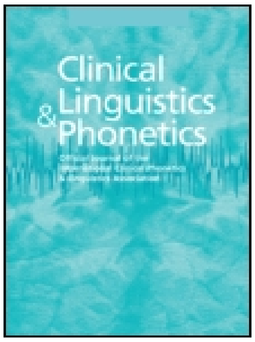

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Acquisition of velars: A whole-word approach

MARGARET KEHOE

Faculty of Psychology and Science of Education, University of Geneva, Geneva, Switzerland

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Abstract
This study focuses on the acquisition of velars in a child, Max, aged 1;09–4;08, with protracted phonological development, possibly as a result of his diverse input conditions: he is an internationally adopted child who produces his first words shortly after exposure to English at 1;09. Max's acquisition of velars is characterised by U-shaped development as well as by a positional velar-fronting process, in which velars are realised consistently in prosodically-weak but inconsistently in prosodically-strong positions. In prosodically-strong positions, they are conditioned by vowel quality, voicing, the place-of-articulation of the post-vocalic consonant and whether they are part of an obstruent–sonorant cluster. The study aims to account for Max's U-shaped pattern of development, his positional velar fronting process and his partial realisation of prosodically-strong velars appealing to generative and usage-based approaches of phonological development.

Keywords: Child phonology, phonological delay, velars, usage-based phonology

Velar consonants are often acquired later in phonological acquisition than consonants of other places of articulation (PoAs) such as labial and coronal at least in English (Stoel-Gammon, 1996). They are frequently involved in phonological processes such as consonant harmony and velar fronting (Inkelas & Rose, 2007; Pater, 2002). They may also be conditioned by a variety of phonetic and phonological factors such as vowel quality, voicing and prosodic context (Inkelas & Rose, 2007; McAllister Byun, 2012). As with other aspects of phonological acquisition, some children follow a developmental trajectory in which velars are not produced, are variably produced, and, finally, are consistently produced (Stoel-Gammon, 1996). There are, however, isolated reports in the literature indicating that some children display U-shaped development of velars, producing velars initially and then passing through a stage in which velars are not produced (Becker & Tessier, 2011; Fikkert & Levelt, 2008). U-shaped development is not isolated to phonological development (Bleile & Tomblin, 1991; Menn, 1983; Stemberger & Bernhardt, 2001; Stemberger, Bernhardt, & Johnson, 1999), but is also observed in other linguistic and cognitive domains (Gershkoff-Stowe & Thelen, 2004; Maratsos, 2000; Marcus et al., 1992; see references in Becker & Tessier, 2011).

Correspondence: Margaret Kehoe, Faculté de psychologie et des sciences de l'éducation, Université de Genève, 42, bd du Pont-d'Arve, 1205 Genève, Switzerland. Tel: +41 223799155. E-mail: Margaret.Winkler-Kehoe@unige.ch

The current study examines the acquisition of velars in a child who displays U-shaped development. The empirical base is the diary and recorded output of Max, a child with protracted phonological development (PPD), possibly as a result of his diverse input conditions: he is an internationally adopted child of Thai origin who produces his first words shortly after exposure to English at 1;09. He is also a multilingual child acquiring French and German, in addition to English (Kehoe, 2015). Max's earliest word productions testify to a prominent velar-initial output pattern. This pattern is extinguished over the course of several months resulting in a period in which few velars are realised. Velars re-establish themselves in post-tonic position but remain variable in pre-tonic position through to the end of the study at 4;08. One of the main questions we ask is ''what explains Max's U-shaped pattern of development?'' What leads a child who seems to have the requisite articulatory capacities to produce velars and who seems to have some sort of phonetic categorisation of them to lose these abilities or at least to not develop them? To explore this question as well as understand Max's positional velar fronting process and his partial realisation of initial velars, we consider different accounts of velar acquisition, some of which are generative in nature (Fikkert & Levelt, 2008) and some of which combine generative and usage-based principles (McAllister Byun, 2012; McAllister Byun, Inkelas, & Rose, 2013).

The focus of this study is on the acquisition of velar stops in English since this is Max's dominant language at the onset of word production; however, we discuss briefly Max's acquisition of velars in his other languages as well. Acquisition of the velar nasal [ŋ] or the velar fricative [χ] in German will not be addressed. We consider /w/, the labio-velar approximant, to be analysed as ''labial'' in Max's speech, although its dual representation may play a role in some of Max's cluster reduction patterns (see section on ''Cluster reduction patterns''). We use the term ''velar'' throughout the manuscript, except for when we are referring to acquisition of the abstract notion of ''dorsality'' or to acquisition of back vowels. In these cases, we use the term ''dorsal''.

In the introduction to this paper, we present a brief overview of representation in an exemplar-based model of phonology. We go on to review recent whole-word approaches to phonology since they are relevant to understanding Max's early patterns (Fikkert & Levelt, 2008; McAllister Byun et al., 2013; Vihman & Croft, 2007). Finally, we summarise what we know on the acquisition of velars, considering findings on velar harmony (Pater & Werle, 2003; Stoel-Gammon, 1996), on positional velar fronting (Inkelas & Rose, 2007; McAllister Byun, 2012), and on factors conditioning the production of velars (McAllister Byun, 2012).

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Representation and current models of phonological development

Despite decades of research and discussion, phonological representations are not well understood and there is little consensus about their properties and when they may be considered ''adult-like'' during the developmental process. The standard view in generative phonology is that children's phonological representations are adult-like from the beginning (Smith, 1973; Stampe, 1973). There are many different conceptualisations of this view ranging from models in which there is a single underlying representation capturing perception and production (Smith, 1973), to models in which there are two underlying representations distinguishing perceptual and articulatory representations (Menn & Matthei, 1992). These models differ in many respects including whether rules or processes operate in real time (i.e. on-line) or not (i.e. off-line) (the latter model allowing for off-line storage and processing); however, they are united in the fact that representations are generally stable (i.e. non-changing) and they are intact early on.

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This modular approach can be contrasted with a multidimensional approach couched within exemplar-based theory, in which representations are viewed as multi-sensory experiences which accumulate gradually over the lifespan. Representations encode auditory, visual, kinaesthetic and somatosensory information on the sounds that an individual has produced or heard others produce (Munson, Beckman, & Edwards, 2011). Clustering of information (i.e. exemplars) create categories, which are characterised in terms of frequency/probability distributions of remembered instances. The frequency and recency of exemplars at a particular location determine the strength of the representation (Pierrehumbert, 2003). Probability distributions change over time as new traces are formed and old ones decay.

Thus, the end-state of a phonological representation in this approach is a complex set of mappings over different physical/sensory domains, as well as mappings to categories at multiple levels of abstraction. Exemplar-based approaches have been inspired by interactionist cognitive or connectionist theories and various attempts have been made to model the emergence of these different types of representation (Plaut & Kello, 1999).

Munson, Edwards, and Beckman (2005) describe phonological knowledge (here interpreted as phonological representation) as consisting of at least four main dimensions: (i) acoustic and perceptual; (ii) articulatory; (iii) higher-level and (iv) social-indexical. Higher-level phonological knowledge emerges as a consequence of generalisations over phonetic information and generalisations over the lexicon (Edwards, Munson, & Beckman, 2011). We will focus on three of these four dimensions when examining Max' data.[1] We believe a multidimensional approach offers insights over and above earlier modular accounts in that phonological representation is not viewed as static but dynamic, it is intimately related to growth in the lexicon, and it is influenced by the child's own productions. In particular, we are interested in Max' abstract knowledge of velars. We define abstract knowledge in this instance as the association of the feature [dorsal] to target velar segments independent of phonetic context. Failure to make this association will result in the emergence of default segments. Following Bernhardt and Stemberger (1998), we assume that default segments contain the most frequent consonantal features such as [coronal] for place. At times, Max appears to have [labial] as default place for velars. This may arise because labials have a higher type (as opposed to token) frequency than coronals (see later Figure 8) or because of independent constraints in Max' phonology which require that words begin with labial consonants (Fikkert & Levelt, 2008).

Recent approaches to whole-word patterns

Waterson (1971) is credited with the earliest documentation of whole-word patterns or templates. Given that the term ''template'' has multiple meanings in the field of linguistics and child phonology (e.g. trochaic metrical template in Gerken, 1994), we will use the more general term ''whole-word pattern'' in this paper. Waterson (1971) observed that her son, P, aged 1;06, produced words such as another, finger, Randall and window with a similar output pattern, namely a CVCV form in which both consonants were nasals (e.g. [ɲaɲa], [ɲẽːɲẽ], [ɲiːɲɪ], [ɲaɲø]). Since Waterson's (1971) study, numerous researchers have observed the presence of whole word patterns in children's speech (Ferguson & Farwell, 1975; Macken, 1979; Menn, 1983); however, only in recent years has a more elaborated approach to whole word phonology been developed in the form of Radical Templatic Phonology by Vihman and colleagues (Menn, Schmidt, &

[1]We do not consider social-indexical knowledge, which is the fourth aspect of phonological knowledge considered by Munson et al. (2005).

Nicholas, 2014; Velleman & Vihman, 2002; Vihman & Croft, 2007; Vihman & Keren-Portnoy, 2013). According to Vihman and Croft (2007), whole word patterns are inductive generalisations based on the phonological model provided by the target word and the child's own phonetic repertoire of sounds and syllables. They stem from three sources: (i) implicit knowledge of the segmental patterns of the ambient language (see Velleman & Vihman, 2002, for distinction between implicit and explicit learning); (ii) the child's individual motor preferences often arising from the pre-linguistic period and (iii) the phonological structure implicit in the child's own lexicon. These whole-word patterns lead to two types of processes in children's speech: Selection and Adaptation (Vihman & Velleman, 2000). Children select words that conform to their whole-word pattern and they adapt words to conform to this pattern. More recently, researchers have provided alternative accounts of whole-word patterns (Fikkert & Levelt, 2008; McAllister Byun et al., 2013).

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Incomplete phonological representation and emergence of phonological constraints

Fikkert and Levelt (2008) have reinterpreted aspects of whole-word phonology within the generative framework with reference to the acquisition of PoA (see Altvater-Mackensen & Fikkert, 2015, for a similar approach to manner-of-articulation). According to Fikkert and Levelt (2008), children's initial patterns are consistent with a stage in which PoA is defined over the entire word. This accounts for consonant–vowel associations in which labial consonants (P) appear with round vowels (O); coronal consonants (T) appear with front vowels (I); velar consonants (K) appear with dorsal vowels (O) and all consonants appear with low vowels (A). Biomechanical limitations may underlie this initial stage (MacNeilage & Davis, 2000); however, Fikkert and Levelt (2008) opt for an account based on children's incomplete storage of perceptual features. Vowels are perceptually salient and, thus, are mapped more readily onto the lexical representation, accounting for the fact that consonants take on the PoA feature of the vowel (e.g. kijk [tɛɪt] KIK → TIT, Eva 1;04.12).

Following the ''one word one feature stage'', both consonants agree in place of articulation but the vowel may differ from the consonant: labial and dorsal consonants may appear with front vowels (PIP and KIK) and coronal consonants may appear with round vowels (TOT). At the next stage, the two consonants may differ in PoA but in a restricted fashion: labials are preferred at the left of the word; dorsals are avoided in this position. Fikkert and Levelt (2008) account for the PoA sequence restrictions by high ranking Labial Left (e.g. [Labial) and No Initial Dorsal (e.g. *[Dorsal) constraints, which emerge over the course of acquisition.

Concerning velar acquisition, Fikkert and Levelt (2008) observe that velar-initial targets may be subject to U-shaped developmental patterns at the initial stages. They are produced accurately in the initial ''holistic'' stage but then are produced unfaithfully when the constraint *[Dorsal enters the grammar. Once the constraint *[Dorsal is demoted, they are produced faithfully again, as seen in the patterns of Noortje in (1).

(1) Noortje's production of initial-velar target words (adapted from Fikkert & Levelt, 2008)

a.	Stage 1	koek	[kuk]	2;03,07	''cookie''
b.	Stage 2	koek	[touk]	2;08,17	''cookie''
c.	Stage 3	kruk	[kyk]	2;09,29	''stool''

Fikkert and Levelt (2008) posit that input frequency plays a role in determining why particular PoA combinations are observed and others not. Dorsal-final target forms (PVK and TVK) are relatively frequent and they are produced early in acquisition, whereas dorsal-initial forms are infrequent and are produced late. These claims on input frequency refer to Dutch and it is not clear whether the same pattern of POA distribution is present in other languages.[2] In sum, Fikkert and Levelt (2008) view whole-word patterns as epiphenomena which arise from two factors: (1) incomplete lexical representations at the beginning and (2) emergent phonological constraints later on.

Articulatory reliability

McAllister Byun et al. (2013) propose that children's early phonology is shaped by two articulatory forces: (i) The desire to be ACCURATE, that is, produce an output form that is a close match to the adult acoustic target and (ii) The desire to be PRECISE, that is, produce an output form whose associated motor plan matches a limited acoustic space. According to the authors, ACCURATE and PRECISE are universal constraints which co-exist along with conventional faithfulness and markedness constraints. They play a role in the child's grammar at the early stages, but decline in importance in the adult grammar once motor-acoustic mappings become more reliable. The constraints are formally defined in terms of the linkage between motor plans and acoustic outcomes in an interface between the grammar and exemplar space referred to as the Articulatory map. ACCURATE assigns a penalty to an output form whose acoustic realisation differs greatly from the target's acoustic realisation. PRECISE assigns a penalty to an output form whose motor plan is associated with a diffuse cloud of acoustic outcomes (i.e. high standard deviation of acoustic realisations). In explaining a U-shaped curve, McAllister Byun and Inkelas (2013) hypothesise that at the beginning, it takes time for traces representing the child's own productions to form well-defined regions of clustering. All traces may be equally unreliable in terms of motor-acoustic mappings leaving the decision to fall to the constraint ACCURATE which will favour the most faithful candidate. Over time, the child produces unfaithful forms which are realised with stable motor-acoustic mappings and faithful forms with less stable mappings, and the constraint PRECISE will be decisive in selecting the stable but unfaithful candidate. Thus, a developmental progression of faithful followed by unfaithful may ensue.

McAllister Byun et al. (2013) also posit that the presence of these two opposing constraints may explain the whole word patterns documented by Vihman and colleagues in the speech of young children. If a particular motor plan becomes stable when most motor routines are not stable, the constraint PRECISE may lead children to use this stable motor routine for many different targets.

In sum, recent accounts of phonological development put the emphasis on incomplete representations or reduced articulatory reliability in explaining children's whole-word patterns.

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Acquisition of velars

As mentioned above, velars are generally acquired later than labials and coronals in phonological acquisition; however, some children still produce velars amongst their first words. Stoel-Gammon (1996) cites findings indicating that 46% of a group of 52 normally-developing English-speaking children produced velar consonants in at least two of their first 10 words. Children acquiring

[2]It may be asked whether words with final velars are more frequent than words with initial velars in the languages that Max is acquiring: English, French and German. Kehoe (2015) did not find major differences between the frequencies of words with initial versus final velars in the English target words selected by Max. With respect to French, studies investigating the percentages of velars in the target words children select during the first word period indicate relatively low frequencies of velars in French (as compared to English, Swedish and Japanese; 12% vs. 23%, 27%, 17%) (De Boysson-Bardies & Vihman, 1991, p. 308). A phonological analysis of the French adaptation of the MCDI indicates 9% and 15% of words containing initial velars for children at 2;0 and 2;6, respectively (Gayraud & Kern, 2007). The authors do not provide place-of-articulation results for word-final position, noting that a large percentage of words are vowel-final. As for German, Lleó, Prinz, El Mogharbel, and Maldonado (1996) cite Ortmann (1975), who on the basis of frequent word forms in German, indicates the frequency of velars to be 8.1%. We do not have any relevant data on the percentages of velars in initial versus final position in German.

languages, in which dorsal consonants are frequent such as Greek, may acquire dorsals even earlier than coronals, suggesting that phoneme frequency influences the order of PoA development (Nicolaidis, Edwards, Beckman, & Tserdanelis, 2003). It is also observed that velars may emerge first in word-final than in word-initial position in English (Bernhardt & Stemberger, 1998; Vihman & Hochberg, 1986).

