Predictors of consonant development and the development of a test of French phonology

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Abstract

The goal of this study was to predict accuracy of consonant production by French-speaking children with speech sound disorders. Articulatory complexity and phoneme frequency was examined in relation to the child's profile of motor or perceptual difficulties. The participants were preschoolers receiving speech therapy. Three had difficulties in the motor domain and five had difficulties with speech perception. The percentage of consonants correct on the Test of French Phonology, developed for this study, was calculated. For both groups, the best predictor was the phoneme's articulatory complexity combined with its phonological context but phoneme frequency was not predictive. The Motor Group had more difficulty with one- and four-syllable words and syllable onsets than the Perceptual Group whereas the Perceptual Group demonstrated lower accuracy for consonants in the syllable coda position. Non-linear phonology as the theoretical framework for the development of the Test of French Phonology was validated.

Résumé

L’objectif de cette étude était de prédire la justesse articulatoire (JA) d’enfants francophones ayant un trouble primaire de l’articulation. La complexité articulatoire et la fréquence d’occurrence des consonnes ont été examinées en lien avec le profile de difficultés des participants. Tous étaient d’âge préscolaire et recevaient des services en orthophonie; trois avaient des difficultés motrices et cinq des difficultés perceptuelles. Le pourcentage de consonnes correctes au Test Francophone de Phonologie (TFP), développé pour cette étude, a été calculé. Pour les deux groupes, le meilleur élément prédisant la JA était la combinaison de la complexité articulatoire du phonème et son contexte phonologique, et la fréquence d’occurrence était non-prédictive. Les enfants avec difficultés motrices avaient une JA inférieure pour les mots d’une ou quatre syllables et les attaques, contrairement aux enfants avec difficultés perceptuelles dont la JA était plus faible pour les codas. L’utilisation de la phonologie non-linéaire comme base théorique du TFP est validée.

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Introduction

For many years, researchers have been studying phonological development of both normally developing children and children with various types of disorders, in order to find what underlies the order of acquisition of sounds. By determining what elements contribute to the acquisition of consonants, it will help clinicians to select the most appropriate approach in the treatment of articulatory difficulties.

Because phonological development is highly similar between languages, many researchers believe that the acquisition of sounds may be explained by a universal order. The first one to make such a claim was Jakobson (1968), who proposed a fixed set of phonological features learned in the same order by every child regardless of the language spoken to them. However, he cautioned that the application of the phonological laws should always take into consideration the sounds' place in the language's sound system. Similarly, Dinnsen et al (1990) and Grunwell (1982) (as cited in Amayreh & Dyson, 2000) proposed two similar sets of features that are not learned linearly, but rather used contrastively with the different contrasts between features organized hierarchically in various stages. The presence of higher level feature contrasts implies the presence of lower level feature contrasts, and as a child demonstrates mastery of higher stages, the more complex is his phonological representation. The advantage of such propositions over the fixed order proposed by Jakobson is the greater individual differences regarding the order of sound acquisition that it can account for (Stokes & To, 2002). It has also been proposed that the order of sound acquisition can be accounted for by a universal and implicational hierarchy of articulatory difficulty (Kent, 1992). Under this hierarchy, the sounds of every language can be classified into four different sets based on their articulatory characteristics, and the sounds of the lower set would be acquired before the sounds from the higher sets. For the English system, the first set comprises the sounds /p m n w h/: most have a rapid articulatory movement (i.e. stop or nasal), the others have slow articulatory movements (glide and fricative), both nasals and stops are present, and the primary places of articulation to be used are the bilabial, alveolar and glottal. The additional sounds found in the second set are / b d g k j f/: many of the new sounds are from the rapid articulatory category, two additional sounds from the slow movement category are also present, which includes the /f/ sound requiring fine force regulation, and the velar place of articulation is now present. The third set includes the sounds /t ŋ r l/: the last items in the rapid movement category are now mastered, the tongue configuration allowing bending is now possible, velopharyngeal valving allows the distinction between nasals and stops, and voicing adjustment allows the distinction between the voiced/voiceless pairs. The last set of sounds comprises /s z ʃ v θ ð ʒ tʃ dʒ/: the tongue configuration and the fine force regulation for the dental, alveolar and palatal fricatives (and affricates) are now possible. The importance of articulatory complexity in sound acquisition has also been pointed out by Amayreh (2003), who proposes that the order of later acquired sounds in Arabic may be, at least partially, explained by the articulatory complexity of sounds; for example, the ‘emphatic’ consonants require a more complex tongue configuration, due to the presence of a secondary articulation at the tongue root. Currently, many researchers still focus their research on testing various implicational laws and other universals that would provide an explanation for the order of acquisition of phonology of every child regardless of the language spoken (e.g. Morrisette, Dinnsen

& Gierut, 2003; Stokes & To, 2002). However, Ingram (1991, as cited in Stokes & To, 2002) has proposed that universality in the acquisition of phonology is restricted to the very first steps of phonological development.

Other propositions focused on language-specific characteristics have been advanced when the universal order of acquisition could not account for individual orders of acquisition. Some propositions totally disregard any universal order of acquisition and propose another single key element. For example, it has been proposed that the saliency of the element within the specific language may be the element determining the order of acquisition rather than feature hierarchy (Hua & Dodd, 2000). However, most researchers try to account for the obtained results by allowing some language-specific elements to interact with the universal order of acquisition. Some authors propose a single language-specific element; others propose a combination of two or three elements. The ambient language element most often proposed is frequency of the phonemes within the language (e.g. Amayreh & Dyson, 2000), which may be further individualized by considering the frequency of sounds within the individual's lexical knowledge and personal experience (Ferguson & Farwell, 1975). Another element considered to be a key one in the order of acquisition of sounds is the functional load of the sound (e.g. Amayreh & Dyson, 2000; Amayreh, 2003). The functional load of a sound is the cost to the language if the contrast between the studied sound and a similar sound is lost, and it takes into account both the number of sounds that would be pronounced the same way and the frequency of these sounds. The functional load if thus the cost to the language when two sounds merge, as determined by the number of new homonyms created. For example, although the sound /ð/ is the most frequent in English, the cost to the language would not be so heavy if it merged with sounds having a similar place of articulation (such as /d/ and /z/), which is translated into a low position (the 16th sounds) when the sounds are ordered by functional load. On the contrary, the sound /w/ is only the fifth sound when ranked accordingly to frequency, but occupies the first place when ordered by functional load (Baayen, Piepenbrock, & Gulikers, 1995, as cited in Stokes and Surendran, 2005). To our knowledge, the information on functional load for French is not available. Since such calculation can be made in different ways, it is very important to take into consideration how the functional load has been calculated in order to compare the results of different studies using this measure (Surendran & Niyogi, 2008). In all these studies on language specific factors, no attempt was made to determine what proportion of the order of acquisition was accounted for by the different components. However, Stokes and Surendran (2005) made such an attempt. Indeed, they investigated the relative importance of articulatory complexity, ambient frequency, and functional load, for both the age of acquisition of consonants and the accuracy of production (see table 1 for a description of the terms). The first comparison, evaluating the age of acquisition of sounds, was between 7 English-speaking children aged between 8-25 months and 51 Cantonese-speaking children aged between 15-30 months. Their results indicated that the main element to account for the age of acquisition was different for the two languages. Indeed, functional load accounted for 55% of the variance in the case of English-speaking children, while for Cantonese-speaking children the main factor was the frequency of the consonant in the ambient language, accounting for 63% of the variance in age of acquisition. The second comparison, evaluating the accuracy of production instead of the age of acquisition, was conducted on an older age group. The comparison made was between 40 25-month-old English-speaking children and 5 24-month-old Dutch-speaking children. Again, the main element to account for the variation differed across languages, and for this aspect of phonological development a different factor accounted for the pattern observed for the English group: articulatory complexity was the main factor for the English-speaking children, accounting for 40% of the variance, while frequency was the main factor for Dutch-speaking children, accounting for 43% of the variance.

Table 1. Description of the terms used in Stokes and Surendran (2005)

Elements	**Description**
Articulatory complexity	Following the model proposed in Kent (1992), with four articulatory complexity levels based on physiologic characteristics.
Ambient frequency	Frequency of occurrence of initial consonants in adult speech (p.580).
Functional load	The weighted sum [by phoneme frequency] of the functional load of the binary oppositions between it and other phonemes… with shared place of articulation (p.580). FL(x, y), the functional load of the binary opposition between two phonemes x and y, is the cost to the language if x and y always sound identical to a listener… in word-initial position. For example, we want FL(p, b) to account for the cost of the words *pat* and *bat* being homophones (p.581).
Age of emergence	The first occurrence of a consonant in at least two different words in a child's conversation…regardless of the accuracy of the attempts (phonetic inventory) (p.583).
Accuracy of production	The number of correct productions, divided by the total number of attempts at the consonant, multiplied by 100 (p.583).

The results obtained by Stokes and Surendran (2005) highlight cross-linguistic variations in the order of acquisition and the accuracy of production of consonants. Indeed, the order of sound acquisition is best accounted for by the sounds' frequency in Cantonese, but by the functional load for English. The authors interpret these results as an indication of the importance of the size of the set of word-initial consonants, the functional load of these consonants, and their articulatory complexity. For instance, in the case of Cantonese, the functional load of the consonants is low compared to the functional load of vowels and tone; Cantonese consonants are easier to produce than English consonants, and there is a smaller set of word-initial consonants than in English. Therefore, a greater importance is put on the frequency of the sounds. On the other hand, in the case of English, a higher articulatory complexity of the consonants and a larger set of word-initial consonants put more importance on their functional load. In the case of the accuracy of production of the consonants of English and Dutch, the importance of articulatory complexity is put forward. Indeed, the main factor accounting for the accuracy of production for English is articulatory complexity, whereas it is frequency for Dutch. The authors account for this difference by the fact that in English, the mean articulatory complexity of the consonants is higher than in Dutch, and that in Dutch there is a smaller set of word-initial consonants than in English.

