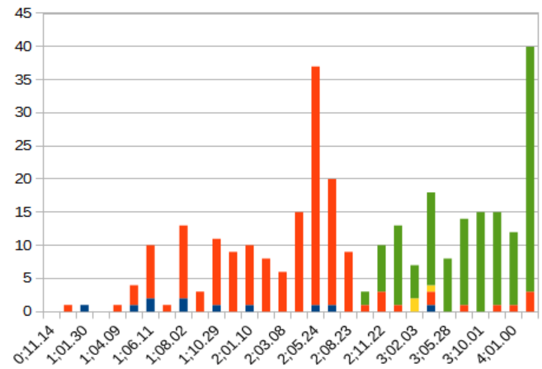


Figure 160: Inês's acquisition of [ʒ] in onset



[ʒ] in onset was also acquired at 2;11.22, with seven accurate productions and three other substitutions. Prior to this, the most common error consisted of 115 substitutions to [d].

6.2. Nasals in onset position

As mentioned above, Inês acquired [m] and [n] within the first two months of recordings. She had acquired [m] in onset by the earliest session, 0;11.14, with 12 accurate productions, as shown in Figure 161.

Figure 161: Inês's acquisition of [m] in onset

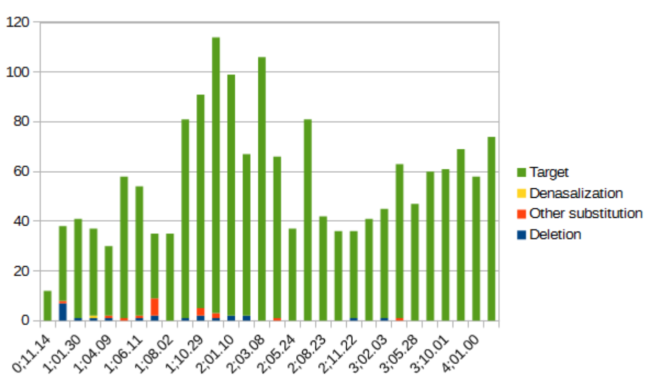
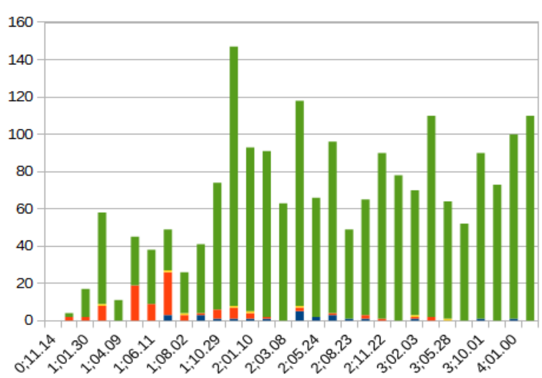


Figure 162: Inês's acquisition of [n] in onset



As displayed in Figure 162, Inês acquired [n] in onset two months later, at 1;01.30, with 15 accurate productions and two other substitutions. In the one session where [n] occurred prior to this, Inês both substituted [n] with [ɲ] and produced it correctly. Two noticeable substitution spikes occurred at 1;05.11 and at 1;07.02. In both cases, all but two cases of substitution involve production of *n̲ão* [ˈn̲ɐ̃w̃] with an initial palatal [ɲ].[8]

6.3. Approximants in onset position

Inês acquired laterals in onset position at 2;01.10, with 30 accurate productions, five substitutions, and four deletions, as shown in Figure 163. Prior to this, [l] frequently underwent substitution to [d] or deletion. [l] also underwent substitution to [ɾ]. However, this substitution primarily occurred in the last three sessions, in both single words and phrases, in what appears to be a random pattern.

Figure 163: Inês's acquisition of [l] in onset

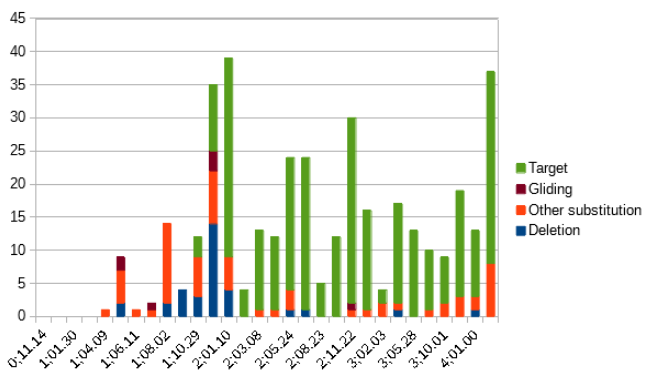
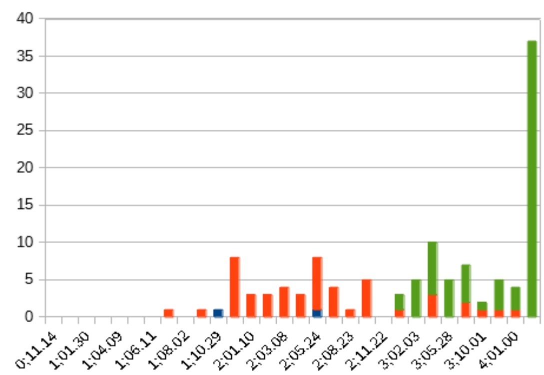


Figure 164: Inês's acquisition of [ʀ] in onset



As illustrated in Figure 164, there is a scarcity of attempts at [ʀ] before the final documented session. Based on the available evidence, Inês acquired [ʀ] in onset at 3;00.15, with two accurate productions and one other substitution. Prior to acquisition, [ʀ] most frequently

8 Inês produced 26 accurate productions (all "n̲ão" [ˈn̲ɐ̃w̃], not said in a repetitive utterance) and 19 substitutions to [ɲ] (all for "n̲ão" [ˈn̲ɐ̃w̃], with all but five said in a two-to-four word repetitive string of "n̲ão n̲ão"). At 1;07.02, 22 accurate productions occurred (all "n̲ão" [ˈn̲ɐ̃w̃]) along with 23 substitutions to [ɲ] (all for "n̲ão" [ˈn̲ɐ̃w̃], except one for "n̲este" [ˈn̲eʃt]), one denasalization (for "n̲ão"), and three deletions (all "n̲ão" [ˈn̲ɐ̃w̃])).

underwent substitution to the stop [g]. Again, this demonstrates the stopping of fricatives that affected Inês's productions of other fricatives in onset position (Burkinshaw 2014).

6.4. Interim summary

Inês acquired all sounds in onset position within the documented period, as summarized in Table 41. Inês acquired all stop and nasal sounds before she acquired any fricatives, and she acquired [l] eleven months earlier than she acquired [ʀ].

Table 41: Inês's onset development

	0;11.14	1;00.25	1;01.30	1;03.06	1;04.09	1;09.19	2;00.11	2;01.10	2;04.19	2;07.16	2;08.23	2;10.20	2;11.22	3;00.15	3;02.03	3;04.06	3;10.01	3;11.12	Not acquired
[m]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[d]	T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[p]	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[n]	—	S/T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	—	V/T	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[k]	—	—	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	S	—	S/T	S/T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[g]	—	—	—	—	S	√	√	√	√	√	√	√	√	√	√	√	√	√	
[l]	—	—	—	—	S	D	D	√	√	√	√	√	√	√	√	√	√	√	
[f]	D	D	—	—	—	S	S	S	S	√	√	√	√	√	√	√	√	√	
[v]	—	—	—	—	S	S	S	S	S	√	√	√	√	√	√	√	√	√	
[s]	—	—	S	S	S	S	S	S	S	S	S/T	√	√	√	√	√	√	√	
[z]	—	—	—	—	S	—	D	—	—	—	—	S	√	√	√	√	√	√	
[ʃ]	—	T	D/S	S	—	S	S	S	S	S/T	S	S	√	√	√	√	√	√	
[ʒ]	—	S	D	—	S	S	S	S	S	S	S	S/T	√	√	√	√	√	√	
[ʀ]	—	—	—	—	—	S	S	S	S	S	S	S	—	√	√	√	√	√	

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

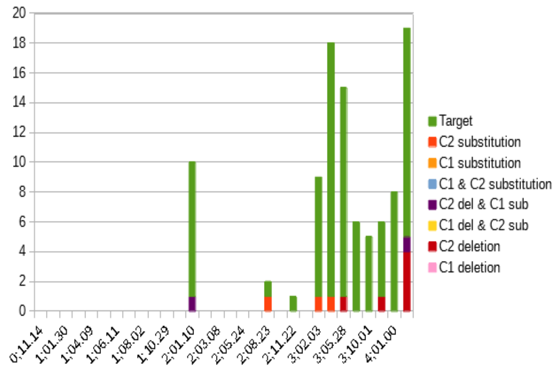
Inês's pattern of stopping appeared to affect both members of cognate fricatives equally, with [z] the only fricative that was acquired after stopping had ended for all other fricatives. As previously discussed, Inês also had a period where stopping was coupled with an incorrect place of articulation: she stopped [f/v] to [t/d] until age 2;01, and then stopped to [p/b] after this age (Burkinshaw 2014; Rose 2014). After 2;01, she produced the fricatives with the right place of articulation, however she continued to stop them.

As I have described Inês's acquisition of singleton onsets, I now move to discuss her acquisition of onset clusters.

6.5. Consonant clusters in onset position

Inês acquired five cluster types over the course of her documented sessions. Overall, she did not make many attempts at consonant-glide clusters. Inês acquired the stop-glide cluster type first at 2;01.10, with nine accurate productions and one C2 deletion with C1 substitution, as illustrated in Figure 165. This was the first session with attempts at this cluster type, and it contained [kw] target clusters only. Overall, there is a dearth of data with 72 attempts at [kw] resulting in 63 correct productions; the most common error consisted of reduction to [k], which occurred six times, with four of these reductions in the last session. Inês also made 24 attempts at [ɡw], which yielded 23 correct targets; however, these emerged later, with correct productions starting at 3;02.03. Inês attempted [dj] only three times, which resulted in two accurate productions; however, given the low number of occurrences of this cluster, its development cannot be assessed with certainty. Also, based on the minimal amount of data available for fricative-glide clusters, we can claim that Inês acquired this cluster type at age 3;02.03. However, she made only two attempts in total which occurred at 3;02.03, resulting in one instance of [sj] produced as [ʧj] and one instance of [ʒj] produced correctly.

Figure 165: Inês's acquisition of stop-glide onset clusters



Based on the minimal evidence available in the corpus, Inês acquired stop-lateral clusters at age 2;08.23, specifically the cluster [kl], as shown in Figure 166. Prior to this, target stop-lateral clusters frequently underwent reduction or C2 substitution. Specifically, the cluster was reduced to the stop consonant until 2;02.01 (slightly after the acquisition of singleton [l] at 2;01.10) where the pattern shifted to an epenthesized vowel occurring between the two target sounds (from 2;03.08 and 2;04.08.23) (Burkinshaw 2014: 48). Inês attempted [bl] only once, at 3;11.12, which resulted in an accurate production. She also attempted [pl] five times, with only one accurate production at 4;01.00. Despite the scarcity of data, it appears that Inês also acquired fricative-lateral clusters at 2;08.23, as illustrated in Figure 167. Prior to this, attempts primarily resulted in C2 deletion with C1 substitution; the most common error pattern changed to C1 & C2 substitution in later sessions. All productions of this cluster type consisted of the cluster [fl], and the small error spike that we observe in the last two sessions resulted from two instances of [fl] produced as [fr]. Inês's production of [f] in onset-clusters followed the same developmental path as her acquisition of fricatives in onset position: [f] was initially produced as [t], then [p], before ultimately being produced accurately as [f] (Burkinshaw 2014: 51).

Figure 166: Inês's acquisition of stop-lateral onset clusters

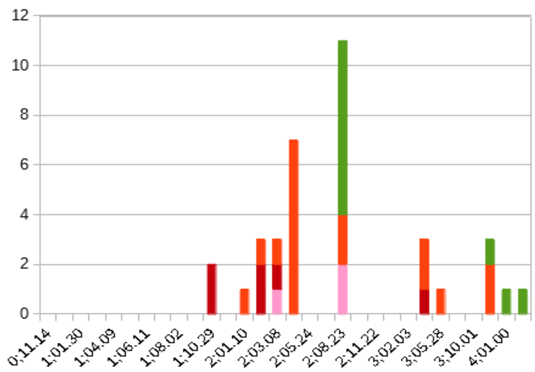
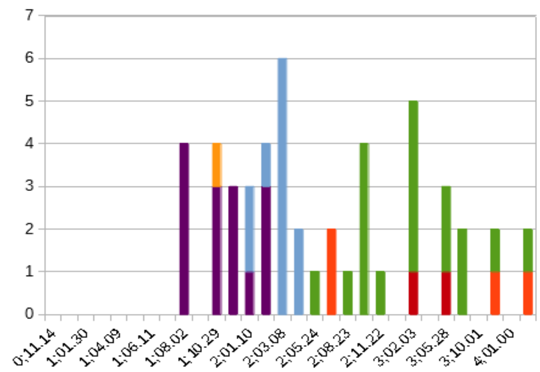


Figure 167: Inês's acquisition of fricative-lateral onset clusters



As shown in Figure 168, stop-rhotic clusters were acquired at 3;10.01, with 18 accurate productions and three C2 deletions. Prior to this, the clusters frequently underwent C2 deletion.

Figure 168: Inês's acquisition of stop-rhotic onset clusters

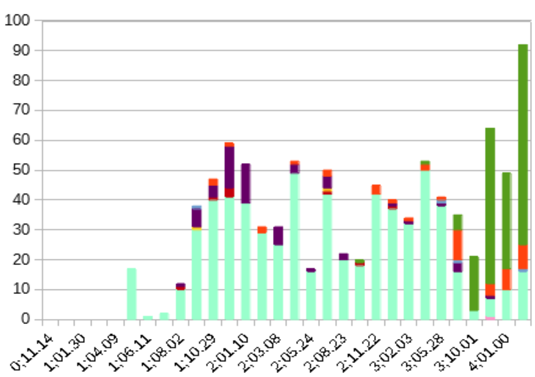
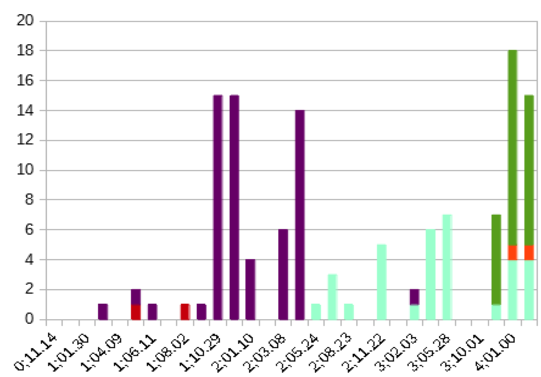


Figure 169: Inês's acquisition of fricative-rhotic onset clusters



Inês acquired fricative-rhotic clusters [fɾ] and [vɾ] at 3;11.12, as illustrated in Figure 169, with six accurate productions and one C2 deletion. Inês only attempted these two types of fricative-rhotic clusters. Prior to acquisition, the clusters frequently underwent C2 deletion with C1 substitution in the earlier sessions, which again reflected her stopping of fricatives. Once stopping resolved at 2;05.24 for the fricative-rhotic clusters, the main error in later sessions was C2 deletion.

6.6. Interim summary

Inês acquired five cluster types during the course of the observation period, as summarized in Table 42. She acquired stop-glide clusters first, followed by stop-lateral, and fricative-lateral clusters. This occurred in parallel to her acquisition of singleton onset [l], which was acquired early at 2;01.10.

Table 42: Inês's onset cluster development

	0;11.14	1;00.25	1;01.30	1;03.06	1;04.09	1;09.19	2;00.11	2;01.10	2;04.19	2;07.16	2;08.23	2;10.20	2;11.22	3;00.15	3;02.03	3;04.06	3;10.01	3;11.12	Not acquired
Stop-glide	—	—	—	—	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
Stop-lateral	—	—	—	—	—	—	—	S	S	—	√	√	√	√	√	√	√	√	
Fricative-lateral	—	—	—	—	—	—	D+S	D+S	D+S	S	√	√	√	√	√	√	√	√	
Stop-rhotic	—	—	—	—	—	R	R/S	R	R	R	R	R	R	R	R	R	√	√	
Fricative-rhotic	—	—	—	—	D+S	D+S	D+S	D+S	R	R	R	—	R	—	R	R	—	√	
Fricative-glide	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	?

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

Inês acquired stop-rhotic clusters next, followed by fricative-rhotic clusters. There was not enough data to clearly assess Inês's development of fricative-glide clusters.

In general, Inês's acquisition of consonant clusters mirrored her acquisition of singleton onsets. She produced stops with target accuracy, whereas fricatives followed the pattern of their singleton counterparts.

As discussed in Burkinshaw (2014: 52), in consonant-rhotic clusters, /ɾ/ consistently underwent deletion until age 3;07.29, where it began to be produced with more accuracy until its acquisition at 3;10.01. [l] in branching onsets did not undergo this deletion pattern, and was produced accurately in this position over a year earlier than /ɾ/.

I now move on to discuss Inês's coda development. Compared to English, German, and French discussed above, Portuguese has a more restrictive coda inventory and only allows [ʃ/ʒ], [ɫ], and [ɾ] in coda position.

6.7. Obstruents in coda position

Fricatives

Stopping did not affect Inês's acquisition of the two word final fricatives that occur in Portuguese. She acquired [ʃ] in coda at 2;00.11, as illustrated in Figure 170, with 64 accurate productions, five other substitutions, and 52 deletions. While this was the first session where accurate productions outnumbered errors, variability persisted; Inês produced the same word with deletions and as target (e.g., Inês produced *mais* [ˈmajʃ] with target [s/ʃ], and with [ʃ] deleted). Deletions became less common as the sessions progressed. The substitutions displayed in the chart below reflect the *sandhi* phenomenon discussed above.

Figure 170: Inês's acquisition of [ʃ] in coda

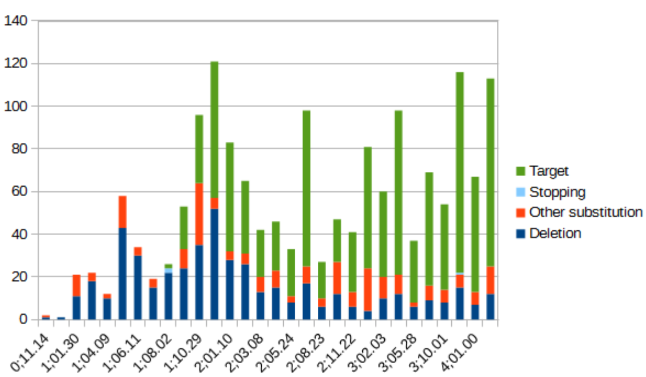
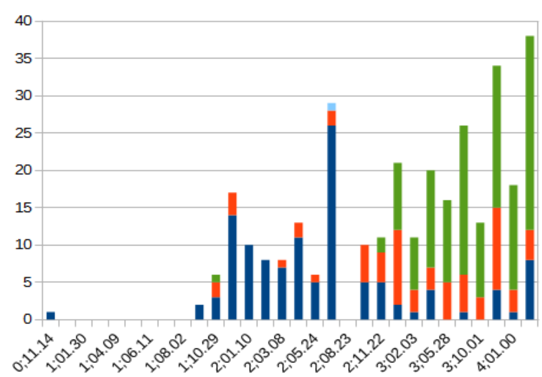


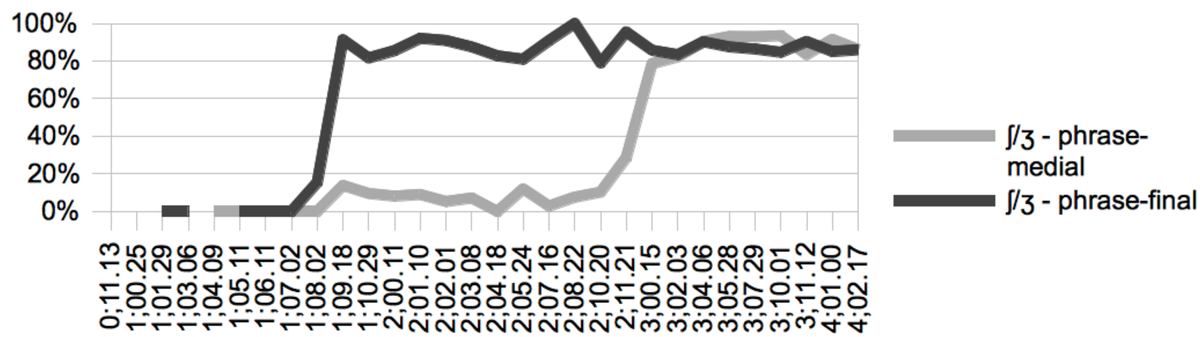
Figure 171: Inês's acquisition of [ʒ] in coda



As shown in Figure 171, the phonetic environment in which Inês would produce the allophone [ʒ] (i.e., before a voiced consonant), did not occur with any frequency until 1;09.19. Inês acquired [ʒ] in coda at 3;02.03, with seven accurate productions, three other substitutions, and one deletion. Prior to this, [ʒ] most commonly underwent deletion; after this, [ʒ] continued to undergo a variety of substitutions.

As mentioned above, in Portuguese, /ʃ/ in coda is resyllabified as the onset of the next syllable when the following word begins with a vowel (Mateus & d'Andrade 2000). As such, the above discussion involving coda /ʃ/ includes both phrase-medial and phrase-final environments. Rose (2014) divided Inês's phrase-medial and phrase-final [ʃ/ʒ] codas, as illustrated in Figure 172.

Figure 172: Inês's phrase-medial vs. phrase-final [ʃ/ʒ] (Rose 2014: 18)



By dividing Inês's coda fricatives into the two groups of resyllabified and real codas, he found that real codas (that occur phrase-finally) were acquired early at 1;09.19. In contrast, resyllabified codas, which pattern as onsets of the next syllable, underwent a period of stopping in parallel with Inês's other onset fricatives reported above, and were acquired much later, at 3;00.15.

6.8. Approximants in coda position

Both coda approximants in Portuguese differ from their counterparts that occur in word-initial position. Like English, the velarized or dark “l” [ɫ] occurs in coda position, and clear [l] in onset position. Inês did not acquire [ɫ] by the end of the documented period, as illustrated in Figure 173. While Inês’s accuracy improved in later sessions, she did not maintain a 50% accuracy rate over any consecutive sessions.

Figure 173: Inês’s acquisition of [ɫ] in coda

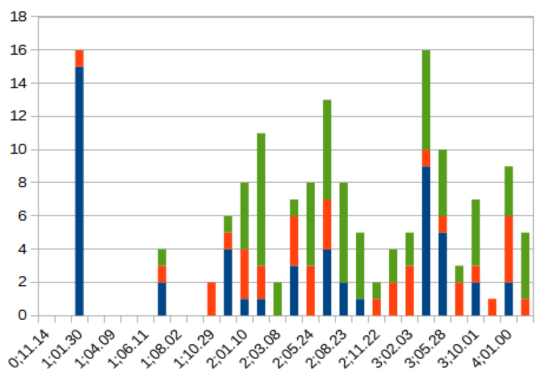
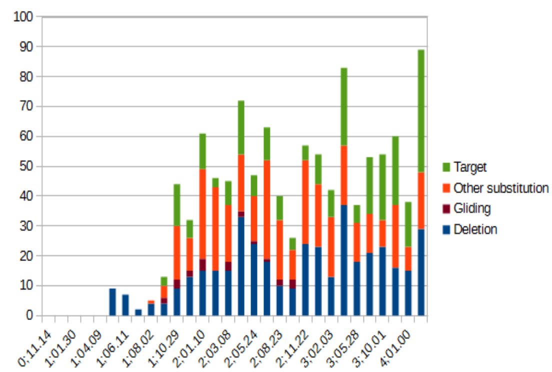


Figure 174: Inês’s acquisition of [ɾ] in coda



Inês also did not acquire [ɾ] in coda by the latest recording available, as shown in Figure 174. Like the rhotic that appears in onset clusters, the rhotic that occurs in singleton codas is the alveolar [ɾ], and not the uvular [ʀ] of singleton onsets. No clear pattern for various substitutions could be observed; for the same word, [ɾ] may have been deleted, produced correctly, or substituted within the same session. For example, Inês produced the word *quer* [kɛɾ] at age 1;10.29 with a [j], [l], with target [ɾ] deleted, or with the target [ɾ] produced accurately.

6.9. Interim summary

Over the course of the documented sessions, Inês acquired the coda fricative [ʃ/ʒ]. She acquired neither coda approximant [ɫ] or [ɾ], and both of these sounds were prone to substitution and deletion, as summarized in Table 43.

Table 43: Inês coda development

	0;11.14	1;00.25	1;01.30	1;03.06	1;04.09	1;09.19	2;00.11	2;01.10	2;04.19	2;07.16	2;08.23	2;10.20	2;11.22	3;00.15	3;02.03	3;04.06	3;10.01	3;11.12	Not acquired
[ʃ]	D/S	D	D/S	D	D	D/T	√	√	√	√	√	√	√	√	√	√	√	√	
[ʒ]	D	—	—	—	—	D	D	D	D	D	—	D/S	D/S	S	√	√	√	√	
[ɫ]	—	—	D	—	—	—	D	S/T	D/S	D/S	D/T	T	S/T	S/T	S	D	S	S	X
[ɾ]	—	—	—	—	—	D	D/S	S	D	S	D	D/S	D/S	D/S	D/S	D	D	D/S	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

Table 44 highlights that Inês acquired stops before fricatives in both onset and onset cluster position. Concerning singleton onsets, Inês acquired all stops before any fricatives, while the acquisition of clusters was influenced not only by stopping, but by the added difficulty of co-occurring laterals and rhotics. Inês's fricative development in singleton onsets and onset clusters also mirrored each other, as both positions showed the same stopping pattern. This pattern did not manifest itself in syllable codas.

Table 44: Summary of Inês's phonological development

0;11.14	1;00.25	1;01.30	1;03.06	1;04.09	1;09.19	2;00.11	2;01.10	2;04.19	2;07.16	2;08.23	2;10.20	2;11.22	3;00.15	3;02.03	3;10.01	3;11.12	Not acquired
ONSET																	
[m]	[d]	[p] [n]	[t] [k]	[b]	[g]		[l]		[f] [v]		[s]	[z] [ʃ] [ʒ]	[ʀ]				
ONSET CLUSTERS																	
							Stop-glide			Stop-lateral Fricative-lateral				Fricative -glide	Stop-rhotic	Fricative -rhotic	
CODA																	
						[ʃ]								[ʒ]			[ɫ] [ɾ]

As can be observed across all syllable positions, rhotic consonants were the most difficult to master. In contrast, the non-velarized [l] of singleton and branching onsets appeared relatively early, whereas the velarized [ɫ] found in coda position was not acquired during the documented period. Deletion and substitution errors persisted for much longer in coda position for both approximants. Additionally, [ɾ] occurred accurately in stop-rhotic clusters at age 3;10.01, after almost two years of the stop-rhotic clusters undergoing reduction to the stop consonant only. This may suggest that [ɾ] is generally more vulnerable to deletion than [ʀ].

As I have now discussed Inês's singleton onset, onset cluster, and singleton coda development, I move on to the last case study to be described, that of English-learner Ben.

7. Ben

English-learning Ben exhibited a speech sound disorder with features of Childhood Apraxia of Speech (CAS). As described in Chapter 2, section 9.2 above, Ben displayed multiple phonological processes, including velar fronting, fricative gliding, prevocalic voicing, final devoicing, cluster simplification, glide epenthesis in onsetless syllables, and gliding/vocalization of liquids (McAllister Byun 2009). These processes will be discussed in detail in the ensuing discussion.

At the beginning of his documented sessions at age 3;09.06, Ben had already acquired six sounds in onset position, as summarized in Table 45.

Table 45: Ben's early consonantal inventory (onset)

	Labial	Coronal			Dorsal	Glottal
		dental	alveolar	alveopalatal		
Stops	b		d			
Fricatives						
Affricates						
Nasals	m		n			
Liquids						
Glides	w			j		

Ben's early inventory of onset consonants included the voiced stops [b] and [d], the nasals [m] and [n], and the glides [w] and [j]. Unlike the other children, Ben also had two coda consonants acquired by the beginning of his recorded sessions: he had acquired coda [p] and [s] by the beginning of his documented period.

With these details in mind, I now begin my description of Ben's phonological development, starting with his acquisition of obstruents in onset position.

7.1. Obstruents in onset position

Stops

As mentioned above, Ben had already acquired [b] and [d] by 3;09.06, as shown in Figure 175 and Figure 176, respectively. Ben produced [b] in onset with five accurate productions and one other substitution, and [d] with nine out of nine accurate productions. He maintained a level of greater than 50% accuracy with both sounds across all subsequent sessions.

Figure 175: Ben's acquisition of [b] in onset

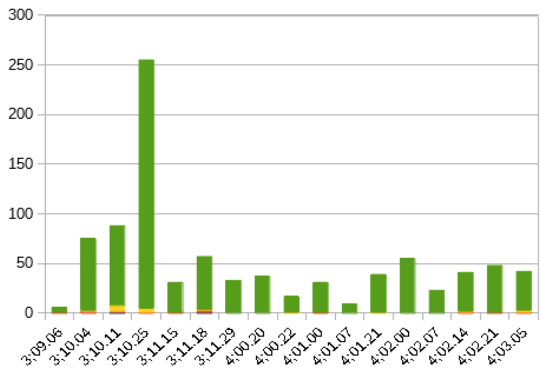
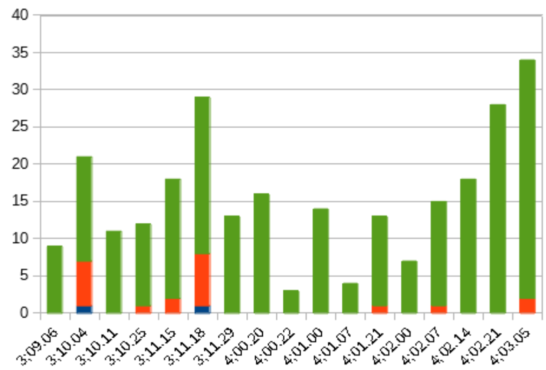


Figure 176: Ben's acquisition of [d] in onset



However, Ben did not acquire the remainder of the stops to be discussed by the end of his documented sessions, at age 4;03.05. As noted in McAllister Byun (2009; 2011), Ben displayed syllable-initial voicing of obstruents; due to this process, he did not reach a level of 50% production accuracy across consecutive sessions with any of the voiceless stops. As illustrated in Figure 177, Ben typically produced [p] as its voiced counterpart [b]. Similarly, he did not acquire [t] in onset and most commonly produced it as its voiced counterpart [d], as displayed in Figure 178.

Figure 177: Ben's acquisition of [p] in onset

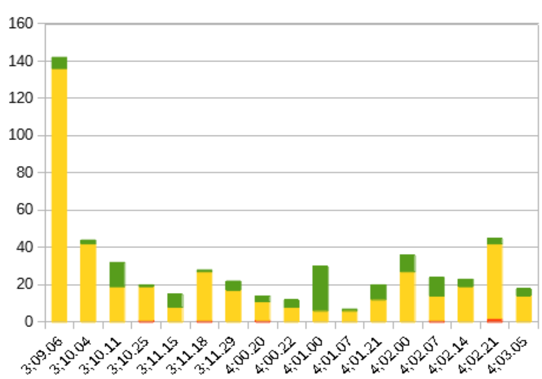
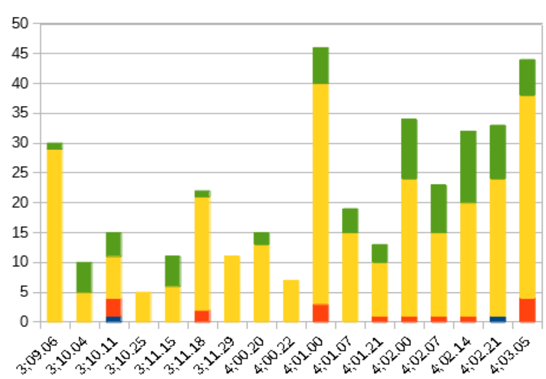


Figure 178: Ben's acquisition of [t] in onset



Ben also did not acquire [k] in onset during the course of the observation period, as shown in Figure 179. The most common error consisted of [k] substituted to [d], which suggests that [k] simultaneously underwent fronting to [t] and voicing to [d]. As previously discussed by McAllister Byun (2009; 2011), Ben displayed Positional Velar Fronting, with velars fronted in only strong positions (i.e., word-initially) but not in weak positions (i.e., word-finally).[9]

Figure 179: Ben's acquisition of [k] in onset

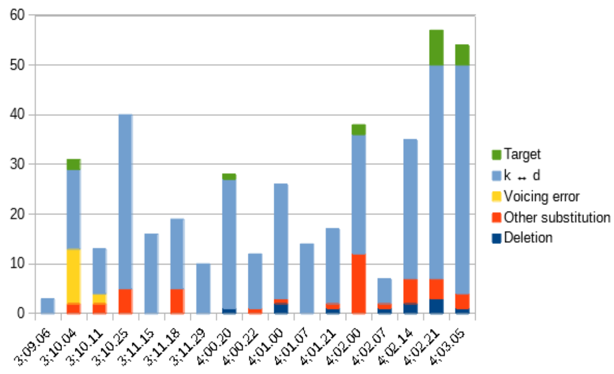
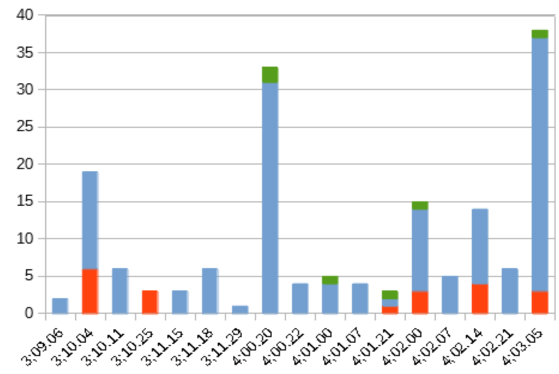


Figure 180: Ben's acquisition of [g] in onset



As illustrated in Figure 180, Ben also did not acquire [g] in onset. In parallel with [k], he most frequently fronted [g] to [d].