Velar harmony

Consonant harmony (i.e. long distance assimilation of consonantal features) involving velars is the most common type of harmony process. A collection of studies suggest that velar harmony manifests for a longer period of time in a given child than other types of harmony (e.g. labial harmony), and may be present in the absence of other types of harmony, at least in English (Pater, 2002; Pater & Werle, 2003; Stoel-Gammon, 1996). They also indicate that the longest-lasting harmony processes are regressive and that the quality of the intervening vowel may play a role in velar harmony: velar harmony is more common when the intervening vowel is a back vowel (Gerlach, 2010; Pater & Werle, 2003; Stoel-Gammon, 1996). Some examples of regressive and progressive velar harmony from Max's data are shown in (2).[3]

(2) Examples of regressive and progressive velar harmony in Max's data

a.	<u>dog</u>	[gæg]	1;10,18
b.	<u>shake</u>	[gek]	1;11,17
c.	<u>(yo)ghurt</u>	[gɪk]	1;10,18
d.	<u>gate</u>	[gek]	1;11.04

Positional velar fronting

Another well-documented phonological process involving velars is the substitution of velar stops by coronal ones. Although, some children may substitute all velar stops with coronals, a positional variant of this process is frequently attested, in which the velar surfaces in word-final position or in word-medial position preceding an unstressed syllable (i.e. syllable-initial word-internal), and is substituted by a coronal in word-initial position or in word-medial position preceding a stressed syllable (Inkelas & Rose, 2007; McAllister Byun, 2012; Stoel-Gammon, 1996). Productions from Max are shown in (3).

(3) Examples of positional velar fronting from Max, aged 3;07

a.	Word-initial	<u>candles</u>	[ˈdændl̩z]
b.	Word-medial pre-tonic	<u>spaghetti</u>	[baˈdɛdi]
c.	Word-final	<u>park</u>	[paːk]
d.	Word-medial post-tonic	<u>sticky</u>	[ˈdɪki]

One puzzling aspect of positional velar fronting is that the velar-coronal contrast is realised in prosodically-weak positions (e.g. word-finally or word-medially preceding unstressed syllables) and is neutralised in prosodically-strong positions (e.g. word-initially or word-medially preceding stressed syllables). The reverse tends to happen in adult languages: segmental contrasts are neutralised in prosodically-weak positions (Inkelas & Rose, 2007; Marshall & Chiat, 2003; McAllister Byun, 2012). This has led authors to posit motor control limitations as the basis of this process. In the context of imperfect articulatory control and anatomical restrictions (i.e. large

[3]Alternatively, the KVK forms are consistent with Fikkert and Levelt's (2008) ''one word one consonantal place feature'' stage.

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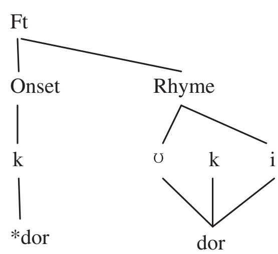
tongue size relative to small oral cavity size), coronal release of velars may take place, particularly in prosodically-strong positions where articulatory gestures tend to be exaggerated (Inkelas & Rose, 2007). McAllister Byun (2012) proposes that the child, when attempting to produce an initial /k/ or /g/, produces a form, which is actually an undifferentiated lingual gesture manifesting both coronal and dorsal place. The final and most audible release is coronal and as a consequence coronal place is perceived. As support for her proposal, McAllister Byun (2012) refers to research using electropalatography which shows that some children with velar fronting produce all their lingual stops with undifferentiated lingual gestures (Gibbon, 1999). That is, there is tongue-palate contact ranging from the alveolar to the palatal/velar regions.

Not all authors ascribe to a motor-speech account of positional velar fronting. Dinnsen and Farris-Trimble (2008) point out that positional velar fronting is observed in older phonologically delayed children, whereas it might be assumed that these children have overcome the anatomical limitations, which lead to coronal release in initial position. Dinnsen and Farris-Trimble (2008) appeal to prominence-assigning markedness constraints, the default ranking of which gives prominence to the final constituent of syllables at the earliest stages of development. The prominence-assigning constraints when ranked along with a general markedness constraint banning dorsals (e.g. *Dorsals) is able to capture the pattern of responses in positional velar fronting, namely correct realisation of velars in prosodically-weak but not -strong positions.

An alternative explanation of positional velar fronting is provided by Bills and Golston (2002) who argue that the inherent dorsality of vowels licenses (or supports) the production of velars in foot rhyme but not in onset position (see also Bernhardt & Stemberger, 1998; Marshall & Chiat, 2003). Foot rhyme is the same environment in which velar nasals and velarised laterals are attested in English and in other languages. The representation of the foot that Bills and Golston (2002) give is not the standard one seen in English stress assignment. Instead, they divide the foot into foot onset and rhyme as shown in (4).

(4) English foot (Bills & Golston, 2002)



In sum, a number of different proposals have been advanced to explain the asymmetrical behaviour of velars in prosodically-strong versus -weak positions. Some are grammatical accounts, appealing to constraints or linguistic principles (e.g. licensing) (Bernhardt & Stemberger, 1998; Bills & Golston, 2002; Dinnsen & Farris-Tremble, 2008), whereas others put the emphasis on child-specific articulatory pressures which interact with the grammar (Inkelas & Rose, 2007; McAllister Byun, 2012).

Conditioning factors influencing the acquisition of velars

In the preceding section, we discussed the influence of prosodic context. We now consider other conditioning factors on velar production. An important one is vowel context. Many authors have observed that velar consonants are associated with dorsal or back vowels in children's earliest productions (Levelt, 1994; Nicolaidis et al., 2003). In a frame-content model of phonological

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development, this association arises because there is no active inter-segmental change from one tongue-position to the next during the close-open phase of the CV syllable (Davis, MacNeilage, & Matyear, 2002). In a grammatical account such as Fikkert and Levelt's (2008), the association between dorsal consonants and back vowels is due to incomplete representation: children represent the whole word with a single PoA feature such as [+dorsal] at the earliest stages of acquisition. Stoel-Gammon (1996) reports that dorsal consonant–vowel associations are actually not frequent in the speech of normally developing English-speaking children, although they may be present in children with phonological delays or disorders (see Bates, Watson, & Scobbie, 2002). For example, in the case study reported by McAllister Byun (2012), Ben, a phonologically disordered English-speaking child, produced velars with 52% accuracy before back vowels and with 35% accuracy before front vowels, a statistically significant difference.

A second factor which may influence velar production is voicing. If children's difficulties with velars stem from motor control factors, sounds which are produced with greater gestural force such as voiceless sounds may pose more difficulty than sounds which are produced with less gestural force such as voiced sounds (McAllister Byun, 2012). In McAllister Byun's (2012) case study, voicing of the target velar was a significant predictor of her participant Ben's realisation of velars (52% accuracy of voiced vs. 36% accuracy of voiceless velars).

Another potential conditioning factor is the nature of the syllable onset, whether it is simple versus complex. Inkelas and Rose (2007) observed that their participant, E, fronted velars in prosodically-strong positions regardless of whether they were part of a simple or a complex onset. In contrast, Bills and Golston (2002) reported that their participant, Sine, who also displayed positional velar fronting, realised velars correctly in obstruent + sonorant clusters but not in /s/ + C clusters (e.g. glasses vs. scoop). This finding was consistent with Bills and Golston's (2002) proposal that velars were produced correctly when they were licensed by an adjacent dorsal element within a foot constituent. In the case of obstruent + sonorant clusters, the dorsal specification (i.e. featural representation) of the liquid or glide licensed the realisation of the dorsal obstruent.

Inkelas and Rose (2007) distinguish between ''true'' velar fronting and velar fronting which arises as an artifact of assimilatory processes (consonant harmony and consonant–vowel associations). In their view, true velar fronting is not dependent on the presence of a coronal consonant or a front vowel. Nevertheless, as discussed above, vowel quality may still condition children's realisations of velars even in the case of true velar fronting (e.g. Ben in McAllister Byun, 2012). As, it will be seen, Max's velar fronting is not the true version of velar fronting as described by Inkelas and Rose (2007) since it is also influenced by PoA. In the current study, we consider not only the PoA of the vowel but also the PoA of the postvocalic consonant following the prosodically strong velar.

Aims of current study

The current study focuses on the acquisition of velars in a child who demonstrates U-shaped development of velars and positional velar fronting. Max's pattern of acquisition is complex so the primary aim of the study is to understand the data. We describe his development of velars in terms of three developmental periods. We also examine conditioning factors that influence his realisation of velars. The secondary aim of the study is to consider his data in terms of current models of phonological acquisition, which are rooted in generative and usage-based principles. We are particularly interested in the emergence of the abstract feature of dorsality across different word positions.

In the analysis of Max's positional velar fronting, we contrast a grammatical account based on featural licensing (Bernhardt & Stemberger, 1998; Bills & Golston, 2002) with one based on

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motor-speech control (Inkelas & Rose, 2007; McAllister Byun, 2012). Direct testing of the motor-speech account would require electropalatography or ultrasound imaging, both of which were unavailable in the current study; thus, we consider indirect ways of distinguishing these two accounts. We predict that the conditioning effects of vowel quality and voicing should diminish over time as motor control improves and that the production of initial velars should be similar across Max's three languages. Here, we assume that many aspects of motor control are language-neutral and should not vary greatly between a bilingual's respective languages (Preston & Seki, 2011). In contrast, a featural licensing account may result in a less linear development of initial velars. This is because featural support is also dependent upon the representation of individual segments (e.g. dorsality of vowels and consonants) within the word, which may also be subject to different developmental trajectories. A featural account may also allow different acquisition patterns of velars across languages depending upon the featural make-up of the individual languages.

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Method

Participant

Max spent the first 1;08 years of his life in a Thai orphanage. His medical report indicated that he was a healthy child with no physical or psychological concerns. At the time of adoption, his care-giver indicated he could say [bababa] (no word referent) and [mʌm mʌm] (for food) but no other words. Following adoption, Max was exposed to English (from his mother) and German (from his father). Consistent exposure to French came at age 2;00 when Max spent 12–15 h per week with a Maman de Jour (i.e. day-care mother). Following adoption, Max was silent for a one-month period in which he made no consonantal vocalisations and produced no words. Post-adoption, Max was a healthy child. He had normal hearing and did not suffer from bouts of otitis media.

We claim that Max has PPD because he displays phonological processes such as positional velar fronting and cluster reduction through to the age of 4;06 years, which is later than is observed for typically developing children. His morphosyntactic development was also slow; he only consistently combined words (in English) at age 2;05. In contrast, cognitive and motor (gross and fine) development was normal or even in advance of his age. We do not dwell on the disordered nature of Max' speech since his individual history makes it difficult to compare his results to phonological normative data. Research on the phonological development of internationally adopted children indicates, however, that delayed phonology is not typical of the majority of children adopted under the age of two years (Glennen, 2007; Pollock & Price, 2005; Pollock, Price, & Fulmer, 2003).[4]

Data-base

Diary study

Diary entries were kept on Max from age 1;09,07, when he produced his first word through to age 4;08 years. Data were collected by his mother, a trained phonologist. During the initial stages of

[4]The reader may be interested in having some information on velar consonants in Thai. Thai has three velar consonants in syllable-initial position (e.g. /k/, /kʰ/, /ŋ/) as well as the labial-velar approximant /w/. It has two velar consonants in syllable-final position (k/, /ŋ/). Data on phoneme frequency in Thai based on a written corpus indicates that /k/ and /kʰ/ are moderately frequent phonemes in initial position having frequencies of 6.76% and 6.22%, respectively (most frequent phoneme is /tʰ/ with frequency of 8.45%). In final position, /k/ has a frequency of 4.91% (most frequent phoneme is /n/ with frequency of 15.69%) (Munthuli et al., 2013, Table 2). Velar clusters include /kr/, /kl/, /kw/, /kʰr/, /kʰl/, /kʰw/.

diary collection, an attempt was made to write down all words produced by Max on a given day, whereby words included both new and previously used words. Later on, once Max produced a large number of words on a given day, it is likely that certain words were missed with a bias towards including new words or new phonetic forms of previously used words. The diarist also noted down variable phonetic forms of a given word. That is, if Max produced the word key as [gi] and [di], both phonetic renditions were documented. However, the diary records did not include the number of times Max produced the [gi] versus the [di] form in a given day. The diary also included notation as to whether the word was imitated or spontaneous, and whether it was a questionable form (i.e. a newly produced word which required verification). To provide an idea of the size of the data-base, it contains 6939 entries from the period 1;09 through to 3;00.

Recordings

From 2;11 through to 4;05, Max's spontaneous speech in English was recorded in informal play sessions with his mother. Sessions were conducted on a monthly or twice-monthly basis resulting in 25 recorded sessions of approximately 20–30 min duration. From 3;07 through to 4;02, Max's spontaneous speech in French was recorded in informal play sessions with his French-speaking baby sitter. Six sessions of 20–30 min duration were completed. The later age of testing in French was because Max was dominant in English. Recordings were not conducted in German due to practical constraints. Max's speech was recorded on a Sony portable minidisc recorder (Mz-R55) using a directional microphone (Sony ECMT S120, Hamburg, Germany) and was phonetically transcribed by his mother.

Inter-rater reliability

Inter-rater reliability was conducted on phrases extracted from the English recordings. The second transcriber was a native English speaker who spoke the same dialect of English as the mother and who was also a second-language speaker of French. In total 76 phrases containing 138 words were extracted across six different recording sessions. Excluding differences in voicing, the consonant-to-consonant agreement for the entire sample was 85% (233/273). Focusing specifically on prosodically-strong and -weak velars, the consonant-to-consonant agreement was 85% (51/60) and 80% (33/41), respectively. Differences between transcribers pertained to confusions between velar and coronal stops for prosodically-strong velars and to confusions between velar stops and the glottal stop for prosodically-weak velars. The reliability results constitute acceptable reliability for a child with PPD.

Coding of the data

All Max's productions of target words containing velars from diary records and recordings were entered into an Excel databank. Each entry included Max's age, the orthographic form of the target word, the phonetic production (in broad IPA transcription), and various codings of the adult target form: quality of the vowel following the prosodically-strong velar (front, back or low), voicing of prosodically-strong velar (/k/, /g/), the PoA of the postvocalic consonant (labial, coronal, dorsal or no consonant), the presence of post-vocalic /l/, and the presence of pre-vocalic consonant clusters (/Cl/, /Cr/, /Cw/). We coded the target form rather than the transcribed form because Max did not make a reliable voicing distinction nor did he produce [l]s or clusters until late in development; however, it could still be the case that he had a covert awareness of these features as found by McAllister Byun (2012) for her subject Ben for voicing. Given that we needed to code the linguistic features of the target form for some of the linguistic variables, we unified the coding system by doing this for all of the variables including vowel quality and the PoA of the postvocalic consonant.

