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Development of phonetic complexity in Arabic, Berber, English and French

(children's productions, targets, Child Directed Speech, and 50 randomly selected words in the adult language)

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**Abstract**

The goal of this study is to provide crosslinguistic data on the acquisition of phonetic complexity among children acquiring four different languages: Tunisian Arabic, Berber, English, and French. Using an adaptation of Jakielski's (2000) Index of Phonetic Complexity (IPC), we carried out an analysis to assess phonetic complexity of children's early vocabulary in the four languages. Four different samples from each language were analyzed: 50 words selected from an adult dictionary of each language, 50 words from child directed speech, 50 words targeted by the child, and the child's actual pronunciations of those 50 words. Globally, we hypothesized that children's early productions would be shaped by universal articulatory constraints, but also by the language they are exposed to, depending on its phonological complexity. Our findings show that Arabic and Berber display higher degrees of complexity compared to English and French, and that children acquiring Arabic and Berber target and produce more complex words than children learning English and French.

Children typically produce their first words around 12 months of age. However, the full mastery of an adult-like sound system is not achieved before 8 (Sander, 1972) or even 10-12 years of age (Smith & McLean-Muse, 1986). In English for instance, some phonemes such as /s/ or consonant clusters such as /spl/ are not acquired before 7 and 9 years of age (Smit, Hand, Freilinger, Bernthal & Bird, 1991). This extended period required for the mastery of the speech sound system of the adult language is due to the fact that young children are neither endowed initially with an adult-like vocal tract configuration nor with the neuromuscular control for producing the range of sounds of their ambient language (Kent & Murray, 1982); Green, Moore, & Reilly, 2002; Stoel-Gammon & Sosa, 2007). These anatomical and neurophysiological constraints result in a restriction on children's early phonetic inventories (Green, Nip, Maassen, & Van Lieshout, 2010; Nip, Green, & Marx, 2009). Children's phonetic inventory is initially composed of sounds produced primarily by the jaw (MacNeilage, Davis, Kinney, & Matyear, 2000), on which they have a better muscle control compared to the motion of lips and tongue movements (Green et al., 2002). As a consequence of these biological universal constraints, children acquiring different languages show a similar restricted inventory of sounds (Locke, 1983, 1995). Indeed, babbling and first-word productions demonstrate universal patterns: children show a preference for labials and coronals, stops, nasals and glides, open syllables, short utterances, few consonant clusters (and if any, they tend to be homorganic), and more reduplication than variegation (MacNeilage, Davis, Kinney, & Matyear, 1999; Oller, Eilers, Steffens, Lynch, & Urbano, 1994; Vihman, Macken, Miller, Simmons, & Miller, 1985). Furthermore, these preferences have been shown to influence the words that children select to produce. Thus, the inventory of children's early vocabulary is not composed of randomly selected words. Rather, it has been suggested that children select words with phonetic characteristics that are already present in their own phonological systems (Ferguson & Farwell, 1975; Schwartz, Leonard, Loeb, & Swanson, 1987; Vihman et al., 1985). Other studies on lexical selectivity have shown that children attempt more complex words targets according to age (Dobrich & Scarborough, 1992). An Index of Phonetic Complexity (henceforth IPC) based on the phonetic regularities observed in the babbling and the

first-word period, was proposed to assess children's phonetic development (Jakielski, 2002; Jakielski, 2000; Jakielski, Maytasse, & Doyle, 2006). The IPC has proven to be a valuable tool for different purposes such as assessing phonological skills in toddlers (Morris, 2009), comparing speech acquisition in bilingual vs. monolingual children (Gildersleeve-Neumann & Wright, 2010), or exploring the relationships between phonetic complexity and stuttering (Howell, 2006, 2007). The IPC, which considers productions composed of less preferred segments and segment associations as more complex, permits one to measure the development of phonetic complexity in both targeted and produced words by children. Ward (2001) documented a lexical selectivity bias in children aged 16 to 24 months through the phonetic complexity of targeted words. In addition, it was shown that IPC scores at 12 months predicted speech and language skills at 18 months (Furey, 2003). Biomechanical constraints of the production system (MacNeilage & Davis, 1990) and lexical selectivity are both universal tendencies.

Crosslinguistic studies hence provide support for a strong determination of early phonetic inventories by biological constraints. However, they do not rule out an influence of the ambient language. Languages differ to a large extent in terms of their phonological inventories and phonotactics, making the input more or less difficult to acquire for children. Crosslinguistic analysis of diverse languages enables us to distinguish between potentially universal and language-specific patterns (Stoel Gammon, 2012). In fact, previous analyses have shown that segmental development, namely word shapes and CV co-occurrences, are influenced by input frequency in the ambient language (Saffran, Newport, Aslin, Tunick, & Barrueco, 1997), as well as by the functional load of segments in the language, i.e. how much use a language makes of its available contrasts (Stokes & Surendran, 2005). As languages vary on those parameters, previous findings suggest that some languages may be acquired at a faster rate than others. For instance, So and Dodd (1995) showed that Cantonese children acquire phonology at a faster rate than English-speaking children as they master the contrastive use of tones and vowels by two years and that few phonological errors occur after age four. Similarly, Caselli et al. (1995) observed that Italian children were slower in vocabulary

acquisition compared to English-speaking children: Italian children lag behind the English group in total vocabulary size at most ages between 8 and 16 months. Another crosslinguistic study, comparing L1 vocabulary growth at 16-30 months of age, found that Galician children produce fewer words than Basque, French and Mexican-Spanish-learning children (Pérez-Pereira et al., 2007). In brief, phonetic development seems to be strongly influenced by universal biological constraints but also by the characteristics of the ambient language.

However, considering the ambient language, one must keep in mind that the type of language to which children are exposed (referred to as Child Directed Speech, henceforth CDS) differs in several important ways from the adult language. When addressing children, caregivers adjust their language by simplifying and clarifying the linguistic material (Ferguson, 1964) in order to engage children's attention and facilitate language acquisition (Snow, 1977; Werker et al., 2007)<sup>1</sup>. CDS is characterized by simplified syntax, shorter utterances, restricted vocabulary, repetitions, phonetic modifications (Kuhl, 2000) increased variations in fundamental frequency and longer pauses (Albin & Echols, 1996; Andruski & Kuhl, 1996; Ferguson, 1977; Papoušek, Papoušek, & Symmes, 1991). Moreover, this specific register used by parents to promote infants' language learning has been shown to be almost universal (Ferguson, 1964; Kitamura, Thanavishuth, Burnham, & Luksaneeyanawin, 2001; Kuhl et al., 1997; Monnot, 1999).