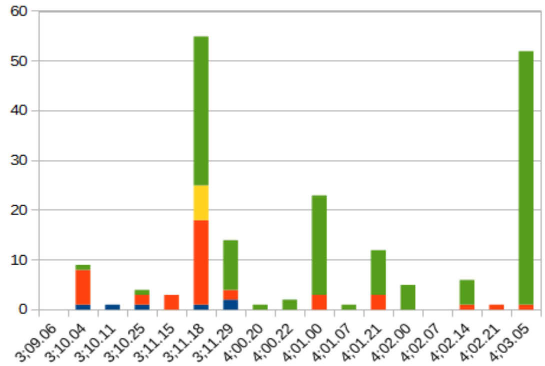
Fricatives

Ben acquired three fricatives over the course of the documented period. In general, Ben displayed the pattern of fricative gliding in onset position, whereby target fricatives are produced as glides (e.g., target *see* [si] produced as *wee* [wi]) (McAllister Byun 2011: 138).

As shown in Figure 181, Ben acquired [ʃ] in onset first at 3;11.18, when he made 30 accurate productions, seven voicing errors, 17 other substitutions, and one deletion. This was the first session where accurate productions outnumbered errors, and errors steadily declined after this session. Prior to then, the most common error consisted of substitutions to [j] (25 times).

9 See Chapter 1, section 3, for a more detailed discussion of Positional Velar Fronting.

Figure 181: Ben's acquisition of [ʃ] in onset



Ben acquired [s] in onset next, at 3;11.29, as illustrated in Figure 182, with 20 accurate productions, one instance of stopping, and 16 other substitutions. Prior to this, [s] most frequently underwent substitution to [j] or [w]. Ben acquired [f] in onset three months later, at 4;03.05, as this was the first session where accurate productions outnumbered substitutions. As shown in Figure 183, in total, Ben made 162 attempts, which resulted in 31 accurate productions, nine deletions, and 92 substitutions to [w] (e.g., eight substitutions to [w] occurred for *farmers*, *forget*, *falling*, *football*, *fork* in the second-to-last session, at 4;02.21). As Ben only exceeded 50% accuracy in the last session, subsequent sessions would have been useful to verify whether he subsequently maintained this level of accuracy.

Figure 182: Ben's acquisition of [s] in onset

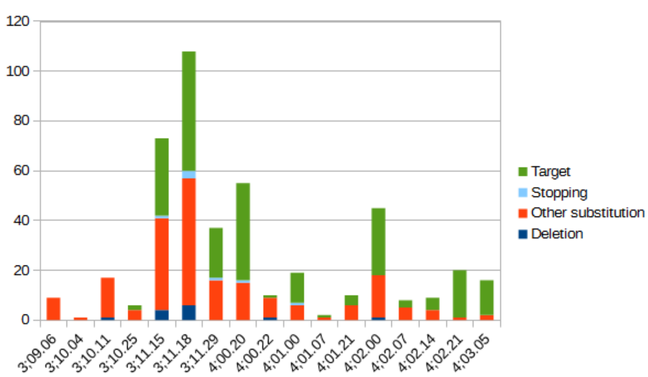
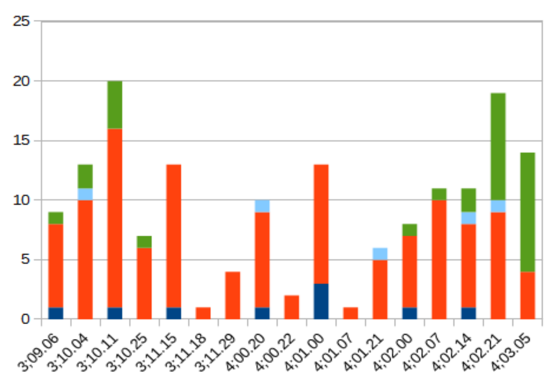


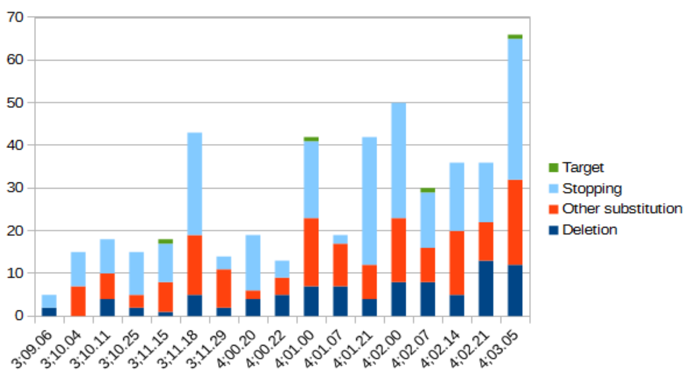
Figure 183: Ben's acquisition of [f] in onset



Ben did not acquire the remainder of the fricatives to be discussed by the end of the documented period, at 4;03.05. He did not acquire [v] in onset, as his three attempts all underwent substitution to [b] (for the words *v̲acuum*, *v̲anilla*). [θ] in onset was also not acquired, with 12 attempts, 10 of which Ben produced as [j] (*th̲irsty*, *th̲ank*, *th̲ink*), and one substitution each to [m] (*th̲irsty*) and [s] (*th̲ing*).

Similarly, Ben did not acquire [ð] in onset, as shown in Figure 184. Out of 481 attempts, the most common errors consisted of stopping to [d] 233 times, and substitution to [j] 101 times. Gliding and stopping occurred for the same words within the same session (e.g., *th̲ey*, *th̲at*, *th̲e* were pronounced with either [d] or [j] all the way into the last session).

Figure 184: Ben's acquisition of [ð] in onset



As illustrated in Figure 185, there is a dearth of data on [z] as Ben made only 16 attempts at this consonant, which resulted in three accurate productions, five voicing errors to [s], seven substitutions to [j], and one substitution to [b].

Figure 185: Ben’s acquisition of [z] in onset

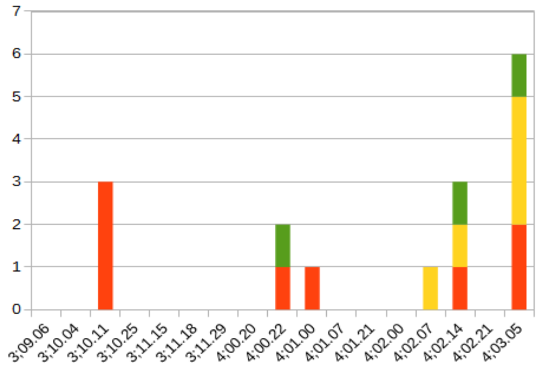
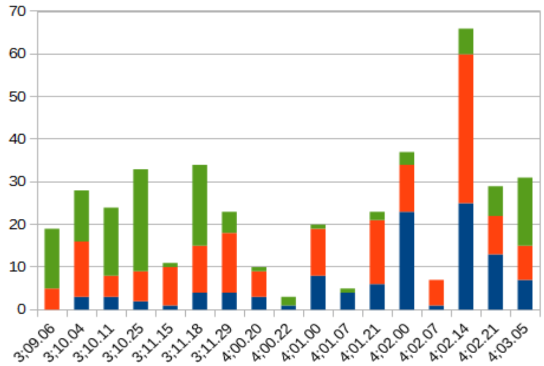


Figure 186: Ben’s acquisition of [h] in onset



As shown in Figure 186, Ben did not acquire [h] in onset. However, [h] did look acquired in Ben’s earlier sessions. For example, in the first session, Ben accurately produced [h] 14 times (*help*, *hats*, *hungry*), with an additional five substitution errors (two [j] for *hungry* and three [w] for *help*, *her*, *high*). However, it appears that his accuracy at [h] decreased from there. For example, at 4;02.14, Ben accurately produced [h] six times in *hers*, *horse*, *holes*, *he*, but substituted it 35 times with other sounds ([j] for *hers*, *her*, *have*, *hit*, *hungry*, *horse*, [n] for *her*, [w] for *high*, *hotel*, *her*, *hers*, *hold*, *Halloween*), and deleted it altogether in 25 other attempts.

Affricates

Based on the minimal evidence available, Ben did not acquire either of the target affricates during his documented period, as shown in Figure 187 and Figure 188. Ben typically produced affricates in onset position as stops (McAllister Byun 2011: 379).

Figure 187: Ben's acquisition of [ʧ] in onset

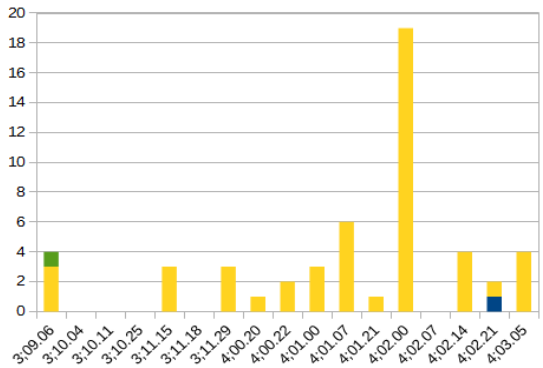
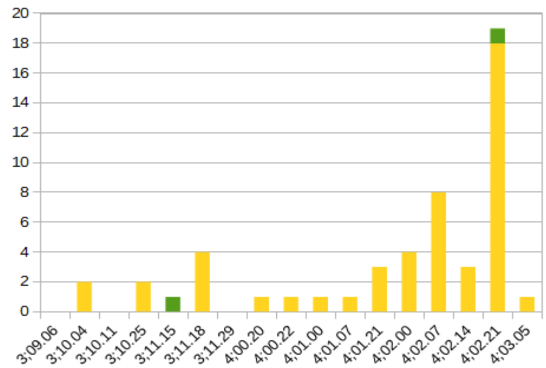


Figure 188: Ben's acquisition of [ʤ] in onset



Out of 52 attempts at [ʧ], Ben made one accurate production (*ch*ip in the very first session), and 46 substitutions to [d] (e.g., *ch*eerios, *ch*eek, *ch*ips). Concerning [ʤ] in onset, 51 attempts resulted primarily in substitutions to [d] (n=43).

7.2. Nasals in onset position

As discussed above, Ben had already acquired both nasals by the beginning of the documented period. As displayed in Figure 189, he acquired [n] in onset by the earliest age available, with seven out of seven accurate productions. The substitution blip that occurred at 4;02.14 consisted mostly of [m] substitution for *n*ose (produced as [mos]); the deletions that occurred in this session come from attempts at *N*ew York (produced as [_uwjuk]).

Figure 189: Ben's acquisition of [n] in onset

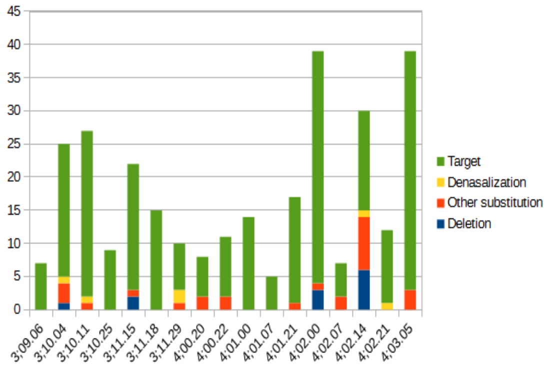
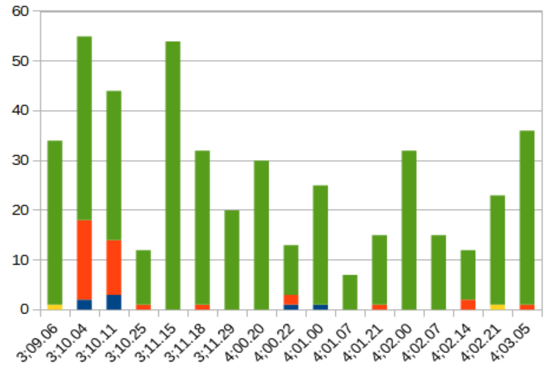


Figure 190: Ben's acquisition of [m] in onset



During his first recorded session, Ben achieved 33 accurate productions of [m] and one denasalization to [b], as shown in Figure 190. The substitution spikes that occurred in the following two sessions, 3;10.04 and 3;10.11, consisted solely of substitution to [w] for the word *moo*.

7.3. Approximants in onset position

As previously stated, Ben had already acquired [w] and [j] in onset by the beginning of his documented period. At 3;09.06, as illustrated in Figure 191, Ben achieved 12 accurate productions for [w], four other substitutions, and four deletions. Ben's [w] productions displayed some variability, however, with the most common substitution yielding a [j] in his productions. This substitution became more prominent from session 3;11.15 onward. Ben often substituted [w] by [j] for the word *want*, but this pattern also occurred in a variety of other words as well (e.g., *whipped*, *with*, *one*, etc.). The sessions where Ben fell below 50% accuracy (3;11.15, 3;11.18, 3;11.29) occurred over a two-week period, with the majority of the errors consisting of substitution to [j] for *want*.

Figure 191: Ben’s acquisition of [w] in onset

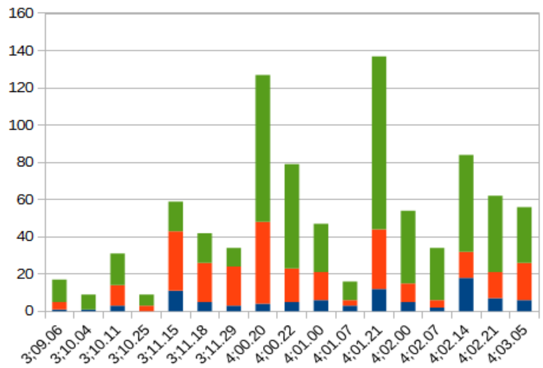
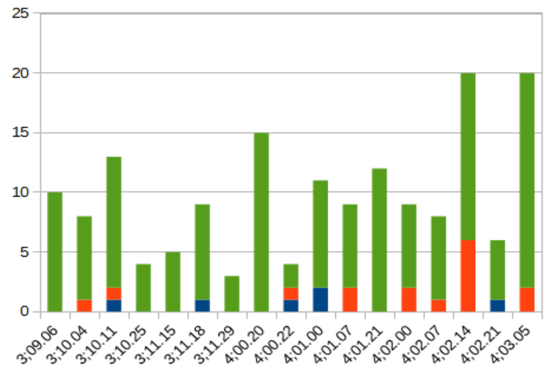


Figure 192: Ben’s acquisition of [j] in onset



Concerning [j], Ben produced 10/10 accurate targets at 3;09.06, as shown in Figure 192. The other substitutions that occurred varied across sounds and words. The rise in substitutions at 4;02.14 consisted of three substitutions by [d] for *y̲our*, *y̲ou*, *y̲eah*, and three variable pronunciations of *New Y̲ork* (with substitution to [w], [ɣ], and [ʁ]).

Finally, Ben did not acquire [l] or [ɹ] during his documented sessions. Laterals in onset position were most frequently glided to [j], as shown in Figure 193.

Figure 193: Ben’s acquisition of laterals in onset

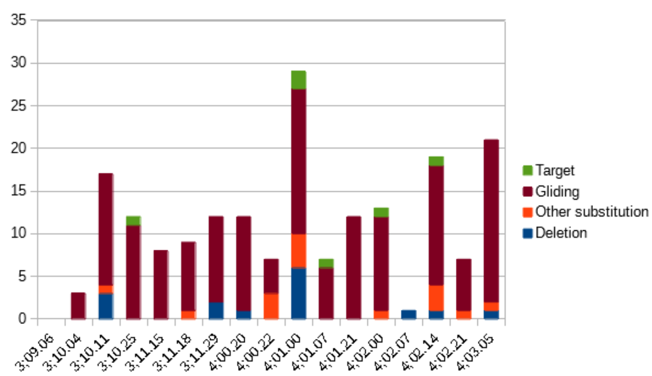
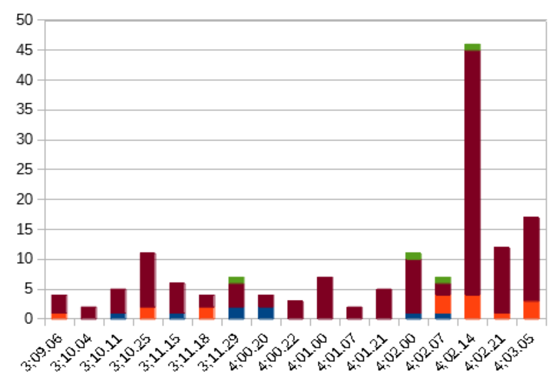


Figure 194: Ben’s acquisition of [ɹ] in onset



Similarly, he also did not acquire [ɹ] in onset. As illustrated in Figure 194, most of Ben’s attempts resulted in gliding to [w].

7.4. Interim summary

At the beginning of his documented sessions, Ben had already acquired [b], [d], [n], [m], [w], and [j]. He went on to acquire three voiceless fricatives ([ʃ], [s], [f]) by his last recording at age 4;03.05, as summarized in Table 46. A wide range of stops, fricatives, affricates, and approximants remained unacquired by the end of Ben's recorded sessions.

Table 46: Ben's onset development

	3;09.06	3;10.04	3;10.11	3;10.25	3;11.18	3;11.29	4;02.07	4;03.05	Not acquired
[n]	√	√	√	√	√	√	√	√	
[m]	√	√	√	√	√	√	√	√	
[w]	√	√	√	√	√	√	√	√	
[j]	√	√	√	√	√	√	√	√	
[b]	√	√	√	√	√	√	√	√	
[d]	√	√	√	√	√	√	√	√	
[ʃ]	—	S	D	S	√	√	√	√	
[s]	S	S	S	S	S	√	√	√	
[f]	S	S	S	S	S	S	S	√	
[p]	V	V	V	V	V	V	V/T	V	X
[t]	V	V/T	V	V	V	V	V	V	X
[k]	S	S/V	S	S	S	S	S	S	X
[g]	S	S	S	S	S	S	S	S	X
[v]	—	—	—	S	—	—	—	S	X
[θ]	—	—	S	—	—	—	V	V/S	X
[ð]	S	S	S	S	S	S	S	S	X
[z]	—	—	S	—	—	—	V	V/S	X
[ʒ]	—	—	—	—	—	—	—	—	X
[h]	T	S/T	T	T	S/T	S	S	S/T	X
[ʧ]	S	—	—	—	—	S	—	S	X
[ʤ]	—	S	—	S	S	—	S	S	X
[l]	—	S	S	S	S	S	D	S	X
[ɹ]	S	S	S	S	S	S	S	S	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

Ben was sensitive to voicing contrasts, with voicing errors occurring for all voiceless stops, and place contrasts, as Ben fronted both [k] and [g] to [d]. Gliding occurred for both liquids in onset position, as Ben glided [l] to [j] and [ɹ] to [w], thereby maintaining a phonetic contrast between the two.

As I have now described Ben's singleton onset development, I move on to describe his onset cluster development.

7.5. Consonant clusters in onset position

In line with his diagnosis as phonologically disordered, Ben did not acquire any of the cluster types under investigation during the documented period; he made minimal attempts at the various cluster types and generally reduced them to a single consonant (McAllister Byun 2009; 2011). As shown in Figure 195 below, the most common error for stop-lateral clusters consisted of C2 deletion, often with C1 undergoing substitution, following the lines of what we observed in singleton onsets. Specifically, Ben produced [bl] as [b] 32 times out of 33 attempts, and [kl] as [d] 19 times out of 39 attempts. The next most common errors with this cluster type consisted of [pl] reduced to [p] eight times and produced as [b] 31 times out of 49 attempts, and [gl] produced as [d] four times out of four attempts. As we can see in Figure 196, Ben also did not acquire stop-rhotic clusters. Ben never produced [ɹ] in a cluster correctly, with most attempts resulting in C2 deletion or C2 deletion with C1 substitution, again in line with his patterns of place or voicing substitution.

Figure 195: Ben's acquisition of stop-lateral onset clusters

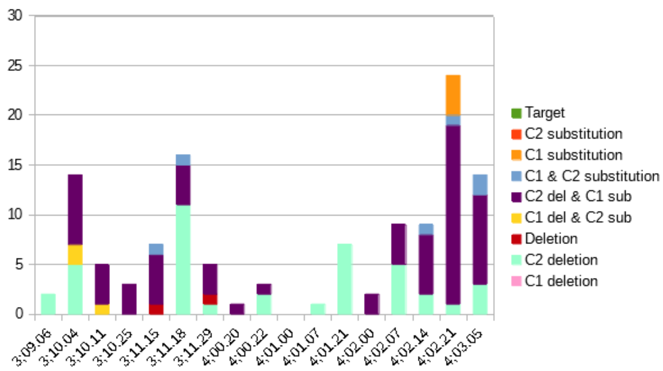
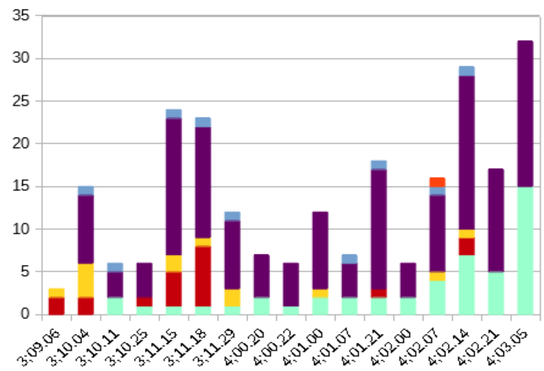


Figure 196: Ben's acquisition of stop-rhotic onset clusters



As expected based on the above descriptions, Ben did not acquire fricative-lateral clusters by the last recorded session. As illustrated in Figure 197, out of 39 total attempts, Ben produced [fl] as [w] 19 times, [fl] as [f] six times, and [fl] as [fw] four times (with single occurrences of various other errors). Ben also did not acquire fricative-rhotic clusters. As displayed in Figure 198, the most common errors consisted of [fɹ] produced as [w] 18 times (out of 28 attempts), and [θɹ] produced as [w] 26 times (out of 41 attempts).

Figure 197: Ben's acquisition of fricative-lateral onset clusters

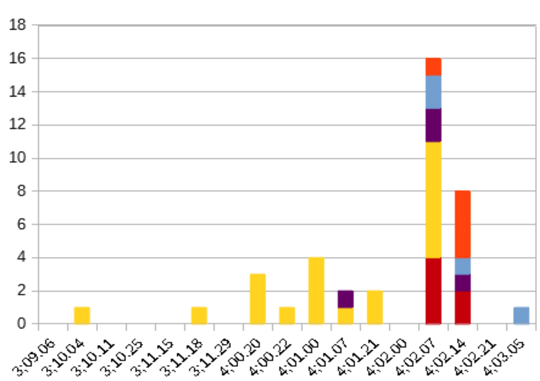
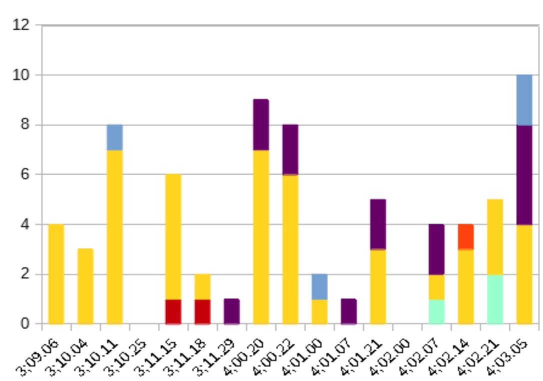
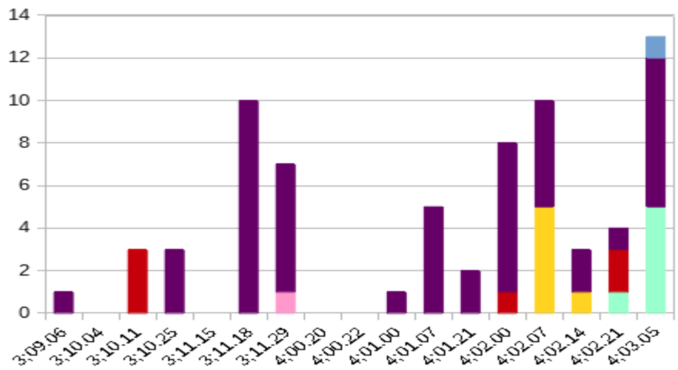


Figure 198: Ben's acquisition of fricative-rhotic onset clusters



Ben also failed to acquire stop-glide clusters, as shown in Figure 199. All attempts underwent reduction, with most resulting in C2 deletion with his usual C1 substitution (e.g., [kw] produced as [d] 25 times). Lastly, Ben did not attempt any nasal-glide or fricative-glide clusters during his documented sessions.

Figure 199: Ben's acquisition of stop-glide onset clusters



7.6. Interim summary

Ben did not acquire any of the cluster types during the recorded period, as summarized in Table 47. Most attempts across all cluster types resulted in C1 or C2 deletion, coupled with the remaining consonant undergoing substitution.

Table 47: Ben's onset cluster development

	3;09.06	3;10.04	3;10.11	3;10.25	3;11.18	3;11.29	4;02.07	4;03.05	Not acquired
Stop-lateral clusters	D	D+S	D+S	D+S	D+S	D+S	D+S	D+S	X
Stop-rhotic clusters	D	D+S	D+S	D+S	D+S	D+S	D+S	D+S	X
Stop-glide clusters	D+S	—	D	D+S	D+S	D+S	D+S	D+S	X
Fricative-lateral clusters	—	D+S	—	—	D+S	—	D+S	S	X
Fricative-rhotic clusters	D+S	D+S	D+S	—	D/S	D+S	D+S	D+S	X
Fricative-glide clusters	—	—	—	—	—	—	—	—	X
Nasal-glide clusters	—	—	—	—	—	—	—	—	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

In parallel to his acquisition of singleton onsets, Ben continued to front [k] and [g] to [d] in his cluster attempts, and he also continued to produce voiceless stops as their voiced counterparts. For example, attempts at the [pl] cluster above most commonly resulted in [b] productions.

Again similar to his onset development, Ben either deleted or glided [l] and [ɹ] in his cluster attempts. While Ben most frequently deleted [l] and [ɹ], on the occasions when he did produce them, both underwent gliding to [w]; this differs from onset position where, when produced, [l] was glided to [j] and [ɹ] to [w].

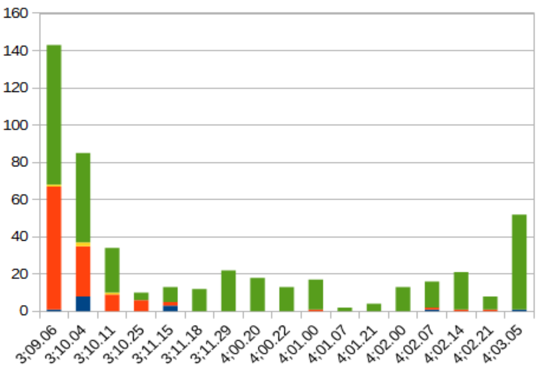
I now move on to discuss Ben's singleton coda development.

7.7. Obstruents in coda position

Stops

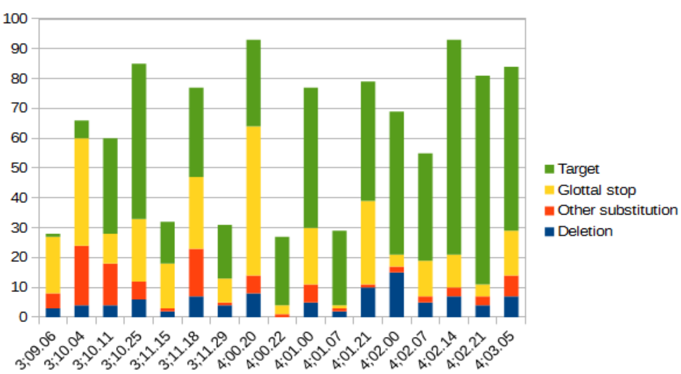
As mentioned above, Ben had already acquired [p] in coda by the earliest session available. In general, before acquisition, Ben substituted voiceless stops with a glottal stop [ʔ] (McAllister Byun 2011: 378). As illustrated in Figure 200, at 3;09.06, he produced 75 accurate targets, one voicing error, 66 other substitutions, and one deletion. In total, of the 114 total substitutions, 109 resulted in glottal stops. The relatively large number of attempts during Ben's first two sessions were due to his repeated productions of *pop*; this word was also the cause of the majority of the [ʔ] substitutions.

Figure 200: Ben’s acquisition of [p] in coda



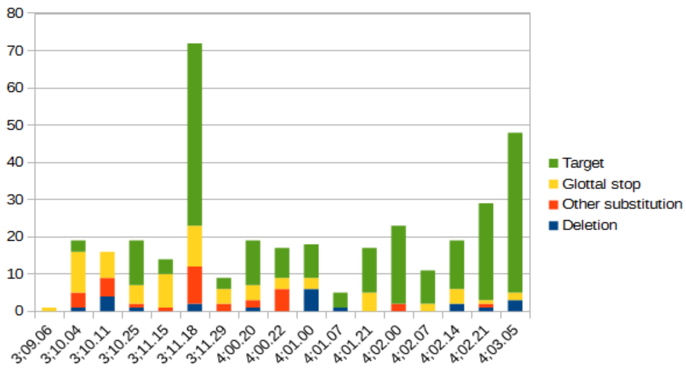
As shown in Figure 201, Ben acquired [t] in coda next, at 3;10.11, with 32 accurate productions, 10 glottal stop substitutions, 14 other substitutions, and four deletions. In general, the glottal stop production occurred in connected speech where an adult could also correctly produce a glottal stop (e.g., *but I like*).

Figure 201: Ben’s acquisition of [t] in coda



Ben acquired [k] in coda position at 3;10.25, as displayed in Figure 202, with 12 productions, five glottal stop substitutions, one other substitution, and one deletion. Ben produced only three correct targets in the three sessions preceding this one, with most errors consisting of glottal stop productions.

Figure 202: Ben’s acquisition of [k] in coda



Ben did not acquire the other stops to be discussed by the last session available, 4;03.05, as Ben devoiced all voiced stops in coda position (McAllister Byun 2009: 45). As shown in Figure 203, he did not acquire [b], with 50 attempts and only one correct production. The most common error consisted of 34 cases of devoicing to [p].