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In terms of vowel quality, [i,ɪ,e,ɛ] were coded as front, [u,ʊ,ɔ,ɒ,o] were coded as rounded and dorsal, and [æ,a,ʌ,aɪ,aʊ] were coded as low. The vowels [æ] and [ʌ] patterned with the low vowel [a] in Max's phonology and, therefore, they were grouped with the low rather than with the front or back vowels respectively. When coding PoA of the post-vocalic consonant, the postvocalic consonant was deemed to be the consonant directly after the vowel. For example, in the target word cockpit, which has a word-internal consonant sequence, the PoA of the postvocalic consonant was coded as dorsal. When coding clusters, only obstruent + sonorant clusters (e.g. /Cl/ as in cloud; /Cr/ as in crab; /Cw/ as in queen) and not /s/ + C clusters (e.g. /sk/ as in skate) were coded, given the findings of Bills and Golston (2002) who observed that the two types of clusters patterned differently in terms of the realisation of velars. /s/ + C clusters are sometimes represented as an adjunct and a simple onset in contrast to /Cl/, /Cr/ and /Cw/ clusters which are represented as branching onsets in English (Barlow, 2001; Goad & Rose, 2004).

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Case study data

Max's development of velars can be separated into three periods: (i) An early whole-word period (1;10–2;04) in which Max produced initial velars; (ii) A no-velar period (2;04–2;08), in which Max realised few velars and (iii) A positional velar fronting period (2;08–4;08), in which Max realised velars in prosodically-weak but not in -strong positions. As it will be seen, Max does realise some velars in prosodically-strong positions and, thus, we look more closely at what conditioning factors influence velar realisation.

Early whole word-period: initial velars

Productions containing velars did not appear in Max's first 10 words but started to appear one month following word onset. They consisted of velar-initial forms followed by front and low vowels (i.e. KI and KA forms). Examples are provided in (5) (see Appendix A for a more extensive set of examples at age 1;11). Few KO target forms were selected during this period; when they were, they were produced with KI or PO outputs (e.g. cold [geɪç] 1;11,09; coat [bov] 1;11.09).

(5) KI and KA forms in Max's early speech (at ages 1;10–1;11)

a. KI(C)
yoghurt [gɛk] 1;10,18, key [gi] 1;10,25, juice [gɪç] 1;11,00, gate [gek] 1;11,04
b. KA(KA)
car [ga] 1;10,21, dog [gæg] 1;11,15, cup [gʌ] 1;11,03, bicycle [gægʌ] 1;11.08

Velar-initial outputs occurred for target words with initial velars (e.g. key, keys, cake, gate, carrot, car, cup), for target words with non-initial velars (e.g. biscuit, dog, egg, shake, yoghurt, bicycle, tiger, truck), and for some target words without any velars (e.g. fish, shoes, juice, tea, cheese). In particular, words beginning with affricates (e.g. /ʧ, ʤ/) were also realised with velar outputs (e.g. cheese [gi] 2;00,00), a pattern that has been observed in other English-speaking children (Gerlach, 2010, p. 90, footnote 74; Menn, 1971).

At 2;01, KO forms entered Max's lexicon and KO output forms started to be consistently produced. Examples are provided in (6) (see Appendix B for a more extensive set of examples at age 2;02).

(6) KO forms in Max's early speech (at age 2;01)

juice [gu] 2;01,16, goose [gu] 2;01,20, hedgehog [gɒ] 2;01,21, goat [goʊ] 2;01,24

Table 1. Summary of velar-initial output patterns according to total number of diary entries from 1;10 to 3;00.

Month	*n*	Total /g, k/	%	KA	KI	KO
1;10	48	15	31	40% (6)	60% (9)	
1;11	482	92	19	40% (37)	57% (52)	3% (3)
2;00	424	57	13	56% (32)	39% (22)	5% (3)
2;01	613	68	11	44% (30)	22% (15)	34% (23)
2;02	582	74	13	16% (12)	18% (13)	66% (49)
2;03	329	17	5	41% (7)	12% (2)	47% (8)
2;04	579	19	3	47% (9)	12% (2)	42% (8)
2;05	740	8	1	38% (3)	25% (2)	38% (3)
2;06	696	14	2	7% (1)	14% (2)	79% (11)
2;07	455	14	3	36% (5)	7% (1)	57% (8)
2;08	477	17	3	12% (2)	12% (2)	76% (13)
2;09	243	14	6	50% (7)	7% (1)	43% (6)
2;10	424	25	6	28% (7)	32% (8)	40% (10)
2;11	388	27	7	33% (9)	22% (6)	44% (12)

n, total number of diary entries per month; /g, k/ is the number of diary entries (i.e. output forms) containing an initial /g/ or /k/. The percentage of KV output forms according to PoA of the vowel is shown in columns 5–7.

Max exhibited some apparent examples of velar harmony during this early period (see (3)); however, his phonology was not characterised by a large number of harmonic patterns. One reason for this was that around 2;00–2;06, he stopped producing CVC and CVCV forms and produced predominantly (C)V forms (Kehoe, 2015). The wholesale deletion of final (and initial) consonants was one way Max satisfied constraints on feature sequences.

Middle period: no velars

Around 2;03, there was a decline in velar-initial outputs. The few dorsal-initial forms that remained tended to be KO (or KA) forms. Table 1 shows the number of velar-initial outputs as a percentage of diary entries on a monthly basis from 1;10, one month following word onset, through to 3;0 years. As can be seen, the percentage of diary entries realised with initial velars declined from 19% at 1;11 to 1% at 2;05.

Examples of lexical targets which started off with initial-velar outputs and which changed over to non-initial-velar outputs are presented in (7). The phonetic forms given in (7) represent the most frequent output form observed in a given month.

(7) Examples of phonetic forms indicating the gradual disappearance of velar consonants

	cat	gate	cup	juice	truck
1;11	[kæ]	[gek]	[kʌ]	[gɪʃ]	[gʌʔ]
2;01	[dæ]	[gek]	[gʌʔ]	[gu]	[dʌʔ]
2;03	[dæ]	[dek]	[bʌʔ]	[gu]	[gʌʔ]
2;05	[dʌʔ]	[det]	[bʌʔ]	[du]	[wʌʔ]

Important to note is that the no-velar period was characterised by disappearance of velars in all positions. For example, some isolated TVK outputs were observed early on (e.g. dog [dɒg] 2;03,12, slug [jek] 2;03.08, egg [deg] 2;03,03); however, these velar codas were produced as coronals during the no-velar period (e.g. dog [dɒd] 2;06,12, slug [jʌd] 2;06.20, egg [ed] 2;06,07).

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Table 2. Percentage correct production of velars according to prosodic position in diary entries.

Month	% Initial[a]	% Med-stress	% Final	% Med-unstress
1;10	71% (5/7)		67% (8/12)	(0/1)[b]
1;11	63% (41/62)		29% (25/86)	43% (9/21)
2;00	54% (36/67)		26% (12/46)	29% (2/7)
2;01	51% (41/80)		25% (18/71)	0% (0/6)
2;02	52% (43/83)		18% (12/68)	(0/2)
2;03	32% (7/22)	0% (0/5)	13% (9/68)	(0/1)
2;04	18% (9/51)	0% (0/8)	11% (8/72)	
2;05	7% (6/85)	20% (1/5)	9% (9/99)	0% (0/13)
2;06	15% (11/75)	(0/1)	1% (1/99)	(1/1)
2;07	24% (12/51)	0% (0/5)	27% (14/51)	24% (4/17)
2;08	29% (14/48)	44% (4/9)	37% (19/52)	44% (8/18)
2;09	32% (10/31)	8% (1/12)	38% (8/21)	21% (3/14)
2;10	40% (21/53)	0 (0/13)	53% (17/32)	42% (5/12)
2;11	38% (17/45)	31% (4/13)	63% (27/43)	50% (9/18)
3;00–3;02	26% (14/53)	0 (0/10)	76% (39/51)	82% (23/28)
3;02–3;04	34% (10/29)	(1/2)	100% (15/15)	88% (14/16)
3;04–3;07	36% (8/22)	14% (1/7)	85% (17/20)	100% (20/20)
3;07–3;09	44% (11/25)	0% (0/6)	93% (26/28)	100% (12/12)
3;09–4;00	56% (20/36)	33% (3/9)	97% (31/32)	100% (17/17)
4;00–4;03	48% (35/73)	(1/4)	98% (86/88)	100% (29/29)
4;03–4;06	64% (14/22)	–	100% (18/18)	100% (11/11)
4;06–4;08	72% (21/29)	(2/2)	100% (18/18)	93% (14/15)

Results are reported on a monthly basis from 1;10 to 3;0 and every two- to three months from 3;0 to 4;08 years.

[a]% Initial, word-initial position; % Med-stress, word-medial position preceding stressed syllables; % Final, syllable or word-final position; % Med-unstress, word-medial position preceding unstressed syllables.

[b]Percentages are not noted when there are fewer than five examples at a given age period.

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Another important point is that velars did not only become coronals during the no-velar period. Target KVP and KVT forms were altered to PVT via processes such as metathesis (e.g. climb [baɪn], cup [bʌʔ]), cluster reduction (e.g. green [win]), and context insensitive substitutions (e.g. kiss [wɪs]), suggesting that constraints on PoA sequences were intimately related to Max's acquisition of velars (Fikkert & Levelt, 2008) or that different default segments (labial vs. coronal) surfaced at different times (Bernhardt & Stemberger, 1998).

Later period: positional velar fronting

The final stage in development was when Max realised velars consistently in prosodically-weak but inconsistently in prosodically-strong positions. Table 2 shows Max's percent correct production of velars in four positions: word-initial (e.g. cat; guitar), word-medial preceding a stressed syllable (e.g. spaghetti), syllable-final (dog and doctor),[5] and word-medial preceding an unstressed syllable (e.g. parking) from 1;10 through to 4;08 years in the dairy records. Figure 1 displays these results graphically, grouping word-initial and word-medial positions preceding stressed syllables as ''prosodically strong'' and syllable-final and word-medial positions preceding unstressed syllables as ''prosodically weak''. As can be seen in Figure 1, velars start

[5]Word-internal syllable-final condition was considered only when Max was able to produce word internal codas, which was at approximately 3;04 years.

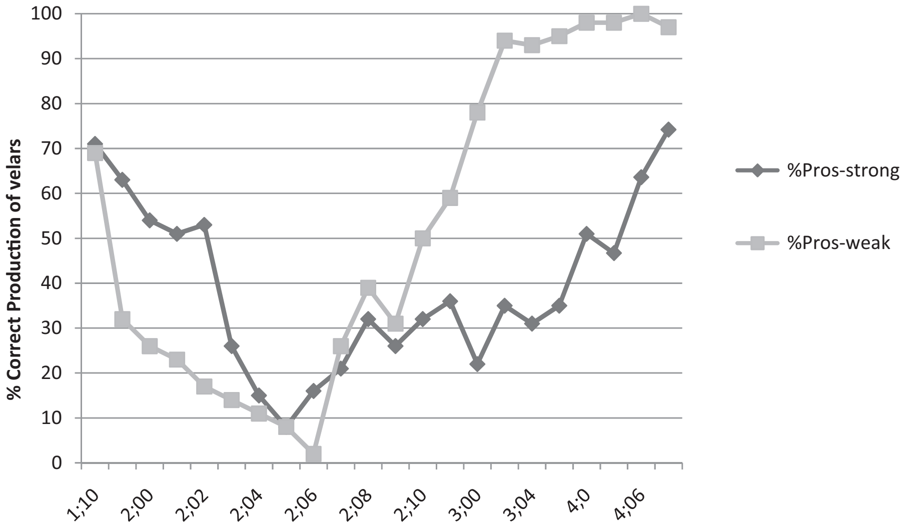

Figure 1. Percent correct production of velars in prosodically-strong versus -weak positions on a monthly basis from 1;10 through to 4;08 in diary records.

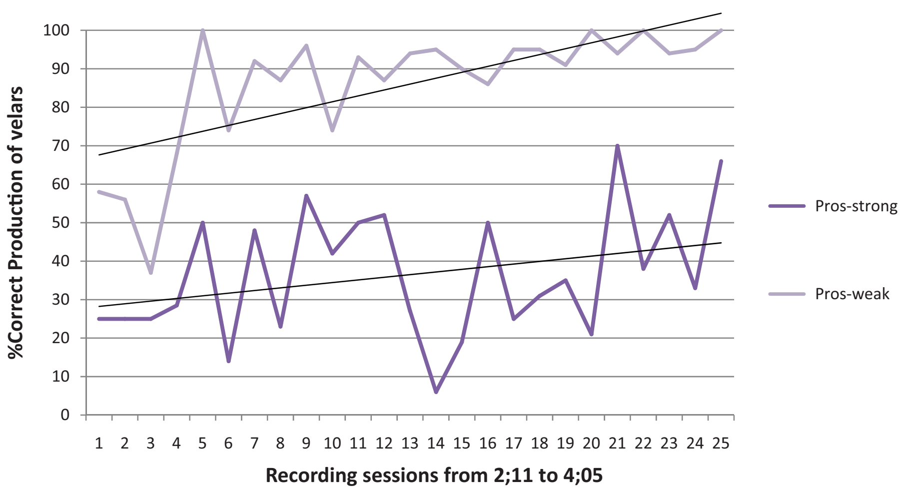

Figure 2. Percent correct production of velars in prosodically-strong versus -weak positions in recording sessions from 2;11 through to 4;05.

to be present in all word positions by 2;08; they are considerably more present in prosodically-weak than in -strong positions by 3;00; and they are produced with a high degree of accuracy (90–100%) in prosodically-weak positions by 3;02. In contrast, the development of velars in prosodically-strong positions is slow; from 2;08 through to 4;03, only gradual improvement (from approximately 30% to 50%) is observed. In the final diary period (4;06–4;08), they are produced with 74% accuracy.

Figure 2 displays the percent correct performance of velars in prosodically-strong versus -weak positions across recording sessions 1–25 (age 2;11–4;05). The findings are consistent with those of the diary entries in showing differences between the realisations of velars in prosodically-strong

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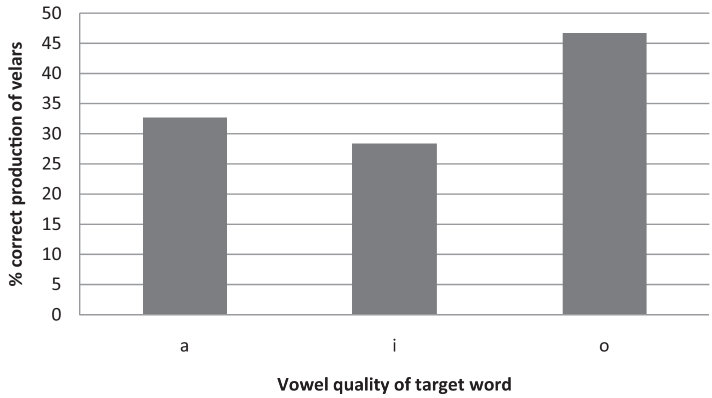

Figure 3. Realisations of prosodically-strong velars according to the vowel quality of the target word (a = low vowels; i = front vowels; o = rounded or back vowels) in recordings (2;11–4;05).

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versus -weak positions; however, they also attest to a greater degree of variability in the realisation of velars in prosodically-strong positions (see zig-zag nature of curve) than in the diary study. This greater variability is because fewer productions were registered in a recording session versus diary month, and there were strong lexical effects on the realisation of velars: some velar-initial target words were always realised with velars and some never were (see later section on lexical effects). Nevertheless, despite the variability, we can observe some developmental progression. At 2;11, velar-initial forms were realised with approximately 30% accuracy and by 4;05 with 50–60% accuracy.