The current study aims at examining the phonetic complexity of words produced by children acquiring four different languages: Arabic (Tunisian vernacular), Berber (Tashlhiyt variety), English (American) and French. These languages show different phonetic and phonological characteristics of interest for early language development, such as word length, word complexity (syllable types, consonant clusters) and phonemic inventory diversity. For example, the Arabic lexicon, which is largely derived from basic consonantal roots, includes many polysyllabic words. In terms of syllable

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<sup>1</sup> However, some studies suggest that CDS is not necessary facilitating as it introduces more variability in input (Benders, 2013), Dille et al, 2014), Dodane and Al-Tamimi, 2007), and Sundberg and Lacerda, 1999)

types, French shows a strong preference for open syllables (76%), English exhibits mostly closed syllables (60%) (Delattre, 1965) and Arabic displays 49,92% of closed vs. 50,08% of open syllables (Hamdi, Ghazali & Barkat-Defradas, 2005). These languages also differ in consonant cluster<sup>2</sup> requirements: in Berber, clusters are only possible in word initial position and in Arabic, they are hardly found in word final position. In French both positions are permitted but a bias towards word initial position is attested. Phonemic inventories are also quite diverse. Indeed, when computing the consonant/vowel ratio, two groups emerge: Berber and Arabic are highly consonantal languages (Ridouane & Fougeron, 2011; Hamdi, Ghazali & Barkat-Defradas, 2002) whereas vowels are more frequent than consonants in French and, to a lesser extent, in English, Berber and Arabic display a significant proportion of fricatives as compared to English and French. Moreover, the phonological inventories of Arabic and Berber put forward a large number of back consonants (i.e. uvulars, pharyngeals and glottals) that are known to be acquired rather late (Omar & Nydell, 2007). In sum, this study aims to provide informative contribution comparing the phonetic development in four languages including Berber and Arabic Studies, languages in which studies of phonetic development are rare.

We elaborated six interrelated hypotheses for our crosslinguistic study:

H1. The different languages should display different degrees of complexity. The dictionary words in Berber and Arabic, which are highly consonantal languages, should have higher complexity scores compared to the more vocalic English and French.

The following IPC parameters are of special interest for our cross linguistic analysis:

- a. *Place of articulation*: More complexity expected in Arabic, due to the many back (i.e. dorsal) consonants, and in French, due to the frequent /ʁ/ (Gromer & Weiss, 1990).
- b. *Clusters*: More complexity expected in Berber and Arabic, in which clusters are more frequent.

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<sup>2</sup> In the present study, the term 'cluster' refers to consonant sequences that occur both within and across syllables.

- c. *Complex articulation*<sup>3</sup> should contribute to complexity in Berber and Arabic.
- d. *Word length*: More complexity on this parameter is expected in Arabic, which shows many polysyllabic words due to the insertion of vocalic patterns and affixes into the root for lexical derivation.
- e. *Final Consonant*: Less complexity is expected in French, due to its preference for open syllables.
- f. *Variation (Place)*: More variation is expected in Arabic, due to the non-homorganic consonantal rule, which constrains the root-skeleton.
- g. *Variation (Manner)*: in Arabic the non-homorganic consonantal rule which constrains the root-skeleton leads to expect this language will attest more variation than the others.
- h. *Rhoticity*<sup>4</sup> will contribute to complexity in American English only.

H2. In each language, we expect the words that mothers use when addressing their children (CDS) to be less complex than the words used in the “adult” language (i.e. represented here through dictionary words).

H3. According to the lexical selectivity hypothesis, children should attempt words (targets) that are less complex to produce than many other words in the adult language (Dictionary).

H4. Given the biomechanical constraint hypothesis, we expect children’s actual productions to be less complex than the targets they attempt.

H5. However, we expect an effect of the ambient language: children acquiring a phonologically more complex language should target and produce more complex forms. Hence, we expect Arabic- and

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<sup>3</sup> When consonant articulation occurs at the same time as another articulation is being made at a different place in the vocal tract, the consonant is said to form a complex articulation.

<sup>4</sup> Rhoticity in English (the pronunciation of the historical rhotic consonant /r/) is one of the most prominent features distinguishing varieties of English. Here we studied the acquisition of American English, which belongs to the rhotic varieties.

Berber-speaking children's IPC scores to be higher than those observed for English- and French-speaking children.

H6. In sum, if a complex parameter is frequent in the ambient language, children should use it or attempt it more often than if it is not present in the ambient language.

Table 1. recapitulates the different hypotheses

H1	Dictionary	Globally, Berber and Arabic should show higher complexity because they are highly consonantal languages  <ul style="list-style-type: none"> <li>a. More complexity in Arabic and French for place of articulation</li> <li>b. More complexity in Berber and Arabic for clusters</li> <li>c. More complexity in Berber and Arabic for complex articulations</li> <li>d. More complexity in Arabic for word length</li> <li>e. Less complexity in French for final consonant</li> <li>f. More complexity in Arabic for variegation (Place)</li> <li>g. More complexity in Arabic for variegation (Manner)</li> <li>h. More complexity in English for Rhoticity</li> </ul>
H2	CDS	Less complexity in CDS compared to Dictionary
H3	Targets	Less complexity in Targets compared to Dictionary
H4	Actual	Less complexity in Actual compared to targets
H5	Targets & Actual	Targets and Actual in Berber and Arabic should be more complex than in French and English
H6	Targets & Actual	Targets and Actual should reflect the ambient language

Table 1. Predictions for Dictionary, CDS, Target and Actual words in the four different languages

## Method

### *Participants*

Sixteen children from four linguistic communities: Arabic (Tunisian vernacular), Berber (Tashlhiyt variety), American English and French were included in the study. The parents did not report any concerns about the children's language development, hearing status, or general development. The Arabic and Berber data are part of The PREMs Project<sup>5</sup> (Principal Investigator:

<sup>5</sup> <http://www.ddl.ish-lyon.cnrs.fr/projets/prems/index.asp?Langue=EN&Page=Presentation>



Sophie Kern). The French data are part of the French Kern corpus (Kern, Davis, & Zink, 2009), and the English data comes from the Providence Corpus (Demuth, Culbertson, & Alter, 2006).

Table 2. Participants' demographic information

Language	n	Sex	Age Range (months;days)
Arabic	4	2M/2F	8;09 – 24;06
Berber	4	2M/2F	7;21 – 18;12
English	4	2M/2F	11;27 – 20;05
French	4	3M/1F	9;09 – 22;22

### *Procedures*

The children were recorded in natural settings at home in interaction with their mother. The recording sessions took place twice a month from the onset of first word production until a few months after the lexical spurt. As Jakielski (2000) recommend to use 50 words to compute the IPC, four lists of 50 words were analyzed for each language: (i) the first 50 words actually produced by each child (hereafter referred to as Actual), (ii) the targets corresponding to these first 50 words, (iii) 50 words randomly extracted from CDS produced by each mother and (iv) 50 words from the adult language randomly selected from dictionaries (See APPENDIX 1 to 4 for an illustration). For each list, an adaptation of the Index of Phonetic Complexity (Jakielski, 2000) was computed (see Table 2). The IPC is based on the phonetic regularities observed during the babbling and the first- words periods. Vocal outputs that are composed of the less preferred segments (or segment associations) in early development are rated as more complex in the IPC. This allows measuring the development of phonetic complexity in both word targets and words actually produced by the children. The IPC consists of eight parameters: consonants by place and manner, vowels by class, word shape and word length (in syllable type and number), singleton consonants by place variegation, contiguous consonants and cluster by type (i.e. homo- vs. hetero-organic). However, as this measure was initially designed to capture the phonetic complexity of English, it must be adapted for crosslinguistic

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comparison in order to account for other determining features of phonetic complexity exhibited in the 4 languages under examination..