Figure 203: Ben's acquisition of [b] in coda

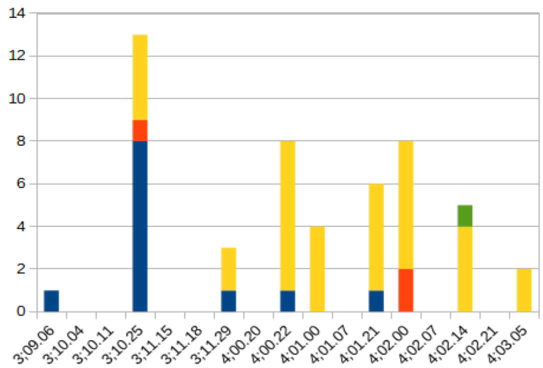


Figure 204: Ben's acquisition of [d] in coda

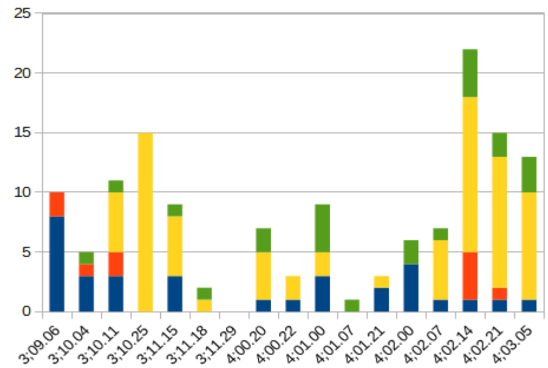
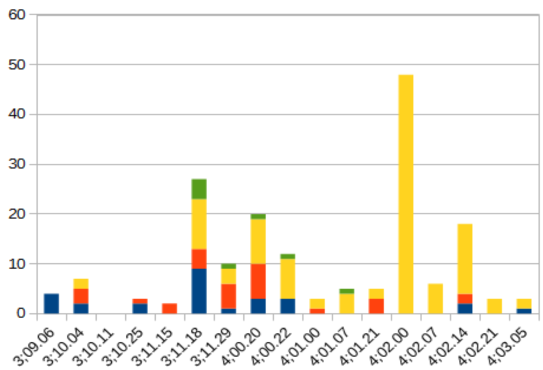


Figure 205: Ben's acquisition of [g] in coda



Ben also did not acquire [d] and [g] in coda, as displayed in Figure 204 and Figure 205, respectively. Out of 138 total attempts at [d], 73 resulted in voicing errors to [t]. Similarly, out of 176 attempts at [g], 113 resulted in voicing errors to voiceless [k].

Fricatives

Ben acquired only two fricatives, [s] and [ʃ], in coda position during his documented sessions. Unlike his word-initial fricatives, Ben's word-final fricatives did not undergo gliding (McAllister Byun 2011: 138). He had acquired [s] by the earliest recording session of 3;09.06, with three out of three accurate productions, as shown in Figure 206. As displayed in Figure 207, he acquired [ʃ] in coda at 3;10.04, with one correct production.

Figure 206: Ben's acquisition of [s] in coda

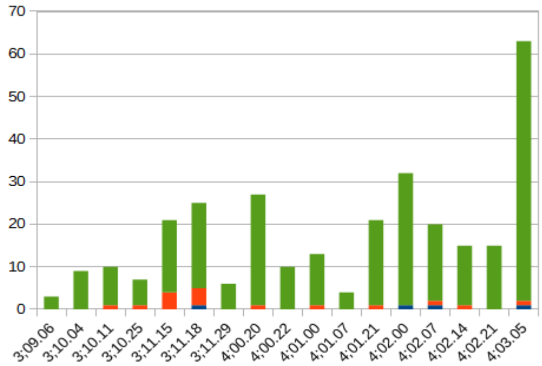
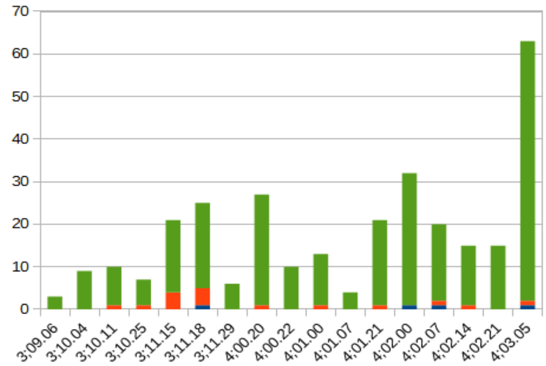


Figure 207: Ben's acquisition of [ʃ] in coda



Based on the minimal evidence available, Ben did not acquire [f] in coda. As illustrated in Figure 208, he made 27 attempts resulting in 17 substitutions to [s], six accurate productions, two substitutions to [θ], and two deletions. He also did not acquire [v] by the latest documented session, as shown in Figure 209. Ben made 57 attempts at [v] with only one accurate production, 25 substitutions to [s] (across a variety of words *of*, *stove*, *have*, etc, with no observable substitution pattern), 14 voicing errors, 14 deletions, and one each of [p], [n], and [j] substitution.

Figure 208: Ben's acquisition of [f] in coda

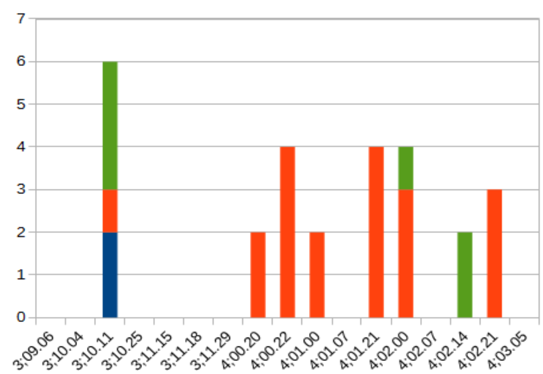
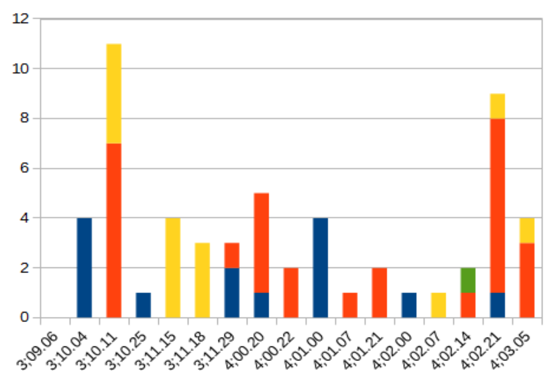
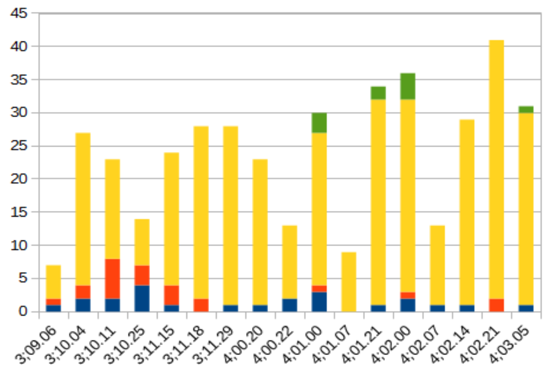


Figure 209: Ben's acquisition of [v] in coda



Ben also did not acquire [z] in coda. Out of 410 attempts, Ben produced 356 as the voicing error [s], as displayed in Figure 210.

Figure 210: Ben's acquisition of [z] in coda

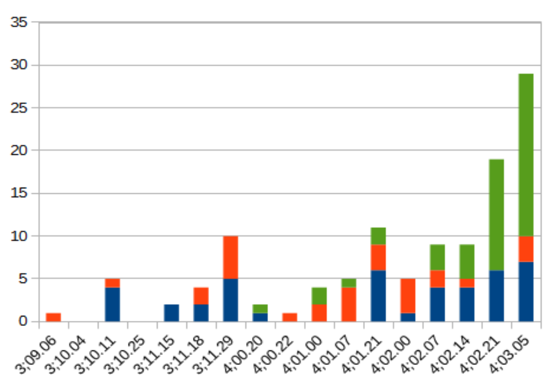


I could not assess Ben's acquisition of [ð] in coda position. He made only one attempt, at 4;01.21, for the connected phrase *wi<u>th</u> these*, which underwent substitution to [s]. Lastly, Ben did not attempt any [ʒ] sounds in coda position.

7.8. Nasals in coda position

As shown in Figure 211, Ben acquired [ŋ] in coda at 4;02.21, with 13 accurate productions and six deletions.

Figure 211: Ben's acquisition of [ŋ] in coda



Prior to this, [ŋ] most frequently underwent deletion or substitution to a variety of sounds.

7.9. Approximants in coda position

Ben did not acquire [ɫ] or [ɹ] in coda by the end of the documented period. As illustrated in Figure 212, 412 attempts at [ɫ] in this position resulted in only three accurate productions, 206 deletions, 47 instances of gliding to both [j] and [w], and 143 vocalizations to various vowels.

Figure 212: Ben's acquisition of laterals in coda

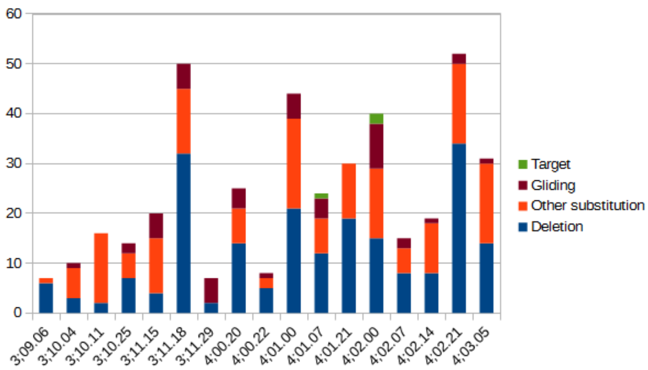
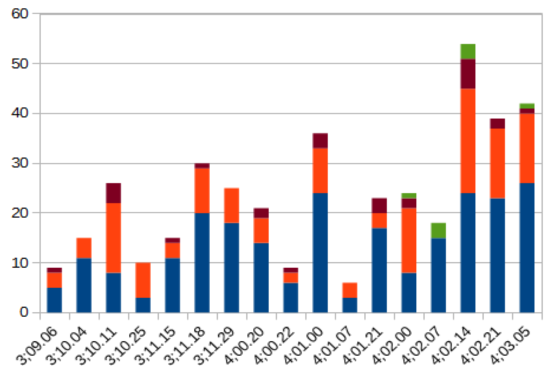


Figure 213: Ben's acquisition of [ɹ] in coda



Ben also did not acquire coda [ɹ], as shown in Figure 213. Ben made 402 attempts which resulted in 236 deletions, 131 other substitutions (mostly to various vowels), 27 instances of gliding to [j] and [w], and eight accurate productions.

7.10. Interim summary

At the start of his sessions, Ben had already acquired two sounds, [p] and [s], in coda position. Ben acquired an additional five sounds by the end of the documented period: he acquired the two voiceless stops [t] and [k], the voiceless fricatives [s] and [ʃ], and the nasal [ŋ], as summarized in Table 48.

Table 48: Ben's coda development

	3;09.06	3;10.04	3;10.11	3;10.25	3;11.18	3;11.29	4;02.21	4;03.05	Not acquired
[p]	√	√	√	√	√	√	√	√	
[s]	√	√	√	√	√	√	√	√	
[ʃ]	—	√	√	√	√	√	√	√	
[t]	S	S	√	√	√	√	√	√	
[k]	S	S	S	√	√	√	√	√	
[ŋ]	S	—	D	—	D/S	D/S	√	√	
[b]	D	—	—	D	—	V	—	V	X
[d]	D	D	V	V	V	—	V	V	X
[g]	D	S	—	D	D/V	S	V	V	X
[f]	—	—	D	—	—	—	—	—	X
[v]	—	D	S	D	V	D	V	S	X
[θ]	—	—	—	—	S	S	S	S	X
[ð]	—	—	—	—	—	—	—	—	X
[z]	V	V	V	V	V	V	V	V	X
[ʒ]	—	—	—	—	—	—	—	—	X
[ɫ]	D	S	S	D	D	S	D	D/S	X
[ɹ]	D	D	S	S	D	D	D	D/S	X

Legend: √ Acquired; X Not acq; — Not attempted; D(eletion); S(ubstitution); V(oicing Error); T(arget); R(eduction)

Ben's acquisition of coda consonants resembled his acquisition of onset consonants in several ways: Ben acquired the nasal [ŋ] and the voiceless fricatives [ʃ] and [s] in coda, similar to his acquisition of nasals, [ʃ], and [s] in onset (however, the voiceless fricative [f] was also acquired in onset position but not in coda).

Fronting did not affect coda [k] and [g] the same way that it affected these sounds in both singleton onsets and onset clusters. In coda position, Ben acquired [k] and its most frequent error consisted of glottal stop substitution. Ben did not acquire coda [g], however this was due to its production as its voiceless counterpart [k], not fronting to [d].

Interestingly, Ben's development displayed a wide number of asymmetries; velar fronting, fricative gliding, and the prevocalic voicing of stops occurred in word-initial but not word-final position, whereas the devoicing of stops affected word-final position only (McAllister Byun 2011; 2012).

In onset position, Ben did not acquire any voiceless stops, as he produced them as their voiced counterparts, yet the reverse occurred in coda position: he did not acquire any voiced stops but produced them as their voiceless counterparts instead. Finally, Ben only acquired voiceless fricatives in both positions. These observations yield the summary in Table 49 below.

Table 49: Summary of Ben's phonological development

3;09.06	3;10.04	3;10.11	3;10.25	3;11.18	3;11.29	4;02.21	4;03.05	Not acquired
ONSET								
[n] [m] [w] [j] [b] [d]				[ʃ]	[s]		[f]	[p] [t] [k] [g] [v] [θ] [ð] [z] [ʒ] [h] [ʧ] [ʤ] [l] [ɹ]
ONSET CLUSTERS								
								Stop-lateral Stop-rhotic Stop-glide Fricative-lateral Fricative-rhotic Fricative-glide Nasal-glide
CODA								
[p] [s]	[ʃ]	[t]	[k]			[ŋ]		[b] [d] [g] [f] [v] [θ] [ð] [z] [ʒ] [ɫ] [ɹ]

Similar again to his onset and cluster development, Ben did not acquire [l] or [ɹ] in coda position. However, [l] and [ɹ] in coda position were most frequently deleted or produced as vowels, instead of glided to [w] or [j] (the most prominent substitution affecting these consonants in onset). When liquids did not undergo deletion, Ben glided or vocalized liquids in all word positions.

8. General summary of case studies

As detailed in the above case studies, certain trends emerged in the children's productions. Stops and nasals were typically the first sounds acquired by all of the children in onset position, and the fricative [h] occurred early for all learners of both Germanic languages. Similarly, to the extent applicable to the different languages that have these consonants in their inventories, onset and coda [ʃ] and [ʒ], and rhotics across all relevant positions, were among the last sounds acquired, if they were acquired at all.

In general, the children learning languages with clear [l] in coda position (i.e., French, German) learned this sound earlier than children who displayed velarized [ɫ] in coda position (i.e., English, Portuguese). However, compared to rhotics, laterals emerged earlier across all word positions with one exception: in German, C[ʀ] clusters emerged before C[l] clusters for both German-learning children.

As for substitutions, only the English [ɹ] underwent gliding. The German children substituted [ʀ] with [h], Inês stopped [ʀ] (to [ɡ]), and Adrien deleted [ʀ].

As previously discussed, in terms of voicing errors, Eleonora produced voicing errors for onset stops, and Wiglaf produced voicing errors for onset stops and fricatives. As noted in McAllister Byun (2009; 2011), Ben displayed syllable-initial voicing of stops. No other children produced voicing errors in onset position; however, Adrien and William displayed some voicing errors for various codas and Ben devoiced all voiced stops in coda position (McAllister Byun 2009: 45).

Fronting only occurred in Germanic languages, with both Ben and Eleonora displaying varying levels of velar fronting. As for consonant harmony, no pattern emerged across languages or language families as Adrien, Eleonora, and Inês displayed consonant harmony across a wide range of phonological environments.

This completes my description of six longitudinal case studies. In the next chapter, I use the descriptions above to provide a systematic assessment of the implicational relationships proposed by Gierut (2007). Wherever relevant, I discuss the various relationships from a theoretical standpoint as well. As we will see, this discussion leads to a general refutation of any hypothesis about implicational relationships, beyond those that describe long-standing observations in child phonology. In subsequent chapters, I return to these case studies to entertain alternative hypotheses about the development of phonological abilities in children.

Chapter 4: Implicational relationships involving segmental development

In this chapter, I use the data from the case studies described in the preceding chapter to evaluate the validity of Gierut's (2007) implicational relationships, building on the related discussions laid out in Chapter 3. As we will see, the relationships fall into several logical classifications: first, several of the relationships derive from basic facts of speech development; second, some relationships draw unwarranted comparisons between unrelated structures; and lastly, many of the relationships interact with specific aspects of some of the languages' phonological systems, but cannot be considered universal, as they are influenced by language specific factors and individual learning paths.

Gierut's implicational relationships use broad category descriptors such as *liquid* and *stop*, which make reference to multiple sounds and sound classes (e.g., *stop* encompasses both obstruent and nasal stops). As we will see, a consequence of this is that within a given phonological category (e.g., fricatives), no distinction is made across other, possibly relevant, phonological dimensions (e.g., place of articulation). Therefore, to evaluate the relationships, only the occurrence of a subset of the category needs to be present to consider a category to be acquired. Gierut's approach also relies on a very permissive criterion to determine acquisition (if a phone or feature is used at all, it is considered present in the child's system). This negatively affects both the explanatory power of the implicational relationships and our ability to make predictions. Below, I evaluate the implicational relationships using more cohesive criteria, in particular that sounds or features have to be acquired by the child, as opposed to simply used in select occurrences, to count toward any of the proposed relationships.

The patterns discussed below show that this type of broad feature classification is too vague, especially for clinical treatment targets. Among other considerations, the data show that all members of a broad feature category should not necessarily be treated equally in terms of complexity or ease of acquisition. For example, if a child is unable to produce fricative consonants, beginning treatment with interdental [θ] may come with more complications than beginning with a fricative sound with another place of articulation, such as alveolar [s]; additionally, strident fricative consonants, such as [s], are acoustically more salient than non-strident fricatives such as [θ], which may aid in their acquisition. This, and other treatment considerations, are discussed further in Chapter 7.

I begin my investigation into the validity of Gierut's (2007) 22 implicational relationships with a comparison of the data from all six children (see Table 61 at the end of this section for a summary of the results). Unless otherwise specified by the relationship, I examined the ages of acquisition among singleton onsets in order to make the cross-linguistic comparisons as uniform as possible. For all relationships, I take into consideration whether other factors besides markedness can account for them (e.g., structural, perceptual, articulatory, or grammatical). These findings will be discussed further in Chapter 6.

1. Relationship between stridency, liquids, stops, and glides

The first implicational relationship described by Gierut (2007) is that whereby "a stridency and/or laterality distinction implies the phonetic occurrence of a liquid, which implies a fricative and/or affricate, which implies a voice distinction among cognate stops, which implies a nasal and a glide."

1.1. Empirical tests

This relationship is, in its very formulation, rather challenging to assess, or to apply to any dataset, as it requires comparison of the age of acquisition for eight different phonological features. The age of acquisition for each sound category (based on the first member of the category acquired) and for each child is summarized in separate tables below. For the part of the relationship involving voicing contrasts, this refers to the age at which a child's voiced and voiceless counterparts of cognate stops were both acquired (one member of the category may be acquired considerably earlier). The data for all six children contradict the predictions made by this implicational relationship.

As shown in Table 50 below, various features from William's data do not fit with Gierut's description of this implicational relationship. William acquired the nasal [m] at 1;04.12, and the glide [w] at 1;06.05. As for the cognate stop contrasts, he acquired [t] at 1;06.05 and [d] at 1;04.12, therefore making the age of acquisition for this pair the later date of 1;06.05; he acquired [k] at 1;04.12, [g] at 1;06.19, [p] at 1;07.08, and [b] at 1;04.12. The earliest member acquired for the other categories was as follows: fricative [h] at 1;04.12; affricate [ʧ] at 1;08.02; liquid/lateral [l] at 1;04.25; and strident [s] at 1;04.12.

Table 50: William's summary for first implicational relationship

	1;04.12	1;04.25	1;06.05	1;06.19	1;07.08	1;08.02
Nasal	√	√	√	√	√	√
Glide			√	√	√	√
Voicing			√ [t/d]	√ [k/g]	√[p/b]	√
Fricative	√	√	√	√	√	√
Affricate						√
Liquid		√	√	√	√	√
Stridency	√	√	√	√	√	√
Lateral		√	√	√	√	√

William's acquisition of affricates in particular proves problematic for this implicational relationship, as they were the last category acquired. Therefore the presence of liquids, stridents, and laterals does not imply affricates as stated in the implicational relationship. Note that this issue cannot be attributed to a gap in the data, as William was making attempts at affricates from the beginning of his documented sessions at age 1;04.12. Additionally, fricatives were among the earliest category acquired; their presence in William's system does not imply the presence of glides or a voicing contrast among cognate stops.

As Gierut does not distinguish between members of each category, it is interesting to note the range of acquisition ages for each. For example, while William acquired the earliest strident [s] at 1;04.12, he did not acquire [ʒ] by the end of the documented period at 2;11.14. See Table 51 for a summary of the age ranges in which different members of each category were acquired; for ease of comparison, and to eliminate positional factors, only onsets were taken into account.

Table 51: Implicational relationship one: age range for acquisition per category for William

	Earliest		Latest	
Nasal	[m]	1;04.12	[n]	1;04.25
Glide	[w]	1;06.05	[j]	1;06.19
Voicing contrasts	[t/d]	1;06.05	[p/b]	1;07.08
Fricative	[h]	1;04.12	[ð]	Not acquired
Affricate	[ʧ]	1;08.02	[ʤ]	1;09.25
Liquid	[l]	1;04.25	[ɹ]	1;07.08
Strident	[s]	1;04.12	[ʒ]	Not acquired
Lateral	[l]	1;04.25		

Similar to William, Adrien's data contradicts this implicational relationship, as illustrated below in Table 52. As discussed in the previous case studies, Adrien acquired the nasal [m] at 1;11.14, and both glides [w] and [j] at 2;09.13. He acquired the contrast between [t/d] by 2;01.13 or earlier, with [t] acquired at 2;00.16 and [d] at 2;01.13. He then acquired the other cognate stop pairs [k/g] and [p/b] at age 2;02.20. He acquired the first member of the remainder of the relevant categories as follows: fricative/strident [v] at 2;02.20, and liquid/lateral [l] at 2;04.16 (affricates could not be evaluated in this relationship, as they do not occur in native French words).

Table 52: Adrien's summary for first implicational relationship

	1;11.14	2;01.13	2;02.20	2;04.16	2;05.13	2;09.13	2;11.11	3;03.13
Nasal	√	√	√	√	√	√	√	√
Glide						√	√	√
Voicing		√[t/d]	√[p/b][k/g]	√	√	√	√	√
Fricative			√	√	√	√	√	√
Affricate	[irrelevant to French]							
Liquid				√	√	√	√	√
Stridency			√	√	√	√	√	√
Lateral				√	√	√	√	√

Adrien's acquisition of glides is problematic for this implicational relationship: he acquired glides after voicing contrasts, liquids, stridents, and laterals, thus contradicting most of the predictions made by this relationship (i.e., that all of these categories imply glides and not vice versa).

Eleonora's data also contradicts this implicational relationship. As we saw in Chapter 3, she acquired nasal [n] at 1;01.11, and glide [j] at 1;08.15. For the voicing contrasts, she acquired both pairs of [t/d] and [p/b] at the same age, 1;02.07. She acquired the [k/g] contrast later, at 1;08.26, with [k] acquired at 1;06.05 and [g] acquired at 1;08.26. The other categories involved in this implicational relationship were acquired as follows: fricative [h] at 1;00.07; liquids/laterals at 1;06.29 with [l]; and stridents at 1;06.15 with [v].

Due to the placeless nature of [h], as it articulatorily results from airflow with no supralaryngeal constriction, others in the literature have classified [h] as a glide (e.g., Locke 1983; Vihman & Velleman 1989). If we do classify [h] as a glide, this can explain its early development in comparison to Eleonora's later fricatives, which do not emerge until six months later. However, the possible exceptionality of [h] is not addressed under Gierut's use of the term fricative.

As shown in Table 53, Eleonora had not acquired affricates by the latest documented corpus session, and therefore her developmental patterns contradict the featural implications proposed by Gierut. Eleonora's acquisition of fricatives also pose a problem, as they do not imply the voicing contrast among cognate stops, nor do they imply glides or nasals.

Table 53: Eleonora's summary for first implicational relationship

	1;00.07	1;01.11	1;02.07	1;06.15	1;06.29	1;08.15	1;08.26	1;10.02	Not acquired
Nasal		√	√	√	√	√	√	√	
Glide						√	√	√	
Voicing			[t/d]/[p/b]	√	√	√	[k/g]	√	
Fricative	√	√	√	√	√	√	√	√	
Affricate									X
Liquid					√	√	√	√	
Stridency				√	√	√	√	√	
Lateral					√	√	√	√	

Wiglaf's data also do not fit with this implicational relationship, as illustrated in Table 54. He acquired the nasal [n] at 1;05.03, the glide [j] at 1;05.26, the voicing contrast between [p/b] at 1;06.12, the fricative [h] at 1;05.26, the affricate/strident [ʦ] at 2;01.07, and the liquid/lateral [l] at 1;10.28. His acquisition of fricatives does not imply a voicing contrast between cognate stops, and his late acquisition of affricates contradicts the hypothesis that affricates imply the presence of liquids/laterals.

Table 54: Wiglaf's summary for first implicational relationship

	1;05.03	1;05.26	1;06.12	1;10.28	1;11.13	2;00.17	2;01.07
Nasal	√	√	√	√	√	√	√
Glide		√	√	√	√	√	√
Voicing			√[p/b]	√	√ [k/g]	√ [t/d]	√
Fricative		√	√	√	√	√	√
Affricate							√
Liquid				√	√	√	√
Stridency							√
Lateral				√	√	√	√

Inês's acquisition data more closely fits with this implicational relationship; however it still does not match the required order of acquisition. Glides and affricates could not be evaluated in this relationship, as they do not occur in Portuguese. Inês acquired nasal [m] at 0;11.14, and fricative [f] at 2;07.16. The contrast between cognate stop pairs were acquired as follows: [t/d] at 1;03.06; [p/b] at age 1;04.09; and [k/g] at age 1;09.19. She acquired liquid/lateral [l] only at 2;01.10.

Inês's acquisition of laterals pose a problem for this implicational relationship: the presence of laterals does not imply stridents or fricatives, nor does the presence of liquids imply fricatives, as shown in Table 55.

Table 55: Inês's summary for first implicational relationship

	0;11.14	1;03.06	1;04.09	1;09.19	2;01.10	2;07.16
Nasal	√	√	√	√	√	√
Glide	[irrelevant to Portuguese]					
Voicing		√[t/d]	√[p/b]	√[k/g]	√	√
Fricative						√
Affricate	[irrelevant to Portuguese]					
Liquid					√	√
Stridency						√
Lateral					√	√

Lastly, as Ben did not acquire many of the target features, his productions do not fit with this implicational relationship, as illustrated in Table 56. Ben had not acquired the voicing contrast between any members of the cognate stops, nor had he acquired any affricates, liquids, or laterals by the end of his available recordings. He acquired both nasals [n] and [m], and glides [w] and [j] by 3;09.06. Ben also acquired the fricative/strident [ʃ] at 3;11.18.

Table 56: Ben's summary for first implicational relationship

	3;09.06	3;11.18	3;11.29	Not acquired
Nasal	√	√	√	
Glide	√	√	√	
Voicing				X
Fricative		√	√	
Affricate				X
Liquid				X
Stridency		√	√	
Lateral				X

In contradiction to the implicational relationship, Ben had acquired fricatives without having acquired a voicing contrast between any of the cognate stops. He also acquired the feature strident without having acquired liquids or affricates.

1.2. Critical discussion

The acquisition patterns of all six children provide evidence against the validity of this implicational relationship. In addition to these observations, it is also important to note that there is no phonological, phonetic, or developmental motivation for this implicational relationship.

As previously discussed in Chapter 1, section 4.1, the evidence provided by Gierut to support this relationship, from Tyler & Figurski (1994), is based on the idiosyncratic treatment progress of one child and on a markedness hierarchy (Dinnsen et al. 1990) that I provide in detail in Table 3 (on page 21). In this hierarchy, a feature from a more complex phonetic level implies the features from less complex levels. Therefore the complex laterals and stridents must imply all of the other categories listed in this relationship (i.e., liquids, fricatives/affricates, voice distinction among cognate stops, nasals, glides). However, once we exclude cross-linguistic markedness as a determining factor, we are left with no independent motivation for this relationship, be it of phonological, phonetic, or developmental nature. The set of phones implied by these features is vast, and any claim about potential implications between them or their development remains largely unsubstantiated.

2. "Consonants imply vowels"

2.1. Empirical tests

To the best of my knowledge, there has never been an attested case of a child that produces consonant sounds but does not have any vowel sounds in their inventory. There are documented cases of consonant-less children (e.g., Rialland, Le Normand & Wauquier 2011) but none of children who have consonants in their productive inventory but lack vowels. Based on practical observation, there is thus evidence for this implicational relationship.

2.2. Critical discussion

While this implicational relationship is borne out by the data, there is no substance to this relationship beyond what has already been well established within the literature.

Across all languages, beginning with early vocalizations, which can be described as vowel sound productions, children follow a generally similar acquisition pattern: they increase in syllable complexity, moving from V to CV then to CV(C) (Macken & Ferguson 1983; Vihman et al. 1985; MacNeilage & Davis 1990). Vowels are thus the first units produced, such that their presence logically implies the presence of consonants.

3. "Affricates imply fricatives"

3.1. Empirical tests

This implicational relationship is attested in the data for all of the children for whom it applies (i.e., it does not apply to Adrien and Inês as French and Portuguese do not have phonemic affricates).

William acquired affricates later than fricatives, with affricate [ʧ] acquired at 1;08.02 and fricative [s] acquired by 1;04.12. Wiglaf also supports this relationships as he acquired the affricate [ʦ] at 2;01.07 and the fricative [h] much earlier at 1;05.26. While Eleonora had not acquired affricates by her latest recorded session, she acquired fricatives at an earlier age ([h] by 1;00.07). Therefore her data support this relationship. Ben follows a similar pattern as he did not acquire affricates by his last session; however, fricative [ʃ] was acquired earlier, at 3;11.18.

3.2. Critical discussion

It is logical to assume that fricatives must be acquired before affricates. As a fricative release is a required part of the production of affricates, the ability to produce frication in isolation would logically precede this. Similar to the above relationship regarding vowels and consonants, this relationship appears to follow logically from considerations about articulatory development. As such, it does not need to be elevated to the rank of any kind of grammatical mechanism.

4. "Fricatives imply stops"

4.1. Empirical tests

William had acquired both categories of fricatives and stops by his earliest recorded session, therefore I cannot use his data to investigate this relationship.

Adrien, Wiglaf, Inês, and Ben's acquisition data supports this implicational relationship. Adrien acquired fricatives at age 2;02.20 with [v], and stop [t] earlier at 2;00.16. Similarly, Wiglaf acquired fricative [h] at 1;05.26, and stop [p] earlier at 1;03.21. Inês acquired fricative [f] at 2;07.16, and stop [d] by 1;00.25. Ben acquired fricatives at 3;11.18 with [ʃ] and stops [b] and [d] earlier by 3;09.06.

Eleonora's data however contradict this implicational relationship. Eleonora had acquired stops at 1;01.11 with [b], however she had already acquired fricative [h] by the earliest documented session at 1;00.07. This implicational relationship thus works for all of the children, except German-learner Eleonora who acquired [h] early.

4.2. Critical discussion

It is generally established in the literature (on data from English-learning children) that stops are one of the earliest-acquired sound categories. Winitz & Irwin (1958) studied 93 children, ages 13-18 months, and found that stops and nasals comprised almost 80% of total consonants produced.

Additionally, Stoel-Gammon (1985) found that early inventories contain stops, nasals, and glides while fricatives and liquids appear later. Stoel-Gammon's study examined longitudinal data of early meaningful speech forms from 34 children, from ages 9-24 months, at three month intervals (all children were nine months of age at the beginning of the study).

While Eleonora's data does contradict this relationship, it is due solely to the early occurrence of laryngeal fricative [h] at 1;00.07, which resulted from her productions of the word *hallo* [ˈhaloː]. She acquired her next fricative, [v], over six months later, at 1;06.15, which would fit with this implicational relationship and the reported literature. Also, as previously mentioned, Locke (1983) classified /h/ as a glide instead of as a fricative, as did Chomsky & Halle (1968). However, the exceptional status of /h/ is not addressed by Gierut.

In spite of its arguable empirical accuracy, this relationship also seems to follow from basic logic in articulatory development: full closure of the vocal tract is articulatorily simpler than partial closure, especially the closure involved in the production of fricatives (and affricate release) as opposed to that posed by approximants (vowels and glides). Among other things, this explains why stopping primarily affects fricatives, as opposed to all continuant sounds (Rose 2014). As discussed by McAllister Byun (2011), the production of fricatives at every place of articulation, involves rather subtle, and difficult to master, articulatory plans. In line with my discussion of the second and third relationships above, it remains disputable that such basic facts about speech articulation be promoted as a form of grammatical implication.