The complexity of consonant acquisition is highlighted by the Stokes and Surendran (2005) study, since there is not a single element that can account cross-linguistically for the order of acquisition or the accuracy of production. Furthermore, within English the factor accounting for the order of acquisition, as determined by a study with a group of children between 8 and 25 months, is not the same as the factor accounting for the accuracy of production, as determined with a group of children of 25 months. The authors interpret the evolution of the main factor accounting for phonological development as a sign that when children show mastery of the phonological system by the age of 24-25 months, they have already stored all of the phonetic characteristics of their language. What is then left to the child to master is the adequate fine-motor gestures required for the correct production of the sounds, which would gradually be learned through a feed-forward loop, that is the links between the articulatory and acoustic properties are strengthened on every production attempt of a segment. It is this learning that would be dependent on either articulatory complexity or ambient frequency of the consonants.

Another aspect to consider is the phonological context of the target sounds, since context has been shown to influence the accuracy of consonant production in many tasks. For example, in Edwards and Beckman (2008) the accuracy of production of initial consonants for children 2- and 3- years old was found to have a significant word length effect, determined by the number of syllables of the target words. This effect was found for three of the four languages they studied, and the forth language showed a trend in the same direction. In Santos, Bueno and Gathercole (2006), the number of syllables has also been shown to influence the number of errors in nonword repetition. Furthermore, the syllable position of the target sounds has to be considered as well. For example, Rvachew and Andrews (2002) found a difference in the match ratio for the sounds' features depending on the sounds' syllable position, for children with speech-sound disorders. In Dutch, the age of acquisition of certain consonants also depends on the sound's syllable position (Beers, 1995, as cited in Mennen, Levelt and Gerrits, 2006). It has also been found that for French, word-initial consonant clusters are acquired earlier than word-final ones (Demuth & Kehoe, 2006; Demuth & McCullough, 2009). It is thus important to consider phonological context in designing word lists used to collect representative speech samples. Indeed, if one selects only onset position for mono- or bi-syllabic words, the accuracy of the pronunciation will be inflated and will not represent adequately the actual ability of the child to produce a specific sound in his/her language.

The present study will explore how two language-specific factors, namely articulatory complexity and phoneme frequency, can account for the accuracy of production of some French consonants for monolingual French-speaking children with speech-sound-disorder (SSD). The role of the phonological context in the accuracy of pronunciation will also be investigated, in itself and in relation with the previously mentioned language-specific factors. Since no test of French phonology currently available takes into consideration the prosodic aspect of the language, such a test has been developed following the non-linear phonological framework, because of the importance it gives to the phonological context. This study aims to investigate whether the difficulties of the children at the perceptual or motor level will have an impact on the main factor accounting for the accuracy of production, just as the consonant characteristics of the language spoken by children impacts the factors accounting for their consonantal development.

Hypotheses

The results in Stokes and Surendran (2005) showed that the accuracy of production of consonants was influenced mostly by their articulatory complexity in the case of English, a more complex language regarding articulation. When the phonological system was easier, as is the case for Dutch, the main factor was the sound frequency. In French, the phonological system has 20 consonants (Martin, 1996) and no stress system (Carton, 1974), which makes it simpler than English, with its 24 consonants (Stokes & Surendran, 2005) and a complex stress system (Ladefoged, 2001). Consequently, the accuracy of production in French should be most affected by the sound frequency, similarly to Dutch, a phonological system with 18 consonants (Booij, 1995) and a stress system (Mennen, Levelt, & Gerrits, 2006).

The present study investigates how the sounds' articulatory complexity and frequency influence the articulatory accuracy of consonants of children with SSD. A classification system proposed by Shriberg et al. (1997) proposes five subtypes of developmental phonological disorders: unknown origin, otitis media with effusion (related to perceptual difficulties), developmental apraxia of speech (related to motor difficulties), developmental psychosocial involvement and special population. In this study, we will focus on children who present with a SSD of unknown origin and have been identified as having difficulties either with speech perception or oral motor proficiency.

The children in the first group show particular difficulties at the speech perception level, as measured by word identification and phonological awareness tasks, while the second group has greater difficulties at the motor control level, as measured by a standard oralperipheral examination with particular emphasis on rate and accuracy during syllable repetition tasks. It is proposed that the predictors of consonant accuracy may differ for these two subgroups of French-speaking children with SSD.

Following from the conclusions of Stokes and Surendran (2005), phoneme frequency should be an important predictor of consonant accuracy by French-speaking children overall, given the somewhat simpler phonology of French relative to English. Furthermore, even in English it has been shown that input frequency has a strong effect on children's production accuracy when repeating nonwords that contain high- or low-frequency phoneme sequences (Munson, Edwards, & Beckman, 2005; Richtsmeier, Goffman, & Hogan, 2009). It is predicted that this effect will be enhanced for French-speaking children with speech perception difficulties because amount of exposure to specific words and phonemes will have an even greater impact on these children's knowledge (or lack of knowledge) of specific phonemes, given previous research showing that children with SSD have difficulty learning perceptual representations for words after minimal exposure to their acoustic form (Munson, Baylis, Krause, & Yim, 2006).

If French-speaking children in general are indeed more influenced by the sounds' frequency, it may not be the case for children presenting with pronounced difficulties at the oral-motor level. The presence of these difficulties is likely to impact the child's phonological system, amplifying the articulatory complexity of the sounds. Therefore it is expected that articulatory complexity of the phonemes will predict accuracy of production for French-speaking children with SSD whose difficulties appear to be primarily in the oral-motor domain.

Two comparisons will be performed to determine which predictor of consonant development, between the sound frequency and the articulatory complexity, provides the best account of French development of children with SSD. A selection of six sounds, / p k b ɡ s ʃ /, which provides a range of combination of frequency and articulatory complexity, was made to do these comparisons. Table 2 below indicates for these sounds their frequency, based on spoken language (Haton-Lamotte, Wioland, Delattre & Valdman, as cited in Carton, 1974) and their articulatory difficulty level, with lower levels having simpler articulatory movements. Note that contrary to Stokes and Surendran (2005), the sound frequency corresponds to the frequency of the sound regardless of its position in the word. This decision is supported by the fact that greater saliency is placed on the last syllable in French, because of the systematic presence of a stress on the final syllable (Ayres-Bennett & Carruthers, 2001). Furthermore, it has been found that 20 month old children are equally able to take into consideration the consonant in word-initial or word-internal positions (Nazzi, 2005). The unit of analysis to be used is the percentage of consonants correct (PCC) of the six target sounds.

Table 2. Frequency and articulatory complexity of the target sounds

	Frequency % of consonant	Articulatory complexity Level based on Kent (1992)
/ p /	7,1	1
/ k /	7,1	2
/ b /	1,9	2
/ g /	1,05	2
/ s /	10,3	4
/ ʃ /	1,05	4

Hypothesis 1 - frequency

The sounds' frequency should be the most important factor of accuracy of production for the children with SSD with difficulties at the perceptual level. For the children in that group, the sound accuracy should be linked to the sounds' frequency of occurrence. Therefore, when the target elements are organized in decreasing order of sound frequency, the PCCs of the sounds should show a negative slope. Although a clear trend should be observable for this main factor, some variability is nonetheless expected since more than one factors impact the accuracy of production.

Hypothesis 2 – articulatory complexity

The sounds' articulatory complexity should be the most important factor of accuracy of production for the children with SSD with difficulties at the oral-motor level. For the children in that group, the sound accuracy should be linked to the sounds' articulatory complexity. Therefore, when the target elements are organized in increasing order of articulatory complexity, the PCCs of the sounds should show a negative slope. Although a clear trend should be observable for this main factor, some variability is nonetheless expected since more than one factors impact the accuracy of production.

Participants

The participants in this study were a subset of the participants enrolled in the ECRIP trial. The participant selection criteria for the ECRIP trial are as follows: diagnosis of primary moderate to severe speech-sound disorder (SSD) with no concomitant developmental conditions, with the exception of language delay; monolingual French speakers from the greater Montreal area, aged between 4;0 and 5;11 (although no child in the current study was older than 5;0), normal hearing, with or without language delay. Each subject was also required to misarticulate at least three phonemes that are expected to be acquired at their age. Only the subjects whose pre-treatment measures were collected between October 2008 and March 2009 were considered. The selected subjects demonstrated a non-ambiguous profile regarding motor and perceptual abilities. The participants selected for inclusion in this study are described in greater detail in the next section after first describing the selection procedures.

Method

Participant selection

The subjects are assigned to the Perceptual Difficulties group (PDG) or the Motor Difficulties group (MDG), based on their performance on the French adaptation of the Speech Assessment and Interactive Learning System (SAILS; AVAAZ, 1994), the French adaptation of the Phonological Awareness Test (PAT; Bird, Bishop, & Freeman, 1995) and the Oral Speech Mechanism Screening Examination-Third edition (OSMSE-3; Ruscello & St-Louis, 2000).

Specifically, children who failed the PAT and at least one block of a SAILS module, or two blocks of any of the SAILS modules (see below for more details), while demonstrating normal oral motor functions as assessed using the OSMSE-3 (see below for more details), were placed in the Perceptual Difficulties group (PDG). Children who demonstrated the opposite profile were placed in the Motor Difficulties group (MDG). Children whose profile was ambiguous were excluded from the study (e.g. normal scores on both aspects or poor performance on both aspects - on both measures of speech perception and oral motor function).

Perceptual abilities were assessed using a French adaptation of the Speech Assessment and Interactive Learning System created by Brosseau-Lapré (SAILS; AVAAZ Innovations, Inc.), a computer game testing the ability to discriminate correct and incorrect ways to pronounce a word. Each module tests a different word whose first consonant is commonly misarticulated, and each token is a recording of different children and adults saying the target word. Half of the tokens are well articulated (e.g. *wheel* ‘roue’ [ʁu]), the others are misarticulated (e.g. [wu]), and the task consists of determining whether the word just heard is correctly pronounced or not. Visual reinforcement is provided when an answer is given (e.g. color is added to the picture). For each target word, two or three sets of words are presented; the first one is a trial block allowing the child to get accustomed to the task, the second block regroups easier tokens to identify, and the last block regroups harder ones for targets often misarticulated with a distortion (i.e. /k/, /g/, /f/ and /v/ do not have a third block). No normative data is currently available in French; it has been determined that a score under 65% correct consists of a failure. The PAT test is a French adaptation by Rvachew and Brosseau-Lapré of the test developed by Bird, Bishop, and Freeman (1995), evaluating the phonological awareness abilities of rhyme matching, initial phoneme matching and segmentation and matching of the initial phoneme. This test requires the child to select one image out of four choices. The testing procedure used was that the first series of 15 items was administered to every child, and the second and third series was administered only if the child could perform the task with help during the practice items. Failed items or untested items were given a score of 0. No normative data is currently available in French; it was decided that a raw score of score 6 or fewer correct responses out of a total of 34 test items would constitute a failure on this test. In both cases, the cut-off scores were established at a level aimed to identify children that seem to randomly select their answers, which indicates their inability to perform the tasks.