#### *Data analysis*

In order to take into consideration the typological peculiarities of our linguistic sample, we first had to integrate into the original IPC model a new parameter relative to consonantal articulation. We called it *consonant by articulation class* in reference to Jakielski's first two parameters (i.e. Consonant by place and manner class and Consonant by place class). This new parameter was created in order to discriminate between simple vs. complex articulations (see n.1). In Arabic and Berber, two types of secondary (or complex) articulation are phonemically attested: pharyngealization (both in Arabic and Berber) and labialization (in Berber only). Basically, during the realization of a pharyngealized consonant (for example [t<sup>ħ</sup>, d<sup>ħ</sup>, ð<sup>ħ</sup>]), the pharynx is constricted and the root of the tongue is retracted. Such consonants, which require a skillful control of the back of the vocal tract (Barkat-Defradas & Embarki, 2009), are acquired very late in development (Omar, 1973). We therefore added 1 point for such complex segments, that are typical of Afro-asiatic languages (Hetzron, 1997). The same rationale was applied for labialization, which consists of adding lip rounding to the principal articulation. We considered radical consonants (i.e. pharyngeals) as particularly complex in terms of the consonant by place class, since they are, on the one hand, even more posterior than dorsals (that are themselves considered as complex in the original IPC model) and, on the other hand, since the mastery of production for these consonants is reported to occur rather late (Amrayeh, 1994; Amrayeh & Dyson, 1998). Lastly, considering the fact that consonantal clusters are frequent in the Western varieties of colloquial Arabic, under the influence of Berber, and can thus be very long (up to seven contiguous consonants), we decided to add up to 2 points when more than two consonantal segments are contiguous. Table 2 recapitulates the different parameters included in our IPC adaptation.

Table 3. Adapted Index of Phonetic Complexity Scoring Scheme (based on Jakielski, 2000)

Parameter		No points for:	One point each for:	Maximum possible points:
1	Consonant by articulation class	Simple	Complex	1 point each
2	Consonant by place class	Labials, Coronals, Glottals	Dorsals Pharyngeals	1 point each
3	Consonant by manner class	Stops, Nasals, Glides	Fricatives, Affricates, Liquids	1 point each
4	Vowel by class	Monophthongs Diphthongs	Rhotics	1 point each
5	Word shape	Word ending in a vowel	Word ending in a consonant	1 point each
6	Word length in syllables	Monosyllabic and disyllabic words	Tri+ syllabic words	1 point each
7	Consonants by place variegation	Reduplicated	Variegated	1 point each
8	Consonants by manner variegation	Reduplicated	Variegated	1 point each
9	Contiguous consonants	Words without a cluster	Words with consonant clusters	CC = 1 point > 2C = 2 points
10	Cluster by type	Homorganic clusters	Heterorganic clusters	1 point each

Our purpose here is to compare the total phonetic complexity of children's production cross-linguistically, as well as the contribution of each of the parameters accounting for it. Translating each word into a phonetic sequence in which each element is described (as a vowel, a consonant, or a secondary articulation, with consonants being identified in terms of place and mode of articulation), we can identify and compute each parameter, and the IPC as their total sum. Table 3 provides an example of IPC scoring for four dictionary words in each language.

**Commenté [DC1]:**

It = ? The production or the complexity?

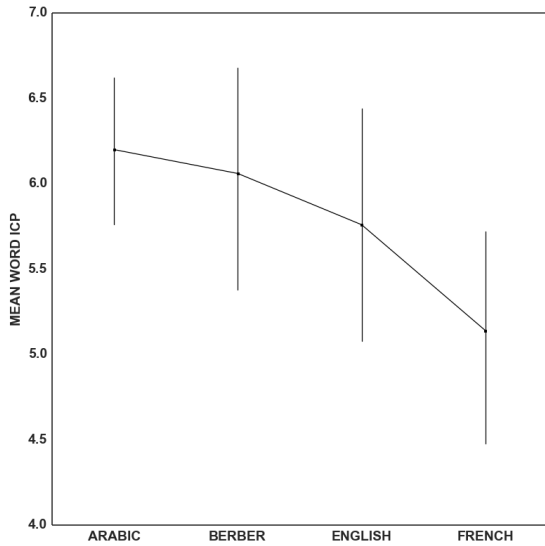
Table 3. Index of Phonetic Complexity Scoring for 4 words in each language

Language	Item	IPA Transcription	Consonant by articulation class	Consonant by place class	Consonant by manner class	Vowel by class	Word shape class	Word length in syllables	Consonants by place	Consonants by manner	Contiguous consonants	Cluster by type	Total IPC
French	fork	fɔʁk	0	1	1	1	0	0	1	1	1	1	7
English	mixture	mɪksʃɜː	0	1	3	1	1	0	1	1	2	1	11
Berber	girl	tafruxt	0	1	2	0	1	1	1	1	2	2	11
Arabic	he fell	sqatˤ	1	1	1	0	1	0	1	1	1	1	8

### Results

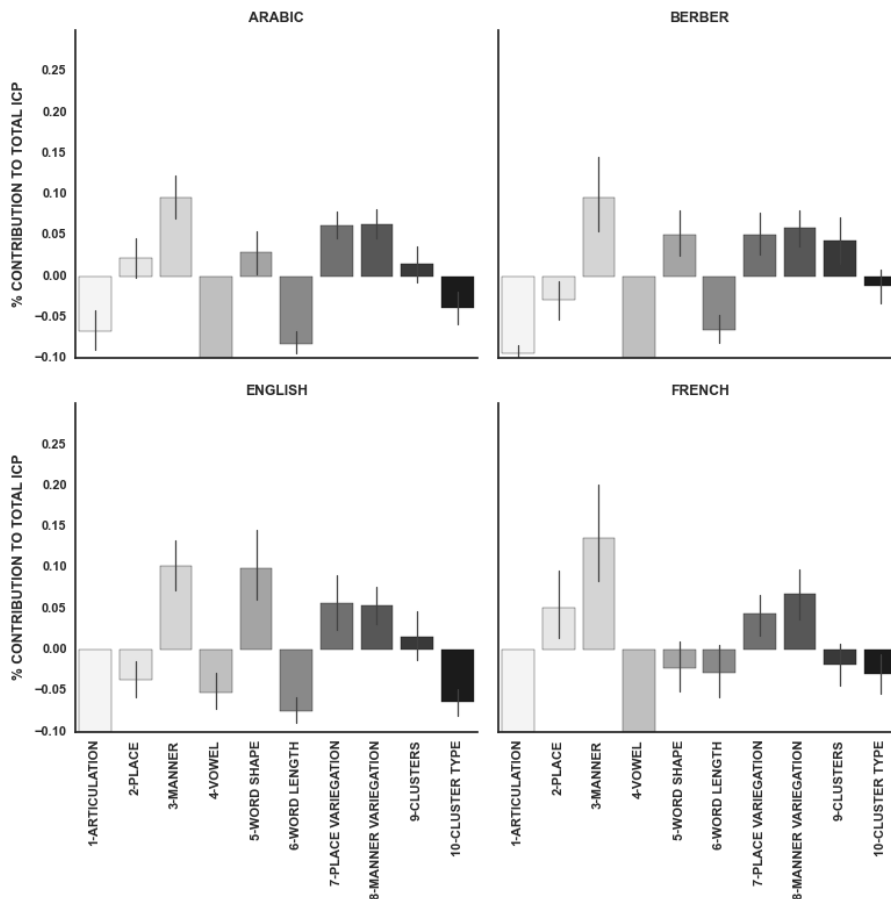
The dictionary sample is a window on the expected mean word phonetic complexity of the languages under study. The sample being rather small, we also computed the confidence interval of the mean with a 5% type I error by bootstrapping the sample to estimate the interval of values for the mean phonetic complexity for the dictionary as a whole. Figure 1 shows that the 4 languages have indeed different mean word IPCs, with a decreasing decline from Arabic > Berber > English > French. As expected given the sample size the 95% confidence intervals are large, but they still support this complexity decline.