5. "Voiced obstruents imply voiceless obstruents"

5.1. Empirical tests

As the term *obstruent* encompasses many sounds, I chose the first occurrence of any sound that was acquired under this category (i.e., any stop, fricative, or affricate) to establish the validity of this implicational relationship.

To examine whether this relationship can be validated by the typical English data, earlier documentation of William's development would have been necessary, as he had acquired both voiced and voiceless obstruents by the earliest age studied, namely voiced stops [b] and [d] and voiceless stop [k], by 1;04.12. Interestingly, while William also had acquired the voiceless fricative [s] at 1;04.12, he did not acquire any voiced fricatives until 1;08.02 (with [z]), and the voiced affricate [ʤ] was not acquired until 1;09.25. Additionally, William did not acquire fricatives [θ] and [ð] by the last recorded session.

Data from three of the remaining children, Adrien, Eleonora, and Wiglaf, support this implicational relationship, at least partially, while data from the other two children, Inês and Ben, undermine it.

Adrien, Eleonora, and Wiglaf's data support this implicational relationship. Adrien acquired the voiceless stop [t] at 2;00.16, and did not acquire a voiced obstruent until 2;01.13 (voiced stop [d]). While this relationship is supported by Adrien's data if we look solely at stops, it no longer holds if fricatives are taken into consideration: Adrien acquired a voiced fricative first ([v] at 2;02.20) and did not acquire a voiceless fricative until almost nine months later ([f] at 2;11,11).

This relationship also receives support from Wiglaf's data, as he acquired the voiceless stop [p] at 1;03.21, and the voiced stop [b] at 1;06.12. Similarly, Eleonora acquired the voiceless fricative [h] by her earliest session 1;00.07, and the voiced stop [b] later, at 1;01.11.

Contrary to Adrien, Eleonora, and Wiglaf, Inês and Ben did not acquire voiceless obstruents before voiced obstruents. Inês acquired the voiced stop [d] at 1;00.25 and the first voiceless obstruent that she acquired appeared later (the voiceless stop [p], at 1;01.30). Ben also had acquired voiced obstruents by his earliest corpus session (3;09.06), with voiced stops [b] and [d], and he did not acquire a voiceless obstruent until the voiceless fricative [ʃ] at 3;11.18. Finally, Ben never acquired any voiceless stops in onset position given the available corpus data, therefore the relationship can be examined by Ben's data only if we use the broad obstruent category.

5.2. Critical discussion

The wide age range over which the children acquired the sounds that fall into these categories highlights the uninformative nature of a broad descriptor like *obstruent* when describing phonological development.

The literature on English phonological development shows that obstruent sounds occur first and most frequently in early child language and that voiceless consonant sounds are typically preferred. Locke (1983) reviewed data from three studies of 124 children, ages 11-12 months. He found that 12 phones made up approximately 95% of the consonant sounds produced: stops [p, t, k, g, t, d], nasals [m, n], glides [w, j, h], and fricative [s]. Locke illustrated that there is a sound preference hierarchy in babbling, with the preferred consonant-like sounds being labial and apical stops (voiceless unaspirated), glides, and nasals. The commonalities between these sounds occurring in both babbles and in early meaningful speech productions suggest a continuity across phonological development (Stoel-Gammon 1985). Stoel-Gammon (1985) also found that voiceless fricatives emerged first (before voiced fricatives) in both initial and final position.

Beyond these general observations, the current data show that this implicational relationship cannot be taken as a universal. While the relationship does receive support from Adrien's data, it only does so if we compare stops to fricatives; Adrien's data also contradicts Stoel-Gammon's observations in that he acquired voiced fricatives considerably earlier than voiceless fricatives. The relationship is also contradicted by the Portuguese data, as voiced stops were acquired before voiceless ones by Inês.

This implicational relationship is also not borne out by the clinical English data, and the exact opposite of the implicational relationship occurs if we look solely at stops: Ben acquired two voiced stops in the absence of any voiceless stops. Therefore, applying a universal hierarchy of sound development to atypical acquisition also seems unwarranted.

6. "Liquids imply nasals"

6.1. Empirical tests

This implicational relationship is supported by data from all six children. William had already acquired the nasal [m] by his earliest available session, 1;04.12, and he did not acquire his first liquid sound until [l] at 1;04.25. Similarly, Adrien had acquired the nasal [m] by his first recorded session, 1;11.14, and did not acquire a liquid sound until 2;04.16 (when he acquired [l]). Eleonora acquired the nasal [n] at 1;01.11 and acquired her first liquid [l] at 1;06.29. Wiglaf acquired [n] at 1;05.03 and the liquid [l] later, at 1;10.28. Inês had also acquired the nasal [m] by the beginning of her data collection at 0;11.14, and acquired [l] at 2;01.10. Ben had not acquired any liquid sounds by the end of his corpus data; however, he had acquired nasals [n] and [m] by his first recorded session, 3;09.06.

6.2. Critical discussion

All six children acquired nasals before liquids. As commonly established in the literature, Winitz & Irwin (1958), Ingram (1981), Locke (1983), and Stoel-Gammon (1985) all found that nasals occur before liquids in both babbles and early meaningful speech. The early occurrence of nasals appears to be a cross-linguistically-valid observation (since at least Jakobson 1941;1968).

Nasals occur early cross-linguistically due to their relative ease of articulation. Once a child learns to control the tongue, and not rely on linked jaw movements, "control over soft palate closure predicts growth in alternation of nasals and orals" (Davis, MacNeilage & Matyear 2002: 77). In comparison, laterals involve rather complex articulation, as they combine opening of the oral cavity with full contact of the tongue tip (Ladefoged & Maddieson 1996; Santos 2007).

In line with other implications discussed above, this relationship appears to reflect basic facts about speech articulation. As such it does not require promotion to that of a grammatical mechanism.

7. "Velars imply coronals"

7.1. Empirical tests

I cannot establish the validity of this relationship using data from William as he had acquired both velars ([k]) and coronals ([d]) by the earliest documented age, 1;04.12. The acquisition data from the other five children however, provide support for this implicational relationship.

Adrien acquired velar [k] at 2;05.23 and coronal [t] earlier, at 2;00.16. Eleonora acquired velar [k] at 1;06.05 and coronal [t] at 1;01.11. Wiglaf acquired [k] at 1;11.13 and coronal [t] at 1;07.11. Inês acquired velar [k] at 1;03.06 and coronal [d] by 1;00.25. Ben did not acquire any velar sounds in onset position by the end of his corpus, but he had acquired coronal [d] in onset position by his first session at 3;09.06. Ben acquired the velar sound [k] in coda position at 3;10.25, however both his onset and coda acquisition of velars support this relationship as he acquired a coronal first in both positions.

7.2. Critical discussion

Velar sounds are produced using the back part of the tongue (the tongue dorsum) as it approaches the soft palate (the velum); velars are typically considered more difficult to produce than coronal sounds due to the relatively imprecise movements of the dorsum (for velar sounds) in comparison to the tongue tip and blade (for coronal sounds) (Ladefoged & Maddieson 1996). Also, as shown in Stoel-Gammon (1985), in late babbles, velars are less commonly attested than coronals or labials, and the acquisition of velars also generally occurs later than coronals in meaningful speech. Coronals also occur more frequently in all of the languages involved in the current study (Casagrande 1984; Dell 1995; Wiese 1996; Hammond 1999; Mateus & d'Andrade 2000; Fox 2007; Smit 2007; Yavaş & Mota 2007). Therefore, both articulatory complexity and frequency conspire to favour the mastery of coronals over velars. In line with the argument made above regarding several of the other relationships, we should not attribute a grammatical status to what may amount to a conspiracy of factors toward a predicted outcome.

Additionally, for all of the children, this implicational relationship receives support only when taking into account the coronal sounds [t] and [d] in onset. As the category of coronal contains a wide array sounds (e.g., [ʃ], [ʒ], [l], [ɹ]), it would be more accurate to state that velars [k] and [g] in onset imply the sounds [t] and [d] in onset. For example, the relationship is not borne out by any of the children's data (with the exception of Ben, who does not acquire velar onset sounds in the current data) if we consider the coronal sounds [ʃ], [ʒ], and [ɹ]. These observations support the phonetic view outlined above over a more general implication between phonological features.

8. "Fricatives in initial position imply fricatives in final position"

8.1. Empirical tests

This relationship is supported by data from Wiglaf, Inês, and Ben. However it is contradicted by data from William, Adrien, and Eleonora.

The data from Wiglaf, Inês, and Ben provide support for this relationship. Wiglaf acquired [h] in onset at 1;05.26 and [f] in coda appeared earlier at 1;05.03. Inês acquired fricative [f] in initial position at 2;07.16 and fricative [ʃ] in coda position earlier at 2;00.11. Ben acquired fricative [ʃ] in onset position at 3;11.18 and fricative [s] in coda position was already acquired by the earliest age, 3;09.06.

In contrast to this, William acquired fricative [s] in onset position by 1;04.12, and his first fricative in coda position, [ʃ], was acquired later, at 1;06.05. William thus acquired the category fricative in onset position without a fricative in coda position. Similarly, Adrien acquired his first fricative in onset position, [v], at age 2;02.20, while in coda position, he acquired his first fricative, [f], only at age 3;00.16. Eleonora had also acquired fricatives in onset position by 1;00.07 with [h], and she acquired fricative [ç] in coda position later, at 1;02.14. Therefore, fricatives in initial position did not imply fricatives in final position in William, Adrien, or Eleonora's data.

8.2. Critical discussion

There is evidence in the literature that children acquire sounds in initial and final position differently. Stoel-Gammon (1985) found that consonants in initial and final position do not develop in an identical way. She stated that a new place and manner generally emerge in initial position before occurring in final position. However, while she also observed that voiceless fricatives appear before voiced fricatives in both word initial and final position, there appeared to be no preference as to whether fricatives emerged in word initial or final position first. This contradicts Ferguson & Farwell (1975), who state that fricatives typically appear first in final position, which agrees with the premise of this implicational relationship. In addition, a multitude of research provides support that fricatives are favoured in weak syllable positions (Chiat 1983; Dinnsen 1996; Edwards 1996; Velleman 1996; Marshall & Chiat 2003; Inkelas & Rose 2007; McAllister Byun, Inkelas & Rose 2016).

Further evidence for this can be drawn from cases of positional fricative stopping, where the tendency is for neutralization to occur in prosodically strong environments (Rose 2014). For example, Inês (as detailed in Chapter 3) stopped fricatives in syllable onset position but not in coda position.

More generally, using the term fricative to describe and predict the children's development does not provide an accurate picture of the children's development of this complex class of sounds. For example, William's age range for acquiring fricatives in onset position spans from 1;04.12 for [h] to beyond 2;11;14 for [ð], as he did not acquire this sound during the documented period. Similarly, Adrien ranged from 2;02.20 for [v] to later than 4;01.13 for [ʃ]; Wiglaf from 1;05.26 for [h] to beyond 2;00.17 for [z]; Eleonora from 1;00;07 for [h] to past 1;10.02 for [ʃ]; and Ben from 3;11.18 for [ʃ] to beyond 4;03.05 for [θ].

9. "Stops in final position imply stops in initial position"

9.1. Empirical tests

This relationship is supported by data from William, Adrien, Eleonora, and Wiglaf. It is not applicable to Portuguese, as the language does not allow stops in coda position. Finally, I cannot evaluate this relationship using Ben's data because he had acquired stops in both initial and final position by his first documented session.

William acquired the stop [k] in coda position at 1;06.05 and the stop [b] (among others) in initial position by his first recorded session, 1;04.12. Adrien acquired the stop [t] in coda position at 2;02.20 and [t] in onset position at 2;00.16. Eleonora acquired the stop [p] in coda position at 1;04.02 and [b] in onset position earlier at 1;01.11. Wiglaf acquired the stop [p] in onset at 1;03.21 and [p] in coda at 1;05.03.

9.2. Critical discussion

This relationship, which involves stops by word position, describes the reverse of the previous relationship involving fricatives by word position (i.e., stops are acquired first in onset, whereas fricatives are acquired first in coda). Therefore, it can be accounted for using precisely the same considerations as previously discussed. As mentioned above, there is evidence for this relationship in the literature, as Stoel-Gammon (1985) found that stops generally appeared in initial position first and then in final position. In terms of place and manner, new sounds typically emerged in initial position. The notion that stops favour strong position is perhaps less prominently discussed in the literature because phonological pressures are more prominent concerning fricatives. Additionally, as CV syllables generally develop before CVC syllables, and as stops are one of the earliest acquired categories, it would be difficult for this relationship to develop in an alternate way.

10. "Word-initial /r/ implies post-vocalic /r/"

10.1. Empirical tests

This relationship is not borne out by any of the children's data. It may be supported by Adrien's data, as he acquired rhotics in onset and coda position at the same age. Ben's data do not permit an assessment of this implication, as he had not acquired either category by the end of his recordings.

William acquired word-initial [ɹ] at 1;07.08, however he did not acquire coda [ɹ] until 2;02.09. Adrien acquired both word-initial and coda [ʁ] at 4;01.13. Eleonora acquired word-initial [ʀ] at 1;10.02 and she did not acquire word-final [ʀ] by her last recorded session, 1;10.25. Similarly, Wiglaf acquired onset [ʀ] at 1;11.13 and did not acquire word-final [ʀ] during his documented sessions. Finally, recall that Portuguese has two different rhotic phonemes. Inês acquired word-initial [ʀ] at 3;00.15 and she did not acquire word-final [ɾ] by her last documented session.

10.2. Critical discussion

While this implicational relationship is contradicted by the data from William, Eleonora, Wiglaf, and Inês, it is supported elsewhere in the literature, for example by Stoel-Gammon (1985), who found that [ɹ] occurs first in word-final position, a fact which is also supported by Templin (1957).

I previously discussed the article that Gierut cites as evidence for this relationship in Chapter 1, section 4.2. To briefly summarize, I raised a number of issues with using the normative data from Smit (1993) in support of this relationship; these include the cross-sectional nature of the data and the compounding lexical factors, as only two words were used to evaluate word-initial /r/, and one word to evaluate intervocalic /r/. Therefore, while this finding may be reflective of a methodological artefact, or appear to hold in terms of some individual learners, it does not seem to be generalizable in light of the current longitudinal data. Additionally, /r/ emerging first in initial position falls in line with the discussion above for onset as a privileged context for phonological development.

11. "Clusters imply singletons"

11.1. Empirical tests

It is logical that the presence of clusters imply singletons, as single consonants generally emerge first in child language development, and this is exactly what we observe in the current data.

11.2. Critical discussion

In line with the discussion above, this relationship follows directly from general observations of phonological development. At a formal level, clusters are either complex constituents within syllables or series of consonantal positions across syllables (coda-onset clusters). At a more phonetic level, clusters imply a series of phonetic dimensions, each with their own acoustic properties and articulatory correlates. Either way, the fact that clusters imply singletons might result directly from the child's building of an increasingly complex system as learning unfolds: singleton positions are predicted to emerge before complex sequences of units or contexts.

As established in the literature, cluster development is contingent on single consonant development (e.g., Fikkert 1994) and this implicational relationship is a logical extension of that fact.

12. "Clusters imply affricates"

12.1. Empirical tests

This relationship is not applicable to Adrien and Inês, as French and Portuguese do not have phonemic affricates. Both Eleonora and Ben require later sessions in order to evaluate this relationship, as neither acquired clusters nor affricates during their documented sessions. William's data supports this relationship, while Wiglaf's data contradicts it.

The earliest cluster type that William acquired is the stop-glide cluster, at age 1;09.25. William acquired the English affricate [ʧ] earlier, at 1;08.02, and [ʤ] at the same age (1;09.25). Therefore, his data supports this implicational relationship. Wiglaf acquired the fricative-rhotic cluster type at 1;10.28, but he acquired his first affricate, [ʦ], later, at 2;01.07, thereby contradicting the predicted order of acquisition.

12.2. Critical discussion

The current data show that, at the very least, the relationship is not universal and therefore cannot relate to universal notions of markedness. Additionally, as discussed above in Chapter 1, section 3, clusters and affricates involve structures at different levels of representation (syllable-level for the complex onset vs. segmental for the affricate). Irrespective of theoretical stance, the phonetic strings involving affricates and clusters do not display the same phonotactics, and therefore must be learned independently of one another.

In addition, this implicational relationship only makes vague predictions: it does not predict the actual order of acquisition for clusters or affricates, as not all cluster types or affricates were acquired in set orders. For example, William acquired stop-glide clusters first, at 1;09.25, while he acquired nasal-glide clusters much later, at 2;11.14. The relationship also makes wrong predictions for some of the individuals, as Wiglaf acquired three different cluster types (fricative-rhotic at 1;10.28, stop-lateral at 1;11.03, and fricative-lateral at 1;11.13) before acquiring a single affricate at 2;01.07. He also did not acquire the other two German affricates ([ʧ] and [p͡f]) by his last documented session.

13. "Clusters with a small sonority difference imply clusters with a greater difference"

13.1. Empirical tests

To investigate this relationship, I evaluated several different types of clusters (excluding all sC clusters, and ʃC clusters for German, as these clusters have been shown to display their own developmental paths in comparison to other branching onsets (e.g., C+liquid) (Barlow 1997; Goad & Rose 2004)). Eleonora and Ben require later sessions to evaluate this relationship, as neither acquired consonant clusters within the periods documented by their corpora. The specifics of this relationship are reflected in William's data. However they are not borne out in Adrien, Inês, and Wiglaf's data.

William acquired stop-glide clusters at 1;09.25, stop-lateral clusters at 1;10.12, stop-rhotic clusters at 2;00.12, fricative-lateral clusters at 2;00.12, fricative-glide clusters at 2;04.03, fricative-rhotic clusters at 2;09.05, and nasal-glide clusters at 2;11.14. Table 57 below summarizes these clusters in the order that is predicted by the implicational relationship, relative to the cluster's initial consonant.

Table 57: Summary of William's onset cluster acquisition

	1;09.25	1;10.12	2;00.12	2;02.21	2;04.03	2;09.05	2;11.14
Stop-glide	√	√	√	√	√	√	√
Stop-rhotic			√	√	√	√	√
Stop-lateral		√	√	√	√	√	√
Fricative-glide					√	√	√
Fricative-rhotic						√	√
Fricative-lateral			√	√	√	√	√
Nasal-glide							√

The cluster type with the smallest sonority difference (nasal-glide) was the last acquired (and therefore does imply the clusters with a larger sonority difference), and the cluster with the largest sonority difference was acquired first. The specifics of this relationship may work for each cluster, as fricative-glide clusters were not attempted until the session where they were first observed to be acquired. There were also minimal attempts at fricative-lateral clusters before acquisition as well.

Adrien acquired fricative-rhotic and stop-rhotic clusters at 4;01.13, as summarized in Table 58 below. As described in Rose (2003), the acoustic evidence for uvular [ʀ] is misleading. Due to the behaviour of [ʁ] in French, this data can be interpreted in a number of ways: if we classify [ʁ] as a fricative, then Adrien's data contradict this relationship; if [ʁ] is considered a liquid, than we cannot use Adrien's data to evaluate this relationship; and lastly, if we regard [ʁ] as a rhotic, than Adrien's data provide minimal support for the relationship.

Table 58: Summary of Adrien's onset cluster acquisition

	4;01.13	4;03.27+ (not acquired)
Stop-lateral		X
Stop-rhotic	√	
Fricative-lateral		X
Fricative-rhotic	√	

Inês acquired stop-glide clusters at age 2;01.10, fricative-lateral clusters at 2;08.23, and stop-lateral clusters at 2;08.23. Fricative-glide clusters may have been acquired at age 3;02.03, however she made only two attempts at this cluster in the corpus. She acquired stop-rhotic clusters at 3;10.01 and fricative-rhotic clusters by 3;11.12, as summarized in Table 59 below. She did not attempt nasal-glide clusters.

Table 59: Summary of Inês's onset cluster acquisition

	2;01.10	2;08.23	3;02.03	3;10.01	3;11.12
Stop-glide	√	√	√	√	√
Stop-rhotic				√	√
Stop-lateral		√	√	√	√
Fricative-glide			?	?	?
Fricative-rhotic					√
Fricative-lateral		√	√	√	√

While the cluster with the greatest sonority difference was acquired first, the specifics of this relationship do not work for each cluster type. For example, Inês's acquisition of fricative-lateral clusters does not imply fricative-glide and stop-rhotic clusters as predicted by the relationship. Inês's late acquisition of the stop-rhotic cluster relates to her late acquisition of the rhotic, which highlights that this relationship might minimally depend on language-specific properties, and arguably learner-specific developmental paths.

Wiglaf acquired fricative-rhotic clusters at 1;10.28, stop-lateral clusters at 1;11.03, and fricative-lateral clusters at 1;11.13. Wiglaf did not acquire the other three clusters, as summarized in Table 60 below. Note as well that Wiglaf did make attempts at the three non-acquired clusters during his documented sessions.

Table 60: Summary of Wiglaf's onset cluster acquisition

	1;10.28	1;11.03	1;11.13	2;01.07+ (not acquired)
Stop-glide				X
Stop-rhotic				X
Stop-lateral		√	√	
Fricative-rhotic	√	√	√	
Fricative-lateral			√	
Nasal-glide				X

Wiglaf's acquisition of clusters contradicts this implicational relationship, as stop-glide clusters were not acquired by the last documented session. Therefore, their presence was not implied by the stop-lateral, fricative-lateral, and fricative-rhotic clusters.

13.2. Critical discussion

This implicational relationship was borne out by William's data. However, the data from Adrien, Inês, and Wiglaf contradict it. Therefore, cross-linguistically, it appears that children do not rely on the Sonority Sequencing Principle to govern the order in which they acquire onset clusters (see also, Barlow 1997 and Goad & Rose 2004 for additional discussion).

I previously discussed the evidence that Gierut (2007) cites in support to this relationship in Chapter 1, section 4.3. In brief, the research cited (Gierut 1999) was undermined with methodological concerns, and documented only a single child's acquisition of clusters that paralleled predictions made by sonority relations to universals. However, my findings do not aim to dismiss the importance of sonority as a general organizing principle in phonology and its relevance to acquisition. William's data above, as well as others in the literature (e.g., Fikkert 1994; Freitas 1997) point at robust patterns of syllable structure development that abide by predictions made by sonority.

However, the influence of sonority on acquisition patterns is arguably not universal, if we only look at the current case studies. The development of onset clusters is also influenced by properties of the target language (Rose 2014) as well as by individual paths in the acquisition of segmental production abilities.

14. "Fricative+liquid clusters imply stop+liquid clusters"

14.1. Empirical tests

This relationship is observed in the data from William and Inês. However, it is contradicted by Wiglaf's data. The other three children would require later sessions to evaluate the validity of this implicational relationship. As we will see below, this prediction applies in a way that is specific to each language, as certain patterns emerged regarding the liquids /l/ and /r/ individually.

William acquired fricative-lateral clusters at 2;00.12, however he acquired fricative-rhotic clusters much later, at 2;09.05. He acquired stop-lateral clusters at 1;10.12 and stop-rhotic clusters later, at 2;00.12. Based on William's data, fricative-lateral clusters imply stop-lateral clusters, and fricative-rhotic clusters imply stop-rhotic clusters. Additionally, while the [l] and [ɹ] clusters pattern differently, there is evidence that the presence of a fricative-liquid cluster implies stop-liquid clusters.

Inês acquired fricative-lateral clusters at 2;08.23 and fricative-rhotic clusters over a year later, at 3;11.12. Similarly, she acquired stop-lateral clusters at 2;08.23 and stop-rhotic clusters much later, at 3;10.01. Therefore, this relationship is attested under the broad term liquid, however it is not borne out if we look at laterals and rhotics separately, as fricative-lateral clusters do not imply stop-rhotic clusters.

Wiglaf's acquisition of clusters follows a different pattern. Wiglaf acquired fricative-rhotic clusters early, at 1;10.28, stop-lateral clusters by 1;11.03, and fricative-lateral clusters at 1;11.13. He did not acquire stop-rhotic clusters by the end of his documented sessions. Therefore, fricative-lateral clusters imply stop-lateral clusters; however, fricative-rhotic clusters were acquired first by Wiglaf and imply neither stop-lateral nor stop-rhotic clusters.

14.2. Critical discussion

As discussed in previous sections, this relationship cannot be considered universal; it depends on linguistic and individual factors. While fricative+liquid clusters imply stop+liquid clusters in William's and Inês's data, the relationship is contradicted by Wiglaf's delayed acquisition of stop-rhotic clusters.

This relationship is arguably contingent on the fact that stops are generally acquired at an earlier age than fricatives, a fact we observe in the literature (for English). As already reported above, Stoel-Gammon (1985) found that early inventories contain stops, nasals, and glides while fricatives and liquids appear later. This is also supported by Winitz & Irwin (1958), Ingram (1981), and Locke (1983) as detailed in the previous discussion of the above implicational relationships.

The results above also bring into question the formal status of the descriptive term *liquid*. The feature liquid is not a feature used in mainstream phonological theory, and it is not useful in making predictions: the children did not acquire lateral and rhotic clusters at the same age, and these clusters patterned differently for all of the children during acquisition. The case study data also show that this relationship is not cross-linguistically verified, as Wiglaf continued to substitute stop-rhotic clusters up to and including his last recorded session.

15. "Liquid onset clusters imply a liquid in coda position"

15.1. Empirical tests

This relationship is supported by Adrien and Wiglaf's data, and by certain onset clusters in William's corpus. This relationship is contradicted by Inês's data. Finally, the data available for Eleonora and Ben prevent us from evaluating the validity of this relationship based on either of these datasets.

Adrien did not acquire fricative-lateral or fricative-rhotic clusters by the end of his documented sessions. He acquired stop-lateral and stop-rhotic clusters both at 4;01.13. Adrien acquired [l] in coda position earlier than these clusters at 2;02.20, thus providing evidence supporting this relationship.

Wiglaf acquired fricative-rhotic clusters at 1;10.28, stop-lateral clusters at 1;11.03, fricative-lateral clusters at 1;11.13, but did not acquire stop-rhotic clusters by the end of his recorded sessions. Like William, Wiglaf acquired the liquid [l] in coda position earlier, at 1;09.19, which provides support for this implicational relationship.

William acquired stop-lateral clusters at 1;10.12, fricative-lateral and stop-rhotic clusters at 2;00.12, and fricative-rhotic clusters at 2;09.05. He acquired [l] in coda position at 2;00.24. According to William's data, fricative-rhotic clusters imply a liquid [l] in coda position. However fricative-lateral clusters, stop-lateral clusters, and stop-rhotic clusters do not imply [l] in coda position.

Inês acquired fricative-lateral and stop-lateral clusters at 2;08.23, stop-rhotic clusters at 3;10.01, and fricative-rhotic clusters at 3;11.12. However, she did not acquire the liquid [ɫ] in coda by the end of her documented sessions, contradicting this implicational relationship.

15.2. Critical discussion

As previously discussed, Stoel-Gammon (1985) found that consonants in initial and final position do not develop in identical ways: place and manner generally emerge in initial position, and then later in final position. However, liquids were an exception which emerged first in word-final position. These findings are supported by the French and German data, while Portuguese-learner Inês's data contradicts it. This may be due to the difference in word-initial and word-final [l] in Portuguese ([l] versus [ɫ]), which would also explain why the relationship works only minimally with the English data. In the face of this weak evidence, one cannot support the validity of this relationship in the type of robust way that would be needed to make claims about it being universal.

16. Summary

Table 61 summarizes the implicational relationships for all of the children. As previously mentioned, the implicational relationships can be divided into a number of logical categories. First, there are several implications that stem from basic speech development facts, and how children progress from the least to the most articulatory complex structure or phone. As detailed above, it is unsurprising that the relationships that can be construed in terms of speech articulation are validated by all of the children's data. These relationships include: "consonants imply vowels"; "affricates imply fricatives"; "liquids imply nasals"; "velars imply coronals"; "stops in final position imply stops in initial position"; and "clusters imply singletons."

The implicational relationships that could be validated for all children rely on phonetic markedness/ease of articulation. For the relationship, "consonants imply vowels," the child is simply improving his/her ability to produce word forms with increasing syllable complexity, for example moving from V to CV then to CV(C) syllables (Macken & Ferguson 1983; Vihman et al. 1985). For "affricates imply fricatives," it is again a matter of complexity, due to the fact that a fricative release is a required part of the production of affricates; therefore the ability to produce such a sound in isolation would logically precede this. For "liquids imply nasals," it is commonly established in the literature (Winitz & Irwin 1958; Ingram 1981; Locke 1983; Stoel-Gammon 1985) that nasals occur before liquids in both babbles and early meaningful speech. The early occurrence of nasals thus appears to be a cross-linguistic phenomenon. The production of nasals requires a lowered velum so that sound energy passes through the nasal cavity in addition to through the oral cavity. It therefore appears easier to create an oral closure while maintaining an open velopharyngeal port (Kent 2004) (creating a nasal stop) than to close both (creating an oral stop). For the relationship "velars imply coronals," velars are typically considered more difficult to produce than coronal sounds due to the relatively imprecise movements of the dorsum (for velar sounds) in comparison to the tongue tip and blade (for coronal sounds). For the relationship "stops in final position imply stops in initial position," onsets are considered prosodically strong positions, as they generally involve more articulatory force than syllable codas (Chiat 1983; Inkelas & Rose 2007). The last relationship that applies to all children, that "clusters imply singletons" is again a matter of increasing complexity. It is logical that the presence of clusters imply singletons, which generally emerge first in child language development, while producing a sequence of sounds requires a more complex series of articulatory movements and coordinated motor control.

Table 61: Implicational relationship summary for all children

Observed implicational relationships	William	Adrien	Eleonora	Inês	Ben	Wiglaf
A stridency and/or laterality distinction implies the phonetic occurrence of a liquid, which implies a fricative and/or affricate, which implies a voice distinction among cognate stops, which implies a nasal and glide.	–	–	–	–	–	–
Consonants imply vowels.	√	√	√	√	√	√
Affricates imply fricatives.	√	**N/A**	√	**N/A**	√	√
Fricatives imply stops.	**Need earlier sessions**	√	–	√	√	√
Voiced obstruents (i.e., stops, fricatives, affricates) imply voiceless obstruents.	**Need earlier sessions**	√	√	–	–	√
Liquids imply nasals.	√	√	√	√	√	√
Velars imply coronals.	**Need earlier sessions**	√	√	√	√	√
Fricatives in initial position imply fricatives in final position.	–	–	–	√	√	√
Stops in final position imply stops in initial position.	√	√	√	**N/A**	**Need earlier sessions**	√
Word-initial /r/ implies post-vocalic /r/.	–	–/√	–	–	**Need later sessions**	–
Clusters imply singletons.	√	√	√	√	√	√
Clusters imply affricates.	√	**N/A**	**Need later sessions**	**N/A**	**Need later sessions**	–
Clusters with a small sonority difference imply clusters with a greater difference.	√	–	**Need later sessions**	–	**Need later sessions**	–
Fricative+Liquid clusters imply Stop+Liquid clusters.	√	**Need later sessions**	**Need later sessions**	√	**Need later sessions**	–
Liquid onset clusters imply a liquid in coda position.	–	√	**Need later sessions**	–	**Need later sessions**	√

Second, a group of implications compare phonetically and phonologically unrelated sounds, features, or syllable positions. These relationships were contradicted by all of the children's data: "a stridency and/or laterality distinction implies the phonetic occurrence of a liquid, which implies a fricative and/or affricate, which implies a voice distinction among cognate stops, which implies a nasal and glide" and "word-initial /r/ implies post-vocalic /r/." These implicational relationships lack foundations in phonological theory, and/or were based on either the idiosyncratic behaviour of a single child, or on universal markedness constraints. The relationship "a stridency and/or laterality distinction implies the phonetic occurrence of a liquid, which implies a fricative and/or affricate, which implies a voice distinction among cognate stops, which implies a nasal and glide" has no basis in phonetic markedness. As discussed in detail in Chapter 1, section 4.1, this relationship is based on a theoretical hierarchy and the promoting of one child's idiosyncratic acquisition pattern to the rank of universals. For the relationship "word-initial /r/ implies post-vocalic /r/," in terms of phonetic markedness, one should note the prosodically strong position of onsets, which gives the child access to a more salient perceptual target and, arguably, a clearer context to develop phonological productive abilities. Additionally, word-initial /r/ target pronunciations remain relatively consistent in adult speech if compared to variable post-vocalic /r/ pronunciations. Indeed, /r/ in English is considered a complex phoneme, which can be articulated in a variety of ways: the tongue may be retroflexed, where the tongue tip curls back in the mouth; the tongue may be bunched, in either the middle or front of the mouth; the lips may be rounded; and "some constrict the lower pharynx by pulling the root of the tongue backward" (Kent 2004: 26). Post-vocalic /r/ can also occur as the nucleus of the syllable (e.g., [ɚ] or [ɝ]) as opposed to word-initial /r/ which occurs as an onset in syllable-initial position. Additionally, post-vocalic /r/, in languages such as English, is influenced by the quality of the preceding vowel, creating a wide variety of /r/ articulations that the child has to master, as opposed to word-initial /r/ which remains relatively consistent.