Phonetic conditioning factors

In this section, we examine conditioning effects on Max's realisation of prosodically-strong velars. We focus on the recorded data because comparable results were obtained in the diary data. The only exception was for the analysis of clusters, in which different findings were obtained. Since the recordings contained a smaller proportion of words with target clusters (i.e. 17% target words with k-or g-initial clusters in recordings vs. 38% in diary entries) and since the recordings were biased towards /Cr/ clusters which were subject to a labial preservation effect (see below; 64% of clusters were /kr, gr/ clusters in recordings vs. 48% in diary entries), it is possible that the recordings provide a less accurate account of the findings than the diary entries. Thus, we include the diary entries for the study of clusters as well. The analysis is based on 522 productions of target words containing velars in prosodically-strong positions present in recording sessions 1–25 (2;11–4;05) and, in the analysis of clusters, on 679 productions of target words containing velars in prosodically-strong positions present in diary entries from 2;06 (after the decline of velars) through to 4;08.

Vowel quality. Figure 3 presents the realisation of prosodically-strong velars according to vowel quality for the entire recording period and Figure 4 presents it for three different time periods; 3;0 (2;11–3;05.30); 3;06 (3;06,00–3;11.30) and 4;00 (4;00.00–4;05). A 2×3 chi-square test indicated that there was a significant effect of vowel quality on velar production ($\chi(2) = 10.72$, $p = 0.005$). Additional 2×2 chi-square tests in combination with a Bonferroni correction ($p = 0.017$ or 0.05/3)[6] indicated that the difference of velar production before dorsal versus low vowels was statistically significant (a vs. o: $\chi(1) = 8.94$, $p = 0.003$) and before dorsal

[6]Analyses using odds ratios (including confidence intervals and Fisher Exact Probability tests) produced equivalent results.

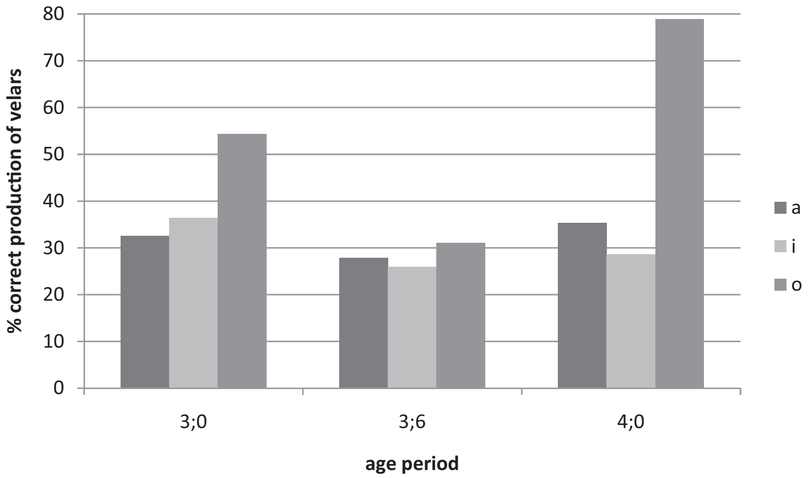

Figure 4. Realisation of prosodically-strong velars according to the vowel quality of the target word (a = low vowels; i = front vowels; o = rounded or back vowels) in the recordings across different age periods: 3;0 (2;11 to 3;05.30); 3;6 (3;06,00 to 3;11.30) and 4;0 (4;00,00 to 4;06).

versus front vowels was marginally significant (i vs. o: $\chi(1) = 5.538$; $p = 0.019$), but the difference before front versus low vowels was not significant (a vs. i: $\chi(1) = 0.003$, $p = 0.956$). Figure 4 reveals that the conditioning effects of vowel quality occurred early on ($\chi(2) = 7.266$, $p = 0.026$) and later on ($\chi(2) = 20.976$, $p < 0.001$) but in the middle period (3;06–4;0), the effect of vowel quality was absent ($\chi(2) = 0.376$, $p = 0.829$). Thus, the conditioning effects of vowel quality were not linear across the developmental period.

Voicing. Figure 5 presents the realisation of initial velars according to the voicing of the velar for the entire recording period and Figure 6 presents it for the three different time periods. Velars were realised more accurately when the target velar was voiced than when it was unvoiced ($\chi(1) = 9.547$, $p = 0.002$). This effect was present across all three time periods but only reached significance in the last time period (3;0: $\chi(1) = 3.388$, $p = 0.066$; 3;6: $\chi(1) = 1.113$, $p = 0.291$; 4;0: $\chi(1) = 11.204$, $p = 0.0008$).

Presence of clusters. In the recorded data, velars were not realised most accurately when they were part of a complex versus simple onset (38.5% vs. 37.4%; $\chi(1) = 0.039$, $p = 0.843$). When different cluster types (/Cl/, /Cr/, /Cw/) were compared to the no cluster condition, there was also no effect of cluster type on velar realisation ($\chi(3) = 3.82$, $p = 0.281$), although, percentage-wise, target /Cl/ and /Cw/ clusters were realised more often with velars than target /Cr/ clusters (/Cl/: 52.6% (10/19); /Cw/ 50.0% (7/14) vs. /Cr/ 31.0% (18/58)).

In the diary data, there was a significant effect of cluster on velar realisation. Velars were produced significantly more often when they were part of a cluster (52.7% or 137/260) than when they were not part of a cluster (22.9% or 96/419; $\chi(1) = 63.130$, $p = 0$). When different cluster types were compared to the no cluster condition, there was also a significant effect on velar realisation ($\chi(3) = 62.248$, $p < 0.00001$). Velars were produced most often with target /Cl/ clusters (67.7% or 65/96), least often with /Cr/ clusters (41.3% or 52/164), and somewhat in between with target /Cw/ clusters (50% or 18/36). These percentages were all significantly different from the no-cluster condition (/Cl/ vs. no clusters: $\chi(1) = 72.938$, $p = 0$; /Cw/ vs. no clusters: $\chi(1) = 12.955$, $p = 0.0003$; /Cr/ vs. no clusters: $\chi(1) = 16.504$, $p = 0.00005$).

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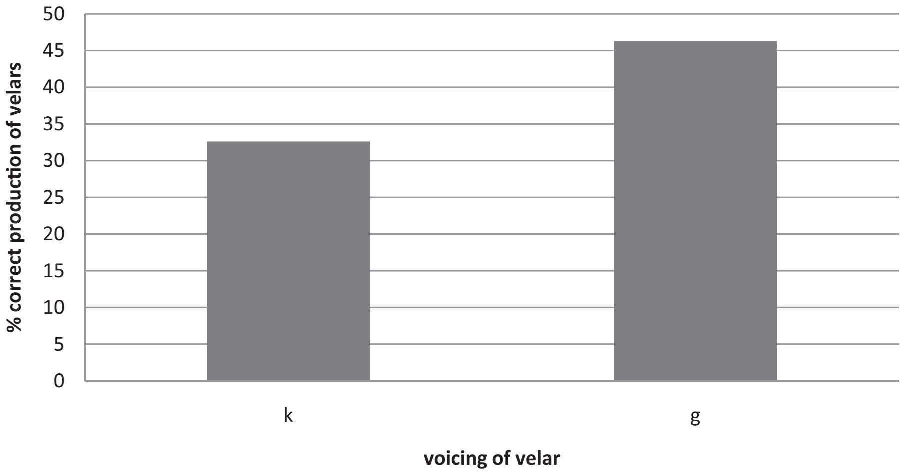

Figure 5. Realisations of prosodically-strong velars according to the voicing of the velar in the target word in the recordings (2;11–4;05).

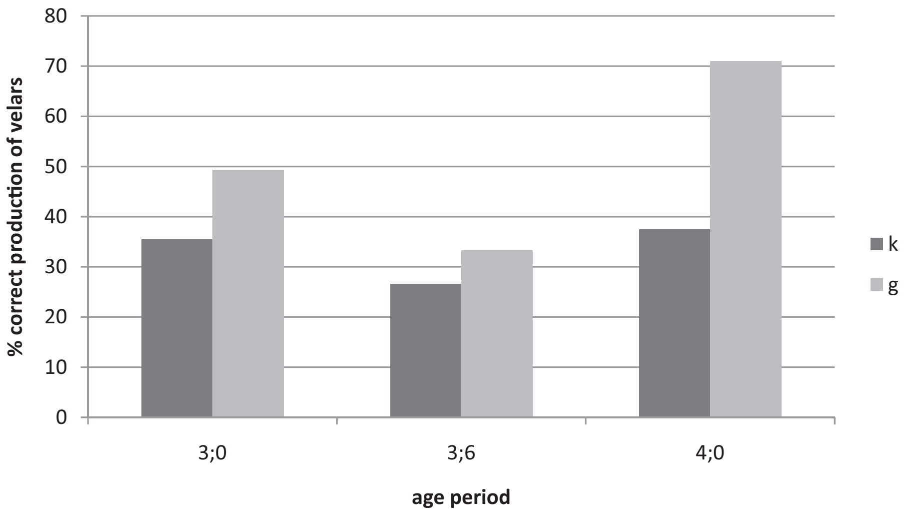

Figure 6. Realization of prosodically-strong velars according to the voicing of the velar in the target word in the recordings across different age periods: 3;0 (2;11 to 3;05.30); 3;6 (3;06,00 to 3;11.30) and 4;0 (4;00,00 to 4;06).

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We interpret these results as indicating that there was an effect of cluster on the realisation of initial velars. The lack of the effect in the recorded data was probably due to the reduced number of clusters, in particular of target /Cl/ and /Cw/ clusters which had the strongest conditioning effect on velar realisation. Target /Cr/ clusters had an ambiguous effect on velar realisation, sometimes conditioning labial-initial and sometimes conditioning velar-initial outputs (see below).

PoA of the post-vocalic consonant. Figure 7 presents the realisation of prosodically-strong velars according to the PoA of the postvocalic consonant and the presence of post-vocalic /l/. The nature of the postvocalic consonant had a strong conditioning effect on the realisation of velars ($\chi(4) = 62.755$, $p < 0.00001$). A series of 2×2 chi-square tests in combination with a Bonferroni

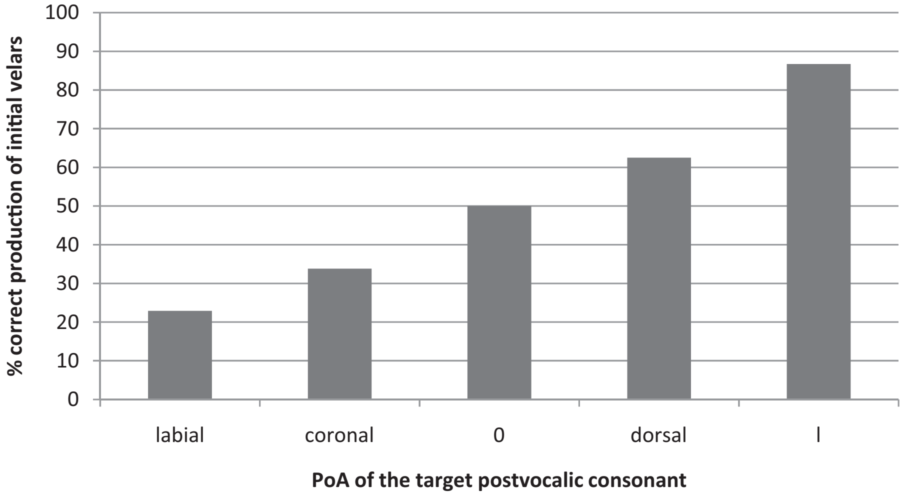

Figure 7. Realization of prosodically-strong velars according to the PoA of the postvocalic consonant (labial, coronal or dorsal, 0 = no postvocalic consonant; l = presence of postvocalic /l/) in the entire recording period (2;11–4;05).

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correction were used to determine which PoA conditions were significantly different from each other. Designating a p value of 0.005 (0.05/10 multiple comparisons) as significant, the condition of postvocalic /l/ was significantly different from all other conditions except post-vocalic velar (/l/ vs. lab: $\chi(1) = 35.57$, $p = 0$; /l/ vs. cor: $\chi(1) = 28.483$, $p = 0$; /l/ vs. Ø: $\chi(1) = 10.290$, $p = 0.001$;/l/ vs. velar: $\chi(1) = 5.020$, $p = 0.025$); the condition of post-vocalic velar was significantly different from post-vocalic labial and coronal but not from the condition in which there was no post-vocalic consonant (vel vs. lab: $\chi(1) = 19.76$, $p = 0.000006$; vel vs. cor: $\chi(1) = 13.031$, $p = 0.0003$; vel vs. Ø: $\chi(1) = 1.378$, $p = 0.240$); the no-post-vocalic consonant condition was significantly different from the post-vocalic labial condition but not from the post-vocalic coronal condition (Ø vs. lab: $\chi(1) = 11.584$, $p = 0.0007$; Ø vs. cor: $\chi(1) = 5.572$, $p = 0.018$). The post-vocalic labial condition was not significantly different from the post-vocalic coronal condition ($\chi(1) = 3.092$, $p = 0.079$). In sum, we observe a gradient effect of post-vocalic PoA on the realisation of prosodically-strong velars with post-vocalic /l/ having the strongest effect and labial place having the weakest effect.

Lexical effects

The above analyses indicated that there were conditioning factors which determined whether prosodically-strong target velars surfaced as velars. Nevertheless, there was strong inter-word variability such that some words containing conditioning factors surfaced with velars and some words, not. Interestingly, there was little intra-word variability: the output patterns for a given word were relatively stable. To illustrate the inter-word variability, Table 3 displays a list of selected target words which were always or almost always realised with initial velars (i.e. 80–100%), variably realised with initial velars (20–80%), or which were never or infrequently (i.e. less than 20%) realised with initial velars throughout the analysis period. Results include words produced in diary entries and recordings. As can be observed, words always or variably produced with initial velars frequently contained dorsal vowels, dorsal consonants, /l/, or clusters, although there were some words not characterised by any dorsal feature which could be produced as velar, most likely due to their high-frequency (e.g. get, can't). Words infrequently produced with velars often contained non-dorsal vowels and non-velar consonants. Nevertheless, certain words

Table 3. List of selected words which were always (80–100%) produced with initial velars, which were variably produced (20–80%) with initial velars, and which were never or infrequently (less than 20% of occurrences) produced with initial velars after the age of 2;06.