*Figure 1. Mean word IPC showing a decreasing decline from Arabic > Berber > English > French. Vertical bars show the 95% confidence interval for the means for the dictionary as a whole.*



Since the IPC is computed as the sum of 10 phonetic parameters, depending on the language, this overall complexity can be attributed to different parameters. Figure 2 shows the individual contribution of each parameter to the overall IPC for the dictionary sample. Contributions are computed as the difference between the proportion of the overall complexity (that is, the IPC the parameter actually accounts for), and what would be expected from a uniform contribution of all parameters. Since there are ten of those, the uniform contribution null hypothesis would set each parameter's contribution at 10%. Specific parameter contributions will thus vary between -0,1-0,9.

Figure 2: Specific parameter contribution with respect to the uniform contribution null hypothesis. Values range from -0,1 to 0,9 for each of the 10 parameters composing the IPC.

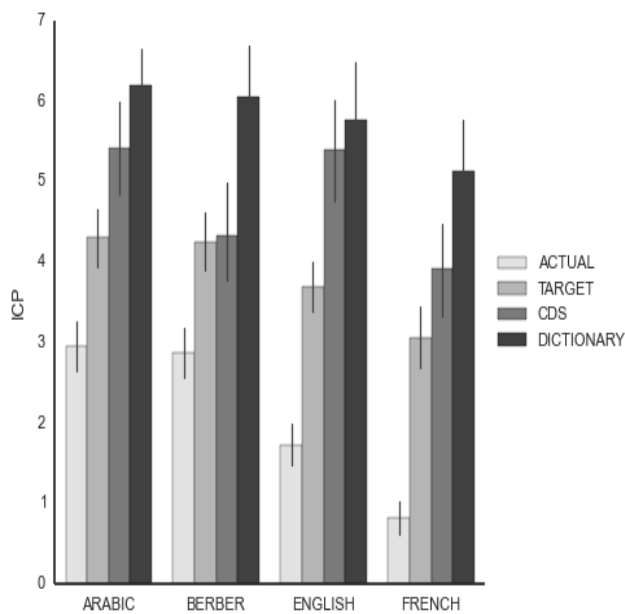


As expected, Arabic and French display a greater contribution of place of articulation, and French exhibits less complexity than all three other languages in word shape due to the preferential open final syllables. However, contrary to our assumptions about consonantal clusters, only Berber displays these as significant contributors to overall phonetic complexity, whereas Arabic and English scale the same, in only slight excess of the 10 % contribution baseline, while French is slightly in deficit for this specific complexity component. The number of syllables does not show differences across languages either. Having distinguished monophthongs and diphthongs in our data description, word length is computed as the number of vowels, assumed to act as syllabic nuclei (except for

Berber, where, null syllabic nuclei were also identified, using Dell and Elmedlaoui's (2012) syllabification algorithm). For this parameter, all four languages exhibited less than the 10% contribution anticipated if all of the parameters make an equal contribution

Complexity measures on the dictionary samples provide the baseline against which children's production and lexical selectivity, but also Child Directed Speech (CDS) can be analyzed. Figure 3 shows the mean IPC values for the different lists in the various languages.

Figure 3. Mean word IPC and 95M confidence intervals for the Dictionary/adult language, CDS, actual child production and target for Arabic, Berber, English and French

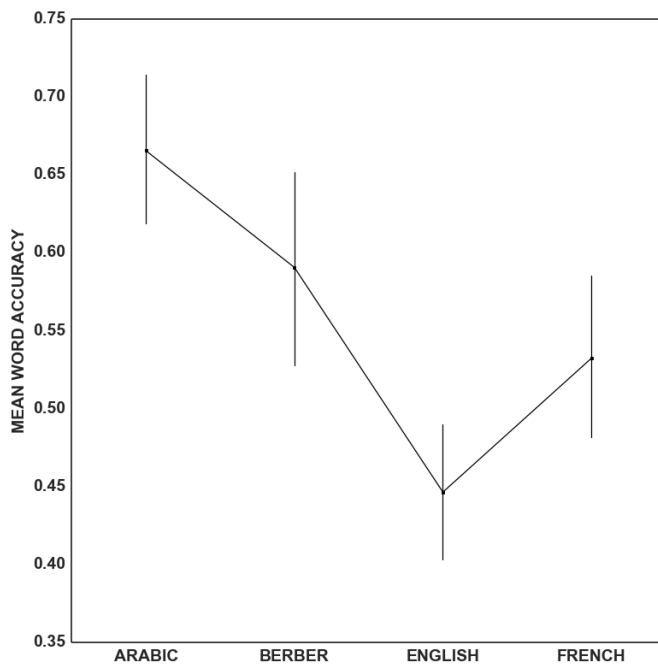


Although the general tendency is that of a decreasing complexity decline from Dictionary/adult language to CDS to Target to Actual child productions, major differences exist between languages. For instance, CDS in Arabic and English shows the highest complexity compared to the dictionary sample, but Berber, while showing a lower mean IPC for CDS, also exhibits comparable levels of phonetic complexity between CDS and the targets selected by children for production. Moreover, Arabic and Berber show similar Target complexity and an Actual-to-Target complexity differential.

But while English and French display lower Target complexity, they also display larger Actual-to-Target complexity differentials, with lower achieved complexity in children's actual production, especially for French.

However, these Actual-to-Target complexity differentials do not necessary translate into Actual-to-Target accuracy. Given that the individual parameters focus primarily on consonants, we computed the Actual-to-Target accuracy in the realization of consonants for the 4 languages (Figure 4).