> "Post vocalic-r (or coda-r) is traditionally described as being realized in two different ways. In one, the vowel is followed by a recognizable /r/ segment; in the other (so-called rhotic vowels, or r-colored vowels (Laver 1994)), the rhotic tongue gesture is deemed to be coterminous with the vowel (see Clark & Yallop 1990)." (Kuecker, Lockenvitz & Müller 2015: 623)

Therefore it is not surprising that /r/ is considered one of the most problematic speech sounds to treat in a clinical setting (Adler-Bock et al. 2007; McAllister Byun & Hitchcock 2012). Based on the above description, it is therefore unclear whether comparisons between word-initial and post-vocalic /r/ are even warranted, as post-vocalic /r/ can be classified as "the vocalic offglide of a rhotic diphthong (e.g., McGowan, Nittrouer & Manning 2004)" (McAllister Byun & Hitchcock 2012: 208).

The last grouping of implications involve relationships that were attested for some children but cannot be taken as universal, as they were contradicted by others. These relationships are influenced by language-specific factors, as well as by individual learning paths. The relationships which varied across the children are as follows: "fricatives imply stops"; "voiced obstruents imply voiceless obstruents"; "fricatives in initial position imply fricatives in final position"; "clusters imply affricates"; "clusters with a small sonority difference imply clusters with a greater difference"; and "fricative+liquid clusters imply stop+liquid clusters." Interestingly, these implicational relationships did not pattern together with language families. For example, the implicational relationship "fricatives in initial position imply fricatives in final position" received support from Germanic language learners Ben (English) and Wiglaf (German); however, it was contradicted by English-learning William and German-learning Eleonora. It thus appears that the results were governed by individual paths of acquisition, and cannot be explained by universal markedness (this will be further discussed below in Chapter 6, section 3). This further argues against any purported universality for these relationships, outside of the very obvious ones (for which no statement needs to be posited, as they would be redundant across different theories of phonology or phonological development that build on notions of phonetic or phonological complexity).

Overall, the results from the investigation into implicational relationships highlights the influence of speech phonetics and phonological distributions in all aspects of development. In the next chapter, I continue this discussion to address the remaining relationships proposed by Gierut (2007), which involve phonological processes as part of their formulation.

Chapter 5: Implicational relationships involving phonological processes

In addition to the 15 implicational relationships discussed above, which involve the acquisition of individual sounds and sound categories, Gierut (2007) also postulated seven relationships involving phonological processes. I cannot evaluate the validity of all of these relationships using the previously described case studies, as these relationships require the occurrence of specific phonological processes, not all of which are attested in the current dataset. Nonetheless, the first three relationships to be described below could be evaluated, as Inês displayed the process of stopping and Ben exhibited both velar fronting and the absence of a voicing contrast in final position.

As we will see, these three relationships, and the remaining four, can also be assessed based on the current literature, in addition to the literature that Gierut (2007) cites as support for the existence of these implicational relationships, which has previously been discussed in Chapter 1, section 4.

1. "Stopping implies liquid gliding"

The first implicational relationship involving processes states that "stopping (e.g., [b] for /v/) implies liquid gliding (e.g., [w] for /r/)." As discussed in Chapter 1, section 4, Gierut's evidence for this relationship comes from Dinnsen & O'Connor (2001a). This relationship is extrapolated from the evidence that Dinnsen & O'Connor use to form the separate relationship stating that "spirantization implies place harmony," which will be addressed below. In brief, Optimality Theory provides theory-internal support for this relationship: as these two processes can be formalized using OT, they must be formally related. However, in the absence of independent motivation, these relationships have no grounding in the articulatory or perceptual domains, or in the types of grammatical pressures that children face while producing speech sounds.

Further, I can evaluate this relationship using my current data, as Portuguese-learner Inês stopped all fricatives in singleton onset and onset cluster position, as described in Chapter 3 section 6 above (see Burkinshaw 2014; Rose 2014 for additional discussion). While Inês's fricatives were systematically affected by this process, she did not display any liquid gliding. As discussed in Chapter 3, section 8, the gliding of liquids only affected the productions of William and Ben, both of whom are learners of English, a language where target [ɹ] is a retroflexed rhotic approximant. In contrast to this, the other languages studied here did not display this process, which may relate to the fact that the rhotics in these languages are not phonetic retroflex approximants: French and German have the uvular fricative [ʀ], and Portuguese displays two rhotic consonants: the alveolar flap [ɾ] occurs in singleton onsets (word-medially) and branching onsets, while the uvular fricative rhotic [ʁ] occurs only in singleton onsets. Minimally, Inês's data contradict the universality of any relationship involving the co-occurrence of stopping and gliding.

Phonological development and articulatory theory also do not predict that stopping should imply gliding. In line with this, I maintain the hypothesis that Inês's stopping of fricatives results from articulatory pressures in combination with positional effects. The articulations required for fricatives require millimetre accuracy, as the articulators create a narrowing in the oral cavity slight enough to induce turbulence in the airflow but without resulting in a full occlusion at the point of articulation (McAllister Byun 2011). However, young children generally have poor motor control over their speech articulators, which often results in producing broad, ballistic gestures (Crelin 1987; Kent 1992; Kent & Miolo 1995). Much like the articulatory pressures that cause Positional Velar Fronting, as discussed in Chapter 1, section 3, we can attribute Inês's stopping to overshooting of the articulatory gesture(s) required for fricatives in syllable onsets (Burkinshaw 2014: 85; see also Chiat 1983; Inkelas & Rose 2007). These prosodically-conditioned ballistic gestures result in full closure of the vocal tract, yielding stop productions for target fricatives.

2. "Velar fronting word-finally implies velar fronting word-initially"

This relationship is well observed within the scientific literature, and supported by my current data. However, Gierut's support for this implicational relationship comes from Morrisette, Dinnsen & Gierut (2003) and, similar to the stopping relationship described above, this relationship also relies on theory-internal considerations within Optimality Theory. As velar consonants are more marked than coronal consonants (e.g., Jakobson 1971), Morrisette, Dinnsen & Gierut (2003) state that no child should have velar sounds but no coronals. Also based on universal markedness, they state that word-initial position is a strong context that preserves place distinctions, thereby warranting place-referring constraints for word-initial position:

> "In terms of context, it was found that some children merge place distinctions in the presumably strong context of word-initial position while preserving those distinctions in other contexts. These facts run counter to observed context effects in fully developed languages" (Morrisette, Dinnsen & Gierut 2003: 352).

However, I argue below that this apparent relationship results from interactions between articulatory constraints and prosody, and can therefore be explained independently of universal markedness and implicational relationships, in line with Inkelas & Rose (2003; 2007).

As described in Chapter 3, section 7, Ben displayed velar fronting in word-initial position. He was the only child in the current data to display velar fronting consistently, and his data conform to the pattern of Positional Velar Fronting, as first described by Stoel-Gammon (1985;

1996). Velar Fronting occurs when velar sounds [k, g] are produced as *fronted* coronal sounds [t, d] (see also Dinnsen 2008; Dinnsen et al. 2011). Positional Velar Fronting (henceforth PVF) occurs when velar sounds are produced as fronted coronal sounds only in certain word/syllable positions; PVF occurs in prosodically strong positions (initial and/or stressed onsets), while target velars are produced accurately in weak positions (codas, word-medial unstressed onsets) (as previously illustrated in Chapter 1, example (1)).

Inkelas & Rose (2003; 2007) (as previously summarized in Chapter 1, section 3) explore the process of PVF from both motor/articulatory (e.g., jaw and tongue movement) and grammatical perspectives (see also McAllister Byun 2009; 2010). The production of velars in prosodically strong positions causes articulatory reactions: the tongue reaches the roof of the mouth too forcibly and causes the linguopalatal contact that is required for velars to extend too far forward (into the coronal region of the palate). This results in the coronal release of target velars in strong positions. The child is grammatically accurate as her production marks the presence of the prosodically strong position, however she is motorically unable to produce the velar consonant correctly within that position (see Chapter 1, section 3, for a more detailed discussion).

As Inkelas & Rose (2003; 2007) argue, PVF is thus caused by a combination of grammatical pressures and articulatory constraints, not only independent from the notion of universal markedness and/or implicational relationships, but also in ways that contradict cross-linguistic observations about neutralization patterns. Instead, Inkelas & Rose's analysis focuses on the child's developing phonological system and its interaction with the child's articulatory development.

3. Voicing contrast

This implicational relationship states that "the absence of a voice contrast in final position implies the absence of a voice contrast in initial position." The evidence that Gierut cites for this relationship was previously discussed in Chapter 1, section 4. She cites Dinnsen, O'Connor & Gierut (2001), who investigate the phonological error patterns of child Amahl, who produced voiced and voiceless obstruents as positionally-determined allophones: he devoiced codas and voiced onsets. The author's claim that Amahl's patterning resulted from two markedness constraints: "avoid voiced obstruents in codas" and "avoid voiceless obstruents in onsets."

Alternatively, we can hypothesize that as Amahl at age 2;2 maintained a contrast in different word positions, he was sensitive to the prosody of word positions. Also, as Amahl's errors resolved quickly at 2;5, this implies that he had relatively accurate perceptual representations of the voiced/voiceless distinction, while his articulation of these sounds remained problematic. Additionally, based on evidence from Imbrie (2005) and Macken & Barton (1980) regarding children displaying different Voice Onset Time (VOT) values than adults, Amahl may have been preserving the contrast between voiced and voiceless stops, however in a way that was not perceivable by the adult listener.

In my current dataset, Ben was the only child that did not display a voicing contrast word-finally (with the exception of the German-learning children who did not, due to the phonotactic constraints of German, described in Chapter 1, section 8.2). In word-final position, Ben produced only voiceless stops and fricatives during his recorded sessions. However, the remainder of his production patterns contradict this relationship, as he had acquired voiced stops and voiceless fricatives in initial position.

4. Progressive place assimilation

The next three implicational relationships relate to assimilation processes. The first of these states that "progressive place assimilation (e.g., [bop̠] *boat*) implies regressive place assimilation (e.g., [g̠ɔg] *dog*)."

Gierut's evidence for this relationship comes from Stoel-Gammon (1996) and extrapolates from Stoel-Gammon's proposed implicational universal "the presence of progressive Velar Assimilation in a child's speech implies the presence of regressive Velar Assimilation" (Stoel-Gammon 1996: 208). Stoel-Gammon investigated the acquisition of velars using longitudinal and cross sectional data from 67 children aged 15-32 months (all of which had normally developing phonological systems with one exception). She found that some children displayed velar fronting in all positions, while others only fronted velars when the target preceded a stressed vowel. Intervocalic velars following a stressed vowel behaved like word-final velars (and were produced accurately, e.g., *tickle* [tɪk̠o]), thus appearing to be syllabified in coda rather than onset position. Intervocalic velars that preceded a stressed vowel acted like word-initial velars, and underwent fronting (e.g., *because* [biˈt̠ʌz]). Chiat (1989) uncovered a similar pattern with fricatives.

Stoel-Gammon (1996) found that no child fronted in word-final position only. From this, she posited the implicational universal that "the presence of velar fronting in word-final position implies its presence in word-initial position" (Stoel-Gammon 1996: 206) (see Chapter 1, section 3; Chapter 5, section 2 for alternate discussions that can account for Positional Velar Fronting).

Stoel-Gammon then moves on to discuss velar assimilation, where a labial or coronal sound is produced as velar: the labial/coronal assimilates to a velar within the same word. Some children in her database displayed both regressive and progressive assimilation (e.g., *kiss* [gik̠] and *dark* [g̠a:k]), and others only regressive (e.g., *truck* [g̠ʌk]) (Stoel-Gammon 1996: 207). None of the children employed progressive assimilation only. Notably, some children who displayed both patterns, such as child AS at 26 months, utilized only regressive assimilation when recorded one month later; progressive velar assimilation had disappeared but regressive assimilation remained. Based on these observations, Stoel-Gammon (1996) formulated the implicational universal "the presence of progressive Velar Assimilation in a child's speech implies the presence of regressive Velar Assimilation" (Stoel-Gammon 1996: 208), which Gierut generalized to all sound types. However, beyond prosody-driven asymmetries such as PVF discussed above, which concerns velar consonants exclusively, as does Stoel-Gammon's own proposal, it remains unclear how Gierut's generalized proposal can receive independent motivation.

5. Manner assimilation

The following relationship, which also focuses on assimilation, states that "manner assimilation (e.g., [n̠ʌn] *won*) implies liquid gliding (e.g., [w] for /r/)." As stated in Chapter 1, section 4, Gierut's evidence for this implicational relationship comes from Dinnsen & O'Connor (2001b). In brief, the author's investigate data from two children who display consonant harmony. The authors state that based on this evidence, the published literature, and the Indiana University archives of more than 200 English-learning children, they have not found a case of harmony that occurs without gliding.

Dinnsen & O'Connor (2001b) then proceed to order the two relationships using Optimality Theory constraints. However, similar to the other relationships discussed above, there is no theoretical backing to this relationship outside of formalization inherent to Optimality Theory. Additionally, the evidence provided to illustrate the interaction between gliding and consonant harmony is not conclusive, as the phonological contexts involved in the data descriptions are not always comparable. However, even if children were to display both of these processes in comparable environments, it would still not mean that these processes feed into each other or that they interact in any way (see 8.1 below for a detailed discussion on how conspiracies in the child's productions can cause unrelated processes to appear connected; see also Rose 2009).

While none of the children in the current case studies displayed systematic patterns of manner assimilation, in light of the discussions above regarding motor planning, positional effects, and articulatory complexity, I can state that there is no theoretical backing to this claim. Parallel to most of the other relationships that have already been discussed, this relationship is merely captured by a stipulated ranking of universal constraints.

6. Spirantization

The last implicational relationship that focuses on assimilation processes expresses that "spirantization (e.g., [s] for /t/) implies place assimilation (e.g., [g̱ɔg] *dog*)." I previously detailed the evidence for this relationship in section 1 of this current chapter (see also Chapter 1, section 4), as Dinnsen & O'Connor (2001a) is also the basis for the implicational relationship "stopping implies gliding."

Recall that spirantization occurred for CHILD 126 for all word-initial [t]s that did not undergo place harmony; all word-initial [t]s underwent spirantization unless the word had a velar consonant, which caused word-initial [t] to undergo place assimilation (see examples (2) through (5) in Chapter 1). While Dinnsen & O'Connor credited this to universal markedness and the associated ranking of OT constraints, it is also plausible that the child's errors in fact were resulting from two separate, interacting processes. In the absence of a velar which triggers place assimilation, the child perceives the aspirated [t], and tries to reproduce its heavy aspiration cue, which can logically take the form of the strident frication involved in [s] production. As further evidence would be needed to fully motivate this hypothesis, I leave the issue open for further research. Minimally, this would constitute another example whereby the child attains a deviant segmental outcome to abide by other, formally independent properties of the target grammar.

7. Syllable deletion

The last relationship to be discussed states that "errors of weak syllable deletion in syllables beginning with an obstruent imply like errors in syllables beginning with a sonorant."

The evidence for this relationship comes from Kehoe & Stoel-Gammon (1997), as previously described in Chapter 1, section 4. Kehoe & Stoel-Gammon (1997) observed a number of patterns in child language, including that "children preserve unstressed syllables with obstruent onsets more frequently than unstressed syllables with sonorant onsets" (Kehoe & Stoel-Gammon 1997: 114). Gierut argued that this behaviour is governed by grammatical relationships. However, this hypothesis goes counter to Kehoe & Stoel-Gammon's explanation, which concerns the syllabification and parsing of sonorant sounds, namely that sonorants tend to syllabify with the preceding vowel when they occur intervocalically (Fallows 1981; Treiman & Danis 1988; Wijnen 1988; Gillis & De Schutter 1997). This causes these sonorants to be syllabified as part of the coda, which results in a medial syllable that lacks an onset. It is this onsetless syllable that undergoes deletion.

Finally, we must also keep in mind that syllables and individual sounds are represented at different levels of the Prosodic Hierarchy, as previously discussed in Chapter 1, Figure 1, and repeated here for convenience in Figure 214.

Figure 214: Prosodic Hierarchy (Selkirk 1978; 1980; McCarthy & Prince 1986)

Prosodic Word (PWd)
|
Foot (Ft)
|
Syllable (σ)
|
(Syllable subconstituents)
|
Timing unit (X)

From a theoretical standpoint, while these levels are interconnected, drawing arbitrary relationships between them, as this last relationship implies, and elevating these relationships to the level of universals, is itself formally unwarranted.

8. Discussion

As we saw above, the majority of the relationships involving phonological processes proposed by Gierut are based on constraint rankings claimed to be universal. However, even in cases where we can observe some apparent correlation between two phonological processes, we cannot find independent motivation linking these processes together. As we saw in the data, apart from relationships that stem from basic facts of speech production, these so-called universals do not receive much support. Additionally, conspiracies can cause unrelated sounds and sound processes to appear related when they are not, as discussed in the following section.

8.1. Conspiracies

Rose (2009) investigates various approaches to phonological development in light of observations that pose challenges to current theories of phonology. An example of this comes from Positional Velar Fronting (PVF), discussed above. As Inkelas & Rose (2003; 2007) argue, this process reveals how the child's grammar interacts with articulatory factors, causing velar sounds to undergo fronting to coronal sounds in prosodically strong positions. Emerging from their analysis is the suggestion that we cannot address the child's grammar, articulatory factors, or prosodic factors as objects that work in isolation. Instead, we need to keep the child's developing phonology within its proper phonetic and phonological contexts, here the articulatory production of target velars across prosodic contexts governed by the child's phonological grammar.

Rose (2009) addresses the well-documented case of Amahl (Smith 1973; Macken & Barton 1980), who displayed a number of phonological error patterns. As shown in (13), Amahl produced the [z] in *puzzle* as [d], however he erroneously produces target [d] as [g] in words like *puddle*.

(13) Chain shift (data from Amahl; Smith 1973) (Rose 2009: 342)
 a. *puzzle* /pʌzl/ → [pʌdl̩] (/z/ → [d])
 b. *puddle* /pʌdl/ → [pʌgɫ̩] (/d/ → [g]; *[d])

These two processes were called a *chain shift* because while Amahl could produce certain sounds like [d], he did not do so in specific environments.

Rose (2009) examines this apparent paradox based on the context in which each sound occurs. There is indeed something else happening in Amahl's grammar outside of the process of stopping, as Amahl can produce [d] but does not do so in the environment in (13b). Macken (1980) explored this contradiction by considering perception:

> "As Macken argues, the child, influenced by the velarity of word-final [ɫ], perceived the /d/ preceding it in puddle as a velar consonant (/g/). Because of this faulty perception, he built a lexical representation for puddle with a word-medial /g/." (Rose 2009: 342)

Therefore the erroneous production of *puddle* as [pʌgɫ̩] in (13) stems from an incorrect "perceptual artefact" (Rose 2009: 342).

Another example of a chain shift from Amahl is provided in (14), where Amahl substitutes target [θ] with an [f], however he produces [θ] in the place of target [s].

(14) Circular chain shift (data from Amahl; Smith 1973) (Rose 2009: 342)
  a. /θ/ → [f] (*thick* /θɪk/ → [fɪk])
  b. /s/ → [θ] (*sick* /sɪk/ → [θɪk])

Similar to the other chain shift in (13), Amahl does not produce target [θ] accurately, despite using it in incorrect environments. Rose (2009) posits that this pattern also "arises from a conspiracy of independent factors, namely perception, which affects the building of lexical representations, and articulation, which yields surface artefacts in output forms" (Rose 2009: 343). First, Rose notes that [f] and [θ] are acoustically very similar (e.g., Levitt et al. 1987), suggesting that Amahl's error may be based, at least in part, on erroneous perception. [f] and [θ] are also often both produced as [f] by native speakers and second language learners of English (e.g., Levitt et al. 1987; Brannen 2002). Based on this information, it is plausible that Amahl could not perceive the contrast between [f] and [θ], and so could not establish an accurate lexical representation for target words containing [θ]. This hypothesis can account for Amahl's incorrect pronunciation of *thick* as [f̲ɪk] in (14).

While incorrect perception of [θ] can capture Amahl's [f] substitution errors, his [θ] productions in place of [s] may have been influenced by different factors. As illustrated in examples (18) and (19) in Chapter 6, due to the increased space that the child's tongue takes up in their oral cavity (Fletcher 1973; Kent 1981; Crelin 1987) when compared to adults, and the anterior position of the child's tongue (Kent 1992), coupled with imprecise motor control, children often produce [s] too far forward resulting in "frontal lisp-like effects" (Rose 2009: 340). Because of factors such as these, children often acquire the /s/ vs. /θ/ contrast late in acquisition (Smit 1993; Bernhardt & Stemberger 1998).

Based on such examples, Rose (2009) argues that if we restrict our investigation into child language to single factors only, we risk missing the larger picture:

> "...the study of phonological development, similar to that of any complex system, requires a multi-dimensional approach that takes into consideration a relatively large number of factors. Such factors include perception-related representational issues, physiological and motoric aspects of speech articulation, influences coming from phonological or statistical properties of the target language and, finally, the child's grammar itself, which is constantly evolving throughout the acquisition period and, presumably, reacting or adapting itself to some of the limitations that are inherent to the child's immature speech production system." (Rose 2009: 330)

In sum, interactions between perception, motor control, child-specific articulatory constraints, and grammatical conditioning, among others, are all likely to influence children's phonological development. This also has implications in the realm of clinical phonology, as we discuss next.

8.2. Clinical applications

As mentioned in Chapter 1, section 3, Gierut looks at speech development from a linear perspective: a sound is not affected by its position within a syllable/word or what level of the prosodic hierarchy it occurs on. It is therefore unclear how non-linear relationships can be accounted for by Gierut's (2007) approach, as it focuses almost exclusively on individual speech sound development. From a theoretical standpoint, it is generally accepted that languages are hierarchically organized, such that larger units (e.g., syllables) influence the behaviour of units lower down on the hierarchy (e.g., sounds, features), as represented by the Prosodic Hierarchy. As children arguably have access to representations beyond the segmental level, we need to recognize this in their development, and our definition of therapy targets.

If, as discussed above, implicational relationships, and notions of universal markedness, cannot readily apply to our definition of treatment targets, we are left with the important challenge of determining what factors are truly relevant to speech therapy. However, "the literature to date has not established a gold standard for intervention for persistent speech sound errors, which has been described as "one of the most neglected research areas in speech therapy" (Gibbon & Paterson 2006: 275)" (McAllister Byun & Hitchcock 2012: 207).

Several recent books have compiled the various practices currently in use in the field of Speech-Language Pathology. Kamhi & Pollock (2005), Williams, McLeod & McCauley (2010), and Bowen (2014) describe various evidence-based practices in SLP. However, it is rather unclear how one can choose between the methods available. For example, Williams, McLeod & McCauley (2010) describe 18 different approaches for treating phonological disorders in children, and state that depending on the client's individual needs, different approaches may be beneficial. Such approaches range from minimal pair therapy (Greenfield & Smith 1976), where treatment focuses on creating a contrast between sounds that the child produces as the same (e.g., *take* and *cake* if the child fronts velars in word-initial position), to descriptions of motor tactile training programs such as PROMPT (Prompts for Restructuring Oral Muscular Phonetic Targets) (e.g., Chumpelik 1984), and visual feedback approaches such as ultrasound based intervention (e.g., Bacsfalvi 2008). Other methods also include complexity-based approaches such as Gierut & Morrisette (2005), and the use of Maximal Oppositions and Treatment of the Empty Set, both of which focus on treating sounds that the child cannot produce. These approaches are also rooted in Optimality Theory, and its notion of focusing therapy on the most complex option is well established in the Speech-Language Pathology literature (e.g., its presence in the three books on evidence-based practice cited above). However, investigating whether other factors outside of complexity-based or universal markedness can account for the literature cited in favour of these complexity approaches, lies outside of the scope of the current thesis.

Baker & McLeod (2011) compiled 134 peer-reviewed studies of clinical remediation of phonological disorders in children, and inventoried 46 different intervention approaches. They found that no one approach was reported as excelling beyond any other. They noticed a dearth of replication research, as few studies actually compared between different approaches.

One study that compared multiple approaches is by Lousada et al. (2013), who found that targeting the phonological system as a whole was more beneficial than treatment based on individual sounds. Lousada et al. (2013) investigated 14 Portuguese-learning children who had a phonological delay, and found that it was more beneficial to target error patterns based on the phonological features describing these patterns, as this allowed for generalizations to other speech sounds. This is one of the few studies where children were exposed to two different therapy types: one that targeted sounds versus one that targeted processes. This study highlights the difficulty in establishing the best clinical approaches, as they all work to some degree. However, as clinicians, we want to know if other approaches would have worked better, or if the gains made by the children can be attributed to additional factors.

While clinicians have access to a wide range of treatment options, certain approaches predominate. Baker & Mcleod (2011) surveyed 231 Australian SLPs and found that they focused clinical treatment on sounds that were stimulable, early developing, and in error across all word positions. Stimulability refers to the child's ability to correctly produce the target sound when provided with a model. Stimulability is established across various positions (e.g., isolation, syllable or word -initial, -medial, -final) and with various levels of cuing (e.g., auditory model, visual model, tactile cues) (Powell et al. 1999).

Baker & McLeod's finding is not surprising because, as a clinician, it is all but impossible to treat targets for which the child has no phonetic knowledge. In line with this, Tyler & Macrae (2010) discuss how children make more gains when treated on sounds for which they are stimulable (in line with Carter & Buck 1958; Kisatsky 1967; Tyler 1996). Logically, a child cannot be treated on a sound for which she has no knowledge; if the child cannot imitate the sound given maximal cues, it is unclear how such sounds can be targeted in the first place.

Based on the above discussion, we thus need a model that allows for all of the factors that affect child phonological development to be taken into account. As we will see in the following chapter, a reformulation of markedness in terms of phonetic conditioning by Hume (2011) will allow us to capture these factors, as well as offer us compelling ways to understand the multi-faceted nature of phonological development.

Chapter 6: Markedness

As discussed briefly in Chapter 1, implicational relationships directly build on assumptions that follow logically from markedness theory. Throughout the above chapters, I have used a subset of markedness descriptors from Hume (2011: 79–81), which I repeat here for convenience:

Table 62: Markedness descriptors (adapted from Hume 2011: 79–81)

Unmarked	**Marked**
Simple	Complex
More frequent	Less frequent
Acquired earlier	Acquired later
Articulatorily simple	Articulatorily difficult

Recall that under Gierut's (2007) hypothesis about the existence of grammatically-driven implicational relationships, if a child has acquired a marked sound, s/he is logically predicted to have acquired all related sounds that are relatively less marked. In order to make predictions, this proposal must rely on a set of assumptions about the relative markedness of the various phonological units involved in these relationships. However, while markedness is a common concept in phonology, it is also more or less ill-defined, as it can refer to a number of different aspects of phonological or phonetic descriptions (Rice 2007). In this chapter, I address some commonly held views of markedness. I then discuss how a phonetically-driven definition of markedness can unify the majority of production patterns observed in this thesis.

1. Overview

As discussed in Chapter 1, Gierut's proposal stems from Chomsky & Halle's (1968) theory of Generative Phonology, which centres around typological universals in the tradition set by

Jakobson (1941). Under this view, markedness generally refers to the frequency of occurrence of a given unit or combination of units within and across languages. For example, Jakobson proposed that all children adhere to a universal order when acquiring the phonemes of their first language(s), no matter the actual language(s), whereby a universally marked sound category implies the acquisition of the corresponding unmarked category.

Chomsky & Halle (1968) later reinterpreted Jakobson's (1941) hypothesis about language universals in terms of innateness. As interpreted within linear approaches to Generative Phonology, markedness forms part of Universal Grammar and defines aspects of our linguistic competence (Chomsky 1965; 1986). Under this view, markedness refers to innate principles and laws that govern languages and lead towards the unmarked form (Chomsky & Halle 1968). Therefore, markedness is taken as a central factor in the shaping of phonemic inventories across languages and throughout all stages of phonological development. Within constraint-based theories of phonology, the universal principles and laws posited within linear phonology have been redefined in terms of markedness constraints (e.g., Optimality Theory; Prince & Smolensky 1993).

This approach to markedness is commonly referred to as Descriptive Markedness (Trubetzkoy 1969), presumably the most widely accepted view of markedness within the literature on phonological theory. It has been used to establish language typologies and to capture asymmetries between different sounds (e.g., one member contains something that the other does not, thereby *marking* it). Under this classification, the term *unmarked* refers to "more frequent, natural, simple, and predictable than the marked observation of the comparison set" (Hume 2011: 80).

How frequently or commonly a sound occurs within and across languages has been another criterion for determining markedness since the very beginning of markedness theory (e.g., Hockett 1955; Greenberg 1966; Trubetzkoy 1969). However, there are controversies as to whether this criterion should be involved in determining markedness relations, and what exact measure of frequency should be used to determine these relations. While typological frequency is used in the literature on generative phonology (Kean 1975; Sagey 1986; Paradis & Prunet 1991), the debate surrounding its usage falls outside of the scope of my current research.

As Gierut generally subscribes to Descriptive Markedness, she makes the prediction that children acquiring their first language(s) must have access to universal principles that govern the shape of phonological systems. These universals are responsible for the order in which children acquire sounds and, by extension, for the existence of implicational relationships.

Descriptive markedness has, in recent years, been questioned in light of alternative approaches to phonology which incorporate phonetic factors as part of explanations for phonological patterning (e.g., Steriade 1999). Within these approaches, markedness has been redefined in terms of *markedness-through-mechanism* (Hume 2011), whereby markedness is determined by the cognitive, physical, and social characteristics that all humans share. I expand on this particular view of markedness in the next section.

2. Markedness-through-mechanism

Markedness-through-mechanism "attributes markedness patterns to a confluence of factors that interact with grammatical systems, and relate to physical, cognitive, and social mechanisms shared by all humans (e.g., Lass 1976; Stampe 1979; Comrie 1983; Menn 1983; Boersma 1998; Blevins 2004; Hume 2004; Mielke 2008)" (Hume 2011: 81). The key observation underlying this view of markedness is that because factors outside of Universal Grammar can account for patterns found across languages, we do not need to rely on innateness to explain these patterns. Under this view, it is thus the mechanisms that are innate, as opposed to universal principles of phonology. For example, Beckman, Yoneyama & Edwards (2003) state that languages follow general tendencies, as opposed to universal rules. They suggest that universal tendencies (e.g., that voiceless unaspirated stops are acquired before aspirated or voiced stops) are rooted in phonetics and the articulatory difficulty with which sounds are produced (e.g., the difficulty in controlling the airflow and coordinating the articulatory gestures required to produce the three varieties of stop voicing).

Mohanan (1992), Boersma (2000), and Bybee (2001) more recently advocated the view that markedness relationships and phonological patterns across the world's languages are phonetic in nature. More generally, the notion that phonetic factors coincide with markedness is not new (e.g., Jakobson & Halle 1956; Greenberg 1966; Chomsky & Halle 1968; Trubetzkoy 1969) and this view can both co-exist with, and outside of, notions of Universal Grammar.

Hume (2011) identifies three types of phonetic conditioning that are key to the discussion of markedness-through-mechanism below: perceptual distinctiveness, phonetic variability of production, and articulatory simplicity. These phonetic factors are commonly used in the literature that engages in discussions of phonetic markedness. Throughout the following few pages, I define and discuss some of the most prominent factors highlighted within this literature, building on Hume's (2011) extensive discussions on the topic.

The first factor, perceptual distinctiveness, refers to how easily a sound can be isolated as a unit in the speech stream, as stated in (15).

(15) *Perceptual distinctiveness*: changes in speech signal influence how salient a sound is and therefore how easily one can detect it. Much debate remains over whether a more salient or less salient sound determines which is marked or unmarked (see Cairns & Feinstein 1982; Clements & Keyser 1983 for the more salient member determining the unmarked, and Kawasaki 1982; Kohler 1990; Hura, Lindblom & Diehl 1992; Jun 1995; Boersma 1998; Hayes, Steriade & Kirchner 2004 for saliency determining the marked).