Always velar-initial	Variable velar-initial	Never velar-initial
crocodile [ˈgɒʔgaɪ] 2;08–4;00	accordion [gɔˈgin], [ˈtɔdiən] 2;09–3;08	car [daː] 2;06–4;05
girl [gɜ] 2;06–4;05	cake [det], [gek] 2;11–3;06	carrot [ˈdæwɪt] 2;06–4;03
glue [gu] 3;00–3;06	can't [dan], [kant] 2;11–4;00	castle [ˈdaːju] 2;06–4;00
goal [goʊ] 3;00–3;01	clock [dɒd], [gɒk] 2;06–4;06	cat [tæt] 2;06–3;08
goblin [ˈgɒbin] 3;00–3;06	cloud [jɒd], [gaʊd] 2;07–3;04	clean [din] 2;06–3;11
goggles [ˈgɒgɔɪz] 3;00–3;04	clown [daʊ], [gaʊn] 2;06–3;10	coffee [ˈdɒfwi] 2;09–4;00
gorilla [ˈgowu] 2;08–2;11	coal [doʊ], [goə] 3;04–4;05	Concorde [ˈdɒnˌdɔd] 3;05–10
(play)ground [ˈbeˈgaʊnd] 2;09–4;00	cockpit [ˈdɒkpɪt], [ˈkɒkpɪt] 3;06–3;07	come [dʌm] 2;11–4;05
kill [ki] 3;04–3;09	garlic [gaːjɛ], [dajɛk] 2;10–3;03	cook(ing) [ˈtʊkin] 2;06–3;07
school [gu] 3;06–3;08	get [dɛt], [gɛt] 2;11–4;00	cow [daʊ] 2;06–4;00
screwdriver [gugaɪgʌ] 2;08–3;00	gloves [wʌb], [gʌb] 2;11–3;11	goat [dot] 2;06–3;07
seagull [igaɪ] 2;11–3;08	go [do], [go] 3;0–4;05	gone [dɔn] 3;00–4;03
squirrel [ˈguwu] 2;06–3;08	going [do.in], [go.in] 3;04–4;05	helicopter [ˈeɪˌdɒpdɛə] 2;08–4;05
	got [dɒt], [gɒt] 3;04–4;05	kiss [wɪs]/[dɪs] 2;06–4;00
	Gordon [ˈdɔdɛn], [ˈgɔdən] 3;03–4;05	kick(er) [ˈdɪkʌ] 2;06–3;08
		spaghetti [ˈbɛˈdædi] 2;09–3;06
		scared [dɛəd] 3;01–3;10

Entries include a phonetic example and the age range in which the words were attested.

containing dorsal vowels (e.g. coffee, goat, and gone), dorsal consonants (e.g. cooking; kick(er)), or clusters (e.g. clean) were never or infrequently realised with initial velars.

Two other aspects of Max's phonology are relevant to his acquisition of velars: his cluster reduction patterns and his velar-initial patterns for non-velar targets.

Cluster reduction patterns

Max's cluster reduction of obstruent–sonorant clusters was determined first by PoA and second by sonority, a pattern originally described by Pater and Barlow (2003). This meant that in onset clusters containing a non-labial obstruent + labial sonorant, Max mainly selected the labial sonorant (e.g. /tr/, /dr/, /kr/, /gr/, /tw/, /kw/ → [w]). Here, we assume that /r/ is specified in early child English as labial (Gnanadesikan, 1995/2004; Pater & Barlow, 2003). In onset clusters containing a non-labial obstruent + non-labial sonorant, Max selected the obstruent (e.g. /kl, gl/ → [k, g]), which was sometimes fronted to [t, d] (e.g. clean → [din]). Examples of his reduction of velar-initial clusters to [w] are crab [wæb] (2;06–3;11), cry [waɪ] 2;06–3;03), crane [wen] (2;05–3;04), and quick [wɪk] (3;11). [w] has dual specification as both labial and velar and, thus, faithfulness to [dorsal] may also play a role in Max's frequent realisation of velar-initial clusters as [w]. Reduction to a [w]-pattern was the most-frequent reduction pattern of /kr/, /gr/, /kw/ clusters. However, some /kr/, /gr/, /kw/ target clusters were also produced with initial velars (e.g. crocodile → [ˈgɒʔgaɪ]; squirrel → [ˈguwu]).

Velar outputs for non-velar targets

Max also consistently produced a selection of words that did not contain word-initial velars with initial velars. If we consider Max's productions after the age of 2;11, that is, after his one-word one feature period, 93 examples were attested in his diary entries or recordings. Of these examples, the majority contained word-initial /tr/ or /dr/ onsets (i.e. 59% or 55/93). The next largest group contained word-initial affricates or /tj/ and /dj/ sequences (i.e. 26% or 24/93). The

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remaining examples could be explained by assimilation (i.e. 8% or 7/93) or appeared to be motivated by preferred output patterns (i.e. 8% or 7/93). See examples in (8).

(8) Non-velar target words which were realised with velar-initial outputs

(a) Words starting with /tr/ and /dr/ clusters
drill [gi]/[gu] 2;11–3;03; trolley [gɒwi] 3;03–3;07; drop [gɒp] 3;08–4;0; (con)troller [gɔɪjʌ] 3;08; strawberry [gɔbi] 3;02–4;00; track [gæk] 2;08–3;07; trunk [gʌŋk] 2;09–3;0; triangle [gaɪnjoz] 3;04
(b) Words starting with affricates (or /tj/, /dj/ onset sequences)
children [gugin] 2;11–4;00; chopping [gɒpɪn] 3;07–3;11; chocolate [gɒkɪt] 3;11–4;00; chewing [guwɪŋ] 3;11; joke [gok] 3;07–4;01; jacket [ˈgækɪt] 3;06; jungle [ˈgʌŋgo] 3;07; tuba [guba] 3;04; dugong [gugɒŋz] 3;11.
(c) Assimilation
digger [gɪgʌ] 3;00; tiger [gaɪgʌ] 3;03; tigger [gɪgʌ] 3;11; like [gaɪk] 3;06
(d) ''Other'' examples possibly motivated by favourite output patterns
star [ga] 3;03; prawn [gɔn] 3;03–3;10; worms [gɔmz] 3;08; down [gaʊn] 3;06.

The examples in (8a) and (8b), whereby a word starting with a /tr/, /dr/ cluster or affricate was produced with an initial velar, may be suggestive of assimilatory effects since many of the listed words contain dorsal vowels, post-vocalic velars or velarised /l/. However, the presence of the underlying /tr/ or /dr/ cluster or affricate appears instrumental in whether the word surfaced with an initial velar, as suggested by the following example: The words stop and top never surfaced with initial velars but drop and chop did (e.g. stop [dɒp] 3;00–4;03; top [dɒp] 3;03; drop [gɒp] 3;00–3;08; chop [gɒp] 3;07–3;11). Apart from the few examples given in (8c), velar assimilation of target TVK sequences was not observed at this stage of development (e.g. talking [tɔkin] 3;06–4;03; stork [dɔk] 3;06; tuktuk [tʊktʊk] 3;07).

Findings in French and German

This section examines Max's acquisition of velars in French and German. The data are scarcer in these languages because Max was dominant in English throughout the study period, and only French and German productions spoken in the presence of his mother were included in the diary entries. Due to the reduced numbers of entries, it was not possible to make comparisons across prosodic context, voicing, vowel context and post-vocalic place. The quantitative analysis focuses on velar realisation in prosodically-strong positions in those age groups in which there were sufficient numbers of productions to make comparisons viable. This includes age group 3;06–4;00 for recordings in English and French, and age group 4;00–4;08 for diary entries in English, French, and German. The results, which are summarised in Table 4, show that at both age groups, velars were realised more accurately in French and German than in English. Chi-square analyses

Table 4. Comparison of realisation of prosodically-strong velars in English versus French and German.

Age period	English % correct	French % correct	German % correct
Recordings			
3;06–4;00	29% (62/211)	83% (59/71)	
Diary entries			
4;00–4;08	56% (73/130)	82% (23/28)	84% (26/31)

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indicated that the differences between languages were significant in the recordings ($\chi(1) = 64.618$, $p = 0$) and in the diary studies ($\chi(2) = 12.849$, $p = 0.002$). Additional 2×2 chi-square tests conducted on the diary entries in combination with a Bonferroni correction (p value = 0.017 or 0.05/3) revealed that velars were realised more accurately in French versus English ($\chi(1) = 6.526$, $p = 0.011$) and in German versus English ($\chi(1) = 8.121$, $p = 0.004$) but not in French versus German ($\chi(1) = 0.031$, $p = 0.860$).

At the later time period (4;00–4;08), a large percentage of the velar-initial forms were target forms containing clusters (En: 68% or 89/130; Fr: 75% or 21/28; Ge: 64% or 20/31). Velars were realised more accurately in French and German clusters (Fr: 90% or 19/21; Ge: 95% or 19/20) than in English clusters (62% or 55/89). Examples of Max's cluster reduction patterns of target /tr/, /dr/, /kr/, /gr/ clusters in French and German are shown in (9). Whereas Max often reduced target /tr/, /dr/, /kr/, /gr/ clusters in English to the labial sonorant (see above), he reduced them to the obstruent element in French and German. Indeed, the preserved segment often surfaced as dorsal, a finding which may, in part, relate to the dorsal/uvular representation of /ʁ/ in French and German.

(9) Examples of cluster reduction patterns in French and German

Fr: /tr/	train [gɛ̃] ''train'' 3;08,10; tres [te] ''very'' 3;10,19; trompette [tɔ̃'pɛt] ''trumpet'' 4;00,22
Ge: /tr/, /dr/	Tropfen [gɒpfɪn] ''drops'' 4;00,15; drin [dɪn] ''inside'' 4;03,10; drei [gaɪ] ''three'' 4;04,28
Fr: /gr/, /kr/	grand [gã] ''tall'' 4;00,03; grave [gav] ''serious'' 3;11,26; gris [gi] ''grey'' 3;11,17; crèpe [gɛp] 3;08,03; grenouille [do'nɔj] ''frog'' 4;01,15
Ge: /gr, /kr/	gross [gos] 3;08,06 ''fat''; krank [kaŋk] ''sick'' 4;00,18; Krach [kaχ] ''noise'' 4;03,10

One additional factor that should be considered in Max's realisation of velars in French is that the prosody of French is very different from that of English. French is generally considered to have phrase-final stress (Dell, 1984), which means that velars in word-initial position are often the onsets of unstressed-syllables. For example, in the quantitative analysis above, prosodically-strong velars were onsets of word-initial unstressed syllables (e.g. ca'mion, ca'nard, cui'llère); word-initial stressed syllables (e.g. 'comme, 'coq, 'grand), and word-medial stressed syllables (e.g. beau'coup, ba'guette). We examined whether the factor stress versus unstress had an influence on the realisation of velars in French. Our analyses showed that in both the French diary and recorded data, the main errors were attempts at word-initial unstressed velar targets (e.g. French diary: stress – 95% correct realisation of velars or 18/19; unstress – 55% correct or 5/9; French recordings: stress – 100% correct or 49/49; unstress – 64% or 14/22). Examples of errors include productions of cabine [ta'bin], canard [ta'naʁ], grenouille [tɔ'ni], cadeau [da'do], coté [to'tɛ], and cassé [ta'se]. These results go in the opposite directions of findings in English, in that the weak (unstressed) position in French was characterised by less accuracy rather than greater accuracy of velars; however, word-initial position may have a special status in terms of prosodic conditioning.[7] Overall, the results suggest that the different prosody of French versus English is not the reason why velars were produced more often in French.[8]

[7]We are not aware of any studies on positional-velar fronting in French. In English, onsets of word-initial unstressed syllables (e.g. guitar) function like prosodically-strong onsets even though they are the onsets of unstressed syllables. It is possible that French functions in a similar way in which case the poorer performance in word-initial position is predicted.

[8]If prosody played the main role in cross-linguistic differences concerning velar realisation, we would predict similar results between English and German, which are both trochaic languages rather than between German and French.

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Summary of data

Max's acquisition of velars can be summarised as follows: At the earliest stages of word production, Max realised many words with a velar-initial output pattern KV(K). The KV(K) output pattern disappeared after 5–6 months and there was a short period in which very few velars were realised. Velars reestablished themselves in prosodically-weak positions but remained intermittent in prosodically-strong positions for a long time. The realisation of velars in prosodically-strong positions was conditioned by vowel quality, voicing of the target velar, whether the velar was part of a (obstruent plus sonorant) cluster and the PoA of the postvocalic segment. All of the conditioning factors, with the exception of voicing, point to the fact that Max was most likely to realise a prosodically-strong velar when another segment in the word was dorsally specified. A small set of words containing word-initial /tr/, /dr/, clusters and affricates also surfaced with initial-velars. While acknowledging that the data are tentative in French and German, the findings suggest that velars were realised more often in French and German than in English.

It is important to note that although Max's data resemble the data of other children with positional velar fronting, the findings are different in many respects. First, Max's did realise initial velars in prosodically-strong positions to some extent: At 2;11, he realised them 30% of the time. This can be compared to E in Inkelas and Rose (2007) who realised them only 18% of the time during the period studied. Second, Max's acquisition of velars was strongly intertwined with PoA. Some velar-initial clusters were realised with labial- rather than just coronal-initial outputs as is typically documented in studies on positional velar fronting (Inkelas & Rose, 2007; McAllister Byun, 2012; Stoel-Gammon, 1996). His production of prosodically-strong velars was also conditioned by dorsality. While the dorsality of the vowel or the sonorant element of the cluster has been found to condition initial velars in some accounts of positional velar fronting (e.g. Ben in McAllister Byun, 2012; Sine in Bills & Golston, 2002), the dorsality effects in Max's data appear to be stronger. Third, Max displayed PPD, either as a result of his diverse input conditions or because he had a functional phonological delay independent of his adoption. One manifestation of this delay was his tendency to reuse the same error patterns over a long period of time.

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Analysis of data

In the following analysis of the data, we aim to understand what underlies Max's: (1) U-shaped patterns of velars; (2) Positional velar-fronting process and (3) Partial realisation of velars in prosodically-strong positions. We are primarily interested in Max's representation of velars from a multidimensional perspective, which includes articulatory, acoustic-perceptual and higher-level knowledge (Munson et al., 2005) and his changing representation of velars across the three developmental stages.[9] We depart from standard generative approaches to phonological acquisition by assuming that Max's representation is not adult-like from the beginning. Unfortunately, no perceptual tests were conducted during the analysis period, so it is impossible to determine whether Max's acoustic-perceptual representation of velars was reduced. We can surmise that he displays decreased perceptual knowledge relative to normally developing English-speaking children because he has had less exposure to language-specific input. In addition, he has

[9]We acknowledge that transcription data are inadequate as a sole source of information on children's articulatory and higher-level representation. Edwards et al. (2011) discuss the importance of other types of methodologies to capture fine-grained representation. We present the transcription data, nevertheless, because our analyses still point to gradient patterns even given the coarseness of the technique.

perceptually assimilated to the phonetic categories of one language (i.e. Thai) and, at the point of first word production, he has had to perceptually assimilate to other languages (i.e. first English and German; later, French). Thus, it is likely that reduced perceptual knowledge may have influenced Max's initial formation of phonetic categories. Nevertheless, there are no indications that a perceptual deficit is the sole cause of his protracted development of velars. We concentrate primarily on Max's articulatory and higher-level knowledge of velars, which we interpret from his errors patterns based on transcribed data.

Whole word stage

The first developmental stage attests to several hundred diary entries of output forms containing initial velars. They are first observed with front vowels and later with back vowels and to a moderate extent, with low vowels at all times. Max's initial association of velars with front vowels is not typical of the most commonly reported consonant–vowel association with velars (Davis et al., 2002; Fikkert & Levelt, 2008). We offer two possible explanations for the velar-front association. First, it may constitute residual effects of Max's exposure to the Thai language, in which, on the verge of producing words, he has perceptually and articulatorily attuned to the language-specific consonant–vowel associations of Thai, which may include a KI pattern. Unfortunately, we are unable to verify this hypothesis without more detailed phonetic information on spoken Thai. An examination of consonant–vowel associations in a written corpus of Thai does not reveal high frequencies for velar consonants and front vowel bigrams versus velar consonants plus other vowel bigrams (Munthuli, Sirimujalin, Tantibundhit, Kosawit, & Onsuwan, 2013); however, a written corpus may not be typical of the speech heard/produced by young children.