The motor abilities were assessed using the Oral Speech Mechanism Screening Examination – 3rd edition (OSMSE-3; Ruscello & St-Louis), a normed method to examine the oral speech mechanism, including the lips, tongue, jaw, teeth, palate, pharynx, velopharyngeal mechanism, breathing and diadochokinesis (DDK) measures. The objective of this assessment was to identify children having difficulty at the oral-motor level, who scored at the low range of normal limits or below normal limits. The first task used for the group assignment was the DDK rates, which is the time it took for the child to utter a set of 16 /pə/ productions , a set of 16 /tə/, a set of 16 /kə/ a set of 12 /pətə/ and a set of 8 /pətəkə/, regardless of sound accuracy and rhythm. These two elements were considered in the function score, the second aspect of oral-motor abilities considered in the group assignment. Since the subjects in the present study are mostly between 4;2 and 4;11 years, the cut-off time (in seconds) used for the DDK and the function scores are those of children between 5;0-5;5 (the youngest age group available in OSMSE-3 normative data). This cut-off point is appropriate to select children with low ability level, since children's alternative motion rates between 4;0 and 5;0 do not significantly improve for normally developing children (William & Stackhouse, 2000), children with SSD show a weaker correlation between age and DDK's rate than normally developing children (Henry, 1990), and DDK has been successfully used to diagnose motor speech disorders with children 4;4 years of age (Maasen, Gabreels, & Schreuder, 1999).

The results of the assessment for the three subjects in the motor group are presented in Table 3. All subjects are between 57 and 60 months. None of the subjects is below the normal limits for the receptive vocabulary, as evaluated by the Échelle de Vocabulaire en Images Peabody (EVIP; Dunn,Dunn, & Theriault-Whalen, 1993). None of the subjects is below the normal limits for the nonverbal IQ, as assessed by the Kaufman Brief Intelligence Test - Second Edition (KBIT-2; Kaufman & Kaufman, 2004). Overall intelligibility was assessed using the PCC from all the items of the Test of French Phonology – version A, which has been developed as part of this thesis, and none of the subjects had a PCC above 75% or below 55%. All subjects have a PAT score above 10 and a mean SAILS score above 70%, which indicates no particular difficulties at the perceptual level. All the children have failed the OSMSE-3 screening, showing that they all have difficulties at the oral-motor level. None of the subjects failed the oral-motor screening due to the structure subtest, which indicates that the articulatory difficulties encountered by the subjects are not imputable to structural malformations.

The results of the assessment for the five subjects in the perceptual group are presented in Table 4. All subjects are between 50 and 58 months. None of the subjects is below the normal limits for the EVIP or for the nonverbal IQ. Three subjects have a PCC above 75%, and none has a PCC below 55%. All subjects but one had a PAT score of 4 or 5, and all but one had a mean SAILS score below 65%. The subject having a high score in the PAT has a low mean SAILS score, and the subject with a high mean SAILS score has a low PAT score. All subjects show difficulties at the perceptual level. All the children have passed the OSMSE-3 screening, showing no particular difficulties at the motor level.

See Appendix 1 for more details on the group assignment and individual scores.

Table 3. Description of subjects in the motor group

Subject	age	EVIP standard score[a]	KBIT-2[b] nonverbal IQ[c]	Global PCC on the TFP[d]	Mean SAILS score	PAT raw score	OSMSE -3[e]
1101	60	116	107	57%	74%	16	fail
1102	57	112	88	68%	73%	16	fail
1104	59	131	119	72%	88%	11	fail
Average (SD)	*59 (2)*	*120 (10)*	*105 (16)*	*66% (8%)*	*78% (8%)*	*14 (3)*	

[a] For the EVIP: mean of 100, SD of 15. Norms available from 2;6 to adulthood

[b] For the KBIT-2: mean of 100, SD of 15. Norms available from 4 to 90 years old

[c] The matrices subtest.

[d] The global PCC is the percentage correct of all the consonants present in the TFP

[e] From the OSMSE-3 assessment. All three subtests have to be succeded to pass the screening. The three subtests are the DDK (must have a time inferior to the cut-off time in at least 4 of the 5 tasks to pass), the function score and the structure score.

Table 4. Description of subjects in the perceptual group

Subject	Age (months)	EVIP standard score	KBIT-2 nonverbal IQ	Global PCC on the TFP	Average SAILS score	PAT raw score	OSMSE
1103	50	129	118	82%	72%	5	pass
1108	51	92	105	58%	55%	4	pass
1110	58	115	101	63%	60%	4	pass
1111	54	99	109	84%	58%	4	pass
1113	56	100	103	79%	50%	16	pass
Average (SD)	*54 (3)*	*107 (12)*	*107 (7)*	*73% (12%)*	*59% (8%)*	*7 (5)*	

TFP development procedures

In order to have a test of phonology representative of French and taking into consideration the phonological context of the target sounds, a new test was created. The test development procedures are outlined below. Two test versions were created to allow more frequent testing of the children.

Word selection

The words in the lists were selected following these steps.

1. The words from the three databases on age of acquisition (AoA) listed below were compiled, and the words acquired before the age of three were divided between word list A and word list B. The distribution between the two lists was performed to create the most balanced lists, in terms of sounds per position.
    a. 'AoA objectif et fréquence lexicale des 262 images de NA≥ 50% de Bonin, Peereman, Malardier, Méot, & Chalard (2003)' (Hazard, De Cara, & Chanquoy, 2007)
        - Provides the children's AoA and the lexical frequency of the images of Bonin et al. (2003) that were identified with the same label by 50% or more of the 30 adults used as control in Hazard et al. (2007).
        - Stimuli were drawings, and the subjects had to perform a picture-naming task.
        - Subjects were 478 children between 2;6 and 10;11. All children had European French as their mother tongue and did not present any language or behavioral disorders.
        - This database provides the age at which at least 75 % of the children in an age range are able to name the object presented in an image
    b. Bonin, Boyer, Méot, Fayol & Droit (2004)
        - Stimuli were photographs of action, and the subjects had to provide an estimation of the age at which they had learned the word illustrated.

- Subjects were 30 young adults studying at Blaise Pascal University, all were native speakers of French.
- This database provides the estimated AoA, using a 5 point scale using 3 year groupings (from 1 [0-3 y.o.] to 5 [12+ y.o.]). The words marked as a ‘1’ were considered.

c. Chalard, Bonin, Méot, Boyer & Fayol (2003).

- Stimuli were line drawings, and the subjects had to perform a picture-naming task.
- Subjects were 280 children between 2;6 and 10;11. All children had European French as their mother tongue.
- This database provides the age at which at least 75 % of the children in an age range are able to name the object presented on an picture

2. Additional words were added to fill the position without sounds, based on words of daily life likely to be known by young children. Priority was given to words for which the age of acquisition was available.
3. Periodically, the word list was revised to remove the words that could be removed without emptying any sound position. Whenever possible, the words from the list obtained in step one were maintained.
4. Additional words were added to fill the target position without sounds, using databases providing the frequency and syllabification, to select words with the required characteristics in terms of number of syllables and sounds. The words most likely to be known by young children were selected.

Information for each test item

The following information was collected for every word in the list.

1. The phonetic transcription was obtained from wiktionnary. Since the pronunciation provided is more characteristic of European French, some of the vowels were adapted to correspond to Quebec French pronunciation (particularly for the sounds / a, ɑ, ɔ/).
2. The syllabification was performed following the syllabification rules proposed by Laporte (1993), as cited in Goslin & Frauenfelder (2000). This theory is based on the possibility to be pronounced in isolation, and proposes two rules for establishing syllable boundaries, indicated with the symbol '.'. The syllable shape was indicated for each word, using the 'c' for consonant, the 'v' for vowel and the 'g' to indicate a glide (regardless of its status as a consonant (in the onset or coda) or as a vowel (in the nucleus)).
    - Rule 1: if a medial consonant cluster contains one of /p t k b d g f v/ followed by either /l r/, these two consonants are considered inseparable
    - Rule 2: divide the cluster before the last symbol that is not a glide
3. Information on syllabic structure was indicated, using 'A' to indicate the *attaque* ('onset'), 'Ab' for Attaque branchante ('branching onset'), 'N' for *Nucleus* ('nuclei'), 'C' for Coda ('coda'), 'Cb' for *Coda branchante* ('branching coda') and 'Gn' for *Glide dans un nucleus* ('glide in the nuclei'). Refer to the Appendix 2- *distribution of the syllable types* for more details on the use of word-final branching codas and codas rather than onsets with empty-headed syllable.

4. The number of syllables of the word was indicated.
5. For each word, the databases on age of acquisition were searched, and whenever available, the age of acquisition for the word was indicated. The search was conducted using the same three sources presented above, and a fourth one, described below.
    a. Cannard, Bonthoux, Blaye, Scheuner, Schreiber & Trinquart (2006).
        - Stimuli were drawings, and the subjects had to perform a picture-naming task.
        - Each item had been presented to 80 children between 2;9 and 8;11 years. All children had European French as their mother tongue.
        - Provides the percentage of children in each age group who were able to correctly name the image. The earliest age at which 75% of the children correctly identified the word was used as the age of acquisition.
        - In the cases where at age 3, 90% or more of the children correctly identified the word, the age of acquisition was considered to be 2 years old.
        - The provided age of acquisition indicates only the age in years (e.g. 4 years old). For the compiled age of acquisition (see below), the age of acquisition was considered to be the end of the given year (e.g. 4 years old was considered to be 4;11).

6. A compiled age of acquisition was calculated, where the average in months is calculated and the corresponding year is kept in the compiled AoA whenever two AoAs were present. ‘X’ years is considered to be between X;0 and X;11.
7. The frequency of the word was extracted from the NOVLEX database (Lambert & Chesnet, 2001).
    - Frequency of written word occurrences, based on textbooks and other books intended for European children in CE2 (8-9 years old).
    - All 36 books used were edited between 1982 and 1998.
    - The 417000 words were analysed and lead to 20600 entries and 9600 lexical roots.