Figure 4. Mean Actual-to-Target accuracy in consonant production for Arabic, Berber, English and French. Vertical bars display the 95% confidence interval



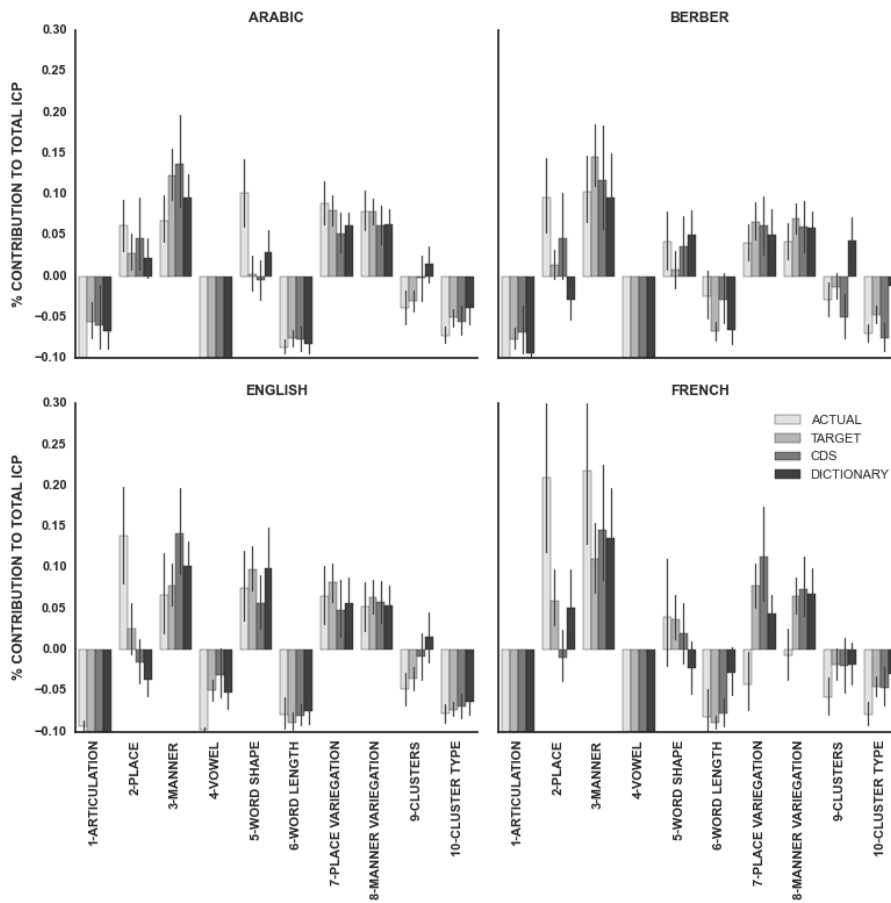
Despite the larger overall Actual-to-Target complexity differential, French children achieve better accuracy, while English children achieve the worst accuracy scores. More importantly though, and despite larger Target complexity, Arabic and Berber children achieve the highest accuracy scores. These results suggest that typological characteristics of the language indeed play a role in the



acquisition process and call for a detailed examination of the individual contribution of each parameter to the overall IPC score of children's actual production, as compared to the language (dictionary) parameter contribution landscape.

Figure 5 shows that not all parameters contribute in the same way to the mean IPC of the child's actual production, depending on the language, with respect to how they contribute in the other samples, and especially, the Dictionary.

Figure 5. Mean parameter contribution by sample (Dictionary, CDS, Target and Actual) and by language (Arabic, Berber, English, French)



For instance, Arabic Actual shows an enhanced tendency for children to produce closed final syllables, irrespective of what is displayed in either the Target or the CDS, thus mirroring more of the dictionary tendency than these two latter samples do. On the other hand, clusters, which contribute to different extents to the IPC of Berber, Arabic and English (dictionary), do not in any of the other samples, suggesting that both CDS and Targets selected by the children tend to misrepresent clusters during this phase of acquisition, thereby reducing the complexity of their production.

A tendency that appears common to all languages, however, is the large contribution of manner of articulation in CDS with respect to Dictionary which is reflected for Arabic and Berber in the Target selected by children for production, while French, where this is not the case, displays an enhanced contribution of manner in the Actual production of the children. Place of articulation also displays a trend common to all languages, with enhanced contributions in Actual production, irrespective of their contribution in the other samples. However, whereas place and manner contribute the most in French to actual production, their variegation contributes the least, contrary to all three other languages.

## **Discussion**

Using an adaptation of Jakielski's (2000) Index of Phonetic Complexity (IPC), we carried out an analysis to assess phonetic complexity of children's early vocabulary in four languages: Arabic, Berber, English and French. Globally, we hypothesized that children's early productions would be shaped by universal articulatory constraints, but also by the language they are exposed to, depending on its phonological complexity.

Considering language-specific aspects, we observed that as hypothesized, some languages of our samples, namely Arabic and Berber, show higher IPC scores (complexity) than English and especially French (H1). The different IPC parameters contribute differently to complexity. Manner and place of articulation contribute significantly to complexity in all four languages, and not only in Arabic and French as predicted by H1a. In other words, children in these languages do not

systematically avoid fricatives or liquids, which are frequent in the ambient language. Similarly for Place of articulation, although children prefer labials and coronals to dorsals in the early period of production, they are able to produce posterior consonants (like dorsals and/or pharyngeals) when required by the ambient language (i.e. typically in Arabic and Berber where they are rather frequent). However, some parameters clearly differ across languages. Clusters are significant contributors to phonetic complexity in Berber, and, to a lesser extent, in Arabic and English (H1b.). As for final consonant, French is confirmed to be easier than the other languages, as expected as predicted by H1e. In contrast, some other parameters that were expected to play a role in complexity scores (H1 c., d., f. g. h.), in particular word length and complex articulation (H1 c. and d.), do not seem to contribute significantly to the global complexity score. In sum, we found a decreasing complexity: Berber < Arabic < English and we hypothesized that these differences in phonetic complexity in the adult languages would influence phonetic development in children acquiring these languages. An obvious assumption is that a phonetically complex language such as Berber would take longer to acquire, and would be more challenging to reach accuracy. Nevertheless, our findings suggest that this is not the case. Although our sample is too small to draw solid conclusions, our data indicate that Berber infants are not delayed in the timing of first words production, given that first words are produced as early as 7 months of age in one of our subjects. Similarly, children acquiring Arabic and Berber show the best accuracy scores compared to the *a priori* easier languages, English and French.

Turning to universal aspects of phonetic development (H2, H3 & H4), our findings are in line with previous work underlying the universal tendency for caregivers to modify their speech when addressing children (H2) (Ferguson, 1964, 1978; Kitamura et al., 2001; Kuhl et al., 1997; Monnot, 1999). Some studies had investigated motherese in Arabic and Berber and cultural differences have been documented in the range of modifications of CDS (Ferguson, 1956, Gumperz & Hymes, 1964, Bynon, 1968, Omar, 1973, Haggan, 2002, Al-Shatty, 2003 and Ferguson, 2004) and the fact that caregivers use a special register to address young children remains indisputable cross-linguistically. The vast majority of CDS studies are focused on semantic, syntactic or prosodic characteristics. Fewer

address the phonetic characteristics of CDS, but Kuhl et al. (1997) for instance showed that mothers in different languages (American English, Russian and Swedish) produce vowels that are acoustically more extreme when addressing their young children, thus providing information about the sound system of the infant's native language in an exaggerated form. CDS thus promotes language learning by separating sounds into contrasting categories. The present study did not focus on potential modifications of segments in CDS, but our findings show that caregivers use words that are less complex than in the adult language. This suggests the operation of lexical selectivity in CDS just as lexical selectivity is hypothesized in children's productions. Thus, one can assume that caregivers reduce the gap between children's restricted articulatory capacities and the necessary capacities to produce phonetically complex words of the adult language.