Second, the velar-front association may constitute the initial effects of Max's exposure to English in which he displays associations not typical of the majority of children but at least attested in some children. Davis et al. (2002) report that of the 15 significant (i.e. above-chance) non-predicted CV associations present in their analysis of the early words of 10 English-speaking children, six were velar-front associations. In terms of articulatory cost (quantified in terms of how far and how fast a given articulator moves from its rest position), Lindblom, Diehl, Park, and Salvi (2011) provide evidence that velar place combined with front vowels is the least costly syllable position, even less costly than velar place combined with back vowels, suggesting a bio-mechanical motivation to Max's patterns.

What needs to be explained is why the velar-front association does not remain in Max's phonology and why a velar-dorsal association develops after a period of time. We posit that these findings may be explained by Max's developing vowel representations. Fikkert and Levelt (2008) propose that perceptually salient vowels are initially specified for PoA but less salient consonants are not. In production, consonants take on the PoA features of the vowel. Max started to produce words one-month following his exposure to English. Thus, it may be assumed that not only his consonants but also his vowels were incompletely specified at the early stages, as is suggested by several examples of consonant vowel associations in Max's data, in which the vowel was deformed rather than the consonant (e.g. <u>bread</u> [bɒ], <u>cold</u> [geɪ], <u>train</u> [wo]). Once Max's vowels became more specified, consonant–vowel associations typical of early phonological development, that is, coronal-front and velar-dorsal, were observed.

So what does Max know about velars in this early whole word phase? We believe that he knows something about velars, because he produces a not insignificant number of velar-initial forms and the accuracy of these forms in terms of the target is relatively high (e.g. 60–70% in the first two months of word production). Thus, he is able to match an acoustic percept of a velar with a velar

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articulatory gesture suggesting lower-level knowledge of an acoustic-perceptual and an articulatory nature. As to higher-level knowledge, Max seems to have some temporary word-based representations of dorsality, because his velar output forms KV(K) are generally associated with input forms which have dorsal specification, either consonantal or vocalic. There is no evidence, however, of any segmental-based representation of dorsality.

Decline of velars

In the middle stage, velar outputs decline in number until they almost disappear. This finding is consistent with proposals by several authors that a constraint emerges after a period of time in some children's developing phonologies accounting for U-shaped effects. In Fikkert and Levelt's (2008) account, a constraint against initial dorsals, *[K emerges once children make generalisations about the PoA characteristics of their developing lexicons. In Max's case, velars are hardly realised at all at a certain point suggesting an even more general constraint, one against all velars.

To determine whether the development of a *K (or *[K) constraint is driven by a frequency analysis of the PoA properties of the input, we examine the proportion of words containing initial velars with relation to the proportion of words starting with other PoAs in Max's developing (cumulative) lexicon during the period 1;10–3;0 years. These results are shown in Figure 8. At each month, we count the number of new word types produced in that month as well as the number of word types produced in the preceding months. The analysis is based on data through to 3;0 because up until this point, it is likely that the diary study has captured most of Max's lexicon. After this time, this assumption becomes less likely, since Max's productive vocabulary increases rapidly, making it difficult to document all words. At 3;0, the cumulative lexicon contains 774 words.

As Figure 8 shows, the proportion of words selected with initial velars is commensurate with that of initial labials in the second month of word production (i.e. 1;10) but by 1;11, Max selects more words with initial labials and coronals than initial velars, a pattern which continues throughout the period 1;11–3;0. Thus, while it is true that Max's lexicon becomes swamped with

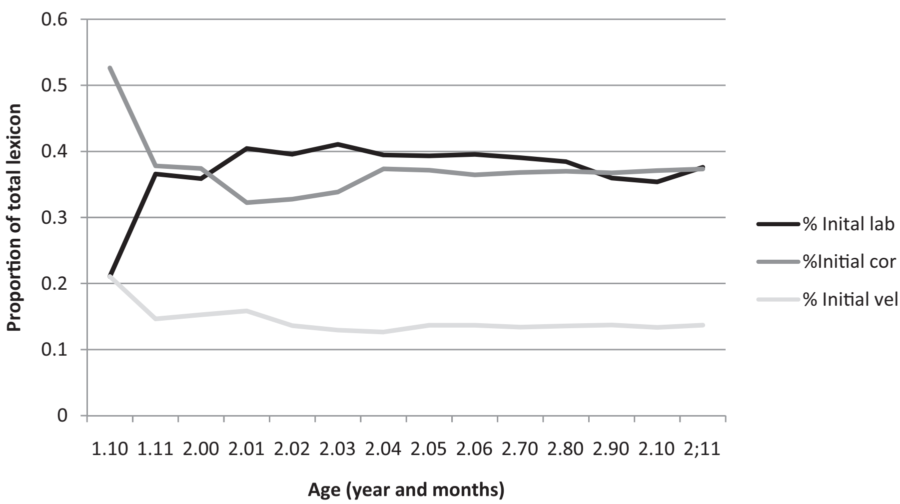

Figure 8. Proportion of labial-, coronal- and velar-initial forms in Max' cumulative lexicon across the period 1;10–3;0 years.

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words starting with consonants other than velars after a short period of time, there are no particular changes in relative frequency of lexical types at 2;03–2;06 that might explain the changes to his output patterns. What is true of Fikkert and Levelt's (2008) claims, however, is that velars start to disappear once words become segmentalised. On the basis of Max's phonetic realisations, we hypothesise that individual segmentation of PoA for consonants and vowels starts to occur in the period 2;04–2;07. This is when we observe the realisation of variegated labial + coronal patterns and when certain ''one word, one feature'' patterns resolve into differentiated forms (e.g. the [wo] form for train changes to [wen]; the [bo] form for bread changes to [bet]).

An alternative account of a U-shaped curve offered by McAllister and colleagues relates to articulatory reliability and the accuracy and precision of motor-acoustic mappings (McAllister Byun & Inkelas, 2013; McAllister Byun et al., 2013). According to McAllister Byun and colleagues, at the earliest stages of word production, all articulatory representations, both target-like and non-target-like, have similar degrees of articulatory reliability and the constraint ACCURATE ensures that the target-like one is selected; however, over time, less complex articulatory targets receive more reliable motor-acoustic mappings and these forms will be preferred over target-like unreliable ones due to high-ranking PRECISE.

Figure 9 shows the ''take-over'' of coronal-initial outputs for velar-initial targets in Max's diary entries during the period 1;10–3;00. We focus on 20 velar-initial targets which were selected prior to the decline in velar-initial outputs (at 2;01 or before) and which were produced on a frequent basis through to 3;0 years. The total number of diary entries for the 20 targets was 421.[10] Figure 9 indicates that coronal-initial outputs were produced from the beginning for velar-initial targets. Over time, they increased in number until, at 2;03–2;04, they overtook the number of velar-initial outputs.

Ultimately, the data do not allow us to determine whether the constraint that enters Max's system is motivated by statistical properties of his developing lexicon or by the increased articulatory reliability of his non-velar outputs, or indeed by a combination of factors: the more coronal- and labial-initial targets that Max includes in his developing lexicon, the more likely that stable and reliable articulatory representations build up for these targets to the detriment of velar targets.[11] Regardless, it seems that the articulatory knowledge of velars that had developed in the initial period has declined by virtue of the fact that Max is no longer producing many velars. We decline to speculate on his higher-level knowledge given the absence of velars at this point.

Positional velar fronting

The final stage is characterised by correct production of velars in prosodically-weak but reduced production in prosodically-strong positions. The prosodic conditioning of Max's velar fronting is consistent with numerous reports of positional velar fronting (Inkelas & Rose, 2007; McAllister Byun, 2012; Stoel-Gammon, 1996). What is novel about Max's version of velar fronting is the conditioning of velars in prosodically-strong positions. Max is most likely to realise a prosodically-strong velar when another segment in the word is dorsally specified. This might suggest that assimilatory effects are the cause of Max's positional velar fronting. However,

[10]The analysis includes the following words: cake (selected at 1;11); car (1;09); carrot (1;11); cart (2;00); cat (1;11); cloud (2;01); coat (1;11); cold (1;11); cow (2;0); cup (1;11); gate (1;11); geese/goose (2;0); glasses (2;0); go (2;01); goat (2;01); grape (2;0); grass (2;0); kaka (1;10); key/keys (1;11); kite (2;01).

[11]The decline of velars occurred around the same time as the beginnings of combinatorial speech for Max (2;03–2;06 for the decline of velars and 2;05–2;06 for the start of combinatorial speech), which may suggest a trading relationship between syntax versus phonology. We do not think the onset of syntax is the principal reason for Max's U-shaped pattern. His production of velars declined but other aspects of his phonology improved including vowel accuracy, emergence of fricatives, the development of codas and the consistent appearance of unstressed syllables.

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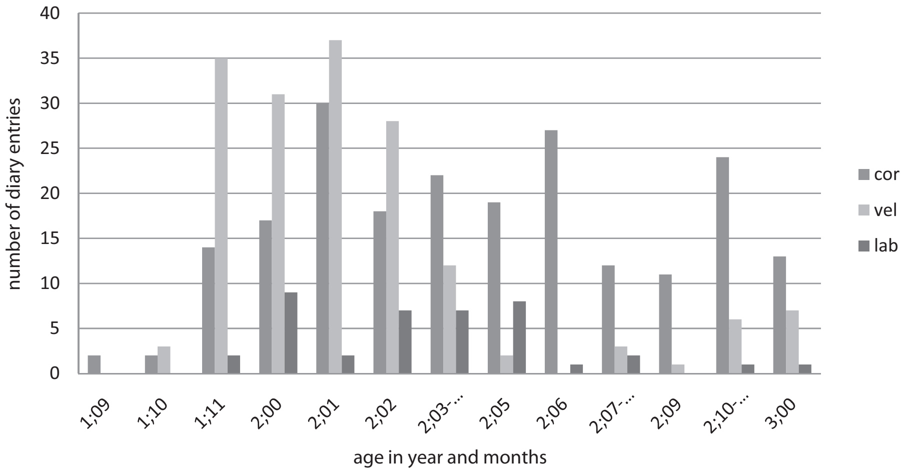

Figure 9. Frequency of error patterns for 20 velar-initial words (selected prior to 2;01) across the period 1;09 to 3;00. This graph shows the take-over of coronal-initial forms at 2;03-2;04. Certain months are grouped together when there were reduced numbers of diary entries.

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assimilation does not provide the complete explanation. Post-vocalic /l/ had a strong conditioning effect on velar production but the other factors had intermediate or even weak effects on velar production. As indicated above, target words containing dorsal vowels, post-vocalic velar consonants, or clusters were also produced with coronal onsets. Furthermore, it could be assumed that assimilatory effects involving dorsality would also target underlying coronals but this was not the case. Target non-velars surfaced as velars, but they consisted of /tr/ and /dr/ clusters and affricates, not generally alveolar consonants on their own.

The fact that Max realises a certain group of structures as velar provides potential evidence that he does have some underlying representation of dorsality. In prosodically-weak positions, Max's categorisation of velar obstruents is commensurate with the adult system. In prosodically-strong positions, Max's categorisation of velars is larger than the adult system because it includes non-velar-initial structures, as shown in (10).

(10) Prosodically-weak target /k/ and /g/ surface as [k] and [g]

Prosodically-strong target /k/, /g/ as well as /kr/, /gr/, /kl/, /gl/, /tr/, /dr/, /ʧ/, /ʤ/ surface as [k] and [g]

In the case of affricates, there are several documented cases of underlying affricates surfacing as velars or triggering velar harmony in child English, suggesting that some children may specify affricates as [dorsal] (Gerlach, 2010; Menn, 1971). This is not without reason, given that their PoA in English, which is (alveo)palatal, is considered by some authors as complex, characterised by both coronal and dorsal place (Keating & Lahiri, 1993). In the case of /tr/ and /dr/ structures, there are several possible reasons why these structures surface as velar in Max's speech. First, velar outputs may arise as a result of transfer from French or German: /tr/ and /dr/ clusters in French and German were often reduced to a velar stop due to assimilation from the underlying uvular [ʁ] (Fr: train → [gɛ̃]; Ger: drei → [gaɪ]), which may have been interpreted as dorsal (Rose, 2000). Thus, cross-linguistic interaction related to the interpretation of /r/ may explain why /tr/ and /dr/ structures sometimes surfaced as dorsals in Max's English. Second, the stop in /tr/ and /dr/ clusters is produced with a high degree of aspiration (Klatt, 1975) and may be perceived by second-language learners of English as /ʧ/ and /ʤ/ (Celce-Murcia, Brinton, & Goodwin, 1996). Max may also have perceived them as such and consequently have interpreted them as ''back''. Third, several authors advance that /r/ is ambiguous in terms of PoA (Goad & Rose, 2004; Rose, 2000). For the most part, Max interpreted English /r/s as labial but in certain phonetic contexts, he may have interpreted them as dorsal. This explanation does not appeal to cross-linguistic interaction but to the ambiguity of /r/ articulation even within English. Allied to this account, Max' realisation of English /r/ as [w] which is dually represented as labial and dorsal may also explain the realisation of some /tr/ and /dr/ structures as dorsal.

Thus, it seems that Max's has some underlying specification of dorsality in prosodically-strong positions not only for velars but also for structures which may be interpreted as velars; however, the data suggest that certain conditions needed to be met before prosodically-strong velars surfaced. They surfaced when followed by another dorsally-specified segment. In a sense, their dorsal specification needed to be enhanced or augmented by other dorsally-specified segments. We use the term ''enhanced'' in a general fashion here, although its usage may have something in common with the specific term of ''feature enhancement'' employed by Stevens, Keyser, and Kawasaki (1986). In ''feature enhancement'' theory, an acoustic difference between two features may be boosted by a supplementary (redundant) feature. For example the acoustic difference between the alveolar and alveolar-palatal sibilants (/s/ vs. /ʃ/) is enhanced by the lip-rounding on /ʃ/, which accentuates its spectral prominence and increases its perceptual distance from /s/. In Max's case, we do not have intrinsic featural enhancement but one that comes from the surrounding context. Underlying velars were boosted or enhanced when they were followed by another dorsally-specified segment within the same word (see (11)). This effect may indeed be assimilatory since it is reported that children are more likely to harmonise velar consonants across back than front vowels (Becker & Tessier, 2011; Pater & Werle, 2003; Stoel-Gammon, 1996), however, we need to include the proviso that the assimilatory effects target consonants which are underlyingly dorsal.[12]

(11) Prosodically-weak target /k/ and /g/ surface as [k] and [g] all the time

Prosodically-strong /k/ and /g/ including /kr/, /gr/, /kl/, /gl/, /tr/, /dr/, /ʧ/, /ʤ/ surface as [k] and [g] only when they are followed by other dorsally specified segments.

The lexical effects evident in the data may not be as unsystematic as they first appear if we assume that conditioning factors have a gradient effect on whether prosodically-strong velars appear. Words characterised by multiple conditioning factors were more likely to surface with prosodically-strong velars than words characterised by fewer factors. As suggested by the examples given in Table 5, <u>crocodile</u> and <u>goggle</u>, which were characterised by four conditioning features, always surfaced with prosodically-strong velars in contrast to <u>clock</u> and <u>cockpit</u>, which were characterised by three and two features, respectively, and which only sometimes surfaced with an initial velar. In the case of <u>coffee</u> and <u>helicopter</u>, both characterised by one feature, there were no documented cases of these words surfacing with prosodically-strong velars. Certain factors appeared to have stronger effects than others. Post-vocalic /l/, for example, had a very strong effect on whether velars would appear; however, its effects were not absolute: <u>goal</u>, <u>girl</u> and <u>gull</u> always surfaced with initial velars but <u>coal</u> and <u>cold</u> did not, suggesting that the presence of velar voicing combined with post-vocalic /l/ made a difference. We acknowledge that not all inter-word variability can be explained by conditioning factors. An example is the word <u>cake</u> which sometimes surfaced with initial velars whereas the word <u>cook(ing)</u> did not, even though the latter has a dorsal vowel. We cannot exclude that accidental gaps in sampling may explain some of these variable findings.