Among other questions, perceptual distinctiveness cannot always readily identify whether marked or unmarked sounds are the easiest to distinguish. Presumably, in the context of child speech development, the easier the child can detect a sound, the easier this sound can be recognized and reproduced. For example, [s] is relatively easy to identify in the speech stream, as it is strident and generally maintains a certain degree of duration. In contrast, the [ɹ] of English can be heavily influenced by its phonetic environment: when preceded by a voiceless obstruent, for example in the word *train,* [ɹ] is partially devoiced; when it is preceded by a vowel, for example in *teacher,* the [ɹ] combines with the vowel to rhotacize it, making it much harder to distinguish from vowels and neighbouring sounds than strident [s].

The second factor is phonetic variability, as summarized in (16), which refers to how a sound may surface in productions.

(16) *Phonetic variability of production*: allophonic variations denote the unmarked category (Greenberg 1966); unmarked sounds show more phonetic variability than the marked sounds in their symmetry relationship (Trubetzkoy 1969).

For example, a sound such as /t/ is considered unmarked in English as it may surface as one of many allophonic variants (e.g., [t], [ʔ], [ɾ], [tʰ], [t̚]), of course depending on the particular dialect of English being described. However, in the context of child speech, this implies that the child has to learn each of the multiple surface allophones and relate them to one another at a more abstract level (Pierrehumbert 2003; Munson, Edwards & Beckman 2012; Pierrehumbert 2016).

Thirdly, as stated in (17), articulatory simplicity refers to levels of difficulty in both production and perception.

(17) *Articulatory simplicity*: the unmarked is less complex to produce in terms of ease of articulation and easier to perceive distinctions in the speech stream (e.g., Calabrese 1995).

Sounds that require the least number of gestures, or least amount of gestural precision, are presumably easier to produce and, as such, likely to be acquired early by the child. For example, obtaining a full closure in the vocal tract (e.g., for a stop consonant production) is generally easier than producing the partial closures involved in the production of fricatives. As mentioned previously, the articulations required for fricatives require millimetre accuracy, as the articulators create a narrowing in the oral cavity slight enough to induce turbulence in the airflow but without resulting in a full occlusion at the point of articulation. This type of distinction is typically exacerbated in child learners, as young children generally have poor motor control over their speech articulators (Crelin 1987; Kent 1992; Kent & Miolo 1995).

In sum, Hume (2011) focuses on three sources for markedness-through-mechanism: perceptual distinctiveness, phonetic variability, and articulatory simplicity. In addition, there are different types of factors that affect child speech more specifically, including child-specific anatomical pressures. The statements in (18) summarize the main physiological differences in children's anatomical structure (as compared to adult's anatomical structure):

(18) Child-specific anatomical pressures (adapted from McAllister Byun, Inkelas & Rose 2016: 147)

a) The tongue is larger in proportion to their vocal tract (Fletcher 1973; Kent 1981; Crelin 1987).
b) The tongue resides in a more anterior position in the oral cavity (Kent 1992).
c) The palate is narrower and lower; up until approximately two years of age, the tongue occupies nearly all of the space in the oral cavity (Crelin 1987).

Children must indeed deal with the additional pressures of having a proportionally larger tongue that sits further to the front in their mouths when compared to an adult oral cavity. Children also face a number of motor planning difficulties, summarized in (19) (still in comparison to adult speakers).

(19) Motor-planning differences in children (adapted from McAllister Byun, Inkelas & Rose 2016: 147)
- a) Children combine multiple movements (e.g., jaw and lips) and move them together as a single unit. "This *linking* of distinct structures appears to simplify the motor-control task by reducing the number of degrees of movement freedom involved" (Green et al. 2000; Gick et al. 2008; see also McAllister Byun 2009; 2012).
- b) The controlling of certain articulators is easier/harder than others: controlling the jaw/mandible is more motorically simple than controlling the more refined tongue movements required for speech. Therefore the child's tongue movements may go through a stage of being less active in articulation as the tongue instead relies on jaw movements for some of its articulations (MacNeilage & Davis 1990; Green, Moore & Reilly 2002).
- c) Children produce more variable speech gestures, as revealed by articulator-movement kinematics (e.g., Smith & Goffman 1998) and studies of linguo-palatal contact (e.g., Fletcher 1989).

As described in (19), children link multiple anatomical structures and move them as a single unit, making discrete gestures difficult. In addition, as stated in (19b), children experience varying degrees of difficulty in controlling different articulators (e.g., the requirements for jaw movements are less precise than tongue movements for speech). As a result, in (19c), children tend to produce more variable speech gestures.

In summary, child speech development is dependent upon the three central components of markedness-through-mechanism (perceptual distinctiveness, phonetic variability, and articulatory simplicity). These phonetic conditioning factors, which can affect different sounds and sound combinations in predictable ways, are also influenced by, and interact with, child-specific anatomical and motor-control differences.

3. The A-map model

As discussed in the preceding section, different phonetic factors, including those which are central to markedness-through-mechanism, as well as child-specific anatomical and motor control issues, interact to influence child phonological productions. Consider, for example, the acquisition of the voiceless alveolar fricative [s]. At the perceptual level, the child hears a combination of acoustic cues that correspond to the place, manner, and voicing properties relevant to the consonant. If the child perceives any of these dimensions incorrectly, this might result in an incorrect perceptual target that she will then try to reproduce, which, in turn, is likely to yield an incorrect production. Assuming a correct perceptual target, the child then has to accurately combine the speech articulations necessary to reproduce the three phonetic dimensions (place, manner, voicing) in her own speech. Additionally, the child needs to fine-tune these articulations to match the finer properties of the target sound. For example, still for [s] production, she must successfully create a grooved tongue configuration, in order to generate the stridency associated to the frequency range of [s] in English. Errors in any one of the main dimensions, or towards the finer phonetic elements of the target consonant, will result in either an incorrect or a distorted production.

In order to capture these phonetic considerations, which are directly relevant to the acquisition process, McAllister Byun, Inkelas & Rose (2016) proposed a new theoretical framework called the A(rticulatory)-map model. The A-map, as its name suggests, focuses on the mapping of perceptual objects onto the sets of speech articulations required to reproduce these objects in speech. For example, while a consonant like [s] is perceptually salient due to its acoustic stridency, it is difficult to map articulatorily due to the precise positioning and grooving of the tongue that is required to accurately generate a strident sound (Gibbon 1999). Conversely, [h] may be harder to perceive in the speech stream, as it is not strident, but it is relatively easy to produce articulatorily, as it simply requires airflow at the level of the glottis, without the involvement of supralaryngeal constrictions.

Important to discussions of child development, the A-map model can be used alongside the continuity assumption (Macnamara 1982; Pinker 1984) (already discussed in Chapter 1, section

1.1), according to which the child grammar reflects the properties of the adult grammar. As the differences between child and adult speech are, under the A-map, rooted in phonetics and child-specific pressures, which relate to anatomy and motor-control (as summarized in (18) and (19) above), the A-map can be applied across a speaker's lifetime, including the period of first language development, or later in life, for example in the context of an acquired speech disorder. Formally, and in line with the continuity assumption, the A-map remains active in the adult grammar, but as motor functions mature, its effects on the adult speaker's overall system are not as salient.

In light of the anatomical and motor-control factors affecting child speech outlined in (18) and (19), the A-map can be used to explain common child-specific phonological patterns. For example, it can be used to explain Positional Velar Fronting (PVF), whereby velars are fronted to coronals in prosodically strong positions (Ingram 1974; Chiat 1983; Stoel-Gammon & Stemberger 1994; Bills & Golston 2002; Inkelas & Rose 2003; Marshall & Chiat 2003; Inkelas & Rose 2007; Dinnsen 2008; Dinnsen et al. 2011; McAllister Byun 2012; McAllister Byun, Inkelas & Rose 2016) (see also Chapter 1, section 3). Due to the proportionally bigger size and anterior placement of the tongue that are characteristic of young children's vocal tracts, the effects of which are exacerbated by relatively poor motor control of the speech articulators, children may produce velar sounds in a more anterior place of lingual articulation. In particular, children who display PVF, instead of fronting all velars regardless of word position, show that they are sensitive to the prosodic form of the words they are attempting to reproduce and strive to maintain the contrast between prosodically strong versus weak positions. As stated in McAllister Byun, Inkelas & Rose (2016: 148):

> The larger gestural excursion needed for prosodic enhancement presents a more challenging motor-control task, increasing the likelihood that the child will use a ballistic gesture that produces undifferentiated linguo-palatal contact (McAllister Byun 2012). In some children, this yields a systematic pattern of place substitution in the context(s) where gestures are largest (Inkelas & Rose 2007).

While this analysis involves both anatomical and motor constraints in relation to prosodic properties of the target system, individual experience will also impact the types of targets the child will attempt to reproduce and how these targets will be realized. In early speech productions, children are often observed to attempt to produce words from a constrained subset of sounds that are consistent with their own phonological abilities, and to avoid words that contain sounds or sound combinations that would fall outside the range of their phonological abilities (Ferguson & Farwell 1975; Leonard et al. 1981; Schwartz & Leonard 1982; Stoel-Gammon & Cooper 1984; Vihman 2014). This phenomenon, referred to as selection and avoidance, has been observed in young children whose vocabulary is around 50-100 words, and suggests a level of self-awareness on the child's part; children must have some knowledge of their own phonological productive abilities, of what sounds and sound combinations they can or cannot reproduce in their own speech. All the same, children are faced with communicative needs where to produce a form inaccurately is better than not producing anything. As McAllister Byun, Inkelas & Rose (2016) suggest, children then might opt for a stable, albeit inaccurate production over a more variable pattern, even if this variable pattern might intermittently hit the target. This stability is viewed as a reflection of grammatical organization within the phonological system.

The A-map describes this preference for stable patterns using two phonological constraints, Accurate and Precise, defined directly after McAllister Byun, Inkelas & Rose (2016: 142) below:

(20) Accurate: penalizes a candidate in proportion to the distance in acoustic-perceptual space between the internal model's prediction of the child's output and the center of the cloud of traces representing the adult target.

In terms of accuracy, the child wants to match adult targets. The more accurate the child's productions are, the less the child gets penalized by this constraint. Accurate thus provides a measure of distance between a perceptual target and its actual realization by the child. Reliability across individual productions for any given target is itself regulated through the second constraint, Precise, in (21), which favours the production of patterns that resemble one another, for any given target:

(21) Precise: penalizes a candidate in proportion to the average distance between traces representing actual outputs and intended outputs (efference copies), which can diverge in cases of performance error.

Given Precise, the child wants to employ a stable motor plan that she can execute with minimal variability. The more precise the child's productions are, the more the output resembles the child's own intended output, which can itself be varying degrees away from the adult target.

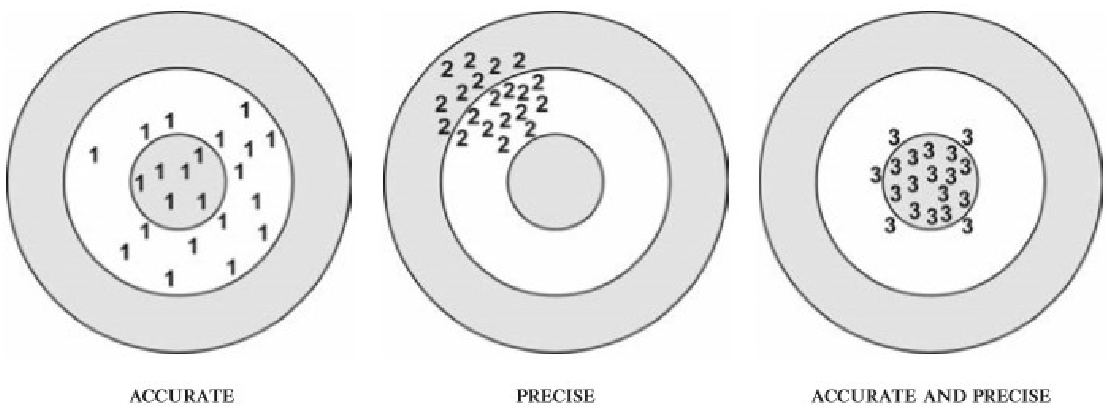
The A-map can also account for phonetic markedness if we consider that these two constraints, Accurate and Precise, operate at given levels of phonetic encoding.

> The A-map model enriches a constraint-based grammar with episodic detail about motor-acoustic mappings in order to reflect an ongoing, grammatically governed competition between the pressures of motor-plan reliability and auditory-perceptual accuracy. (McAllister Byun, Inkelas & Rose 2016: 151)

In the discussion below, I focus primarily on motor-acoustic mappings involved in the perception and production of individual speech sounds. Returning to our example of English [s] production, a child who is trying to be accurate may produce this target sibilant some of the time but might also produce similar sounds that involve different (and presumably less complex) tongue gestures and configurations (e.g., /t/, /s̺/). In the context whereby, as hypothesized by McAllister Byun, Inkelas & Rose (2016), the child's grammar matures toward articulatory reliability, then one of these alternative productions is predicted to become the favourite grammatical outcome. Ultimately, the child reaches the adult stage for a given target when she is able to produce this target in both accurate and precise ways: she can then reliably realize this target in an adult-like fashion.

McAllister Byun, Inkelas & Rose (2016) illustrate these scenarios using a dartboard schematic where the bulls-eye represents the accurate adult-like motor-acoustic mapping.

Figure 215: A-map target representation (from McAllister Byun, Inkelas & Rose 2016: 150)



In the above figure, the 1s represent variable mappings that hover around the bulls-eye, each of which correspond to an attempt at a given target where a child is aiming for overall accuracy at the expense of reliability (precision). This scenario corresponds to a series of dissimilar perceptual-articulatory mappings, some correct, some varying degrees away from the target. The 2s represent off-target mappings with limited variability. Here the child is focusing on reliably producing a substitution for a perceptual target that she cannot yet produce accurately. Lastly, the

3s represent a combination of accuracy and precision for a perceptual-articulatory mapping, which we can associate to the child's mastery of the adult target form.

In order to encode these relationships between perceived targets and the multiple attempts at reproducing these targets under the scenarios in Figure 215, the A-map adheres to exemplar-based models of phonology (e.g., Johnson 1997; Johnson & Mullennix 1997; Pierrehumbert 2001; Pierrehumbert 2002; Pierrehumbert 2003; Johnson 2006), where individual speakers store detailed copies of the phonetic dimensions involved in their perception and/or production of speech forms. These exemplar "traces" are kept in a multidimensional map, which encodes the relevant sensory-motor information; this exemplar space constantly evolves as new traces are formed and old ones fade away.

Within this map, exemplars of the same category cluster together into representational clouds within which "a region of high probability represents the center of a phoneme category, while low-probability regions represent boundaries between categories (Pierrehumbert 2003; Munson, Edwards & Beckman 2005; see also Menn, Schmidt & Nicholas 2009; 2013)" (McAllister Byun, Inkelas & Rose 2016: 152). The A-map explicitly references three such exemplar clouds. In the first cloud, a perceptual target is defined through the cluster of episodic traces associated to a given perceptual category within the ambient language. The second cloud consists of the episodic traces formed by the child's self-perception of the acoustic outcomes of her own attempts at reproducing this target. How the child selects her preferred articulatory productions for a given perceptual target involves a third, perhaps more abstract set of representations, which serve to make predictions about acoustic outcomes given a specific set of articulatory gestures. This third cloud offers the child an INTERNAL MODEL (Wolpert & Kawato 1998; Wolpert, Ghahramani & Flanagan 2001; Guenther, Ghosh & Tourville 2006; Shiller, Rvachew & Brosseau-Lapré 2010; Tian & Poeppel 2010; Hickok 2012; Scott 2012), which “represents an individual’s knowledge of mappings between motor actions and their associated sensory consequences” (McAllister Byun, Inkelas & Rose 2016: 152). In the context of speech production, this includes a motor plan with auditory and associated somatosensory components, which originate from the child’s previous productions of this particular speech unit. More specifically, the A-map relies on an INTERNAL FORWARD MODEL, which directionally makes predictions regarding the outcome of performing a particular motor plan. This prediction is encoded in the form of an EFFERENCE COPY, which details the sensory components that relate to the intended motor plan. Efference copies thus provide the child with the ability to encode predictions toward an articulatory speech target. After execution of this speech articulation, the efference copy then serves as a basis to self assess whether the production was on-target, that is whether the produced form matched the predicted properties encoded in the efference copy. In summary, for the child in the process of acquiring a given category, learning is guided by predictions made prior to the execution of speech articulations, combined with later assessments of the validity of the produced articulations against these predictions. If a mismatch occurs between the predicted outcomes and the actual sensory results, the child registers this as an error and may attempt to correct it during a later attempt.

As illustrated in McAllister Byun, Inkelas & Rose (2016), and reproduced in (22) below, T represents the centre of the adult target category that the child is trying to match: it is “the center of the cloud of traces of perceptually encoded adult inputs” (McAllister Byun, Inkelas & Rose 2016: 154). E denotes the centre of the cloud of efference copies generated by the child’s previous attempts at this category: it encodes the sensory outcomes that the child is expecting based on previous attempts at this motor plan. Lastly, the A marks the centre of the cloud consisting of the child’s perceptual traces of the acoustic results of executing the motor plan.

(22) Clouds in motor-acoustic exemplar space representing the adult target (T), the child's actual outputs for an associated motor plan (A), and efference copies representing the expected sensory consequences of planned outputs of that motor plan (E) (McAllister Byun, Inkelas & Rose 2016: 154)

Under the A-map, the constraints ACCURATE and PRECISE, as defined above in (20) and (21), make direct reference to this motor-acoustic exemplar space. ACCURATE is evaluated as the "distance in phonetic space between T, the center of the cloud of traces of perceptually encoded adult inputs, and E, the center of the cloud of efference copies representing the predicted sensory consequences of executing that motor plan" (McAllister Byun, Inkelas & Rose 2016: 154). This distance is expected to exceed zero if the anatomical and motor properties exhibited by a child (detailed in (18) and (19) above) hinder this child's replication of the adult target. PRECISE is defined as "the average distance in phonetic space between pairs of traces in clouds A and E — that is, the average distance, for any given motor plan, between a trace representing the child's actual output and the trace of the concurrently generated efference copy representing the child's intended output" (McAllister Byun, Inkelas & Rose 2016: 154). If the child fails to reproduce an intended mapping, the trace for the efference copy and the trace of the outcome will occur in two different locations within the exemplar space.

Finally, the actual distance between the centres of each cloud, in particular between the efference copy E and the perceptually encoded acoustic outputs A, also has an effect on phonological outcomes. This is captured by McAllister Byun, Inkelas & Rose (2016) through a noise function, defined in (23) (McAllister Byun, Inkelas & Rose 2016: 156):

(23) Noise($MP_{[i]}$): The average distance between pairs of episodic traces—one efference copy and one perceptually encoded acoustic output—generated in connection with previous executions of a given motor plan $MP_{[i]}$.

Noise($MP_{[i]}$) measures the average distance between traces (efference copies and corresponding perceptually encoded acoustic outputs) associated with past executions of a specific speech target [*i*]. In lay terms, this noise function provides a measure of certainty about the likeliness of actually producing the outcomes associated to a given motor plan: the larger the distance between the E and A cloud centres, the lower the likeliness of a form to be produced as intended.

Under this measure, Precise and Accurate can be formulated in terms of numerical values: Precise will penalize an unstable motor plan, which corresponds to a large *Noise(MP)* function. If, on the other hand, a speech target displays a stable motor plan, this results in a small *Noise(MP)*, yielding a minimal penalty from the Precise constraint. Following the same reasoning, Accurate penalizes a candidate that is further away from the adult target. Finally, the interaction between Precise and Accurate within the learners grammar is crucial to the analysis. These different constraints may favour different candidates for any given adult target, and it is the relative weighting of these two constraints by the child's grammar that determines which outcome is ultimately produced.

McAllister Byun, Inkelas & Rose (2016) operationalize the A-map model within Harmonic Grammar (Legendre, Miyata & Smolensky 1990; Smolensky & Legendre 2006; Pater 2009). Harmonic Grammar, henceforth HG, similar to most constraint-based approaches to phonetics and phonology, allows for the inclusion of phonetic detail in determining constraint interactions (Flemming 2001). Unlike Optimality Theory, in which rankings impose a fixed relationship between constraints, HG encodes interactions between constraints through weighting: HG constraints are assigned a numerical value, and each possible candidate form receives a score based on the constraints it violates and their relative weights. Each candidate thus receives a HARMONY (H) score: the most "harmonious" or least penalized candidate is the one produced by the child.

In the next section, I summarize the example of fricative stopping from McAllister Byun, Inkelas & Rose (2016), which illustrates how ACCURATE and PRECISE interact within a phonological grammar. I then discuss an analogous case, that of r-gliding, using the same framework. These two toy examples highlight the phonetic space that the constraints refer to, and also relate to some of the phonetic dimensions that will be central to the discussion in the next chapter.

4. Toy Examples

4.1. Toy Example 1: Positional Fricative Stopping (after McAllister Byun et al. 2016)

Inês's production patterns were previously described in detail in Chapter 3, section 6. To briefly summarize, Inês stopped fricatives in both singleton onsets and onset clusters, while fricatives in coda position remained unaffected by this process (Burkinshaw 2014; Rose 2014).

As previously discussed in section 2, different types of articulatory pressures may result in fricative stopping (McAllister Byun 2011). Young children generally have poor motor control over their speech articulators, which often results in producing broad, ballistic articulatory gestures (Crelin 1987; Kent 1992; Kent & Miolo 1995). Much like the articulatory pressures that cause Positional Velar Fronting, as discussed in Chapter 1, section 3, we can attribute Inês's stopping pattern to overshooting of the articulatory gestures required for fricative constriction in syllable onsets, which are prosodically strong positions (Burkinshaw 2014: 85; see also Chiat 1983; Marshall & Chiat 2003; Inkelas & Rose 2007).

McAllister Byun, Inkelas & Rose (2016) use the A-map framework to model Inês's fricative productions. In the tableau in (24), reproduced after McAllister Byun, Inkelas & Rose (2016: 162), there is no difference in the weightings of Accurate and Precise. The analysis rests on differences in the noise functions associated to each of the output candidates. In (25a), [ʒa] represents an accurate acoustic-perceptual mapping of the adult target. According to McAllister Byun, Inkelas & Rose (2016), the child's internal model for fricatives in this position contains "a corresponding mapping from the motor plan to a close approximation of the acoustic-perceptual properties of adult |ʒa|" (p. 162). Therefore, efference copies that exist as a result of the child's previous attempts at the motor plan are close to the intended target; this results in a negligible violation of the Accurate constraint, here denoted with a magnitude of 0. However, while the candidate in (25a) would be highly accurate, we must recall from Chapter 3, section 6.1 that, during her stopping stage, Inês was not reliable in her execution of this motor plan; her productions for target fricatives in onsets involved various types of errors, resulting in outcomes such as [ja], [da], and [za]. Therefore, output candidate (25a) carries a high *Noise(MP)* value of -4, which captures her general pattern of violation against the constraint Precise.

(24) Comparison of candidates for target |ʒa| (evaluation of onset position) (McAllister Byun, Inkelas & Rose 2016: 162)

	Adult target: |ʒa|	ACCURATE	PRECISE	*H*
		w = 1	*w* = 1	
a.	ʒa	0	-4	-4
b. ☞	da	-1	-2	-3

In contrast to this, the candidate in (25b), [da], displays a motor plan that the child can produce much more reliably, resulting in a lower *Noise(MP)* value, set at -2, thereby incurring a lesser violation of PRECISE. However, as the child is not faithful to the adult target with these productions, the candidate in (25b) also involves a violation of ACCURATE. In spite of this, (25b) displays the lowest overall *H* score, and thus represents the pattern most often produced by the child in syllable onsets.

As illustrated in (25), a different outcome occurs when we look at Inês's fricatives in syllable-final position, where candidate (26a) emerges as most harmonic, which is the expected behaviour based on the negligible noise function for ACCURATE in the case of candidate (26a).

In order to capture Inês's production pattern in syllable codas, the authors have altered the severity of the PRECISE violation of the faithful target (by half) in (26a) to reflect the literature that suggests that the motoric demands and articulatory precision required to produce a fricative in final position, as opposed to initial, are lower (e.g., Tuller & Kelso 1990; Tuller & Kelso 1991; Krakow 1999; Nam, Goldstein & Saltzman 2009; Giulivi et al. 2011; McAllister Byun 2011). The authors also reduced the ACCURATE violation in (26b) (to -0.5) due to "the well-documented phenomenon whereby contrasts in postvocalic position have lower perceptual salience than prevocalic contrasts (e.g. Steriade 2001)" (McAllister Byun, Inkelas & Rose 2016: 162).

(25) Comparison of candidates for target |maiʃ| (evaluation of coda position) (McAllister Byun, Inkelas & Rose 2016: 163)

	Adult target: |maiʃ|	ACCURATE	PRECISE	*H*
		w = 1	*w* = 1	
a. ☞	maiʃ	0	-2	-2
b.	mait	-0.5	-2	-2.5

The noise function is negligible for ACCURATE in the case of candidate (26a), which implies that any other candidate (e.g., that in (26b)), will yield higher noise and thus will be disfavoured by the grammar. The effects of ACCURATE and PRECISE thus reflect the child's past behaviours, as the exemplar traces representing the child's actual output and the traces of efference copies representing the child's intended output for fricatives in this position generally occupy the same acoustic space.

In their self-assessment of this analysis, McAllister Byun, Inkelas & Rose (2016) recognize that it is not ideal to hand assign weights and the severity of the PRECISE violation within Harmonic Grammar tableaus; however, in order to empirically establish these constraints and violations, we would need access to a child's actual production and perception experience for both auditory and acoustic dimensions. Their hope is that future research may involve empirical or computational verification of these issues, as access to recorded corpora is becoming increasingly easier (Rose & MacWhinney 2014) and as computational models of motor control become more elaborate (e.g., Gick et al. 2014).

Finally, also important to child phonological development under the A-map model, "children can differ in the initial weights assigned to PRECISE and ACCURATE" (McAllister Byun, Inkelas & Rose 2016: 99). The constraint weightings may also change based on the factors that affect children's individual learning paths of acquisition. As the A-map reflects children's past attempts at motor plans and takes into account child-specific factors, this model is unique in that it can account for the variety of phonological patterns exhibited by children across the span of development.

I now move on to applying this framework to the gliding of rhotics in English. In the toy example to follow, I adopt McAllister Byun, Inkelas & Rose's (2016) approach to assign weightings to the A-map constraints Accurate and Precise, in order to capture how a child may reliably produce a glided production instead of the target rhotic.

4.2. Toy Example 2: Rhotic Gliding

Rhotic gliding to [w] in English is a well established phonological process. In the current case studies, rhotics underwent gliding for the two English-learning children only, and only in onset position. In the toy example below, I use this process in order to further illustrate how the A-map can capture phonological behaviours in child language.

In the tableau in (26), candidate selection relates to motor stability, as encoded by the noise function associated to each output candidate. The candidate in (27a) represents an accurate acoustic-perceptual mapping of the adult target. The child's internal model for "red" involves a motor plan that resembles the acoustic-perceptual properties of the adult form [ɹɛd], which results in a negligible violation of the Accurate constraint (here assigned a value of 0). However, while candidate (27a) most closely resembles the adult target, the child cannot yet reliably reproduce it and her attempts at this speech target result in a variety of outputs including gliding the rhotic to [w], gliding to [j], and [ɹ] deletion. This instability in her productions results in a high *Noise(MP)* penalty of -4, which captures the larger violation against the constraint Precise.

(26) Comparison on candidates for target |ɹɛd|

	Adult target: |ɹɛd|	ACCURATE	PRECISE	*H*
		w = 1	*w* = 1	
a.	ɹɛd	0	-4	-4
b. ☞	wɛd	-2	-1	-3

The other candidate, in (27b), /wɛd/, displays a motor plan that the child can produce much more reliably, which results in a lower *Noise(MP)* penalty of -1 for PRECISE. However, by reliably producing /wɛd/, the child is not accurately reproducing the adult target: her cloud of efference copies that are associated with this production reside in a different location than the adult target. This is captured through a violation (-2) for ACCURATE. Due to the fact the candidate in (27b) has the lowest H score, it is produced by the child over the more faithful candidate in (27a). This explains why the glided candidate [w] is favoured by the child over any other candidate.

I now move on to the final chapter of this thesis, where I discuss how the intuitions behind the A-map, as described above, can be coupled with the phonetic factors involved in markedness-through-mechanism (Hume 2011) to describe the phonological patterns observed in the current case studies. Throughout this discussion, I will refer to the A-map model outside of the HG framework shown in the toy examples above, as providing a formal analysis of each of the patterns observed in the data is beyond the goals of this thesis. I will instead focus the discussion on the most central patterns highlighted in Chapter 3 and Chapter 4 using the A-map's concepts of precision and accuracy, while relying on markedness-through-mechanism and the phonetic dimensions at play within the patterns observed, in order to determine the level of difficulty in mapping the perceptual information the child receives on to corresponding articulatory motor plans.

Chapter 7: Discussion and conclusion

In the previous chapter, I evaluated different views of markedness, which led to establishing the phonetically driven approach of markedness-through-mechanism (Hume 2011) as a more promising approach to child phonological development than traditional approaches to markedness based on typological evidence. Among other considerations, markedness-through-mechanism incorporates notions of perceptual distinctiveness, phonetic variability, and articulatory simplicity, each of which is expected to play a role in shaping phonological systems and, by extension, their acquisition. In this chapter, I discuss how using these notions can expand our understanding and treatment of speech sound disorders.

I illustrate this discussion with eight robustly attested phonological patterns uncovered through the longitudinal case studies described in Chapter 3. I begin with a summary description of each of these patterns, which can be grouped into the broader categories of place, manner, and voicing substitutions, as well as of deletion patterns. In the ensuing discussion, I focus primarily on perceptual and articulatory factors, as they play a larger role in the current data; when pertinent, I will mention possible influences from variability in the input language.

1. Robust phonological patterns: evidence from empirical studies

In this section, I revisit eight patterns which were attested in the corpus data described in Chapter 3. These patterns, some of which are restricted to a single corpus, others observed in many or all of them, are all robust in that they account for significant aspects of the phonological behaviours of individual children and were observed during relatively long time intervals.

For all intents and purposes, I take as a starting point the fact, central to the A-map model (McAllister Byun, Inkelas & Rose 2016) that the child must perceive acoustic cues for the correct place, manner, and voicing dimensions of the target phones, which she then has to map on to corresponding motor-acoustic outputs. Errors may therefore result from incorrect or incomplete perception, incorrect mapping of the perceived forms into articulatory motor plans, or incorrect articulatory execution of the intended mappings. Under this view, we must consider the three phonetic dimensions listed above (place, manner, voicing), which minimally describe the main phonetic properties of consonants (vowels have their own set of dimensions: height, frontness, lip rounding, and tenseness; however, these are not directly pertinent to the current discussion). As we will see, by considering how perception and articulation (as well as variability) might influence the acquisition of each of these three consonantal dimensions and their motor-acoustic mappings, the A-map provides a conceptual framework to capture phonological processes in ways that provide clear suggestions toward treatment.

The characterization of consonants through these three phonetic dimensions is also warranted by the observation that, for every substitution pattern illustrated below, only one consonantal dimension is typically affected, suggesting that it is the motor-acoustic mapping of this particular dimension that is not fully acquired. For example, as discussed further below, the stopping of fricatives such as [s/z] into [t/d] affects the manner dimension of the target consonants. This suggests that the child may have not yet developed the type of articulatory constriction required to reproduce the fricative noise dimension of the phonetic signal, while she remains faithful to the place and voicing dimensions of the target consonant. I return to this process below.

Table 63 displays the eight robustly attested patterns observed within the individual case studies described in Chapter 3, alongside the children who displayed these patterns in their productions. The first six patterns are grouped according to the broad phonetic dimensions of place, manner, and voicing. Specifically, these patterns consist of velar fronting, [θ] substitution to [f], [ʀ] substitution to [h], fricative stopping, rhotic gliding, and voicing errors. Finally, the last two patterns involve segmental deletion, namely /r/ deletion and [h] deletion.