As predicted by H3, children also seem to select the words they produce or attempt to produce depending on their phonetic complexity (Ferguson & Farwell, 1975; Schwartz et al., 1987; Vihman et al., 1985). Indeed, in the four languages under study, we observed that words attempted (Target) or produced (Actual) by children have lower complexity scores than CDS or adult words (H3 and H4). Finally, the fact that in all the four languages, actual productions show reduced complexity compared to attempted (and obviously CDS or adult) words illustrates the fact that during this early period of first word productions, children's early phonetic inventories are strongly limited by anatomical and neurophysiological constraints (Green et al., 2002, 2010; MacNeilage et al., 2000; Stoel-Gammon & Sosa, 2007).

Looking at the detailed parameters that children either produce or avoid depending on the language, our findings show a mixed influence of language specificity and neurophysiological constraints. Globally, children's actual productions tend to reflect the tendencies displayed in adult productions (H5 and H6). The fact that children's use of closed syllables (Actual) in Arabic mirrors the adult language (dictionary words) but not targets nor CDS remains to be explained. However, clusters, which are strong contributors of complexity in Berber (and to a lesser extent in Arabic and English), seem to be avoided by children acquiring these languages. This finding is not surprising, as

consonant clusters appear to be especially challenging for children. Indeed, they are not produced before age 2 and their acquisition is one of the longest-lasting aspects of speech acquisition in normally developing children (McLeod, Van Doorn, & Reed, 2001). In sum, the different IPC parameters are not equally difficult for children to produce: while some (such as producing fricatives or dorsals) can be overcome by children even at a very early age in spite of biological constraints, others (such as consonant clusters) need more time to master.

APPENDIX 1. Examples of ARABIC data

	Actual IPA	Target IPA	Translation	CDS IPA	Translation	Dictionary IPA	Translation
1	mɛm:æ	mama	mommy	tˈɑ:h	to fall	ʃəjb	medical
2	itæjj	tˈɑj	Peek a boo	ʔi:zæ	he comes	ħuku:m	monopole
3	pæ	papa	daddy	tˈɑtˈɑ	tata	ħi:la	ruse
4	dæ	la:	no	ʔaħħæ:	ouch !	farlæχla	fieldmouse
5	ʔi	ʔej	yes	kiχχæ	eew !	msisa	bracelet
6	tæ:h	tˈɑ:h	it fell	qu:l	tell	ħəwəl	to try
7	bæj	bah	ok	næħħi:	remove	qa:l	tell
8	æm	mam:i	mum	ʔahajjæ:	here it is	mraħħəm	marble
9	bæh	baħ	It disappeared	wi:ni	where is it ?	zra:ʕi:	agricultural
10	ʔejzi	ʔi:za	come here !	ju:	what is it ?	mdˈəl	straw
11	bɛj	baj baj	bye-bye	daddu:ʃ	walk	mudˈif	stewart
12	tɛd:	ʃi:d:	hold !	jezzi	stop !	butˈɑ-in	ventricle
13	ʔæh:	ʔaħ:	ouch !	træh	show me !	dəħʃ	baby donkey
14	hup	ħutˈ:	put down !	ba:h	gone (nothing !)	wəsx	fouling
15	zəzæ	dʒa:zɑ	chicken	alo	hello	səqqa:t	gourmet
16	ħibɛʃ	mænhibɛʃ	I don't want	ʔaʕmil	do	kursi	saddle
17	ktib	ʔiktibli	write (to me)	hæ:t	put	ʕrəq	sweat
18	ka	kask	your helmet	læ:	no	ħadd	fence
19	tæ:ʕi	mtæ:ʕi	mine	ʔej	go !	riija:ga	bib
20	bebe	bebe	baby	χu:	brother	qəm	estimate
21	kak:æ	kaka	poo	kaka	poo	məstəyəl	profiteer
22	tat:a	batˈ:ɑ	canard	ji:mʃi	he goes	bəlyɑ	oriental slipper
23	tata	tˈɑtˈɑ	beat !	sˈɑhi:t	thank you	ʃkara	bag
24	ħutæ:	ħuta:	fish	ʔaqɛf	up !	bəqra:z	tea pot
25	bab	dub	ours	bæʕ	bèè (bleat noise)	ħe:l	weather
26	nɑ:n	ħsˈɑ:n	horse	ʒi:b	bring	sˈəffa	clarify
27	næhnæ	lihnæ	here	hæðɪka	this one	məlle:h	seller
28	mæ mæ	mæ:	water	ħutˈ	place	da-ijəb	melting
29	kæk	qird	monkey	ʔistannæ	wait	qəfza	jump
30	tæ:h	muftæ:h	key	ʔælʕib	play	da:r	home
31	taw taw	taw:a	now	ʃʕær	hair	ma:t	perish
32	dæb:u:sæ	dab:uzæ	bottle	mtaʕ	his	rʒaʕ	take back
33	ʃbi:k	ʃbi:k	what happens to you ?	sˈɑfiq	applaud !	tˈbi:b	doctor
34	ʔuxdæn	ʔuxzur	watch !	ʃnuwæ	what	fəħħəm	explain
35	kas:ar	tkas:ir	you broke	bismilah	bless you	ħdər	argue
36	bæz	xubz	bread	ʕaqu:la	nice	sqətˈ	fall
37	fasu:	ʕasˈfu:ra	bird	ʔaʕtˈi	give	ʕri:b	unheard-of
38	tax:a	kix:a	eew !	matmissij	don't touch	bətˈtˈəl	idle
39	ʕam	ʕam:i	my uncle	ʔuqʕud	sit down !	mʕalləm	expert
40	ku:ra	ku:ra	ball	ʕa:di	there	səndu:q	coffin
41	di	ħaði	this one	ʃbi:k	what happens	ħənd	magnet
42	tiz:a	ħizha	lift it up	nrakablik	I'll put it together	qəmr	moon
43	laħda	laħðˈɑ	one minute please	tkallim	talk	qəsma	part
44	kuja	xuja	my brother	nχabbi:h	I hide	stəχbər	be informed
45	ku:	qu:m	get up !	ħsˈɑ:n	horse	zəʕʕada	spatula

46	nan:i	nan:i	sleep !	ʕasˈfu:ra	bird	aθat	furniture
47	ʔahu	ʔahuwa	here it is !	matibki:ʃ	hurry up (don't cry)	mædwəd	nursery
48	tat:	ʃtat:ti	(he) beats	kifæ:ʃ	how ?	rqi:q	menu
49	ræjæ	mræjæ	mirror	nhizz	bring	dərbuka	drum
50	stan:æ	ʔistana	wait !	su:q	market	ʕilaqa	Coat rack