[12]Max's data could also be accounted for within an Optimality Theory constraint framework such as Bernhardt and Stemberger's (1998), in which the realisation of velars occurs only when the weakly established feature [dorsal] is multiply linked within the word. Velar fronting would arise when the feature [dorsal] is too weak to appear because it is not multiply linked.

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Table 5. Possible explanation of inter-word variability based on conditioning factors.

Word	Velar realisation	Dor vowel[a]	Vel cons	cluster	/l/	voicing
crocodile	Always	✓	✓	✓	✓	
goggles	Always	✓	✓		✓	✓
clock	Variable	✓	✓	✓		
cockpit	Variable	✓	✓			
coffee	Never	✓				
Heli'copter	Never	✓				

[a]Conditioning factors include dorsal vowel; post-vocalic velar consonant, obstruent–sonorant cluster, post-vocalic /l/ or the presence of velar voicing.

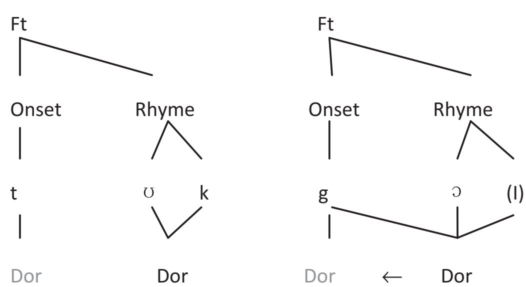
Returning to our original question of what Max knows about dorsals, we believe that Max's knowledge (articulatory and higher-level) of prosodically-weak dorsals is now well developed, but his knowledge of prosodically-strong dorsals, is not. His categorisation of initial velars includes consonants other than velar stops (i.e. affricates and coronal-initial clusters) and initial velars only surface when supported by other dorsally-specified segments within the same word, suggesting that their representation remains incomplete.

Exploring featural licensing versus motor-speech accounts of positional velar fronting

Finally we examine whether Max's positional velar fronting is more consistent with grammatical accounts based on featural support or motor-control. If we consider the grammatical account of Bills and Golston's (2002), the key concept is that the inherent dorsality of vowels licenses or supports the realisation of velars in prosodically-weak positions. Since dorsality appears to be a key concept in understanding Max's realisation of velars in prosodically strong positions, it is tempting to extend the fore-mentioned authors' approaches to explain Max's realisation of velars in both prosodically-weak and -strong positions. In Bills and Golston's approach (2002), the dorsal feature-sharing only takes place within the foot rhyme (everything following the onset), whereas, in Max's case, there seems to be dorsal feature-sharing which implicates both onset and rhyme, that is, the entire word. Prosodically-strong dorsally-specified segments surface when contextually enhanced by other dorsally-specified segments which follow them. In (12), we display examples of the two types of feature-sharing: one involving the rhyme only (12a) and one involving the entire word (12b). In (12b), feature enhancement or assimilation allows the partially represented dorsal segments (here indicated in grey font) to surface.

(12) Dorsal-feature sharing within the foot versus the whole word for Max

(a) cook [tʊk] (b) girl [gɔɪ]



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As shown by the examples in (13), output forms containing prosodically-strong velars were constrained segmentally, giving the appearance of late-occurring ‘‘dorsal’’ whole word patterns.

(13) Output forms containing prosodically-strong velars

a. ⟨gu⟩	school [guː], glue [gu.i], screw [gu.i], drill [guː]
b. ⟨gVwV⟩	squirrel [ˈguwu], gorilla [ˈgowu], goal [ˈgowʌ]
c. ⟨gVjV⟩	trolley [ˈgɒji], controller [ˈgɔɪji]
b. ⟨gVgin⟩	Claudine [ˈgɔgin], accordion [ˈgɔgin], children [ˈgugin]
e. ⟨gVgV⟩	crocodile [ˈgɒgaɪz], goggles [ˈgɒgɔɪz]

We assume that the phonetic grounding of this featural account is related to the articulatory conditions which favour velar production. A dorsal gesture is easier to produce when situated between or following a vowel due to the inherent dorsality of vowels (i.e. the raised tongue body). Producing a dorsal gesture at the beginning of a stressed syllable is an articulatory challenge, which can only be overcome in Max’s case, by him producing a continuous velar gesture throughout the entire word.

We do not consider that the effect is solely articulatory, however, but is also related to how the conditioning factors were perceived and represented acoustically. That is, the presence of a post-vocalic /l/, dorsal vowel, etc. in the acoustic signal allowed Max to extract the feature [dorsal] which then spread to the prosodically-strong velar more easily than when the target word did not have these features. We make this claim because certain words were always realised as dorsal although the factors that cued their dorsality (such as presence of clusters or post-vocalic /l/) were not realised articulatorily until a long time after. It may be the case that there was a covert contrast from the beginning in Max’s speech but given his phonological delay, we posit that the effect reflects acoustic-perceptual factors. Later when Max’s phonology developed, the realisation of the conditioning factors in Max’s speech was probably the reason for the enhanced effects of dorsality across time (see Figures 4 and 6).

We now examine whether Max’s realisation of velars is equally consistent with a grammatical account, based on undifferentiated lingual gestures. According to McAllister Byun (2012), consonant–vowel associations, such as velar-back and coronal-front, are predicted under such an account since they reflect undifferentiated control of tongue and jaw. In a similar vein, conditioning by voicing is also predicted since voiceless sounds are produced with greater gestural force than voiced sounds and, thus, may more often lead to undifferentiated lingual gestures. Furthermore, undifferentiated gestures may give rise to coronal backing depending upon the direction of the release. This could explain the fact that Max also produced non-velar targets as velars.

Earlier in the article, we indicated that we had no direct ways to test this account (e.g. electropalatography) but that we would consider indirect ways. We posited that the influence of conditioning factors should decline over time as motor control improves and that similar realisation patterns should be observed across Max’s three languages, assuming that aspects of motor control are language-neutral (Preston & Seki, 2011). Instead, we observed that the effects of vowel quality actually grew stronger (e.g. compare periods 3;6 and 4;0 in Figure 4) rather than diminished, and, Max’s realisation of velars was different across his languages: He realised prosodically-strong velars more accurately in French and German than in English.

We hypothesise that the cross-linguistic differences arose because English was acquired and produced at a time when Max’s phonological representations were extremely unstable. Max’s did not start to produce many word in French and German until after the age of 3;0–3;06 years, when phonological representations had become more stable and had segmentalised. In addition,

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Max developed a labial-initial constraint early on in English, largely as a result of his interpretation of the English /r/ as labial. As consequence, many target velar-initial clusters surfaced as labial. In contrast, Max interpreted the German and French /r/ as ‘‘back’’ and produced many target velar-initial clusters as dorsal. Overall, the feature [dorsal] was more closely connected to word representations in French and German than in English. The nonlinear pattern of vowel conditioning on Max’ realisation of prosodically-strong velars may have arisen because various aspects of Max’s phonology (e.g. post-vocalic consonants, clusters, /l/) developed at different times and they may have had differing effects on the realisation of prosodically strong velars, neutralising or reinforcing the effects of vowel conditioning at certain periods (e.g. at 3;06 see Figure 4). It must be equally noted that Max had a tendency to reuse the same errors patterns which meant that many of his early formed representations in English remained active in his phonology over a long period of time. The continuous use of the same output pattern reinforced the dorsality effects as well, possibly resulting in the increased association of velar consonants with dorsal vowels observed in the final recording stage (4;0–4;05).

In conclusion, we propose that Max’s positional velar fronting process can be explained according to a featural account in which dorsality develops first in prosodically-weak positions and is extended into prosodically-strong positions by some sort of featural enhancement or by assimilatory processes which target underlying velars. The featural effect appears to be gradient in nature in that the combination of several factors increases the likelihood that an underlying velar surfaces as velar. In the remainder of this paper, we consider two other side issues that fall out of the current analysis. These include: (1) the role of whole-word patterns and (2) sub-types of positional velar fronting.

Whole-word patterns

Max’s earliest word productions are consistent with whole-word accounts of phonology. Apart from his velar pattern, Max evidenced several other whole word patterns including a final sibilant pattern (e.g. <u>fish</u> [ɪʃ], <u>juice</u> [ɪç], <u>light</u> [aɪç]), a nasal pattern (e.g. <u>mouse</u> [mʌm], <u>man</u> [mam], <u>nose</u> [nan]) and a stop pattern (e.g. <u>compote</u> [bæˈbʌ], <u>tiger</u> [ˈdædʌ], <u>bicycle</u> [ˈgægʌ]. Max’s production patterns resemble many other English-speaking children’s, including Waterson’s (1971) P, who also had sibilant, nasal and stop patterns. What is interesting about Max’s data is that he developed these output patterns after having been exposed to English for very little time (i.e. 1–2 months). Thus, Max’s early output patterns do not appear to derive from implicit knowledge of ambient-language structure (Vihman & Croft, 2007). Rather, they appear to be early transient (articulatory) representations which reflect the phonological patterns of his developing lexicon. Importantly, they appear to influence early word selection. In the case of Max’s velar-initial patterns, we observe a higher proportion of velar-initial words selected in the first month of word production compared to later months (see Figure 8). In addition, anecdotal evidence indicates that certain words such as <u>shake</u> and <u>gate</u> whose output forms conformed to Max’s whole word patterns (e.g. ⟨gek⟩) entered his lexicon easefully whereas other words (e.g. <u>fish</u>) required longer exposure before they were produced. Despite the apparent advantages that templates give to word learning, the role they play in phonological advancement is less clear. In Max’s case, his early use of velars was not exploited: certain consonant–vowel associations (e.g. velar + front vowels) which were produced as parts of whole word patterns at 1;10 were not consistently acquired even later at 4;05. Thus, without any abstract categorisation, these early production patterns were not further consolidated and disappeared, giving credence to the fact that phonological representations, particularly articulatory or acoustic-perceptual ones, change over time.

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Positional velar fronting

The literature on phonological acquisitions attests to several documented cases of positional velar fronting which differ in the degree to which velars are produced in prosodically-strong positions. E's production of prosodically-strong velars was not conditioned by vowel quality or their presence in a cluster (Inkelas & Rose, 2007) whereas Sine's was influenced by cluster membership (Bills & Golston, 2002) and Ben's was influenced by vowel quality and voicing (McAllister Byun, 2012). Max's velar production was influenced by several factors. It could be argued that Max's version of velar fronting is not actually velar fronting but is best captured under PoA or assimilatory effects. We propose instead that positional velar fronting exists in different forms which vary according to the conditioning factors which influence the production of prosodically-strong velars. At one extreme, are those forms that are not conditioned by PoA effects (e.g. the velar fronting of E in Inkelas & Rose, 2007) and at the other extreme, are those forms that are. Max's version lies towards the PoA end. The question we ask is whether all of these forms receive a unified explanation or whether certain forms reflect motor-control origins more clearly than others, a question that could be pursued in future research

Conclusion

This study provided a detailed account of one child's acquisition of velars. The results support current approaches to phonological development which view phonological representations as dynamic and multidimensional. Despite the fact that Max produced a large number of velar forms early on, his articulatory representations did not remain stable presumably because they did not lead to abstract categorisation. Our findings support a developmental progression from holistic word-based dorsal representation though to segmental representation of dorsals in prosodically-weak and then finally in prosodically strong positions.

In this study, we examined different accounts which might explain the time course of Max's U-shaped pattern as well as his positional velar fronting process and production of prosodically-strong velars. In the analysis of Max's U-shaped pattern, we considered an account based on statistical analysis of PoA patterns in the input (Fikkert & Levelt, 2008) and one based on articulatory reliability (McAllister Byun et al., 2013). We were unable to distinguish the two accounts using the current data set, the main generalisation being that initial velars started to disappear when representations shifted from whole-word to segmental. The fact that some initial velars did not disappear suggests that whole-word patterns remained for a limited set of target words. One could ask the question as to what sort of data would allow us to distinguish the two different accounts of U-shaped patterns. The answer would be a detailed frequency analysis of Max's own unique lexical input which would include both type and token frequency as well as data on the articulatory accuracy of Max's early word productions. Unfortunately, this type of detailed information on both input and output patterns is rarely collected in phonological acquisition studies.

In the analysis of Max's velar fronting process, we considered two grammatical accounts, one based on featural licensing (Bernhardt & Stemberger, 1998; Bills & Golston, 2002) and the other based on undifferentiated lingual gestures (McAllister Byun, 2012). We cannot definitely exclude the latter account due to lack of electropalatography or ultrasound measures; however, indirect evidence does not support a motor control account. Rather the findings support a featural licensing account in which velars first develop in phonetic environments which support dorsality (i.e. prosodically-weak) and later in environments which are less supportive of dorsality (i.e. prosodically-strong). Even in the latter, augmentation of dorsality via phonetic context was required, suggesting abstract knowledge of velars in prosodically-strong environments was not completely acquired at the end of the study period. Why Max displayed this pattern of velar acquisition may relate to his history as an adopted child, who experienced lack of language input and a change of language input, both events likely to lead to incomplete phonological representations at the point of word production. Nevertheless, other children who do not have Max's history frequently exhibit U-shaped learning and positional phonological processes. Thus, their results may not be so different from his when viewed in closer detail.

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Declaration of interest

The author reports no conflict of interest.

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References

Altvater-Mackensen, N., & Fikkert, P. (2015). A cross-linguistic perspective on the acquisition of manner of articulation contrasts in the productions of Dutch and German children. *Language Acquisition*, *22*, 2–39.

Barlow, J. (2001). The structure of /s/-sequences: Evidence from a disordered system. *Journal of Child Language*, *28*, 291–324.

Bates, S., Watson, J., & Scobbie, J. (2002). Context-conditioned error patterns in disordered systems. In M. Ball, & F. Gibbon (Eds.), *Vowel disorders* (pp. 146–185). Woburn, MA: Butterworth-Heinemann.

Becker, M., & Tessier, A.-M. (2011). Trajectories of faithfulness in child-specific phonology. *Phonology*, *28*, 163–196.

Bernhardt, B., & Stemberger, J. (1998). *Handbook of phonological development from the perspective of constraint-based nonlinear phonology*. San Diego, CA: Academic Press.

Bills, S., & Golston, C. (2002). Prosodic and linear licensing in English acquisition. In L. Carmichael, C.-H. Huang, & V. Samiian (Eds.), *Proceedings of the Western Conference on Linguistics 2001* (pp. 13–26). Fresno: California State University.

Bleile, K., & Tomblin, B. (1991). Regressions in the phonological development of two children. *Journal of Psychological Research*, *20*, 483–499.

Celce-Murcia, M., Brinton, D., & Goodwin, J. (1996). *Teaching pronunciation. A reference for teachers of English to speakers of other languages*. New York, NY: Cambridge University Press.

Davis, B., MacNeilage, P., & Matyear, C. (2002). Acquisition of serial complexity in speech production: A comparison of phonetic and phonological approaches to first word production. *Phonetica*, *59*, 75–107.