In order to achieve a representative sample of French while keeping a reasonable number of items, some of the selected words are known to be harder for children to pronounce (e.g. ‘bibliothèque’, *bookshelf*). It is not expected that younger children will be able to spontaneously name these few more complex items; however, since such complex words are present in the language, it is nonetheless important to assess the child’s ability to produce them. The two final versions of the test contain 54 words each, represented using 20 pictures. Appendix 2 provides the details on the characteristics of the Test of French Phonology versions A and B.

Computer program

A computer program has been developed to automate the analysis process and limit errors related to long and fastidious analysis required using non-linear phonology. Using this program, two types of information are requested for each target word: how the children pronounced the word, and for each sound what is the corresponding syllable position, using the following code: ‘A’ indicates the *attaque* (‘onset’), ‘Ab’ the Attaque branchante (‘branching onset’), ‘N’ the *Nucleus* (‘nuclei’), ‘C’ the Coda (‘coda’), ‘Cb’ the *Coda branchante* (‘branching coda’) and ‘Gn’ the *Glide dans un nucleus* (‘glide in the nuclei’). (e.g. ‘drôle’ (*funny*): [dRol], AbAbNC). Following this data entry, an automatic comparison between the target and the obtained pronunciations is performed at the phone level allowing the calculation of many elements, including the PCCs of every sound in the test and for each target sound.

Pilot testing of the TFP

The first step in the pilot testing consisted of the determination of the adequacy of the pictures and the sentences used to prompt the target words. To test this, the TFP was administered to two children, a 3;4 boy and a 4;6 girl. The testing was recorded using a digital video camera, and the test administration was analysed to determine if some elicitation prompts were inadequate to elicit the target words, and to determine if some pictures were inappropriate in some way (e.g. not recognizable by the child, containing a distracting element, etc.).

The main modification following this first phase of pilot testing consisted of having two elicitation prompts to obtain a spontaneous utterance: the first one is highly linked to the content of the picture, and the second one is more similar to a riddle or contains a highly used sequence of words containing the target. This way, there are more chances to elicit spontaneous language. In some cases, when the target is less likely to be known by young children or if alternative words are possible, a word of the same family is presented at the beginning of the elicitation prompt to increase the likelihood that the child will say the target word. The use of a similar word in the prompt should not affect the child's pronunciation of the target, since many researchers have shown no significant difference between spontaneous pronunciation and imitation (e.g. Wertzner, Sotelo & Amaro, 2005; Bernthal & Bankson, 2004). The second set of modifications concerns the pictures: four were modified, either because it contained a distracting element or because it was not efficacious in eliciting the target word. The version used in the ECRIP trial and presented in the Appendix 2 is the modified version following analysis.

Transcription reliability

The transcription reliability of the TFP-A was calculated using the data collected with the eight subjects of the present study. The first transcription is the on-line transcription from the clinician who had administered the test and the second transcription is an off-line transcription made from the video recording. For every sound, the two transcriptions were compared to the target sound and judged as the same if in both cases it was judged correctly pronounced or if both were judged as incorrectly pronounced. Using this method, the transcription reliability is 94% (see Appendix 3 for more details).

Data analysis

The analysis strategy was purely descriptive because of the exploratory nature of the study. Supporting this decision is the small size of the sample, and the absence of published studies of francophone children with SSD that would guide the current research. Furthermore, preliminary examination of the data obtained from the ECRIP trial reveals that the error patterns produced by French speaking children with SSD are very different from those observed in English children. Consequently, prior studies of Anglophone children with SSD cannot be used to guide this research either.

The data comes from two sources. The first one is the Test of French Phonology (TFP; Paul & Rvachew), a photographic picture naming task prompting spontaneous elicitation, obtained as pre-test under the ECRIP trial (available for every child). The children's responses were video-and audio-recorded and submitted to broad transcription by two independent transcribers, and disagreements were resolved through consensus. This consensus transcription was used to calculate the percentage of correct articulations for each of the target phonemes /p b k g s ʃ/ using all the attempts for the singleton consonants. The second source of data was individualized production probes targeting the therapy targets of each child (e.g. /s/ in various positions), obtained prior to the first therapy session. The children's responses to these probes were elicited via delayed imitation of words depicted by clip-art on a computer monitor in groups of five organized by target phoneme and syllable position. The production probe transcriptions used for the PCCs calculation were the off-line transcriptions from the video-recording. Again, the percentage of correct production for each of the target phonemes /p b k g s ʃ/ was calculated. A global PCC for each of the target element was calculated using the results from both the TFP and the production probes. For the rest of the text, the PCC numbers presented refer to this global PCC.

The Percents Consonant Correct (PCC) were placed into a table for each subject, and an average PCC across subjects was computed for each group. Comparisons were made using graphs of the PCCs for the relevant phonemes, phonological context and the interaction between these elements when appropriate.

Table 3 below indicates the expected relative importance of the various PCCs for the selected sounds, for each group of children with SSD. For Hypothesis 1 - frequency, the sounds listed as having the same frequency were ordered according to the frequency presented in a second source (lexique.org). For Hypothesis 2 – articulatory complexity, the sounds from the same level were ordered according to the following guidelines: 1- for the same place of articulation, voiceless is easier than voiced (i.e. /k/ is easier than /g/), 2- voicing addition is easier than a new place of articulation (i.e. /b/ is easier than /k/ and /g/) and 3- /ʃ/ is more complex than /s/, because of its additional labial component (Martin, 1996).

Table 5. Hypothesized relation between the sounds' PCCs

Hypothesis 1 – Frequency For the perceptual difficulty group	
/ s /	+++
/ k /	+ +
/ p /	+ +
/ b /	+
/ g /	+
/ ʃ /	+

Hypothesis 2 – Articulatory complexity For the motor difficulty group	
/ p /	+ + +
/ b /	+ +
/ k /	+ +
/ g /	+ +
/ s /	+
/ ʃ /	+

Test items

The test items share a core number of words from the TFP, and vary because of the individual selection of the production probes based on the therapy target of the child. Presented in table 6 below is the number of opportunities per subject for each of the target sounds by syllable position, for the singleton elements only. A detailed list of the target words for each child and the obtained pronunciation for each target sound can be found in Appendix 4.

Table 6. Number of opportunities per subject, per target sound and syllable position

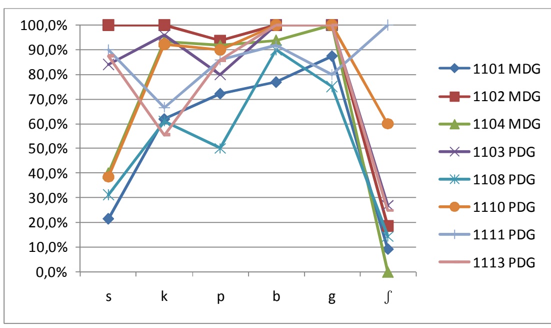
Sound	Position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG *
/p/	Onset	15	12	19	10	8	6	10	4
	Coda	3	4	5	5	6	4	4	3
/b/	Onset	11	9	14	10	8	9	11	5
	Coda	2	1	2	2	2	1	1	1
/k/	Onset	18	14	13	19	13	10	7	7
	Coda	3	2	2	5	5	3	2	2
/g/	Onset	7	5	5	6	3	4	4	3
	Coda	1	1	1	1	1	1	1	1
/s/	Onset	24	12	12	17	9	10	8	6
	Coda	4	4	3	8	7	3	2	2
/ʃ/	Onset	10	21	14	19	12	19	4	3
	Coda	1	6	1	7	2	6	1	1

* The production probes video for subject 1113 could not be used, therefore only the information from the TFP was available

Results and analysis

The PCC of the target sounds were plotted in the graphs below, with the sounds ordered following the decreasing order of frequency (Figure 1) and the increasing order of articulatory complexity (Figure 2), as presented in Table 5. In both cases, the first sounds should show a higher PCC than the last sounds to be congruent with the hypothesis. The left graph shows the results per subject, while the one at the right presents the results of all the subjects together, as well as by subgroups.

Figure 1: PCC of each target sound, with the sounds in decreasing order of frequency (regardless of the target sound's syllable position and the target word's length). The results per subject are shown at the left; the results per group at the right.



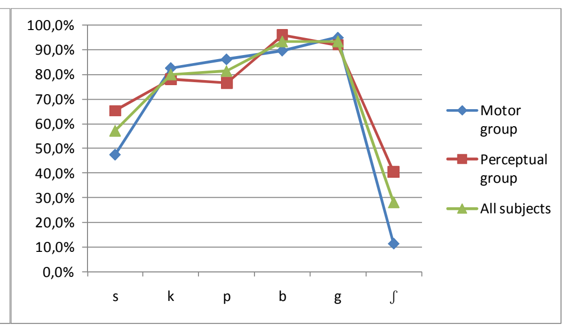
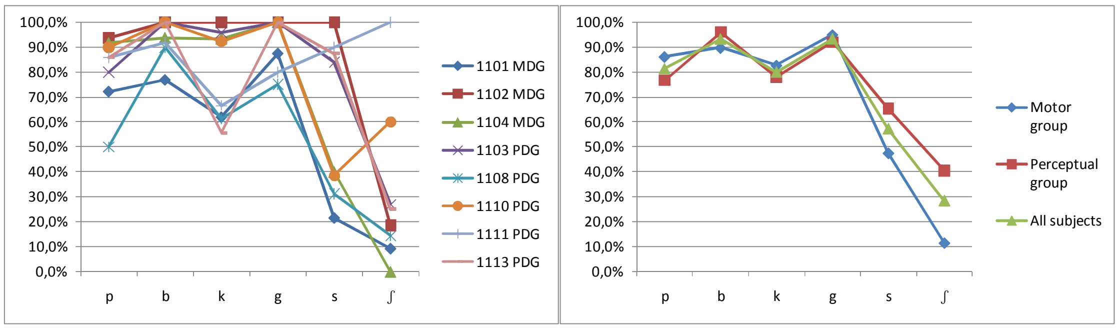


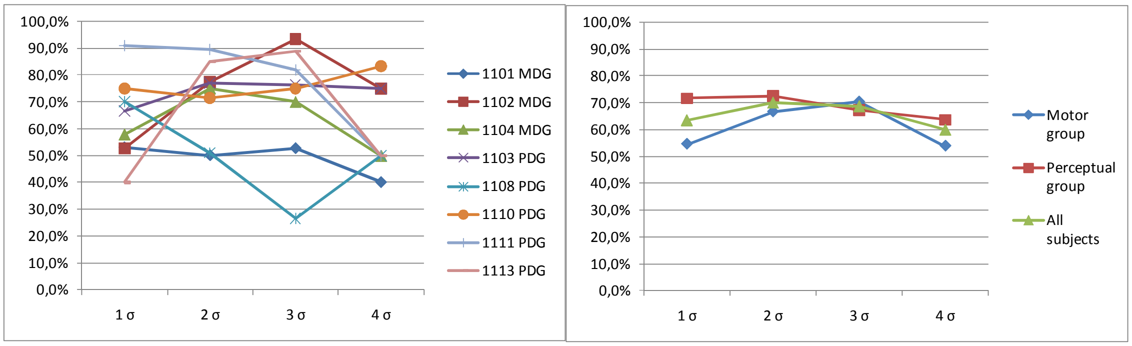
Figure 2: PCC of each target sounds, with the sounds in increasing order of the articulatory complexity (regardless of the target sound's syllable position and the target word's length). The results per subject are shown at the left; the results per group at the right.