APPENDIX 2. Examples of BERBER data

	Actual IPA	Target IPA	Translation	CDS IPA	Translation	Dictionary IPA	Translation
1	b:ab:a	bajbaj	goodbye	d:aħ	hit (have a pain)	ara	give
2	baba:	baba	dad	ʕaw	noise	aman	water
3	am:a:	mama	mom	aratid	give it to me	afus	hand
4	hb:a	sˈb:atˁ	shoes	ixʃ	it is bad (thing)	ilm	skin
5	ajal:a	lal:a	auntie	tit:i	sit down	krf	tie
6	ha:h	hak	take	x:iʃ	it is bad (thing)	adr	press
7	man:ama	lmunika	toy	ʃaʃ:a	a donky	rgl	close
8	q:aq:a	ʔika	like this	fuf:u	hot/fire	ifta	he went
9	t:a	xt:a	this one (fem.)	baʕ:a	sheep	usin	they took
10	b:aħ	b:aħ	disappeared	b:aħ	It's over	awid	bring!
11	maməm	mum:u	toy (generic)	d:aw	walk / go	inijas	tell him
12	hat:i	hat:i	here it is (fem.)	dajd:a	fall down	ufiy	I found
13	aj:a:	taj:a:	another one (fem.)	baʕ:atin	sheep	lkmy	I arrived
14	ʃeʃ	ʃaʃ:a	horse (baby talk)	ʃt:i	grandfather	tam:nt	honey
15	b:ɛhb:a	aħb:udˁ	tummy	kak:a	chocolate	takurt:	ball
16	bula	bula	this is a light bulb	et:ej	move !	agrzam	lion
17	mna	magana	this is a watch	buʕ:u	monster	tafruxt	girl
18	qaq:a	kukuʕ:u	cock (baby talk)	tinxarin	nose	afrux	boy
19	alaqa	alq:aʕ	sheep	tabat:ˁaħt	foot	imi	mouth
20	a:la:	ara	give me	tafust	hand	argaz	man
21	baʕp:ɛʕ	lbanan	banana	tamz:ˁuxt	ear	tamyart	woman
22	t:ɛtet:e	ʔid	here	tagaj:ut	head	amadl	hill
23	tʃtʃk	juʃkad	he came	timimit	mouth	amdlu	cloud
24	a:pb:	ib:i	it is ripped	tiwalin	eyes	skr	do
25	aca:ca	agaj:u	head	mimij	mouth	fl	let
26	mem:e	ʕmti	my aunt	tabit:u	eyes	ls	wear
27	handb:a	and:u	we are going	tidˁudˁin	fingers	gn	sleep
28	fu	ʃuf	look	ʃk:ata	eat (it)	izˁuran	veins
29	ne:n:e	nin:i	sleep (baby talk)	tas:awalt	trousers	azˁalim	onion
30	aʃ:e	adʃ:Ɂ	I will eat	banana	banana	tiwit	you took away
31	aj:i:	haj:i	here I am	biz:u	baby	tabrat	letter
32	haʃtʃk:a	ijq:a	it is tough	tˁrʃt	break	smun	pick up
33	ʃual	ʃuw:r	slow down	ʕan:	car	knu	lean
34	anana	wijn:a	mom's one	babat	shoes	kru	rent
35	ʃaʃa:	matˁeja	tomatoes	fuf:u	fire/ hot	igawr	he sit down
36	bak:aʔ	baraka	that's enough	ak:ik	give / Show	tkʃmt	you entered
37	Ɂ:a	Ɂw:a	this one	baja	biscuits	ssnkr	wake
38	alti	xalti	my aunt	st:ii	grandfather	udm	face
39	mamiand:u	manisrand:u	where	ħmal	donkey	idam:n	blood
40	d	adˁadˁ	finger	ʕ:u	fermented milk	ayrum	bread
41	mim:i	amuf:	cat	daʕ	also	juda	it's enough
42	bwa	iswa	he drank	x:ix:ij	dirty	izra	he saw
43	j:ah	jah	yes	kukuʕ:u	cok	alim	straw
44	:uf:uʔ	sf:uwt	get him out	ħaħ:a	boho / cut	afunas	bull
45	f:uf:u	if:uɁ	he went out	d:aħ:ati	hit (me)	ajdi	dog
46	m:am	im:im	it's tasty	b:ˁatˁ	shoes	ngr	between

47	px:u	bux:ʊf	here's the insect	hawa	cow	tirtm	food
48	f:aʔ	f:	eat	hawhaw	dog	azur	terrace
49	s:as:a	shs:a	be quite	t'anun	yogourt	izgr	he crossed
50	ad:a	td:'r'	she felt down	tiziz:it	meat	xdmn	they worked

APPENDIX 3. Examples of ENGLISH data

	Actual IPA	Target IPA	Translation	CDS IPA	Translation	Dictionary IPA	Translation
1	dʌ'be	bʌmbəl'bi:	bumble-bee	'ækrə bæt	acrobat	ə'si:təs	acetous
2	dæ'deɪ	dædi:	daddy	ə'dɔr	adore	'ɑrtʃ duk	archduke
3	ə'zi	dɜrti:	dirty	ænt	ant	'bæktɪs	bacchus
4	dʌwɪ	dəgi:	doggie	ə'sli:p	asleep	'bæstʃən	bastion
5	dʌdi	dʌki:	duckie	'berbi, sɪtər	babysitter	'bætəl	battle
6	abwi:	berbi:	baby	'bætəl	battle	klæʃ	clash
7	hʌ	kəʊ	cow	'bɪskət	biscuit	kɔɪn	coin
8	dʌ	dət	dot	'keɪfəl	careful	kʌm	come
9	hʌbu	lɒbstər	lobster	tʃək	chalk	'saɪklɪn	cyclin
10	ʌme	mami:	mommy	'dɑrlɪŋ	darling	dæl'meɪʃən	dalmatian
11	mʌm	mu:n	moon	'dɪfərənt	different	dɛd	dead
12	bə'be	pʌpi:	puppy	'ɪzi	easy	dɪs'grʌntəld	disgruntled
13	ɔ'wɒl	bɒl	ball	en'dʒɔɪ	enjoy	'estʃu, ɛri	estuary
14	ɛ	aɪ	eye	fɑ:m	farm	'frɪzɪŋ	freezing
15	ɑtʃi	anti:	auntie	'fɪlθi	filthy	fju:z	fuse
16	kɪzɪ	kɪti:	kitty	dʒə'ræf	giraffe	heɪz	haze
17	æ:	rɔr	roar	gɜ:rl	girl	'hevi	heavy
18	dɪθhɪ	ti:tʃər	teacher	gret	great	'haɪbər, neɪt	hibernate
19	dʌʔdæ	bækpæk	backpack	gɪ'tɑr	guitar	'ɪn, sest	incest
20	bə	bɛr	bear	'hevi	heavy	ɪn'tu:n	intone
21	peɪ	bai	bye	hɔrs	horse	'lɑgər	lager
22	dʌkʰ	stʌk	stuck	'ɪn, sekt	insect	lɪv	live
23	bu	blu:	blue	'ɪtʃi	itchy	mætʃ	match
24	bək	boʊt	boat	'dʒækət	jacket	'mentəl	mental
25	bʊk	bʊk	book	'dʒʌŋgəlɪŋ	juggling	'mɪkstʃər	mixture
26	bə	bəʊ	bow	'kæŋgə'ru	kangaroo	'peɪpəl	papal
27	bu	bru:m	broom	kɑɪt	kite	'rəʊmən	roman
28	gʊ'keɪ	kʊki:	cookie	'leɪtər	later	rul	rule
29	dʊʃ	fu:z	shoes	lɪv	leave	'skɜ:slɪ	scarcely
30	bu	bɜrd	bird	'lɪkɪŋ	licking	tæb	tab
31	bək	blæk	black	lʌv	love	'tækəl	tackle
32	pɪ'teɪ	pɪglət	piglet	'mægnət	magnet	'vɪəməns	vehemence
33	bu	bu:ts	boots	mɪn	mean	'vɜ:dʒənəl	virginal
34	bʌ'baʊwɪs	bʌbəlz	bubbles	'mʌŋki	monkey	və'sɪfərəsli	vociferously
35	bə:	bʌg	bug	neɪm	name	'wɪkli	weekly
36	keɪk	keɪk	cake	'nekləs	necklace	wɑɪld	wild
37	kɑ:	kɑr	car	nɑɪs	nice	kæɪrɪdʒ	carriage
38	kʌk	klɒk	clock	'ɔrəndʒ	orange	tɛkst	text
39	fləʊ	flawər	flower	'peɪntɪŋ	painting	bɒks	box
40	fu:	fu:d	food	'pɪktʃər	picture	'aʊt, laɪn	outline
41	kɪk	kɪk	kick	'reɪni	rainy	pækt	pact
42	mu	mu:s	moose	rɔr	roar	pʊt	put
43	pɪk	pɪŋk	pink	'sændi	sandy	rɪ'pʌblək	republic
44	dɔʃ	stɑr	stars	'skrʌbɪŋ	scrubbing	raɪt	right
45	se:	sʌn	sun	sɪt	seat	'sædnəs	sadness
46	fwi	θri:	three	spə'geti	spaghetti	snæp	snap
47	tɔs	tu:z	toes	'tɪkət	ticket	skwɪz	squeeze