De Boysson-Bardies, B., & Vihman, M. (1991). Adaptation to language: Evidence from babbling and first words in four languages. *Language*, *67*, 297–319.

Dell, F. (1984). L'accentuation dans les phrases en français. In F. Dell, D. Hirst, J.-R. Vergnaud (Eds.), *Forme sonore du langage* (pp. 65–122). Paris: Hermann.

Dinnsen, D., & Farris-Trimble, A. (2008). The prominence paradox. In D. Dinnsen, & J. Gierut (Eds.), *Optimality theory, phonological acquisition and disorders* (pp. 277–308). London: Equinox Publishing.

Edwards, J., Munson, B., & Beckman, M. (2011). Lexicon–phonology relationships and dynamics of early language development. *Journal of Child Language*, *38*, 35–40.

Ferguson, C., & Farwell, C. (1975). Words and sounds in early language acquisition. *Language*, *51*, 419–439.

Fikkert, P., & Levelt, C. (2008). How does place fall into place? The lexicon and emergent constraints in the developing phonological grammar. In P. Avery, B. E. Dresher, & K. Rice (Eds.), *Contrast in phonology: Perception and acquisition* (pp. 219–256). Berlin: Mouton.

Gayraud, F., & Kern, S. (2007). Caractéristiques phonologiques des noms en fonction de l'âge d'acquisition. *Enfance*, *59*, 324–338.

Gerken, L. (1994). A metrical template account of children's weak syllable omissions from multisyllabic words. *Journal of Child Language*, *21*, 565–584.

Gerlach, S. (2010). *The acquisition of consonant feature sequences: Harmony, metathesis and deletion patterns in phonological development* (Unpublished doctoral dissertation). University of Minnesota.

Gershkoff-Stowe, L., & Thelen, E. (2004). U-shaped changes in behavior: A dynamic systems perspective. *Journal of Cognition and Development*, *5*, 11–36.

Gibbon, F. (1999). Undifferentiated lingual gestures in children with articulation/phonological disorders. *Journal of Speech, Language, and Hearing Research*, *42*, 382–397.

Glennen, S. (2007). Predicting language outcomes for internationally adopted children. *Journal of Speech, Language, and Hearing*, *50*, 529–548.

Gnanadesikan, A. (2004). Markedness and faithfulness constraints in child phonology. In R. Kager, J. Pater, & W. Zonneveld (Eds.), *Constraints in phonological acquisition* (pp. 73–108). Cambridge: Cambridge University Press. Available (1995) on Rutgers Optimality Archive.

Goad, H., & Rose, Y. (2004). Input elaboration, head faithfulness and evidence for representation in the acquisition of left-edge clusters in West-Germanic. In R. Kager, J. Pater, & W. Zonneveld (Eds.), *Constraints in phonological acquisition* (pp. 109–157). Cambridge: Cambridge University Press.

Inkelas, S., & Rose, Y. (2007). Positional neutralization: A case study from child language. *Language*, *83*, 707–736.

Kehoe, M. (2015). When place does not fall into place: A case study of a child with diverse linguistic input. In Yavas, M. (Ed.), *Unusual productions in phonology: Universals and language specific considerations* (pp. 159–182). New York, NY: Psychology Press.

Keating, P., & Lahiri, A. (1993). Fronted velars, palatized velars, and palatals. *Phonetica*, *50*, 73–101.

Klatt, D. (1975). Voice onset time, frication, and aspiration in word-initial consonant clusters. *Journal of Speech and Hearing Research*, *18*, 686–706.

Lindblom, B., Diehl, R., Park, S.-H., & Salvi, G. (2011). Sound systems are shaped by their users. The recombination of phonetic substance. In G. N. Clements, & R. Ridouane (Eds.), *Where do phonological features come from? Cognitive, physical and developmental bases of distinctive speech categories* (pp. 68–97). Amsterdam: John Benjamins Publishing Company.

Levelt, C. (1994). *On the acquisition of place* (Doctoral dissertation). Holland Institute of Generative Linguistics, Leiden University.

Lleó, C., Prinz, M., El Mogharbel, C., & Maldonado, A. (1996). Early phonological acquisition of German and Spanish: A reinterpretation of the continuity issue within the principles and parameters model. In C. E. Johnson, & J. Gilbert (Eds.), *Children's language*. (Vol. 9, pp. 11–31). Mahwah, NJ: Lawrence Erlbaum Associates.

Macken, M. (1979). Developmental reorganization of phonology. *Lingua*, *49*, 11–49.

MacNeilage, P., & Davis, B. (2000). Origin of the internal structure of word forms. *Science*, *288*, 527–531.

Maratsos, M. (2000). More overregularizations after all: New data and discussion on Marcus, Pinker, Ullman, Hollander, Rosen and Xu. *Journal of Child Language*, *27*, 183–212.

Marcus, G., Pinker, S., Ullman, M., Hollander, M., Rosen, T., & Xu, F. (1992). Overregularisations in language acquisition. *Monographs of the Society for Research in Child Development*, *57*(4), 1–182.

Marshall, C., & Chiat, S. (2003). A foot domain account of prosodically conditioned substitutions. *Clinical Linguistics and Phonetics*, *17*, 645–657.

McAllister Byun, T. (2012). Positional velar fronting: An updated articulatory account. *Journal of Child Language*, *39*, 1043–1076.

McAllister Byun, T., & Inkelas, S. (2013). Child consonant harmony and phonologization of performance errors. *Working Papers from the 43rd Meeting of the North East Linguistic Society*, New York, NY.

McAllister Byun, T., Inkelas, S., & Rose, Y. (2013). The A-map model: Articulatory reliability in child-specific phonology. *UC Berkeley Phonology Lab Annual Report*, 60–109.

Menn, L. (1971). Phonotactic rules in beginning speech. *Lingua*, *26*, 225–251.

Menn, L. (1983). Development of articulatory, phonetic, and phonological capabilities. In B. Butterworth (Ed.), *Language production* (Vol. 2, pp. 3–49). London: Academic Press.

Menn, L., & Matthei, E. (1992). The 'two-lexicon' account of child phonology: Looking back, looking ahead. In C. Ferguson, L. Menn, & C. Stoel-Gammon (Eds.), *Phonological development: Models, research, implications* (pp. 211–247). Timonium, MD: York Press.

Menn, L., Schmidt, E., & Nicholas, B. (2014). Challenges to theories, charges to a model: The linked-attractor model of phonological development. In M. Vihman, & T. Keren-Portnoy (Eds.), *The emergence of phonology. Whole-word approaches and cross-linguistic evidence* (pp. 460–502). Cambridge: Cambridge University Press.

Munson, B., Beckman, M., & Edwards, J. (2011). Phonological representation in language acquisition: Climbing the ladder of abstraction. In A. Cohn, C. Fougeron, & M. Huffman (Eds.), *The Oxford handbook of laboratory phonology* (pp. 288–309). New York: Oxford University Press.

Munson, B., Edwards, J., & Beckman, M. (2005). Phonological knowledge in typical and atypical speech-sound development. *Topics in Language Disorders*, *25*, 190–206.

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Munthuli, A., Sirimujalin, P., Tantibundhit, C., Kosawit, K., & Onsuwan, C. (2013). A corpus-based study of phoneme distribution in Thai. *Paper presented at the 10th International Symposium on Natural Language Processing*, Phuket, Thailand.

Nicolaidis, K., Edwards, J., Beckman, M., & Tserdanelis, G. (2003). Acquisition of lingual obstruents in Greek. In G. Catsimali, E. Anagnostopoulou, A. Kalokerinos, & I. Kappa (Eds.), *Proceedings of the 6th International Conference on Greek Linguistics*. Rethymno: Linguistics Lab.

Ortmann, W. (1975). *Beispielwörter für deutsche Ausspracheübungen. 7591 hochfrequente Wortformen der Kaeding-Zählung, rechnersortiert nach Einzellauten, Lautverbindungen, Silbenzahl and Akzentposition* [Examples of words for German pronunciation drills. 7951 highly frequent word forms of the Kaeding count, computerized according to single sounds, sound combinations, numbers of syllables and stress position]. München: Goethe Institute.

Pater, J. (2002). Form and substance in phonological development. In I. Mikkelson, & C. Potts (Eds.), *WCFFL 21 Proceedings* (pp. 348–372). Somerville, MA: Cascadilla Press.

Pater, J., & Barlow, J. (2003). Constraint conflict in cluster reduction. *Journal of Child Language*, *30*, 487–526.

Pater, J., & Werle, A. (2003). Direction of assimilation in child consonant harmony. *The Canadian Journal of Linguistics*, *48*, 385–408.

Pierrehumbert, J. (2003). Phonetic diversity, statistical learning, and acquisition of phonology. *Language and Speech*, *46*, 115–154.

Plaut, D., & Kello, C. T. (1999). The emergence of phonology from the interplay of speech comprehension and production: A distributed connectionist approach. In B. MacWhinney (Ed.), *The emergence of language* (pp. 381–415). Mahwah, NJ: Erlbaum.

Pollock, K., & Price, J. (2005). Phonological skills of children adopted from China: Implications for assessment. *Seminars in Speech and Language*, *26*, 54–63.

Pollock, K. E., Price, J. R., & Fulmer, K. C. (2003). Speech-language acquisition in children adopted from China: A longitudinal investigation of two children. *Journal of Multilingual Communication Disorders*, *1*, 184–193.

Preston, J. & Seki, A. (2011). Identifying residual speech sound disorders in bilingual children: A Japanese-English case study. *American Journal of Speech-Language Pathology*, *20*, 73–85.

Rose, Y. (2000). *Headedness and prosodic licensing in the L1 acquisition of phonology* (Unpublished doctoral dissertation). McGill University.

Smith, N. (1973). *The acquisition of phonology: A case study*. Cambridge: Cambridge University Press.

Stampe, D. (1973). *A dissertation on natural phonology* (Unpublished doctoral dissertation). University of Chicago.

Stemberger, J., & Bernhardt, B. (2001). *U-shaped learning in language acquisition, and restrictions on error correction*. Rutgers Optimality Archive. Retrieved from: http://roa.rutgers.edu/files/472-1101/472-1101-STEMBERGER-0-0.PDF.

Stemberger, J. P., Bernhardt, B. H., & Johnson, C. E. (1999). *U-shaped learning in phonological development*. Rutgers Optimality Archives. Retrieved from: http://roa.rutgers.edu/files/471-1101/471-1101-STEMBERGER-0-0.PDF.

Stevens, K., Keyser, S., & Kawasaki, H. (1986). Toward a phonetic and phonological theory of redundant features. In J. S. Perkell, & D. H. Klatt (Eds.), *Invariance and variability in speech processes*. (pp. 426–449). Hillsdale, NJ: Lawrence Erlbaum Associates.

Stoel-Gammon, C. (1996). On the acquisition of velars in English. In B. Bernhardt, J. Gilbert, & D. Ingram (Eds.), *Proceedings of the UBC International Conference on Phonological Acquisition* (pp. 201–214). Somerville, MA: Cascadilla Press.

Velleman, S., & Vihman, M. (2002). Whole-word phonology and templates. *Language, Speech, & Hearing Services in Schools*, *33*, 9–23.

Vihman, M., & Croft, W. (2007). Phonological development: Toward a ''radical'' templatic phonology. *Linguistics*, *45*, 683–725.

Vihman, M. M., & Hochberg, J. G. (1986). Velars and final consonants in early words. In: J. A. Fishman, A. Tabouret-Keller, M. Clyne, B. Krishnamurti, & M. Abdulaziz (Eds.), *The Fergusonian impact* (pp. 37–49). Berlin: Mouton de Gruyter.

Vihman, M., & Keren-Portnoy, T. (2013). *The emergence of phonology. Whole-word approaches and cross-linguistic evidence*. Cambridge: Cambridge University Press.

Vihman, M., & Velleman, S. (2000). The construction of a first phonology. *Phonetica*, *57*, 255–266.

Waterson, N. (1971). Child phonology: A prosodic view. *Journal of Linguistics*, *7*, 179–211.

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Appendix A

A selection of velar-initial forms present at age 1;11 in diary entries. The entries are organised according to the ipa output form.

Word	ipa	age	word	age	ipa
carrot	gæ	1;11.03	cake	gek	1;11.14
carrot	gæ	1;11.07	egg	gek	1;11.07
strawberry	gæ	1;11.09	gate	gek	1;11.04
daddy	gæ.i	1;11.03	gate	gek	1;11.05
dog	gæg	1;11.20	shake	gek	1;11.16
dog	gæg	1;11.21	shake	gek	1;11.17
egg	gæg	1;11.10	shake	gek	1;11.18
egg	gæg	1;11.12	yoghurt	gek	1;11.17
egg	gæg	1;11.14	yoghurt	gek	1;11.18
gate	gæg	1;11.11	shake	gɛk	1;11.18
gate	gæg	1;11.22	gate	geʔ	1;11.04
yoghurt	gæg	1;11.08	biscuit	gɪ	1;11.05
bicycle	gægʌ	1;11.08	biscuit	gɪ	1;11.24
bicycle	gægʌ	1;11.09	cheese	gi	1;11.27
tiger	gaɪgʌ	1;11.14	key	gi	1;11.09
tiger	gaɪgʌ	1;11.15	key	gi	1;11.08
gate	geg	1;11.22	tea	giː	1;11.13
egg	gɛg	1;11.14	tea	giː	1;11.17
egg	gɛg	1;11.17	fish	giːç	1;11.08
cold	geɪ	1;11.07	juice	gɪç	1;11.00
cold	geɪ	1;11.09	keys	gɪç	1;11.02
egg	geɪ	1;11.07	shoes	gɪç	1;11.04
gate	geɪ	1;11.04	juice	gɪʃ	1;11.24

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Appendix B

A selection of velar-initial forms present at 2;02 in diary entries. The entries are organised according to the ipa output form.

word	ipa	age	word	ipa	age
cow	gaʊ	2;2.08	cold	goʊ	2;2.13
cow	gaʊ	2;2.16	cold	goʊ	2;2.19
cow	gaʊ	2;2.22	cold	goʊ	2;2.20
apricot	gɒʔ	2;2.11	go	goʊ	2;2.10
apricot	gɒʔ	2;2.12	goat	goʊ	2;2.25
stop	gɒʔ	2;2.10	goose	gu	2;2.12
truck	gɒʔ	2;2.27	goose	gu	2;2.22
truck	gɒʔ	2;2.30	juice	gu	2;2.22
strawberry	gɔ	2;2.09	juice	gu	2;2.23
stairs	gɛə	2;2.00	juice	gu	2;2.28
stairs	gɛə	2;2.01	pool	gu	2;2.10
egg	gɛg	2;2.16	pool	gu	2;2.15
egg	gɛg	2;2.30	pool	gu	2;2.23
dog	gek	2;2.23	school	gu	2;2.10
gate	gek	2;2.10	school	gu	2;2.12
gate	gek	2;2.21	squirrel	gu	2;2.08
jeep	gi	2;2.23	squirrel	gu	2;2.13
tea	gi	2;2.12	squirrel	gu.u	2;2.12
grapes	go	2;2.11	glasses	gʌ	2;2.21
carrot	go	2;2.11	glasses	gʌ	2;2.22
broken	goʊ	2;2.19	glasses	gʌ	2;2.30
carrot	goʊ	2;2.10	glasses	gʌʔ	2;2.00
coat	goʊ	2;2.15	glasses	gʌʔ	2;2.08
cold	goʊ	2;2.12	truck	gʌʔ	2;2.25

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