These results show that both groups have the same pattern of accuracy. However, the motor group shows more pronounced difficulties with the sounds having a greater articulatory complexity (i.e. /s/ and /ʃ/), while the perceptual group shows more difficulty with the less complex sound /p/.

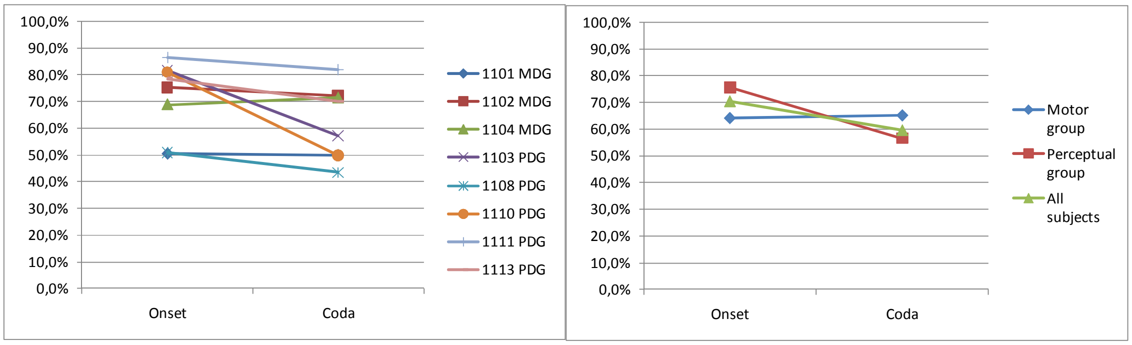
To investigate the role of phonological context in accuracy of consonant production, two elements were analysed, namely the word length and the syllable position. The following graphs show the PCCs of all sounds, depending on the target words' number of syllables in Figure 3 or the target sound's syllable position in Figure 4. The left figure shows the results per subject, while the one at the right present the results of all the subjects together, as well as by subgroups.

Figure 3: PCC of all target sounds, depending on the target words' length (as determined by the number of syllable). The results per subject are shown at the left; the results per group at the right.



The results show a stable average PCC for 1- and 2- syllables words and a lower PCC for 3- and 4-syllables words for the perceptual group. On the other hand, the motor group have the lowest PCC for 1- and 4-syllable words, and relatively similar PCCs for the 2- and 3- syllables words. Individual results however show that there are two types of subjects: some show a decrease in their PCCs as the word's length increases (with the peak at 2- or 3-syllables words), while the other type shows an increase in their PCCs. Both types are observed in the perceptual and the motor groups.

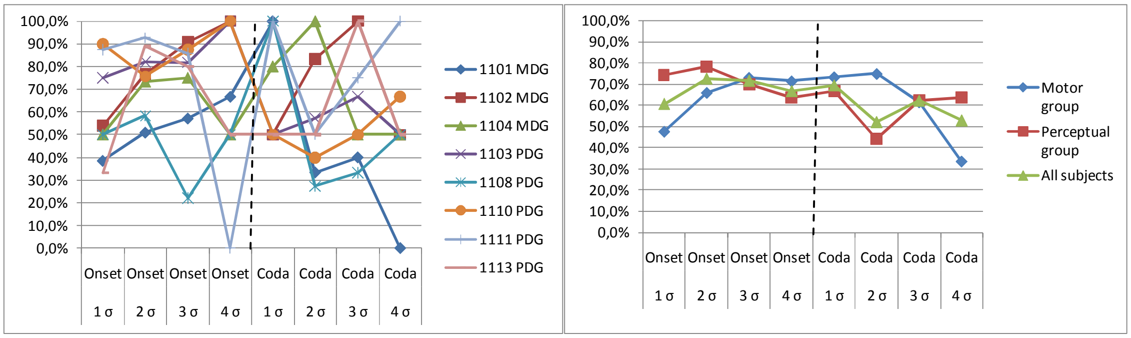
Figure 4: PCC of all target sounds, depending on the target sound's syllable position. The results per subject are shown at the left; the results per group at the right.



The perceptual group shows a decrease in accuracy between the coda and the onset, but not the motor group. However, as we can see in the individual results most subjects have only a slight decrease in the PCCs of codas, with only two subjects in the perceptual group having an important variation.

In the following figure 5, both elements of the phonological context are taking into consideration, regrouping all the target sounds' PCCs. The left figure shows the results per subject, while the one at the right presents the results of all the subjects together, as well as by subgroups.

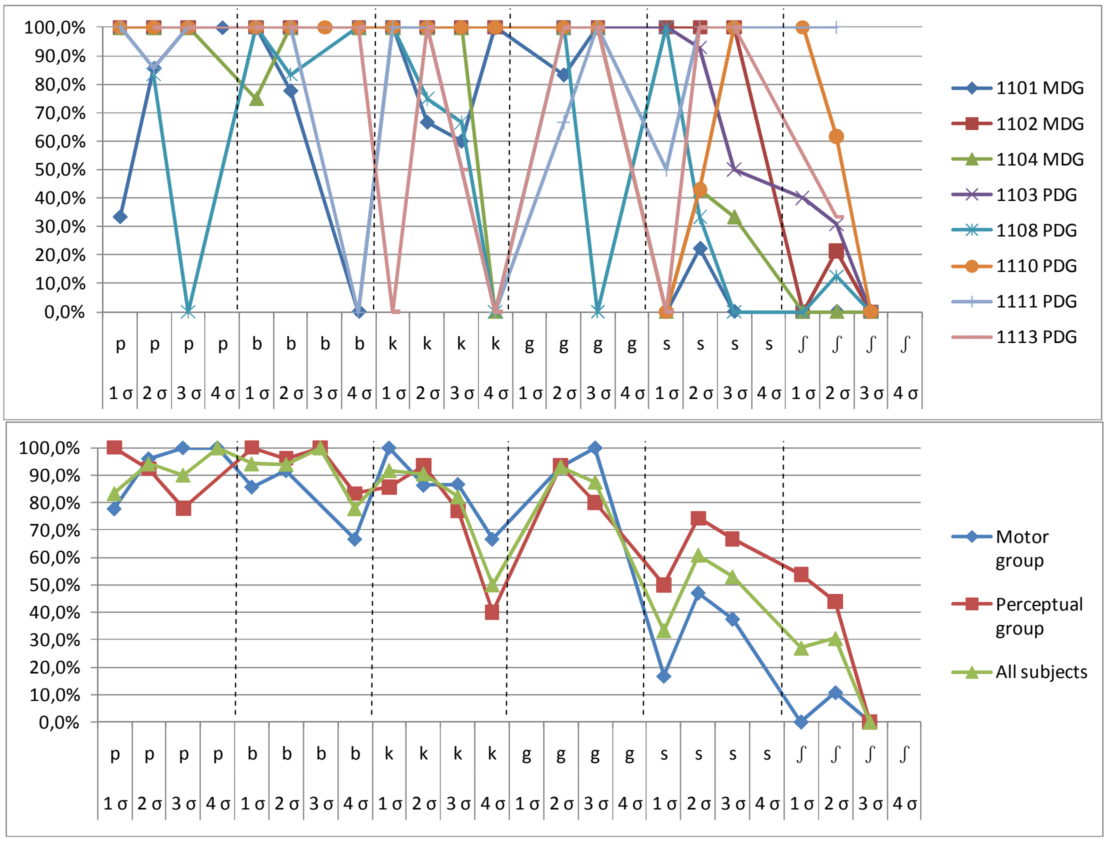
Figure 5: PCC of all target sounds, depending on the target word's length (as determined by the number of syllable) and the target sound's syllable position. The results per subject are shown at the left; the results per group at the right.



The perceptual group shows a particular difficulty with the coda of 2-syllable words, and the motor group shows greater difficulties with the onset of 1- and 2-syllable words and with the codas of 3- and 4- syllable words. The individual results are highly variable.