48	wet	wet	wet	'ju:nɪ kɔ:rn	unicorn	taɪm	thyme
49	ɹɹpɔ	ɹɹpəl	purple	wæks	wax	'traɪəl	trial
50	dʒi:	tri:	tree	'jeləʊ	yellow	vʊʊg	vogue

APPENDIX 4. Examples of FRENCH data

	Actual IPA	Target IPA	Translation	CDS IPA	Translation	Dictionary IPA	Translation
1	ma:ma	mamā	mummy	ʍəgəʊd	look	ōtɔʊs	sprain
2	pa:	papa	daddy	komōse	start	bɔʊtɪj	trinket
3	tɔʊtɔ tɔe:	dodo	sleep	pəs	think	ōtuzjasmə	get enthusiastic
4	pa:	pē	bread	vjē	come	eʊezi	heresy
5	tɔe:de:	tete	suck	tɛlmā	so much	ʍətɔe	withdrawal
6	ta:te	tastɪn	sandwich	ivɛʍ	winter	tɔʊve	find
7	da:da:	gato	cake	dusmā	slowly	kʍəvezō	flat
8	æbi:	abɛj	bee	pø	can	kanəʍ	duck
9	bɛbe:	bebe	baby	dədā	inside	dʊlʊʍø	painful
10	te:te	tete	head	gɔā	big	libɛʍəlɪzəm	liberalism
11	tata:	tata	auntie	fɛ	do	pɔʊvɪzɪjō	supply
12	bibi:	bottle	baby	vɔʋala	here	ʒødi	Thursday
13	ɔp	ɔp	hop	kɔm	like	kɔɪst	Christ
14	awo:	alo	hello	atā	wait	avəʍɪ	damage
15	kuku:	kuku	hello	lezəʍ	lizard	ōgəʍ	shed
16	apo:	pōpje	fireman	dakəʍ	okay	ʍəzɔʋəʍ	razor
17	po:	po	pot	ale	go	tā	time
18	kokæ	tōtō	uncle	əʍɪv	arrive	atəʋde	linger
19	ape:	pəpje	paper	avātaʒ	advantage	kuʃe	lying
20	æma:ʋə:	kamɛʋə	camera	mɔʋē	less	məʋʃā	seller
21	tete:	tete	sucking	dā	in	səkwe	shake
22	koke:	elikōptɛʍ	helicopter	pɔʋtik	crossbar	tɔiko	knitting
23	ɔʋa:	oʋəʋʋəʍ	bye bye	pʊsē	chick	vā	wind
24	tatɔ:	klakson	horn	amne	brought	dɛʋɛgle	upset
25	ba:	bal	ball	ʍəpɛl	remember	dɛʍm	dermis
26	ba:	bē	bath	ʒø	games	ɔtɔmatik	automatic
27	apa:	lapē	rabbit	butō	button	ōgōʋse	constrain
28	bi:bo:	bibɔʋō	bottle	tele	TV	ɔʋɔɪʍ	offer
29	gu:	lego	lego	komā	how	vəly	hairy
30	mɔ:	məʍ	bite	lɛs	let	vele	vellum paper
31	ma:	mal	hurt	lynet	glasses	ɛʋb	grass
32	ne:ne	mimi	cute	əplɛ	called	dɛʋɛlɛ	parade
33	apo:	fəpɔ	hat	pʋasō	fish	kale	wedge
34	ame:	fɛʋme	closed	pɛnɪbl	tiresome	kōtɔʋəpɛtɔɪ	spoonerism
35	bɛ	tōb	fall	vəʃ	cow	ɛpənʋɪʍ	blooming
36	pu:	pul	hen	ētɛʋdi	forbidden	dɔsil	docile
37	fwa	fɔʋa	cold	ʃɔset	socks	ʃās	chance
38	vɔ:	pɪl	jumper	gəʋsō	boy	əpsā	absent
39	ka:	kask	helmet	pətit	small	əspɪk	aspic
40	py:	py	stink	kat	four	fəʍ	woman
41	afa:	pəʋfōe	perfume	pɔe	ready	mənɪfɛstəsɔʋō	demonstration
42	nɔ:ne	kɔksɪnɛl	ladybird	tabl	table.	pɛje	pay
43	ane:	fɛʋme	close	əspɪvətəʍ	vacuum cleaner	sē	saint
44	bu:	bul	ball	mōtɔ	show	tɪʋəʋəʍ	infantryman

45	af	ʒɪʁaf	<i>giraffe</i>	telekomãd	<i>remote control</i>	ynite	<i>unit</i>
46	ɔu:	fɔsyʁ	<i>shoe</i>	dəbu	<i>stand</i>	ɔnɔʁe	<i>honor</i>
47	bube:	pubɛl	<i>trash</i>	nuʁityʁ	<i>food</i>	etɛ	<i>off</i>
48	dada:	salad	<i>salad</i>	kanaj	<i>raffish</i>	kã	<i>camp</i>
49	ʁo:gʁɛ	dekʁɔʒe	<i>pick up</i>	pubɛl	<i>trash</i>	sɛʁɔm	<i>serum</i>
50	api:	apɪ	<i>press</i>	mãʒe	<i>eat</i>	kãtɔnad	<i>No one in particular</i>

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