Table 63: Robustly attested patterns from current cross-linguistic investigation

Place substitution	Velar fronting	Ben: onset [k], [g] (English)
	[θ] substitution to [f]	William: onset (English)
	[ʀ] substitution to [h]	Wiglaf: onset (German) Eleonora: onset (German)
Manner substitution	Fricative stopping	Inês: onset fricatives (Portuguese) William: onset [ð] (English)
	Rhotic gliding	Ben: onset (English) William: onset (English)
Voicing errors	Voicing	Eleonora: onset stops (German) Wiglaf: onset stops and fricatives (German)
Deletion	/r/ deletion	Coda: all languages
	[h] deletion	William: onset (English)

Below, I discuss each of these patterns using the notions of markedness-through-mechanism which they primarily involve. I contextualize these notions within the conceptual frame of the A-map, in order to describe both the perceptual targets and the factors potentially affecting the motor-acoustic mapping of these targets on to adult-like speech forms. As we will see, these elements, taken together, provide us with important cues toward clinical treatment.

2. Place substitution

I begin this discussion by exploring place substitution. Because of its positional nature, I first address the process of Positional Velar Fronting displayed by English-learning Ben which, as already discussed in Chapter 5, section 2, involves both a markedness component and grammatical conditioning (at the prosodic level). I then move on to two specific cases of substitution: [θ] to [f] substitution by English-learning William and [ʀ] to [h] substitution by both learners of German, Eleonora and Wiglaf.

2.1. Velar fronting

As described in Chapter 3, section 7, English-learning Ben displayed velar fronting in word-initial position. He is the only child in the current data to display velar fronting consistently. His data conform to the pattern of Positional Velar Fronting, as first described by Stoel-Gammon (1985; 1996), whereby velars are fronted to a coronal place of articulation in syllable onsets.

2.1.1. Perceptual factors

When compared to other places of articulation, velars are relatively easy to perceive: “velars have stronger place cues than coronals and labials when they are unreleased” and the “place cues of unreleased dorsals are more perceptible than those of unreleased labials, which in turn are more perceptible than those of unreleased coronals” (Jun 2004: 64). Additionally, when preceded or followed by a vowel, “velars can form a robust acoustic cue for place of articulation” (Stevens & Keyser 1989, as cited in Jun 2004: 64).

As velar consonants have more robust acoustic cues than coronal consonants, it seems unlikely that a child would incorrectly perceive the place of articulation of a velar sound as coronal. It is therefore likely that the child’s error arises from issues that are independent from perception.

2.1.2. Articulatory factors

Inkelas & Rose (2007) situate PVF within the realm of speech articulation, itself influenced by grammatical (prosodic) conditioning. The physiological differences of the child’s vocal tract and motor control differences affecting child speech (as listed in (18) and (19)) contribute to PVF and "these facts generally imply that velar consonants should be articulated closer to the front area of the palate across young children, even those not exhibiting (P)VF" (Inkelas & Rose 2007: 722).

Velars, especially in prosodically strong positions, are difficult to master because their production in these positions may trigger articulatory reactions: when the tongue reaches the roof of the mouth too forcibly, it may cause the linguopalatal contact that is required for velars to extend too far forward into the coronal region of the palate, as stated in Inkelas & Rose (2007: 723):

> ... the inherent peculiarity of the tongue (a muscular hydrostat, the only muscular system of this kind in the human body) affects the production of lingual consonants in two ways. First, when producing stop coronals and velars, young children initially use ballistic tongue movements whose relative force lacks the refined control typically seen in older speakers. Second, as evidenced by the relatively late development of liquid contrasts in English (e.g. Dinnsen 1992; Bernhardt & Stemberger 1998), it is only at relatively late stages that children attain the 'motoric developments [that] pertain primarily to tongue shaping and fine force control' (Kent 1992: 75–76).

This results in the coronal release of target velars in these positions, hence the mismatch between the target velar articulation and its coronal realization.

2.1.3. Hypothesis

Under Inkelas & Rose's (2003; 2007) hypothesis, Ben's Positional Velar Fronting results from a combination of grammatically conditioned articulatory factors (see also McAllister Byun 2009; 2010). As mentioned just above, in prosodically strong positions, the linguopalatal contact that is required for velar production extends too far forward (into the coronal region) in the mouth. This results in the coronal release of target velars in strong position. Ben was thus grammatically (prosodically) accurate, given that his production correctly enhances articulatory strength in prosodically strong positions; however, he was segmentally inaccurate, hindered by articulatory constraints preventing velar release in these positions.

In terms of the A-map, Ben could thus reliably produce coronals for target velars in prosodically strong positions, thereby satisfying the demands of the PRECISE constraint at the expense of ACCURATE, as he could neither reliably nor accurately produce velars in strong positions.

2.2. [θ] substitution to [f]

The next case of place substitution to be discussed was previously detailed in Chapter 3, section 2, where William produced target interdental fricative [θ] as labiodental fricative [f] in onset position. This occurred both before and after William reached the acquisition threshold of 50% accuracy for [θ], as his remaining errors after reaching this threshold also consisted of substitution to [f].

2.2.1. Perceptual factors

It is likely that William had arrived at an incorrect motor-acoustic mapping for target [θ] in syllable onsets. Rose (2009) highlights that [f] and [θ] are phonetically very similar (both voiceless fricatives, one labiodental and the other interdental, respectively), with relatively similar acoustic traces (e.g., Levitt et al. 1987). [f] and [θ] are also often both produced as [f] by native speakers (depending on their dialects) and by second language learners of English (e.g., Levitt et al. 1987; Brannen 2002), adding further evidence to the phonetic similarity of these two consonants.

2.2.2. Articulatory factors

It is, however, difficult to account for [f] substitution for [θ] using phonological or straightforward anatomical pressures, as there is no anatomical/phonological motivation for this substitution to occur. While we can minimally claim that interdental articulations may be difficult to acquire, [θ] and [f] involve two distinct major places of articulation, leaving articulatory over-reach or under-reach as unlikely explanations. However, it is possible that William's attempts at [θ] production which result in [f] are distinct motorically from his attempts at [f] productions, and that this difference was not perceived by the adult transcriber. Under this eventuality, William would have been producing a "covert contrast," that is a motor-acoustic mapping for [θ] that was in reality distinct from that of target [f], but resulted in productions too close to [f] for an adult listener to distinguish from actual productions of target [f] (Scobbie et al. 1996; see next section for further discussion of potential covert contrast). However, in the absence of crucial evidence to support this possibility, I restrict my discussion below to the facts suggested by the transcript data.

2.2.3. Hypothesis

Building on the evidence available, we can hypothesize that if children cannot perceive the subtle acoustic difference between [θ] and [f], or if they cannot reproduce the perceived difference through distinct articulations, then [f] substitution for [θ] offers an outcome that can be produced reliably. Similar to the [ð] substitution pattern to be discussed below, we can minimally hypothesize, following the A-map reasoning, that William was favouring precision over accuracy in his productions of target [θ].

2.3. [ʀ] substitution to [h]

The next place substitution pattern to be discussed is that of [ʀ] with [h] in onset position evidenced by the German-learning children. Interestingly, despite a similar uvular [ʀ] also present in French, French-learning Adrien did not display this pattern. Indeed, prior to Adrien's acquisition of [ʀ] in onset, this consonant underwent deletion instead of substitution. This will be analyzed further in 2.3.3 below.

2.3.1. Perceptual factors

It is difficult to perceive the precise phonetic dimensions for [ʀ]. From an auditory perspective, when a child hears [ʀ], she typically hears a uvular fricative or trill. As described in Rose (2003), the acoustic evidence for the uvular rhotic is generally misleading:

> The phonetic evidence from French [ʁ] is, however, potentially misleading. First, as an approximant, [ʁ] does not have a phonetically consistent place of articulation, as it can be realized at different points of articulation ranging from the posterior area of the soft palate to the uvula: this variation, which suggests placelessness, is found both within and across French-speaking individuals. However, French [ʁ] can also be analysed as Dorsal-specified. (Rose 2003: 428).[10]

This statement is also supported by Ladefoged & Maddieson (1996: 225), who refer to [ʀ] as a variable acoustic object. This minimally implies that [ʀ] can be, from a perceptual standpoint, a bit of a moving target, upon which it may be difficult to map an articulatory motor plan.

2.3.2. Articulatory factors

In addition, [ʀ] is also relatively difficult to produce. In order to articulate this consonant, one must gradually constrict the uvular area of the vocal tract into a relatively subtle place of

10 Note that Rose (2003) makes reference to [ʁ], as opposed to [ʀ]. However, this difference is one of convention: [ʀ] and [ʁ] can be used interchangeably across most dialects of French; note as well the emphasis on place of articulation, which applies to all uvular rhotic variants, in both French and German.

articulation. The level of articulatory precision involved in adult-like uvular rhotic continuants requires relatively mature motor control.

2.3.3. Hypothesis

As [ʀ] is both difficult to perceive and difficult to articulate, its mapping may involve mismatches in both perception and production. However, assuming that the child has an accurate perceptual representation of [ʀ], and also abstracting away from the voicing dimension, also variable, she can correctly preserve the back constriction of [ʀ] through [h] productions. Under this hypothesis, [ʀ] → [h] offers a reliable place of articulation across productions for this consonant.

Returning to our discussion of French, the aforementioned asymmetry between German ([ʀ] → [h]) and French ([ʀ] → Ø) can in theory be explained in two different ways. The first is methodological: under the assumption that French children may debuccalize target [ʀ] and produce it as [h] similar to the German children, it is possible that this process went unnoticed by the French transcriber of the French-Yamaguchi corpus (Yamaguchi 2012). [h] is indeed not a phoneme in French; it is thus possible that its production fell below the transcriber's threshold of perception, as a form of covert contrast, which "can be identified in all cases where a systematic acoustic (and related articulatory) difference between two sounds goes unnoticed by human listeners" (Rose, McAllister & Inkelas To appear: 14). The second possibility, which also relates to the fact that [h] is a phoneme of German but not of French, draws on this distinction at the phonological level. Given the presence of [h] in German, and the similarity of the source of its acoustic cues with those of [ʀ], it is plausible that [h] offers a phonetically acceptable substitute for [ʀ] in this language. Grammatically, this would both result in a relatively low violation of Accurate and be an opportunity to satisfy the requirements of Precise, as the German children are capable of routinely producing [h] in their spoken forms.

This latter hypothesis is also consistent with the French data. Given that such an optimal (harmonic) substitute for [ʀ] is not available in French, deletions may offer the best alternative. From the perspective of Accurate, [ʀ] deletion may offer a lesser violation than the production of phonetically remote substitute consonants such as [g] or [j]. From the perspective of Precise, deletion also offers an optimal outcome, as it satisfies this constraint by default: there can be no difference in outcomes in the absence of sound production.

This completes our discussion of place substitutions. As we have seen, all cases involve a trade off between phonetic similarity of target and actual forms and articulatory reliability; given the robustness of the processes involved, and in line with the original proposal by McAllister Byun, Inkelas & Rose (2016), articulatory reliability, encoded through Precise, appears to hold the grammatical upper hand. In the next section, we turn to manner substitutions.

3. Manner substitution

We begin this section by analyzing the source of two different types of stopping: stopping of all fricatives regardless of place, and the place-specific stopping of [ð]. As we will see, different stopping patterns may be analyzed in different ways, when understood in their proper contexts. I then extend our discussion to the English-specific pattern of rhotic gliding, and explore why it only affects rhotics in this particular language, given our current dataset.

3.1.1. Stopping

As previously discussed in Chapter 3, section 6.1, Inês's fricative development in both singleton onsets and onset clusters displayed the same stopping pattern. In a nutshell, Inês realized labial, coronal, and uvular fricatives as stops within syllable onsets.[11] Fricatives in coda position remained unaffected by this process.

3.1.2. Perceptual factors

The perceptual dimension, that is, Inês's ability to perceive obstruent frication, is arguably not the cause of Inês's stopping of fricatives. First, given the absence of stopping in coda position, Inês was evidently able to perceive the relevant acoustic cues in that position. As perception is generally favoured in syllable onset (e.g., Bladon 1983; Manuel 1991), and as fricative noise is generally highly perceptible across syllable positions (Steriade 2001), perception of this acoustic cue should be even easier in syllable onsets than it is in codas. More generally, due to their continuant nature, fricative sounds have more robust place cues when compared to stops and nasals, enabling fricatives to maintain their internal cues throughout much of their phonetic duration (Jun 2004: 62). None of these observations would support a perception-based analysis of this stopping pattern.

3.1.3. Articulatory factors

From an articulatory perspective, however, fricatives do impose a set of challenges to the speaker. The articulations required to produce fricative constrictions require millimetre accuracy, as the articulators must create a narrowing in the oral cavity slight enough to induce turbulence in the airflow but without resulting in a full occlusion at the point of articulation (McAllister Byun 2011: 386). As we will see below, some fricatives also involve additional articulatory details, for example tongue grooving. Together, subtle articulatory gestures and configurations constitute

11 Labial fricatives were variably produced as coronal (stops) during the earliest portion of the stopping stage. Inês first resolved this labial neutralization process, several months before she resolved the stopping stage (Burkinshaw 2014; Rose 2014). In this section, I focus the discussion on the more robust stopping pattern.

many obstacles to young speakers who generally have poor motor control over their speech articulators, which often results in producing broad, ballistic gestures (Crelin 1987; Kent 1992; Kent & Miolo 1995), a fact already discussed in light of the Positional Velar Fronting pattern discussed previously.

3.1.4. Hypothesis

Recall that Inês's pattern of stopping was positionally-conditioned: it occurred in syllable onsets but not in codas. Much like the articulatory pressures that cause PVF, we can attribute Inês's stopping to an overshooting of the articulatory gesture(s) required for fricatives in syllable onsets, which are prosodically strong positions (Burkinshaw 2014: 85; see also Chiat 1983; Inkelas & Rose 2007). These prosodically-conditioned ballistic gestures yield full closure of the vocal tract, resulting in stop productions for target fricatives (see Chapter 6, section 4.1, and McAllister Byun, Inkelas & Rose (2016) for additional discussion in the context of the A-map).

Therefore, Inês's production of stops in place of fricatives resulted in no significant violation of Precise, as she could produce stops reliably. This production pattern was thus more harmonic than the adult fricative target, which she could not reliably or accurately produce in syllable onsets.

3.2. Stopping of [ð]

While stopping affected all of Inês's fricatives (labial, coronal, and uvular), the same process only affected one specific type of fricatives in the speech of English-learning William: the voiced interdental fricative [ð]. As we saw in Chapter 3, section 2.1, William had not acquired [θ] or [ð] in onset position by the end of his documented sessions. While he most frequently stopped [ð] to

[d] (the substitution we focus on in this section), William produced target [θ] as [f], as already discussed in detail in section 2.2 above.

3.2.1. Perceptual factors and the influence of phonetic variability

Interdental fricatives are "non-sibilant fricatives, with the turbulence being produced at the interdental or dental constriction" (Ladefoged & Maddieson 1996: 144). Concretely, this translates into weaker perceptual cues to fricative continuancy. Presumably, given the robustness of phonetic cues generally attributed to fricatives (recall from 3.1.2 above), William would have accurately perceived the three phonetic dimensions required to form his perceptual representation for target [ð]: interdental place, fricative manner, and voicing. However, concerning this consonant in particular, it is plausible that William's perception was affected by the phonetic variability and relatively low salience that we observe in the production of this consonant by English speakers. As mentioned in Chapter 3, section 2.1, [ð] is rarely used in English onsets beyond function words (e.g. "this, that, the"). Additionally, due to both connected speech processes and the frequent use of [ð] as part of function words (which are unstressed, i.e., not perceptually salient), the phonetic realization of this consonant can be extremely variable in the adult language. For example, phrases such as *in <u>th</u>e car* may result in *<u>th</u>e* being produced with a lenited or assimilated [ð], leaving little acoustic or perceptual evidence of interdental frication.

3.2.2. Articulatory factors

Concerning the articulation of interdentals, in American English, the tip of the tongue typically "protrudes between the teeth so that the turbulence is produced between the blade of the tongue and the upper incisors" (Ladefoged & Maddieson 1996: 143). The articulation of this constriction is thus relatively complex, and likely to mature over an extended period of time. As we will see next, these two factors (perceptual and articulatory) appear to conspire in yielding William's stopping pattern of [ð].

3.2.3. Hypothesis

The variability of [ð] in English may have influenced William's categorization of this consonant as a fricative, as weak acoustic cues combine with connected speech processes and limited distribution (outside of function words). Alternatively, as previously discussed, fricative constrictions require millimetre accuracy (McAllister Byun 2011). This is particularly true of interdental fricatives, which require tongue precision both for their placement between the teeth (place of articulation) and for the generation of fricative noise constrictions. As William had not reached this level of precise motor control, he could not produce target [ð] accurately. Therefore his attempts resulted in [d] productions, involving a full closure of the airflow. Here again, the child has prioritized the requirements of PRECISE over ACCURATE, as he settled on the more reliable [d] production, despite its violation against ACCURATE.

Note that we cannot determine from the available data if the closure in William's [d] production for target [ð] is dental or alveolar: it is possible that William fully neutralized the contrast between [ð] and [d] (Inkelas & Rose 2007) resulting in an alveolar closure, or he may have produced an incomplete (manner-only) neutralization producing a dental closure, as outlined in the discussion of William's substitution of [θ] in section 2.2 above. Again here, more evidence would be needed to fully address this issue. Minimally, however, we can conclude that William did not prioritize frication in his articulations of [ð]. Given the variable input he was exposed to for this consonant, and given and that he was maintaining frication for all other target fricatives (even with [θ] substituted with [f]), his idiosyncratic behaviour with [ð] suggests that he had not categorized this consonant as a fricative.

3.3. Rhotic gliding

Rhotic gliding to [w] in English is a well established phonological process “even though the labiality of English [ɹ] is phonetic and plays no role in the phonological behaviour of this consonant in the adult language” (Rose 2003: 428; see also Stevens & Keyser 2010). Across languages, however, rhotic gliding to [w] does not stand out as a general process: across all children in the present case studies, rhotic gliding appears to affect the speech of English-learning children only. This suggests that English [ɹ] patterns differently when compared to the rhotics of French and German (uvular fricatives or trills), and Portuguese (uvular fricative and alveolar flap or tap).

3.3.1. Perceptual factors

The perceptual mapping of [ɹ] in English is aided by the fact that the production of this consonant in syllable onsets remains relatively consistent and consonant-like, especially when compared to post-vocalic [ɹ], which can be classified as “the vocalic offglide of a rhotic diphthong (e.g., McGowan, Nittrouer & Manning 2004)” (McAllister Byun & Hitchcock 2012: 208). Additionally, enhancement gestures, such as lip protrusion/roundness, make the sound easier to perceive, as the “articulatory gesture is superimposed on the defining gesture, and thereby enhances the perceptual saliency of the feature” (Stevens & Keyser 2010: 16). While [ɹ]’s acoustic cues remain consonant-like in onset position, and are enhanced by lip rounding, mapping this acoustic signal on to the correct place of articulation may still prove difficult, as children have to determine which lingual pattern of articulation to attempt (retroflexed vs. bunched tongue movement) and also have to determine the role of lip rounding as enhancing the resonance created through tongue body articulation.

3.3.2. Articulatory factors

[ɹ] is considered one of the most difficult phones for English-learning children to produce (Adler-Bock et al. 2007; McAllister Byun & Hitchcock 2012). In terms of articulation, /ɹ/ in English is considered a complex phoneme: the tongue may be retroflexed or bunched; the lips may be rounded (Kent 2004). Therefore when attempting onset [ɹ], children must figure out one of the correct lingual motor-acoustic mappings that will result in an [ɹ] sound, and must not overemphasize the enhancement, lip-rounding gesture. If children rely too heavily on the enhancement gesture, the attempt may result in a [w] production.

3.3.3. Hypothesis

The fact that [ɹ] appears to be glided to [w] predominantly in English suggests that there is something unique about this consonant. While the gliding of [ɹ] may result from issues in deciphering perceptual cues, this possibility is less likely word-initially, as [ɹ] unambiguously patterns as a consonant in this position. As for articulatory factors, assuming an accurate perception of [ɹ], the child may produce a mismatch resulting in [w] due to immature motor control: it is easier to preserve the enhancement lip-rounding gesture than to accurately reproduce the tongue movement involved in the production of this consonant.

As suggested in the r-gliding toy example discussed in the preceding chapter, [w] offers a motor plan that the child can produce reliably, which results in a lesser penalty against PRECISE than alternative, less reliable productions.

4. Voicing errors

The next robustly attested pattern consists of voicing errors, as displayed by the two German-learners Eleonora and Wiglaf. Both children displayed a sizable number of voicing errors during their acquisition of obstruents in onset position. Additionally, Ben, who displayed atypical development of English, voiced all stops in onset position and devoiced all stops in coda position (McAllister Byun 2009). While the remainder of the children in Chapter 3 also displayed voicing variability in their productions, their error patterns were not as predominant or consistent as that of Ben and the two German-learners.

4.1. Perceptual factors

Recall from Chapter 2, section 2.2, and from Chapter 3, section 4, that German has syllable-final devoicing which causes all syllable-final obstruents to be realized as voiceless in post-vocalic positions (Wiese 1996). From the child's perspective, this adds a certain degree of complexity to syllable onsets, which does involve a contrast between voiced and voiceless obstruents. However, the complexity of acquiring this contrast arguably lies outside of perceptual considerations, as children can perceive voicing contrasts at three months of age (Eimas et al. 1971; Eimas & Corbit 1973), and also given that voicing contrasts in onsets are generally more salient than in codas (e.g., Bladon 1983; Manuel 1991). It is thus unlikely that voicing errors affecting onset consonants would arise from errors in perception.

4.2. Articulatory factors

While perceptually distinguishing a voicing contrast in syllable onsets is generally easy, producing this contrast is arguably more difficult, especially for obstruent stops. To acquire this contrast, children must be able to time and coordinate the vibration of their vocal folds with the release of consonant closure at the accurate place of articulation for the obstruent they are attempting. I focus on this issue in the next subsection.

4.3. Hypothesis

Imbrie (2005) found that between the ages of 2;6-3;3, children display different Voice Onset Time (VOT) values than adults, "providing evidence that 2-3 year-olds are still developing appropriate time and glottal adjustments for onset voicing distinctions" (Song, Demuth & Shattuck-Hufnagel 2012: 3037). The voicing errors observed in the learners' productions likely result from immature motor control, as they are not at an age where they can accurately coordinate their supralaryngeal articulators with their vocal folds. Due to the sizable number of errors and variability in the German-learners' productions, it appears that the children were aiming for accuracy in their productions. They did not reliably produce voicing distinctions, and also did not settle on any clear voicing or devoicing pattern, which suggests that ACCURATE had a more prominent effect on their productions than PRECISE in this particular case, capturing actual attempts at the target voicing specification even if they were often unsuccessful. Under this view, and assuming that stop and fricative voicing are driven by the same grammatical constraints, this hypothesis offers an explanation that abstracts away from the articulatory differences involved in stop versus fricative voicing.

Similar to the other potential covert contrasts discussed above, it is also possible that the children were marking a distinction that could not be perceived by the adult listener. Finally, it is also possible that the error patterns observed in both German-learners, but not in the typical learners of the other languages covered in Chapter 3, relate to phonetic characteristics of German, to the German children's particular dialect, or an interplay between these and the asymmetric distribution of voicing contrasts in this language described just above. However, a full verification of these latter hypotheses extend beyond the scope of this thesis.

5. Deletion

The last two robustly attested patterns involve deletion. The first pattern, /r/ deletion, affected the codas of all four languages. The second pattern affected English [h] in syllable onsets. As we will see next, these deletion patterns occur overwhelmingly in contexts where the target phones are in perceptually weak phonological environments.

5.1. /r/ deletion

Coda /r/ deletion was apparent across all of the languages under investigation, despite the phonetic differences between rhotic consonants across these languages. As previously discussed, the uvular fricative [ʀ] of French and German is produced with tongue dorsum constriction around the uvular portion of the soft palate. It therefore differs articulatorily from the English alveolar rhotic [ɹ], where the tip or blade of the tongue forms a bunched or retroflex constriction behind the alveolar ridge. Portuguese coda /r/ differs again, as it consists of the flap [ɾ]; it is a difficult articulatory object to reproduce (Freitas 1997; Bedore 1999; Costa 2010), the specifics of which are described below. While the children also frequently deleted laterals in syllable codas, especially during early stages of development, the deletion of rhotic consonants continued on for a much longer period, and typically in a more systematic fashion. Also important is the basic observation that all of the rhotics underwent actual deletion, instead of the types of substitution patterns observed above.

5.1.1. Perceptual factors

In general, perceptual cues tend to be weaker in post-vocalic positions than in syllable onsets (e.g., Bladon 1983; Manuel 1991). Starting with German and French [ʁ], as previously discussed in section 2.3.1 above, the place and manner of this consonant are difficult to define perceptually, which in turn arguably makes it hard to implement motorically; in any emergentist framework such as the A-map, this also yields a challenge for the child trying to uncover which articulators to employ in the first place. Similarly, the Portuguese flap [ɾ] may be difficult to map perceptually, in this case due to the millisecond-long point of constriction between the tongue apex and the alveolar ridge involved in coda flap production, resulting in an extremely short duration for this consonant. Lastly, post-vocalic /r/ in English can occur as the rhyme of the syllable (e.g., [ɚ] or [ɝ]), as rhotics in this position "merge in various ways with contiguous vowels" (Ladefoged & Maddieson 1996: 216). This yields a wide variety of /r/ articulations that the child has to master, and also a much harder target to define, especially if compared to syllable-initial /r/ which, as described above, is much more consonant-like.

5.1.2. Articulatory factors

Rhotics in each of the languages under consideration thus offer many articulatory challenges to the learner: to produce German and French [ʁ] post-vocalically, a child has to transition from a full opening for a vowel to a closure at a relatively subtle posterior place of articulation, as already described in section 2.3.2 above, which makes it hard to define articulatorily. Portuguese [ɾ] is also a difficult articulatory object to reproduce, as it is "... a sound in which brief contact between the articulators is made by moving the active articulator tangentially to the site of the contact, so that it strikes the upper surface of the vocal tract in passing" (Ladefoged & Maddieson 1996: 231). The "hit-and-run" nature of this ballistic gesture (Catford 1977: 130) is thus rather subtle and calls for a high level of articulatory maturity. Finally, postvocalic /r/ in English, due to its syllabicity and concomitant merger with preceding vowels, may involve different articulatory plans across different vocalic contexts, which makes it inherently difficult to generalize.

5.1.3. Hypothesis

Despite the perceptual and articulatory specifics of the word-final rhotics described above for each language, all of the children deleted these consonants in a relatively uniform pattern. Recall as well that while rhotics in onsets primarily underwent substitution, in coda they underwent deletion. Building on the observations above, I hypothesize that the underlying factor relates to the perceptual-articulatory mapping of these rhotics, which is arguably difficult to attain due to different combinations of perceptual and articulatory pressures.

From a structural standpoint, one could hypothesize that the child's development of syllable structure may not allow for coda positions at early stages in phonological development (e.g., Rose 2000; Kirk & Demuth 2003; Almeida 2011). However, this argument would hold only if the children were deleting all their target codas, which is clearly not the case, especially at the later ages when the children were displaying rhotic coda deletion while producing other consonants in the same position.

A more likely hypothesis relates to the general observation that aside from a few counter-examples (e.g., Steriade 1999), codas are generally harder to perceive than onsets (e.g., Bladon 1983; Manuel 1991). In addition to the different phonetically-related issues involved in each type of rhotic described above, it is thus plausible that children also have difficulty mapping the weak acoustic cues they perceive for these consonants in syllable codas on to any type of reliable articulatory plan, yielding deletion as the only stable production pattern. Under this hypothesis, one can claim that the children are in fact maintaining precision in their productions by reliably deleting these challenging rhotics.

5.2. [h] deletion

Moving on to the last robustly attested pattern, that of [h] deletion in syllable onsets in English, we must first recall from Chapter 3, section 2.1, that William initially deleted all occurrences of word-initial [h], and then moved on to a stage where [h] was only deleted in prosodically weak position. The other English-learner, Ben, did not display this pattern; however, due to methodological differences between the two corpora, and also given Ben's status as phonologically disordered, it is possible that the corpus documenting his productive abilities is not conducive of verifying the accuracy of his [h] productions, especially in function words and other prosodically weak contexts which, as I summarize next, are central to William's variable behaviours during the latter part of his development period.

5.2.1. Perceptual factors and phonetic variability

Perception may have played a role in William's deletion of [h], as this fricative consonant is not strident, which implies overall weaker acoustic cues. Because [h] can also be weakened or deleted when in the onset of an unstressed syllable in English, it is also plausible that William was not always certain where [h] must appear. This is supported by the fact that even after William reached the mastery threshold for this consonant, he continued to optionally delete it during the remainder of the documented period. William's variable behaviour during this latter period actually aligns with the variability of [h] in adult English, where [h] deletion occurs in connected speech contexts when /h/ is located in prosodically weak positions (e.g., phrases like "give <u>h</u>im," where the [h] generally undergoes deletion).

5.2.2. Articulatory factors

As previously discussed, [h] is easy to produce articulatorily, as it simply requires minimal airflow constriction at the level of the glottis. It does not require articulatory precision or mature motor control at the level of supralaryngeal articulators, which suggests William's deletions of this sound were likely not primarily influenced by immature motor control.

5.2.3. Hypothesis

Given the considerations discussed above, about the variable patterning of [h] both in English and in William's productions, we can attribute William's development of this consonant directly to the phonetic variability of [h] in English. As [h] can be weakened or deleted when in an unstressed syllable, William initially had difficulty mapping these weak and variable acoustic cues on to a reliable motor-acoustic plan (similar to the case of rhotic deletion described above), before he acquired the prosodically-defined rules of [h] production in the language. Under this hypothesis, a revision of the target forms in the corpus to eliminate the target [h]s that should logically not appear in prosodically weak contexts (as opposed to the citation forms used in the original corpus, where [h] is always present) would indeed produce a development curve that generally matches the other onset consonants affected by weak acoustic cues discussed above. This revision would also offer evidence for the development of grammatically-conditioned phonological rules, a topic I leave open for future research.

6. Interim summary

Taken together, the eight robustly-attested patterns discussed above highlight the fact that different phonological patterns, or at times similar patterns, may result from different underlying sources involving different combinations of perceptual and articulatory factors, in combination with variable aspects of the linguistic signal to the learner. Considered within the A-map framework, the patterns observed may result from either incorrect mappings of perceptual objects, or errors in the motor-acoustic mapping of these objects, with phonetic or phonologically-driven variability adding an additional layer of complexity to the learning process. In the section below, I discuss how these observations should guide our general approaches to treatment options.

7. Implications for clinical treatment

As highlighted in the discussion of the robustly attested patterns in the sections above, many of the tendencies we observe in children's production patterns make logical sense from a phonetic standpoint. Building on this logic, and on the tenets of the A-map, there should be a strong consideration of acoustic and articulatory factors in our definition of speech targets and clinical outcomes. For example, in Bedore, Leonard & Gandour's (1994) clinical treatment study of a four-year-old English-learning girl who substituted a dental click for all of her target sibilants (i.e., /s, z, ʃ, ʒ, ʧ, ʤ/), treatment focused exclusively on the target sibilant /s/ (as previously discussed in Chapter 1, section 2). This resulted in the child showing a rapid and non-linear progression: it took only two treatment sessions over a one-week period to remedy the child's general substitution pattern, during which she generalized across all target sibilants, which she started producing correctly in spontaneous speech. This suggests that the child had relatively accurate perceptual representations of the target sibilants, while her articulation of these sounds remained problematic. Once the child acquired an adequate mapping for [s], she could rapidly generalize to the full class of strident fricatives. In line with this observation, I will briefly sketch possible treatment approaches for each of the patterns described in the previous section. This discussion is by no means exhaustive as it does not consider the individual children's overall phonological system; in a similar way, the application of the suggestions below to any child would need to be contextualized in light of the individual child's overall speech abilities.

7.1. Place substitution

7.1.1. Positional Velar Fronting

As discussed above, Positional Velar Fronting is a grammatically-conditioned pattern that affects the place dimension of target velars: the child is grammatically accurate as her production marks the presence of the prosodically strong position, however she is motorically unable to produce the velar consonant correctly (Inkelas & Rose 2003; 2007). Given these observations, therapy should focus on accurate tongue placement and refinement of the ballistic gesture in strong positions. As the child has already mastered velar productions in weak position, contextualizing therapy in strong positions should offer a useful key; for example by using velar productions in weak positions as a starting point for the replication of the relevant place of articulation in strong positions.

7.1.2. [θ] substitution to [f]

William's substitution of [θ] to [f] arguably resulted from issues in perception, given that [θ] and [f] are acoustically similar. If William could not perceive this sound accurately, he logically could not reproduce it. Building on this, therapy should first focus on correctly identifying the sound contrast in isolation, and then expand to syllables, words, phrases, and lastly connected speech. Once the child has mapped the perceptual distinction correctly (for example, that there is an interdental voiceless fricative in addition to a labiodental voiceless fricative in the language), generalization of this mapping to other syllable/word positions should follow.