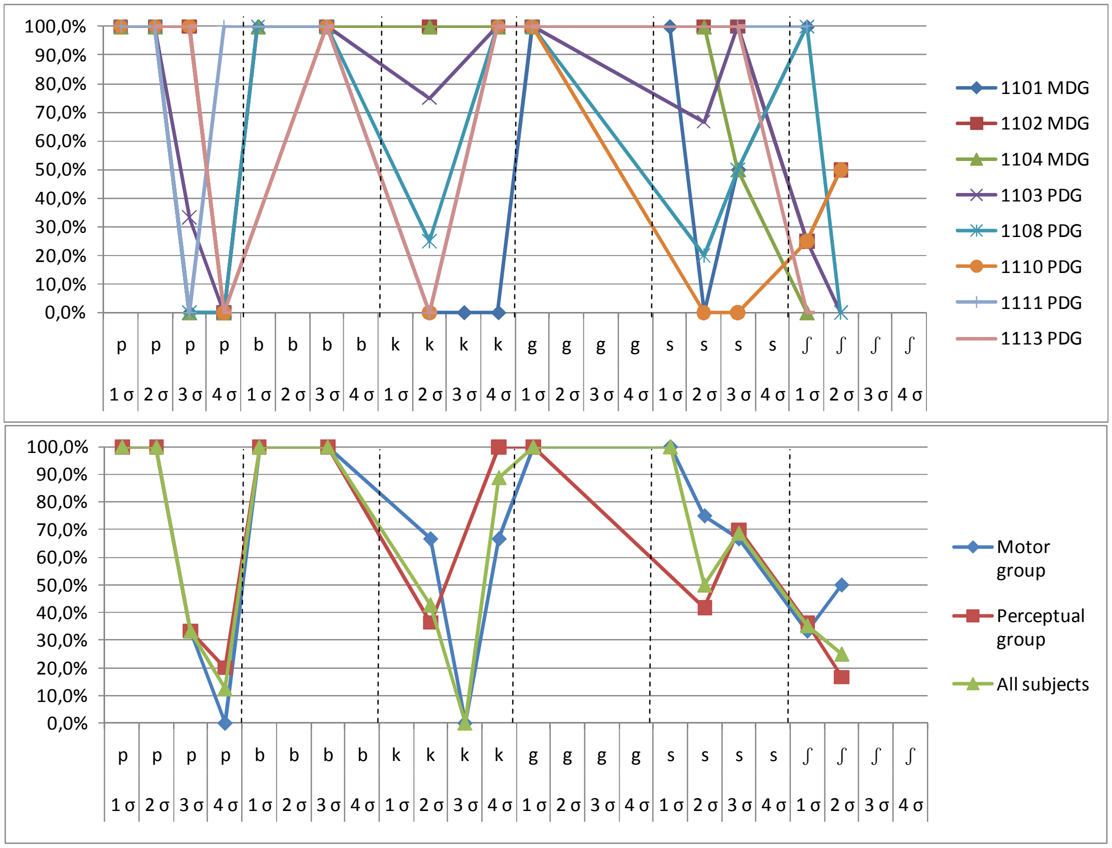
The following figures show the PCCs of the target sounds depending on their phonological context, Figure 6 for the sounds at the onset position, and Figure 7 for the sounds at the coda position. The number of opportunities per subject for each element is found in Appendix 5. The top graph shows the results per subject, while the one at the bottom presents the results of all the subjects together, as well as by subgroups.

Figure 6: PCC of each target sound at the onset position, with the sound in increasing order of articulatory complexity, depending on the target words' length (as determined by the number of syllable). The results per subject are shown at the top; the results per group at the bottom.



When the number of syllables of the target word and the target sounds are taken into consideration for the sounds at the onset position, the accuracy of the sounds' production clearly decreases as the articulatory complexity of the sounds increases. Furthermore, the motor group shows more pronounced difficulties with the sounds having a higher articulatory complexity (i.e. /s/ and /ʃ/) than the perceptual group, for all target word lengths. However, the individual results show a lot of variation.

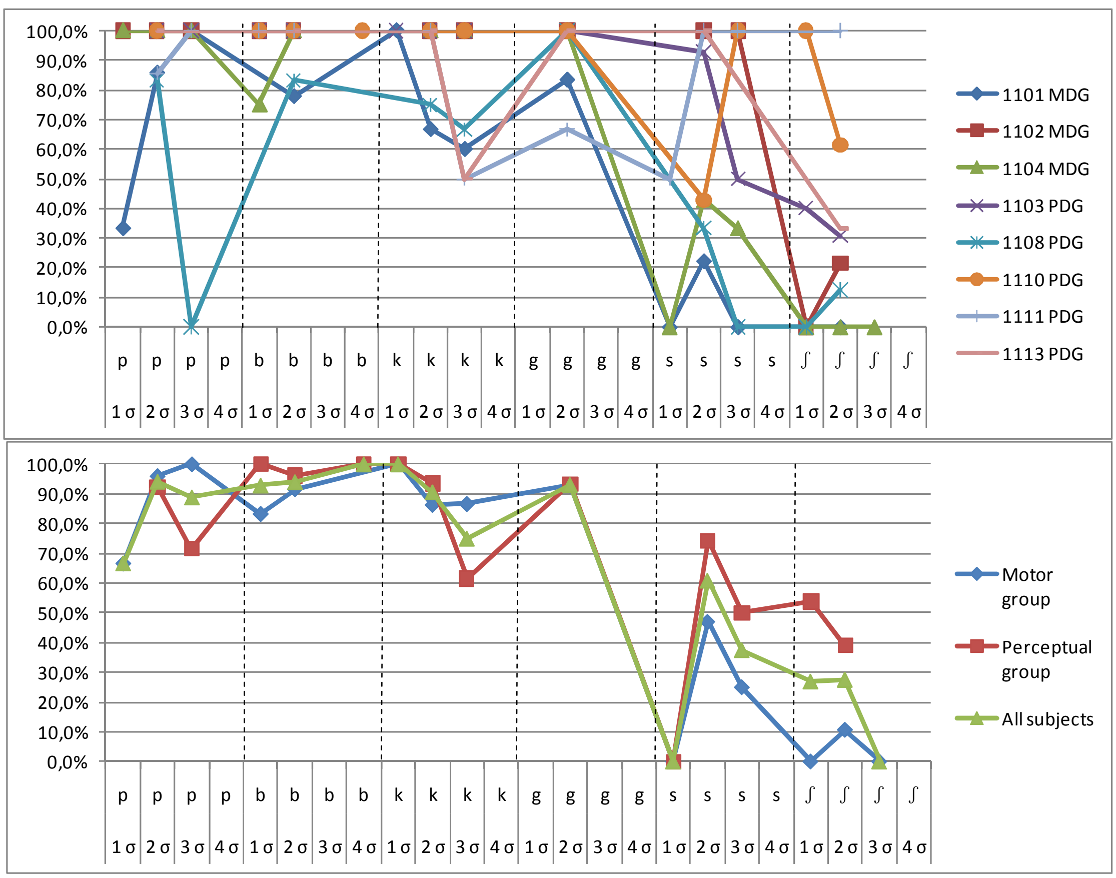
Figure 7: PCC of each target sound at the coda position, with the sounds in increasing order articulatory complexity, depending on the target word length (as determined by the number of syllable). The results per subject are shown at the top; the results per group at the bottom.



The results for the sounds at the coda position, when the target sounds are ordered by articulatory complexity and target word length, does not have items for many of the target elements. Nonetheless, we can observe that the PCCs are overall lower than for the corresponding onset elements. Also, the coda elements are more influenced by the word length even for sounds with lower articulatory complexity. Again, there was a lot of individual variation.

In order to eliminate some of the individual variations, Figure 8 presents the same elements as Figure 6. However, the PCC were calculated only when subjects had a minimum of two opportunities for the target element. The top figure shows the results per subject, while the one at the bottom presents the results of all the subjects together, as well as by subgroups.

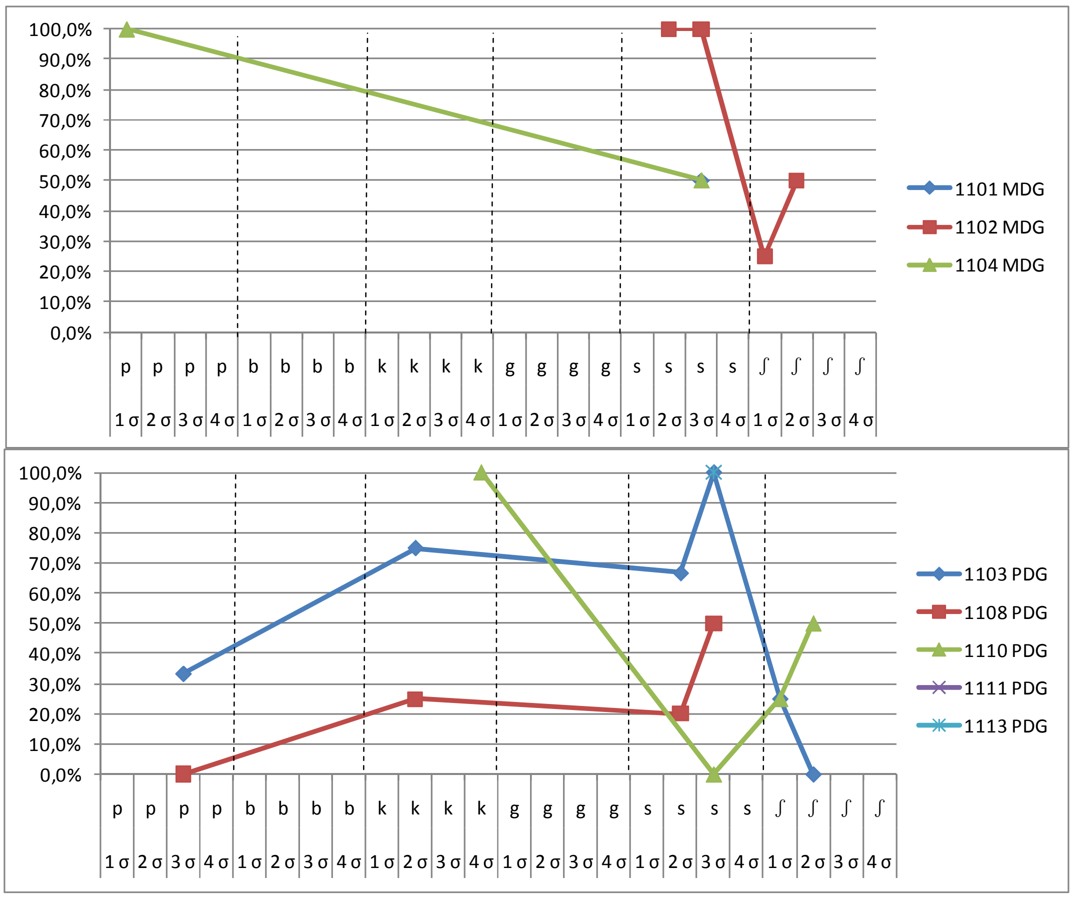
Figure 8: PCC of each target sounds at the onset position, with the sound in increasing order of articulatory complexity, depending on the target words' length (as determined by the number of syllable), with a minimum of 2 opportunities per subject for each element. The results per subject are shown at the top; the results per group at the bottom.



When a minimum of two opportunities is required for each target element, the individual results show much less variability. Overall, sounds with higher articulatory complexity show lower PCCs, and for a given sound the PCCs are stable or decrease as the number of syllables increases. The groups results are unexpectedly low for two elements, namely the /p/ in one-syllable words for the motor group and the /p/ in three-syllable words for the perceptual group. These are due to a single subject having an extremely low PCC for that element, while the other subjects have a high PCC. The effect of word length is particularly apparent for the sounds /k/, /s/ and /ʃ/, although the latter two show extremely low PCCs for 1 syllable words.

For Figure 9, due to the small number of observations for all target elements, only the individual results are presented, with the subjects in the motor group in the top figure and the subjects on the perceptual group in the bottom one.

Figure 9: PCC of each target sounds at the coda position, with the sounds in increasing order of articulatory complexity, depending on the target words' length (as determined by the number of syllable), with a minimum of two opportunities per subject for each target element. The results for the subjects in the motor group are shown at the top; the results for the subjects in the perceptual group at the bottom.



When a minimum of two opportunities is required, only a few elements remain. Nonetheless, these results show a more pronounced difficulty with the sounds at the coda position thant those at the onset position, since PCCs at the coda are lower.

Discussion

The PCCs of the target sounds elicited either from the spontaneous word elicitation task obtained from the TFP or the delayed imitation task obtained on the production probes of the therapy targets have been used as an indicator of the accuracy of production of these sounds. Then, these PCCs have been organised to reflect two hypotheses: the frequency hypothesis and the articulatory complexity hypothesis. In both cases, the sounds were ordered to present the sounds predicted to be the most accurate sounds first and the least accurate last. The obtained results showed clearly that both the motor and the perceptual groups followed the same hypothesis, namely the articulatory complexity hypothesis. The only major difference between the two groups is the more pronounced difficulty of the motor group with the harder to articulate sounds, namely /s/ and /ʃ/. These results indicate that, although French has a simpler phonological system than English, the accuracy of production of children with SSD is best accounted for by the same element. Since the origin of the disorder, either perceptual or motor difficulties, does not affect this element, it is likely that normally developing children would also be affected by this factor. Although articulatory complexity is clearly the element that most affects the accuracy of production, some unexpected variations with the sounds with a simpler articulation are nonetheless present. In itself, the articulatory complexity of the sounds is thus not sufficient to explain all of the obtained results. The implication of the phonological context has been taken into consideration to further explain the results.

When only one of the elements related to the phonological context, namely word length, as determined by the number of syllables, or the syllable positions are taken into consideration, a lot of individual variations occur. Even when both of these elements are considered simultaneously, the individual variations are very high and prevent drawing clear conclusions regarding the impact of these elements on the accuracy of production. However, if these elements are combined with the articulatory complexity hypothesis, the obtained results best explained the production accuracy of children. As the sounds are more complicated to articulate, the less accurate they become. Furthermore, production accuracy for a given sound decreased as the number of syllables increased. This is particularly apparent for the /k/, /s/ and /ʃ/. The only unexpected results concern the 1-syllable words for the /s/ for both groups and the /ʃ/ in the motor group, which shows a lower PCC than the 2-syllables words. These results may be explained by the fact that these two sounds were often selected as therapy targets, and thus were elicited many times in the production probes of children with particular difficulties with these sounds. Again, the more pronounced difficulty of the motor group with the harder to articulate sounds can be observed even when phonological context is considered. Finally, the comparison between syllable positions at the individual level shows that for a given sound and word length, the PCCs at the onset is similar or above the PCCs at the coda. These results indicate that when assessing the phonological abilities of children, it is important to consider the phonological context in addition to the target sounds. The use of the non-linear phonology as framework for the development of a test of phonology is thus supported by the obtained results.

The more important difficulty of the motor group for more complex sounds can be explained using the DIVA model (Direction Into Velocities of Articulator; Guenther, 1994). This computational model explains the improvement of a child’s motor control through practice by the gradual development of three subsystems. The first two subsystems are the auditory feedback control and the somatosensory feedback control, which are both feedback control subsystems transmitting information via the auditory/somatosensory state and error maps before providing commands to the articulatory velocity and position maps controlling musculature. The third system is the feedforward control system, which provides these commands directly or via the cerebellum. Under this model, the first step in learning consists of the creation of associations between somatosensory, auditory and articulatory information via a stage similar to babbling. Based on the knowledge gained during that period and the presentation of speech, the next step consists of the mapping between the acoustic signals of speech elements with their corresponding auditory targets. Once these target regions associated with a sound are generated, it becomes possible to attempt their production using the auditory feedback subsystem. Every time the sound is produced, the commands passing through the auditory state and error maps are incorporated into the feedforward subsystem. This more direct subsystem is thus gradually finely tuned, and will eventually become the main commands to be used during production. At the same time, the somatosensory feedback system is also developed at each production attempt. Eventually, the feedback systems are not required during normal speech production, because the feedforward system has become sufficiently accurate to produce errorless productions (Guenther, 2006).

In the case of children with SSD due to motor difficulties, it is likely that the feedforward commands take longer to be finely tuned due to errors related to diminished motor control. Indeed, the fine details related to the production of the more complex sounds are hard to produce, and the actual motor movements the child executes may not be the intended movement. This leads to a discrepancy between the articulatory velocity and position maps (the intention) and the auditory and somatosensory maps of the feedback subsystem (what has really been obtained or done). Because of this discrepancy, it is likely that the child takes longer to develop an efficient feedforward subsystem, leading to a longer and more severe period of inaccurate production.

There are four major limitations in this study. First, the very low number of subjects, particularly in the motor group, made it impossible to use inferential statistics. Second, the differences in the target words across subjects, and the unbalanced difficulty of the items used to evaluate the accuracy of the target sounds, may have biased the results. This is particularly true for the sounds /s/ and /ʃ/, which were over-represented for children having difficulty with these sounds, since they were therapy targets and tested more intensively in the production probes. Third, the low number of items for each of the target elements when both the phonological context and articulatory complexity of the sounds are considered may misrepresent the true accuracy level of the subjects. Finally, the ordering of the target elements follows an ordinal scale, which means that for each factor, namely the articulatory compexity and the frequency, each target consonant is located at various degree of difference along the scale.

In order to investigate in more depth the relation between articulatory complexity of the sounds and the phonological context, further studies controlling for these two elements, using more test items for each target element, and using more subjects should be performed. Furthermore, testing normally developing children would allow confirming that the accuracy of sound production of all Francophone children is linked to the articulatory complexity of the sounds. If the consonantal development of normally developing children shows that the articulatory complexity of the sounds is indeed the primary factor accounting for the accuracy of production in French, we might expect between French and English different age of acquisition for the same phoneme as a consequence of their different phonological systems' complexity. Being less complex than English, French consonants should be mastered faster by children speaking that language. Our current state of knowledge does not allow one to make definite conclusions on that matter, due to the sparse published documents about sound acquisition in French (e.g. Aicart-de Falco & Vion, 1987; Houdebine, 1985). The high variability in reported age of acquisition for English phonemes, which is highly linked to the different research methods and criteria used to declare a phoneme mastered (Roseberry-McKibbin & Hegde, 2006), also precludes conclusions on that matter. Furthermore, previous studies in French and English have not been conducted from the perspective on non-linear phonology, and thus interactions among the segmental and prosodic ties of the phonological hierarchy have not been taken into account.

Future research comparing French and English consonantal acquisition must use the same research method and mastery criterion, as well as a representative sample of each language that considers the segments as well as the phonological context, in order to shed some light on this issue.

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- http://www.unice.fr/LPEQ/base_AoA/aoa_intro.php.
- http://www.lexique.org/listes/liste_phonemes.txt
- BD2I : http://webu2.upmf-grenoble.fr/Banque_images/
- LEXIQUE : http://www.lexique.org/telLexique.php
- NOVLEX: http://www2.mshs.univ-poitiers.fr/novlex/
- OMNILEX : http://www.omnilex.uottawa.ca./scrQueryDatabase.asp

Appendix 1: Subject description and group assignment of subjects

Failed elements highlighted in pink; 2 orange = motor group (MDG), 2 green = perceptual group (PDG), 1 each = ambiguous

The subject 1107 droped-out of the ECRIP study.

	1101	**1102**	**1103**	**1104**	**1105**	**1106**	**1108**	**1109**	**1110**	**1111**	**1112**	**1113**
Group assignment	MDG	MDG	PDG	MDG	ambi.	n/a	PDG	ambi.	PDG	PDG	ambi.	PDG

		1101	**1102**	**1103**	**1104**	**1105**	**1106**	**1108**	**1109**	**1110**	**1111**	**1112**	**1113**
	age (year ;month)	5;0	4;9	4;2	4;11	4;5	n/a	4;3	4;9	4;10	4;6	4;0	4 ;8
OSMSE	DDK (/5)	5	3	5	4	4	n/a	5	5	5	5	3	5
	Structure	31	31	31	31	31	n/a	29	31	28	31	31	31
	Function	19	21	23	17	18	n/a	20	20	20	21	20	21
	pass/fail*	fail	fail	Pass	fail	fail	n/a	pass	pass	pass	pass	fail	pass

		1101	**1102**	**1103**	**1104**	**1105**	**1106**	**1108**	**1109**	**1110**	**1111**	**1112**	**1113**
Perceptual abilities	PAT	16	16	5	11	4	5	4	10	4	4	5	16
	Sails-module	fée	chat	cœur	chat	chat	roue	chat	n/a	gris	lait	seau	chat
	block 1	80	90	40	70	80	50	50		10	70	60	40
	block 2		80	40	100	80	80	50		50	60	50	60
	Sails-module	chat	jeu	chat	jeu	tache	tuque	jeu		clou	gris	œuf	tache
	block 1	80	70	70	90	90	100	70		90	40	50	50
	block 2	70	70	100	80	90	80	50		100	70		50
	Sails-module	cœur	gris	tache	lait	jeu	clou			chat	roue	roue	
	block 1	70	50	80	100	90	40			60	40	70	
	block 2	70	80	100	90	100	60			50	70	75	
	pass/fail	pass	pass	Fail	pass	fail	fail	fail	pass	fail	fail	fail	fail

Appendix 2 - TFP characteristics

Difficulty of the word list

The two word lists have been matched in terms of word difficulty, as evaluated by the average age of acquisition and average word frequency.