7.1.3. [ʀ] substitution to [h]

[ʀ] substitution to [h] in German arguably results from articulatory simplification. In this case, the focus of therapy should be on the uvular place dimension, which can be a much more difficult place of articulation for the child to establish. Once the child becomes aware of this place of articulation and can perform consonantal constrictions around the uvula, [ʀ] production should begin to emerge.

7.2. Manner substitution

7.2.1. Stopping

As previously outlined, the stopping of fricative sounds, as displayed by Inês (and similar to Positional Velar Fronting), results in part from prosodic conditioning. Keeping with the logic expressed above, it is the motor-acoustic mapping in prosodically strong positions that should be targeted in therapy. This involves focusing therapy on fricative noise. In this respect, a sound approach would be to work on one (or a subset) of stimulable fricatives in prosodically weak positions with a focus on extending the relevant constriction to prosodically strong positions. In line with the observation from Bedore, Leonard & Gandour (1994) above about how fricative constrictions at one place of articulation can be extended to other places, this should trigger generalization to other places of articulation. In case it does not, extending therapy to these remaining problematic places of articulation should further facilitate generalization.

In comparison, treatment for interdental stopping as displayed by William should first focus on perception, in order to establish a clear interdental (that is not stopped or lenited due to variability allowed in the target system). This work might require a careful approach to clearly define the perceptual target, as the weak acoustic cues of [ð] combine with connected speech processes in English in ways that may hinder accurate perception of this sound. Under the eventuality that the child can in fact perceive the perceptual object correctly, it would be logical to think that the issue lies in the target motor-acoustic mapping of the interdental place of articulation. In this case, the issue would relate to the articulatory gestures involved in interdental fricative productions; treatment should then focus on refinement of the tongue gesture so that it does not extend into full closure.

7.2.2. Rhotic gliding

To treat rhotic gliding, one should first ensure that the child's perception of rhotics is accurate. To address perception, separating /r/ from vowels will make them easier to perceive and will also remove possible rounding influences from vowels such as [o] and [u]. As rhotic gliding can occur in onset, onset cluster, and coda position, initially focusing treatment on onset positions could prove beneficial, as in this position /r/ consistently patterns as a consonant and is minimally influenced by neighbouring vowels. Additionally, it may be helpful to focus treatment on onset clusters that do not contain a labial obstruent (e.g., /tr, dr, kr/) to maximally reduce labial (lip rounding) influence. Finally, in all contexts where ultrasound-based methods for bio-feedback are available, the clinician should ideally use it to help establishing correct lingual movement (Adler-Bock et al. 2007).

7.3. Voicing errors

Given that voicing can be articulatorily expressed in different ways (e.g., through VOT for stop consonants vs. continuous phonation in the case of continuant consonants), voicing errors can also arise from a range of articulatory factors. While distinguishing voicing contrasts should be relatively easy, especially in syllable onsets, producing this contrast can be more difficult: for stops, the children have to time and coordinate the vibration of their vocal folds against the release of consonant closure at the accurate place for the sound they are trying to produce. For fricatives, the children must combine phonation with continuous airflow, itself constricted at the relevant place of articulation. Therefore, therapy should focus on marking the voicing distinction between the relevant consonant types. One may achieve this with the use of minimal pairs that differ only in voicing, such as "pea" vs. "bee" and "fine" vs. "vine." These may help the child determine the duration and/or onset of phonation that is required to establish a contrast that is perceivable by the adult listener. Minimal pairs are helpful in that they provide tangible examples of words that require precise phonation times. The can also be illustrated using pictures for use with younger learners (e.g., you can ask the child "did you mean to say pea or bee?" and the child can point to the corresponding picture to clarify, enabling the clinician to respond with appropriate feedback).

7.4. Deletion

7.4.1. /r/ deletion

Moving to the deletion of coda /r/, errors can stem from an incorrect perceptual representation, an error in the motor-acoustic mapping, or both. However, as all of the children studied in this thesis deleted rhotics in the less salient coda position, focusing on making /r/ perceptually salient in this position should be key. For all languages, treatment should first ensure that the child has accurately determined the correct perceptual dimensions in coda position. Separating /r/ from vowels by pausing between the vowel and the /r/, extending the duration of the /r/, or clapping out the individual sounds (segmenting the word into the phones that make up the word) will help make the rhotics easier to perceive in the speech stream, as vowels can be co-articulated with /r/ and mask some of their acoustic signal. Using these methods, the children would benefit from acoustic cues potentially more useful than what is available in typical speech, which should offer the relevant basis to establish appropriate motor-acoustic mappings.

7.4.2. [h] deletion

Lastly, as we saw in section 5.2, William's deletion of onset [h] (similar to his substitution of [θ] to [f]), arguably was due to the perceptually weak status of [h], which undergoes weakening or deletion when in an unstressed syllable. In this context, therapy should first focus on correctly identifying the sound in isolation, and then on refining this skill in larger contexts; for example, within individual syllables, words, all the way to connected speech. Once the child has mapped the perceptual dimensions correctly (in particular for all initial and stressed syllables, which are the contexts where [h] production is obligatory in English), she should be able to extend this mapping to other, less salient contexts, and from there master the more subtle aspects of context-driven lenition and deletion of this consonant across all phonological contexts.

In sum, the treatment options discussed above highlight a compelling tandem between articulatory factors, which tend to manifest themselves more prominently in child language due to the anatomical and motor properties that characterize child speakers, and perceptual factors, whereby difficulties are more readily predicted in contexts where the perceptual cues are either difficult to identify and/or display variable patterns. This tandem can itself be captured through the A-map, which provides us with a framework to capture the mappings between perceptual objects and the speech articulations required to reproduce these objects. By incorporating predictions from markedness-through-mechanism (Hume 2011) within this framework, we are in a position to address the nature of child phonological patterns in ways that are both theoretically-informed and clinically applicable. The latter is particularly true as the resulting analyses incorporate considerations which are directly relevant to the remediation of phonological disorders.

8. Conclusion

I began this dissertation with a critical evaluation of implicational relationships in phonological development as proposed by Gierut (2007), whose logic is anchored within typological markedness. In order to properly test this hypothesis, I conducted a longitudinal, cross-linguistic study of six children learning four different languages, focusing on the development of consonant production in syllable onsets and codas. As we saw through this theoretical and empirical assessment of Gierut's proposal, while some implicational relationships capture what seem like inescapable logic about certain aspects of development, most of them remain conceptually questionable and empirically unfounded. Building on this conclusion, I then discussed alternative views of markedness, which led to the establishment of the phonetically-driven approach of markedness-through-mechanism (Hume 2011) as a more promising approach to capture not only facts about adult phonological systems but also their acquisition. Among other components, I focused on perceptual distinctiveness, articulatory simplicity, and phonetic variability as leading factors affecting the development of phonological productive abilities. I then operationalized this approach to markedness within the A-map model (McAllister Byun, Inkelas & Rose 2016), which can readily capture how perceptual distinctiveness, articulatory simplicity, and phonetic variability may interact within children's developing phonological systems. Returning to the cross-linguistic developmental data, I revisited eight robustly attested patterns from my corpus study, each of which highlights ways in which phonetic conditioning, both in perception and articulation, can ultimately influence phonological development. Finally, because of its grounding both in the phonetic properties of target languages and their implications for the development of speech articulation, this discussion offered a compelling basis for sketching potential approaches to the treatment of these production patterns within clinical contexts.

In a nutshell, combining markedness-through-mechanism with the A-map offers a new way to frame the phonological patterns we observe in child phonological development that is both theoretically and empirically consistent. This approach also offers key intuitions about the treatment of phonological disorders, which highlights that developmental patterns of phonological production can arise from different combinations of factors. This also implies that neither our understanding of developmental patterns nor our approach to treating error patterns in speech production can be prescribed in ways that will cover all attested cases across all languages. It is therefore ultimately in the hands of the Speech-Language Pathologist to determine which factors, perceptual or articulatory, in relation to the phonological and phonetic properties of the target language, must be addressed in each individual case, in order to determine what phonological or phonetic dimensions have been incompletely or incorrectly analyzed by the child, thereby preventing the reproduction of target motor-acoustic mapping.

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Appendix

1. Phonological development: ages of acquisition

The following charts summarize the phonological development of each child. The letter(s) listed in the charts below represent the most common production type by that child for any given session. If multiple production types were common, multiple letters are listed. For example, if the child frequently (and nearly equally) substituted and deleted the target sound in a session, both D (for deletion) and S (for substitution) were included. The legend provided in Table 64 provides the additional information required to interpret the charts. Occasionally, T (for target) is listed as the most common production prior to the date of acquisition. This session would not have been chosen as the starting point of acquisition because 1) there was only one production of the target sound (and therefore not enough evidence) or 2) because this one session with accurate targets was then followed by sessions that consisted primarily of non-targets. Cases where the later occurs can be easily observed in the charts below.

Table 64: Legend for chart interpretation

Symbol	Meaning
√	Acquired
X	Not acquired
—	No attempts at target sound
D	Deletion: when describing clusters, this refers to both members of the cluster being deleted.
S	Substitution: when describing clusters, this refers to one or both of the target sounds being substituted in the absence of deletion.
V	Voicing error
T	Target
R	Reduction: this applies to clusters only and describes when one member of the cluster is deleted.
D+S	Deletion + Substitution: this applies to clusters only and describes when one member of the cluster is deleted and one member is substituted.

Table 65: William’s onset cluster development

	1;04.12	1;04.25	1;06.05	1;06.19	1;07.08	1;08.02	1;09.12	1;09.25	1;10.12	1;11.00	1;11.15	2;00.12	2;00.24	2;01.26	2;02.09	2;02.21	2;04.03	2;04.16	2;09.05	2;11.14	Not acquired
Stop-glide	R/S/T	S/T	—	—	—	R/T/D+S	R	√	√	√	√	√	√	√	√	√	√	√	√	√	
Stop-lateral	—	—	—	R	R/D+S	R/T	R/S/T	R/T	√	√	√	√	√	√	√	√	√	√	√	√	
Stop-rhotic	D+S	R/D+S	—	R/S	—	R/D+S	R/D+S	D+S	S	S	S/T	√	√	√	√	√	√	√	√	√	
Fricative-lateral	—	—	—	—	R	—	—	—	—	—	—	√	√	√	√	√	√	√	√	√	
Fricative-glide	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	√	√	√	√	
Fricative-rhotic	R	—	—	—	—	R	D+S	—	—	—	—	—	—	D+S	S	—	S	T	√	√	
Nasal-glide	—	—	—	—	—	—	—	—	—	—	—	—	—	S	—	—	S	—	T	√	

Table 66: William’s onset cluster development

	1;04.12	1;04.25	1;06.05	1;06.19	1;07.08	1;08.02	1;09.12	1;09.25	1;10.12	1;11.00	1;11.15	2;00.12	2;00.24	2;01.26	2;02.09	2;02.21	2;04.03	2;04.16	2;09.05	2;11.14	Not acquired
Stop-glide	R/S/T	S/T	—	—	—	R/T/D+S	R	√	√	√	√	√	√	√	√	√	√	√	√	√	
Stop-lateral	—	—	—	R	R/D+S	R/T	R/S/T	R/T	√	√	√	√	√	√	√	√	√	√	√	√	
Stop-rhotic	D+S	R/D+S	—	R/S	—	R/D+S	R/D+S	D+S	S	S	S/T	√	√	√	√	√	√	√	√	√	
Fricative-lateral	—	—	—	—	R	—	—	—	—	—	—	√	√	√	√	√	√	√	√	√	
Fricative-glide	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	√	√	√	√	
Fricative-rhotic	R	—	—	—	—	R	D+S	—	—	—	—	—	—	D+S	S	—	S	T	√	√	
Nasal-glide	—	—	—	—	—	—	—	—	—	—	—	—	—	S	—	—	S	—	T	√	

Table 67: William’s coda development

	1;04.12	1;04.25	1;06.05	1;06.19	1;07.08	1;08.02	1;09.12	1;09.25	1;10.12	1;11.00	1;11.15	2;00.12	2;00.24	2;01.26	2;02.09	2;02.21	2;04.03	2;04.16	2;09.05	2;11.14	Not acquired
[k]	D	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[ʃ]	—	S	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[f]	D	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	D	S	D	T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[s]	D	V	T	T	D/T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[ŋ]	D/S	—	—	D	D/S	S/T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	—	—	—	—	—	—	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
[d]	D	—	—	D	D	D	D	D	S	D/S/T	√	√	√	√	√	√	√	√	√	√	
[z]	D	S	T	V	S/T	D/T	V/T	V	S/T	V	T	V	√	√	√	√	√	√	√	√	
[l]	D	D	D	D	D	D	D/S	D	D	D	T	D	√	√	√	√	√	√	√	√	
[v]	—	—	—	S	—	D	D	D/T	—	T	—	—	—	√	√	√	√	√	√	√	
[p]	S	S	T	T	S/T	D/T	—	T	S	T	D	T	—	D	√	√	√	√	√	√	
[ɹ]	D	D	D	D	D	D	D	D	D	D/S	D/S	S	D/T	S	√	√	√	√	√	√	
[g]	S	—	—	—	V	V	T	V	V	V	—	V	—	S/T	—	—	√	√	√	√	
[θ]	—	—	—	—	—	D	S	—	T	—	—	—	—	S	—	—	D/S/T	S	D	S	X
[ð]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
[ʒ]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	S	—	X

Table 68: Eleonora’s onset development

	1;00.07	1;01.11	1;02.07	1;02.14	1;04.02	1;04.08	1;04.23	1;05.23	1;06.05	1;06.15	1;06.29	1;08.15	1;08.26	1;10.02	Not acquired
[h]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	T	√	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[n]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[p]	T	V	√	√	√	√	√	√	√	√	√	√	√	√	
[d]	—	S/T	√	√	√	√	√	√	√	√	√	√	√	√	
[m]	S	T	√	√	√	√	√	√	√	√	√	√	√	√	
[k]	—	—	—	—	S	—	—	—	√	√	√	√	√	√	
[v]	—	S	S	S	—	D	—	T	—	√	√	√	√	√	
[l]	—	—	—	S	—	—	—	—	—	—	√	√	√	√	
[f]	—	S	—	—	S	D	—	—	—	S	S	√	√	√	
[j]	—	—	—	—	—	S	—	—	S	—	S	√	√	√	
[g]	—	—	—	S	S	—	—	S	T	S	V	V	√	√	
[ʀ]	D/S	S	—	D	—	D/S	S	—	S	S	S	—	S	√	
[z]	—	—	—	—	—	S	—	—	—	—	—	S	T	—	X
[ʃ]	—	—	—	S	S	S	—	—	—	S	—	S	S	S	X
[p͡f]	—	—	—	—	—	—	—	—	—	—	S	—	S	—	X
[ʦ]	—	—	—	—	S	S	—	—	S	S	—	S	T	S	X
[ʧ]	—	—	—	—	—	—	—	—	—	S	—	—	—	—	X

Table 69: Eleonora's onset cluster development

	1;00.07	1;01.11	1;02.07	1;02.14	1;04.02	1;04.08	1;04.23	1;05.23	1;06.05	1;06.15	1;06.29	1;08.15	1;08.26	1;10.02	Not acquired
Stop-rhotic clusters	—	R	R	—	—	D+S	—	—	—	R/D +S	R	R/D +S	D+S	√	X
Stop-lateral clusters	—	—	R	D+S	—	—	—	—	—	R	—	T	R/D	—	X
Stop-glide clusters	R	D+S	—	D+S	—	S	—	—	S	—	—	—	—	—	X
Fricative -rhotic clusters	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
Fricative -lateral	—	—	—	—	—	—	—	—	—	R	—	—	—	S	X
Nasal-glide	—	—	—	—	—	—	—	—	—	—	—	—	D+S	—	X

Table 70: Eleonora's coda development

	1;00.07	1;01.11	1;02.07	1;02.14	1;04.02	1;04.08	1;04.23	1;05.23	1;06.05	1;06.15	1;06.29	1;08.15	1;08.26	1;10.02	Not acquired
[ç]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
[p]	—	—	—	—	√	√	√	√	√	√	√	√	√	√	
[t]	—	—	—	—	—	√	√	√	√	√	√	√	√	√	
[l]	—	—	D	D	D/T	D	√	√	√	√	√	√	√	√	
[k]	—	—	D	D/S	S	S	S	√	√	√	√	√	√	√	
[f]	—	—	—	—	T	S	T	√	√	√	√	√	√	√	
[x]	—	—	S	—	—	S	—	√	√	√	√	√	√	√	
[s]	—	S	T	T	S	S	—	—	√	√	√	√	√	√	
[ʃ]	—	S	—	—	—	—	—	—	—	—	—	S	—	S	X
[p͡f]	—	—	D	—	—	—	—	—	—	—	—	—	—	—	X
[ʀ]	S	—	D	—	D	D	S	D	D	D/S	D/S	D	D	D	X
[ŋ]	—	—	—	—	—	—	—	—	—	S	—	D/T	—	—	X

Table 71: Wiglaf's onset development

	1;03.21	1;05.03	1;05.26	1;06.12	1;07.11	1;08.02	1;08.13	1;09.02	1;09.09	1;09.19	1;10.28	1;11.03	1;11.13	2;00.17	2;01.07	Not acquired
[p]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[n]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[j]	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[m]	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[h]	D	—	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	S	T	V	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	T	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
[v]	S	T	—	S	S	S	√	√	√	√	√	√	√	√	√	
[l]	—	—	—	—	—	—	S	S	S	S	√	√	√	√	√	
[f]	—	—	—	—	—	—	—	V	V	S	V	√	√	√	√	
[k]	—	—	—	—	—	S	S	S	S	S	T	S/T	√	√	√	
[g]	—	—	—	—	—	V	—	S	S	S	—	V	√	√	√	
[ʁ]	—	—	S	S	S	S	S	S	S	S	S	S	√	√	√	
[d]	V	T	V	V	V	V	V	V	V	V	V	V	V	√	√	
[ʦ]	—	—	—	—	—	—	D	S	S	S	T	S/T	S/T	S/T	√	
[z]	—	—	—	—	—	—	S	S	S	S	S/T	V	V	S/T	S	X
[ʃ]	—	—	—	—	—	—	—	—	S	S	S	S	S	S	—	X
[ʧ]	—	—	—	—	—	—	—	—	—	—	—	—	S	—	—	X
[p͡f]	—	—	—	—	—	—	—	S	—	—	—	—	—	S	—	X

Table 72: Wiglaf's onset cluster development

	1;03.21	1;05.03	1;05.26	1;06.12	1;07.11	1;08.02	1;08.13	1;09.02	1;09.09	1;09.19	1;10.28	1;11.03	1;11.13	2;00.17	2;01.07	Not acquired
Fricative-rhotic clusters	—	—	—	—	—	—	—	—	—	—	√	√	√	√	√	
Stop-lateral clusters	—	—	—	—	—	D+S	D+S	D+S	D+S	D+S	S/T	√	√	√	√	
Fricative-lateral clusters	—	—	—	—	—	—	—	—	—	—	—	—	√	√	√	
Stop-glide clusters	—	—	—	—	—	—	—	—	—	—	S	—	R	—	—	X
Stop-rhotic clusters	—	—	—	—	—	R	D+S	R/D +S	D+S	R/D +S	S	S	S	S	S	X
Nasal-glide clusters	—	—	—	—	—	—	—	R	D	—	—	—	T	—	—	X

Table 73: Wiglaf's coda development

	1;03.21	1;05.03	1;05.26	1;06.12	1;07.11	1;08.02	1;08.13	1;09.02	1;09.09	1;09.19	1;10.28	1;11.03	1;11.13	2;00.17	2;01.07	Not acquired
[p]	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[f]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[s]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	D	—	D/S	D	—	√	√	√	√	√	√	√	√	√	√	
[k]	—	—	—	S	—	D	—	√	√	√	√	√	√	√	√	
[x]	—	—	—	—	—	—	S	S	√	√	√	√	√	√	√	
[l]	—	—	S	T	D/T	D/T	S/T	D/T	D	√	√	√	√	√	√	
[ç]	—	—	—	—	—	—	—	—	—	—	√	√	√	√	√	
[ŋ]	—	—	—	—	—	—	—	—	—	—	—	—	√	√	√	
[ʃ]	—	—	—	—	—	—	S	—	—	—	S	—	—	—	S	X
[ʀ]	—	—	D	D/S	D	D	D	D/S	D	D	D	D	D/S	D/S	D/S	X
[p͡f]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X

Table 74: Adrien's onset development

	1;11.14	2;00.16	2;01.13	2;02.20	2;04.16	2;05.23	2;07.19	2;09.13	2;10.15	2;11.11	3;00.16	3;02.11	3;03.13	3;05.15	3;10.14	3;11.13	4;00.16	4;01.13	Not acquired
[m]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[n]	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[d]	V	V	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[p]	—	V	V	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	—	T	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[v]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[l]	—	S	T	S	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[k]	—	—	—	S	S	√	√	√	√	√	√	√	√	√	√	√	√	√	
[g]	—	—	S	S	—	S	√	√	√	√	√	√	√	√	√	√	√	√	
[w]	—	—	—	T	S/T	S	S	√	√	√	√	√	√	√	√	√	√	√	
[j]	—	—	—	—	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
[f]	—	—	—	—	—	S/T	T	S	S	√	√	√	√	√	√	√	√	√	
[ɥ]	—	—	—	—	—	—	—	—	S	—	√	√	√	√	√	√	√	√	
[s]	—	—	—	S	S/T	S/T	S	S	S	S/T	S	S/T	√	√	√	√	√	√	
[ʁ]	—	—	—	D	—	S	D	D	D/S	—	D	D	S	D	D	D	√	√	
[z]	—	—	—	—	—	—	—	—	—	—	S	—	D	—	—	—	—	T	X
[ʃ]	—	—	—	—	—	S	S	S	S	S	S	S	S	S	S	S	S	S	X
[ʒ]	—	—	—	S	D	D/S	S	S	S	S	S	S	S	S	S	S	S	S	X

Table 75: Adrien’s onset cluster development

	1;11.14	2;00.16	2;01.13	2;02.20	2;04.16	2;05.23	2;07.19	2;09.13	2;10.15	2;11.11	3;00.16	3;02.11	3;03.13	3;05.15	3;10.14	3;11.13	4;00.16	4;01.13	Not acquired
Stop-rhotic	—	—	—	—	D	—	D/ D+ S	R	R	R	R	R	R/D +S	R	R	R	R	√	
Fricative-rhotic	—	—	—	—	—	—	—	D+ S	R/D +S	—	D+ S	R	R/D +S	—	R	R	R	√	
Stop-lateral	—	—	—	—	R	R/D +S	R	—	R	—	R	R	D+ S	R	R	R	R	R	X
Fricative-lateral	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—	—	R	—	X

Table 76: Adrien’s coda development

	1;11.14	2;00.16	2;01.13	2;02.20	2;04.16	2;05.23	2;07.19	2;09.13	2;10.15	2;11.11	3;00.16	3;02.11	3;03.13	3;05.15	3;10.14	3;11.13	4;00.16	4;01.13	Not acquired
[t]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[l]	—	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[p]	—	—	—	T	—	D/S	—	—	√	√	√	√	√	√	√	√	√	√	
[f]	—	—	—	—	—	—	—	—	—	—	√	√	√	√	√	√	√	√	
[k]	—	—	—	—	—	T	—	—	D	—	S	D/S	T	√	√	√	√	√	
[s]	—	—	—	S	—	—		—	—	T	S/T	T	D	√	√	√	√	√	
[z]	—	—	—	—	—	S	D	—	S	—	—	—	—	—	—	√	√	√	
[ʁ]	—	—	D	S	D	D/S	D	D/S	D	D	D	D	D	D	D	D	√	√	
[v]	—	—	—	—	—	—	—	—	—	—	—	V/T	D	V	V/T	V	V/T	√	
[d]	—	—	—	—	—	—	—	—	—	—	—	—	—	S	S	S/T	S	—	X
[ʃ]	—	—	—	—	—	—	—	—	S	S/T	S	S	—	S/T	—	S/T	—	S/T	X
[ʒ]	—	—	—	—	—	S	—	S	S	—	V	—	—	—	—	T	S	—	X
[b]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	T	S	—	X
[g]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	S/T	—	—	X

Table 77: Inês's onset development

	0;11.14	1;00.25	1;01.30	1;03.06	1;04.09	1;09.19	2;00.11	2;01.10	2;04.19	2;07.16	2;08.23	2;10.20	2;11.22	3;00.15	3;02.03	3;04.06	3;10.01	3;11.12	Not acquired
[m]	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[d]	T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[p]	—	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[n]	—	S/T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[t]	—	V/T	—	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[k]	—	—	D	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[b]	S	—	S/T	S/T	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
[g]	—	—	—	—	S	√	√	√	√	√	√	√	√	√	√	√	√	√	
[l]	—	—	—	—	S	D	D	√	√	√	√	√	√	√	√	√	√	√	
[f]	D	D	—	—	—	S	S	S	S	√	√	√	√	√	√	√	√	√	
[v]	—	—	—	—	S	S	S	S	S	√	√	√	√	√	√	√	√	√	
[s]	—	—	S	S	S	S	S	S	S	S	S/T	√	√	√	√	√	√	√	
[z]	—	—	—	—	S	—	D	—	—	—	—	S	√	√	√	√	√	√	
[ʃ]	—	T	D/S	S	—	S	S	S	S	S/T	S	S	√	√	√	√	√	√	
[ʒ]	—	S	D	—	S	S	S	S	S	S	S	S/T	√	√	√	√	√	√	
[ʀ]	—	—	—	—	—	S	S	S	S	S	S	S	—	√	√	√	√	√	

Table 78: Inês's onset cluster development

	0;11.14	1;00.25	1;01.30	1;03.06	1;04.09	1;09.19	2;00.11	2;01.10	2;04.19	2;07.16	2;08.23	2;10.20	2;11.22	3;00.15	3;02.03	3;04.06	3;10.01	3;11.12	Not acquired
Stop-glide	—	—	—	—	—	—	—	√	√	√	√	√	√	√	√	√	√	√	
Stop-lateral	—	—	—	—	—	—	—	S	S	—	√	√	√	√	√	√	√	√	
Fricative-lateral	—	—	—	—	—	—	D+S	D+S	D+S	S	√	√	√	√	√	√	√	√	
Stop-rhotic	—	—	—	—	—	R	R/S	R	R	R	R	R	R	R	R	R	√	√	
Fricative-rhotic	—	—	—	—	D+S	D+S	D+S	D+S	R	R	R	—	R	—	R	R	—	√	
Fricative-glide	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	?

Table 79: Inês coda development

	0;11.14	1;00.25	1;01.30	1;03.06	1;04.09	1;09.19	2;00.11	2;01.10	2;04.19	2;07.16	2;08.23	2;10.20	2;11.22	3;00.15	3;02.03	3;04.06	3;10.01	3;11.12	Not acquired
[ʃ]	D/S	D	D/S	D	D	D/T	√	√	√	√	√	√	√	√	√	√	√	√	
[ʒ]	D	—	—	—	—	D	D	D	D	D	—	D/S	D/S	S	√	√	√	√	
[ɫ]	—	—	D	—	—	—	D	S/T	D/S	D/S	D/T	T	S/T	S/T	S	D	S	S	X
[ɾ]	—	—	—	—	—	D	D/S	S	D	S	D	D/S	D/S	D/S	D/S	D	D	D/S	X

Table 80: Ben's onset development

	3;09.06	3;10.04	3;10.11	3;10.25	3;11.18	3;11.29	4;02.07	4;03.05	Not acquired
[n]	√	√	√	√	√	√	√	√	
[m]	√	√	√	√	√	√	√	√	
[w]	√	√	√	√	√	√	√	√	
[j]	√	√	√	√	√	√	√	√	
[b]	√	√	√	√	√	√	√	√	
[d]	√	√	√	√	√	√	√	√	
[ʃ]	—	S	D	S	√	√	√	√	
[s]	S	S	S	S	S	√	√	√	
[f]	S	S	S	S	S	S	S	√	
[p]	V	V	V	V	V	V	V/T	V	X
[t]	V	V/T	V	V	V	V	V	V	X
[k]	S	S/V	S	S	S	S	S	S	X
[g]	S	S	S	S	S	S	S	S	X
[v]	—	—	—	S	—	—	—	S	X
[θ]	—	—	S	—	—	—	V	V/S	X
[ð]	S	S	S	S	S	S	S	S	X
[z]	—	—	S	—	—	—	V	V/S	X
[ʒ]	—	—	—	—	—	—	—	—	X
[h]	T	S/T	T	T	S/T	S	S	S/T	X
[ʧ]	S	—	—	—	—	S	—	S	X
[ʤ]	—	S	—	S	S	—	S	S	X
[l]	—	S	S	S	S	S	D	S	X
[ɹ]	S	S	S	S	S	S	S	S	X

Table 81: Ben's onset cluster development

	3;09.06	3;10.04	3;10.11	3;10.25	3;11.18	3;11.29	4;02.07	4;03.05	Not acquired
Stop-lateral clusters	D	D+S	D+S	D+S	D+S	D+S	D+S	D+S	X
Stop-rhotic clusters	D	D+S	D+S	D+S	D+S	D+S	D+S	D+S	X
Stop-glide clusters	D+S	—	D	D+S	D+S	D+S	D+S	D+S	X
Fricative-lateral clusters	—	D+S	—	—	D+S	—	D+S	S	X
Fricative-rhotic clusters	D+S	D+S	D+S	—	D/S	D+S	D+S	D+S	X
Fricative-glide clusters	—	—	—	—	—	—	—	—	X
Nasal-glide clusters	—	—	—	—	—	—	—	—	X

Table 82: Ben's coda development

	3;09.06	3;10.04	3;10.11	3;10.25	3;11.18	3;11.29	4;02.21	4;03.05	Not acquired
[p]	√	√	√	√	√	√	√	√	
[s]	√	√	√	√	√	√	√	√	
[ʃ]	—	√	√	√	√	√	√	√	
[t]	S	S	√	√	√	√	√	√	
[k]	S	S	S	√	√	√	√	√	
[ŋ]	S	—	D	—	D/S	D/S	√	√	
[b]	D	—	—	D	—	V	—	V	X
[d]	D	D	V	V	V	—	V	V	X
[g]	D	S	—	D	D/V	S	V	V	X
[f]	—	—	D	—	—	—	—	—	X
[v]	—	D	S	D	V	D	V	S	X
[θ]	—	—	—	—	S	S	S	S	X
[ð]	—	—	—	—	—	—	—	—	X
[z]	V	V	V	V	V	V	V	V	X
[ʒ]	—	—	—	—	—	—	—	—	X
[ɫ]	D	S	S	D	D	S	D	D/S	X
[ɹ]	D	D	S	S	D	D	D	D/S	X

2. Implicational relationship summary

Table 83: Implicational relationship summary for all children

Observed implicational relationships	William	Adrien	Eleonora	Inês	Ben	Wiglaf
A stridency and/or laterality distinction implies the phonetic occurrence of a liquid, which implies a fricative and/or affricate, which implies a voice distinction among cognate stops, which implies a nasal and glide.	–	–	–	–	–	–
Consonants imply vowels.	√	√	√	√	√	√
Affricates imply fricatives.	√	**N/A**	√	**N/A**	√	√
Fricatives imply stops.	**Need earlier sessions**	√	–	√	√	√
Voiced obstruents (i.e., stops, fricatives, affricates) imply voiceless obstruents.	**Need earlier sessions**	√	√	–	–	√
Liquids imply nasals.	√	√	√	√	√	√
Velars imply coronals.	**Need earlier sessions**	√	√	√	√	√
Fricatives in initial position imply fricatives in final position.	–	–	–	√	√	√
Stops in final position imply stops in initial position.	√	√	√	**N/A**	**Need earlier sessions**	√
Word-initial /r/ implies post-vocalic /r/.	–	–/√	–	–	**Need later sessions**	–
Clusters imply singletons.	√	√	√	√	√	√
Clusters imply affricates.	√	**N/A**	**Need later sessions**	**N/A**	**Need later sessions**	–
Clusters with a small sonority difference imply clusters with a greater difference.	√	–	**Need later sessions**	–	**Need later sessions**	–
Fricative+Liquid clusters imply Stop+Liquid clusters.	√	**Need later sessions**	**Need later sessions**	√	**Need later sessions**	–
Liquid onset clusters imply a liquid in coda position.	–	√	**Need later sessions**	–	**Need later sessions**	√