The age of acquisition information is based on four different sources reporting actual age of acquisition: Hazard, De Cara & Chanquoy (2007); Chalard, Bonin, Méot, Boyer & Fayol (2003); Bonin, Boyer, Méot, Fayol, & Droit (2004); and Cannard, Bonthoux, Blaye, Scheuner, Schreiber & Trinquart (2006). All these sources used set of drawings to elicit the target words, and the age reported as the age of acquisition is the age at which 75% of the children could correctly identify the drawing. In the cases where two sources report different age of acquisition, the average has been calculated and used as the age of acquisition for the word. In the cases where the age was reported in years, it has been considered to be at the end of that year, i.e. 2 years was interpreted as 2;11.

Table 7. Distribution of the words according to the age of acquisition of the words, test versions A and B

Age of acquisition	**Nb of words** **Version A**	**Nb of words** **Version B**
2-2;12	12	11
3-3;12	10	9
4-4;12	5	7
5-5;12	2	4

Age of acquisition	**Nb of words** **Version A**	**Nb of words** **Version B**
6-6;12	3	1
7-7;12	2	3
not available	20	19
Number of words	*54*	*54*
Average age of acquisition	*3,41*	*3,54*

The choice of frequency database is important if that information is to be used as an indication of the age of acquisition. Indeed, as reported by Hazard, De Cara & Chanquoy (2007), the age of acquisition is better correlated with frequency reported in database based on children literature rather than on adult literature. The relation between the two is that the higher the frequency of the word is, the younger its age of acquisition. The database used to determine the average frequency of the word lists was NOVLEX (Chesnet & Lambert, 2001), an European database based on 19 school books and 19 extra-scholar books intended for children 8-9 years old. The database proposes two types of frequency: the '*base d'occurrence'*, where all the derivations of a word are considered individually, and the '*base lexicale'*, which regroups the derived words under its root. Eg. In the '*base d'occurrence*', *bouquet* = 3570, *bouquets* = 952, but in the '*base lexicale*', *bouquet* = 3570 + 952 = 4522. The frequency used in the analysis is the frequency provided in the '*base lexicale'*. Presented below is the summary of the information for each test version.

Table 8. Distribution of the words according to the frequency of the words, test versions A and B

Lexical frequency	**Nb of words** **Version A**	**Nb of words** **Version B**
under 1000	6	11
1000-9999	23	19
10000-99999	21	22
100000+	1	1
na	3	1
Number of words	*54*	*54*
Average frequency	*15877*	*16105*

To conclude on the similarity of the two versions' difficulty, we can reasonably say that the two versions are highly similar. Based on the information on the age of acquisition, the version A is marginally easier than the version B, with an average age of acquisition of 0,13 year younger. On the other hand, using the frequency average as the indicator of the difficulty, the version B would be marginally easier than version A, with a frequency average higher by 228.

Syllable types, word length and comparison to French

In French, the syllable is made of an onset and a rhyme, which is further divided into a nucleus and a coda (Bernhardt & Stemberger, 1998; Casagrande, 1984; Goldsmith, 1990). All these positions can branch (i.e. they can contain two elements) (Encrevé, 1988; Goldsmith, 1990), and the two branching elements may have a distinct place of articulation (e.g. ‘plat’ [pla] (*flat*)). However, a growing body of research suggests that in French the final consonant clusters are complex onsets of empty-headed syllable (OEHS) or a singleton coda followed by an OEHS (Steele, 2002; Féry, 2003; Goad & Brannen, 2003; Demuth & Kehoe, 2006). Contrary to English, with its syllabic liquids and nasals, only the vowel can occupy the nucleus position (Ayres-Bennett & Carruthers, 2001; Casagrande, 1984). However, the nucleus can branch to have a glide preceeding the vowel (Kaye & Lowenstamm, 1984, cited in Encrevé, 1988). Finally, although the onset position may appear empty (e.g. ‘ami’ [ami] (*friend*)), its skeletal tier is always present in the underlying representation, which allows for the liaison to occur (e.g. ‘l’ami’ [lami] (*the friend*)). In French, the two obligatory elements are thus the onset (which may or may not be empty) and the nuclei (Brousseau & Nikiema, 2001).

It has been decided that word-final consonants will be identified as codas or branching codas. To support this decision is the fact that this issue about syllabification has not yet been resolved, since there are facts supporting both the OEHS and the coda position theories (Demuth & Kehoe, 2006), and that the available information on French syllable distribution (see below) follows the coda theory.

Based on this language specific information, the following elements should be part of the evaluation of the phonology of children to ensure that the whole set of possible syllable shapes is tested. For each element, the number of words per test version testing a specific syllable shape is indicated.

Table 9. Number of opportunities for the target elements other than phonemes per test

	Number of words Version A	**Number of words Version B**
empty onset	12 (9 initial, 3 internal)	13 (10 initial, 3 internal)
branching onset	13 (10 initial, 3 internal)	10 (8 initial, 2 internal)
coda – singleton	36 (9 internal, 27 final)	36 (7 internal, 29 final)
coda – branching	6 (0 internal, 6 final)	6 (2 internal, 4 final)
branching nucleus (i.e. glide + vowel)	11	8
total number of syllables	107 syllables	111 syllables

The two lists have been created to be comparable to French phonology. Following the selected theory of non-linear phonology, both word shapes and phoneme distribution were considered. Please note that, contrary to English, stress is predictable and it has no contrastive value (Walker, 1984). It is thus not taken into account in the analysis. More details on these elements will be presented in the next section.

Presented below is the summary of the information on word shape, using information extract from NOVLEX database regarding the percentage of word depending on the number of syllables for children, and from LEXIQUE 3.45 for information on adults.

Table 10. Distribution of words based on the number of syllable for both versions, and comparison with French

Number of syllable per words	**Percentage of words Version A**	**Percentage of words Version B**	**In French – Children**	**In French - Adults**
1 syllable	28%	24%	13%	7%
2 syllables	50%	50%	42%	33%
3 syllables	19%	22%	34%	41%
4 syllables	4%	4%	9%	15%
> 4 syllables	0%	0%	2%	4%

The table shows that the two test versions are comparable to each other in terms of percentage of words per number of syllables. However, there are differences when compared to the distribution in French – Children, mainly due to an over-representation of mono- and bi-syllabic words and an under-representation of tri- and four- syllabic words. These differences are voluntary and aimed at decreasing the level of difficulty of the word lists. Indeed, the TFP is aimed at children as young as 2 and 3 years old, which is considerably younger than the age used in the database NOVLEX (based on literature for children 8-9 years-old), and it is well-known that the vocabulary of young children is mainly composed of short words. Furthermore, if we consider the proportion of words per number of syllables for the adults and children distribution, we can observe the same differences, i.e. an over-representation of mono- and bi-syllabic words and an under-representation of tri- and four- syllabic words for the children. It is thus reasonable to believe that the obtained percentages of the two test versions are representative of French for younger children.

Another element to consider in the description of the word shape is the type of syllables present in the words. The main categories of syllables are the open syllables (i.e. without a coda), and the closed syllables (i.e. with a coda). There is also the distinction between the presence of singleton consonants and of consonant clusters. Presented below are the characteristics of the two word lists for these elements, and the percentage that are found in French based on Vallée (2004).

Table 11. Distribution of the syllable type per test version, and comparison with French

	Percentage of syllable Version A	**Percentage of syllable Version B**	**In French**
syllables with a coda (word-internal or word-final)	36%	36%	27%
syllables with a cluster (onset or coda)	15%	12%	18%

This table shows that the two test versions are highly similar. However, there is a somewhat significant over-representation of closed syllables and a slight under-representation of clusters. This can be explained by the necessity to select the minimal number of words that would cover all sounds in all positions. To have the word lists correspond to the distribution of French would require many more words, and it was considered that the obtained percentages were not sufficiently different from the distribution of French to require such an addition. Indeed, because the TFP is intended to test children, it is important to keep the word list as short as possible, to ensure better cooperation from the child up to the end of the test.

Furthermore, there are two cluster-reduction rules that prevent the use of many final consonant clusters, since it is important that there is only one acceptable pronunciation per target word. Using words that can to be reduced in their pronunciation does not provide information on the capability of the child to pronounce the cluster, since the reduction may be due to the application of the rule or inability to pronounce the cluster. These rules are the following:

Final consonant cluster reduction

Word final stops, when preceded by another stop or by a fricative, can be deleted. This rule affects mainly /t/, since /p k/ are rarely preceded by another stop or by a fricative, and the voiced /b d g/ never are. For example, ‘casque’ (*helmet*) can be pronounced [kask] or [kas] (Ostiguy, Sarrasin and Irons, 1985:123).

/r l/ deletion

The liquids /r l/ can be deleted word finally when preceded by a stop or a fricative. For example, ‘couple’ (*couple*) can be pronounced [kʊpl] or [kʊp] (Ostiguy, Sarrasin and Irons, 1985:124).

Distribution of phonemes

There are 17 phonemic consonants in French that are uncontroversial and three glides, as presented in the table below (Laboratoire de Phonétique et Phonologie de l'Université Laval à Québec). The sounds at the left of the slash are voiceless sounds, and the ones at the right are the voiced sounds.

Table 12. French consonants

	Bilabial	Labiodental	Apico-alveolar	presdorsal-alveolar	Predorso-postalveolar	Dorso-palatal	Dorso-velar	Postdorso-uvular
Stops	p / b		t / d				k / g	
Fricatives		f /v	/ l	s / z	ʃ / ʒ			/ ʁ
Nasals	m		n			ɲ		
Glides (fricatives)						j / ɥ	/ w	

The well-known affricates [t^s d^z] used in Quebec French are absent from this table because these sounds are allophones of /t d/ (Kim, 2001; Walker, 1984). Concerning the sound /ʁ/, it exists some variations in its pronunciation, such as [r ʀ ɹ]. However, these forms are less frequent or are specific to certain region, which lead to consider only /ʁ/ as phonemic (Ostiguy, Sarrasin & Irons, 1985; Ayres-Bennett & Carruthers, 2001; Martin, 1996).

In Quebec French, there are 12 oral vowels and 4 nasal vowels, as indicated in the table below (Laboratoire de Phonétique et Phonologie de l'Université Laval à Québec). The sounds at the right of a slash are nasal vowels.

Table 13. French vowels

	Anterior		Central	Posterior	
	unrounded	rounded	unrounded	unrounded	rounded
high	i	y			u
mid-high	e	ø			o
mid			ə		
mid-low	ɛ / ɛ̃	œ / œ̃			ɔ / ɔ̃
low	a			ɑ / ɑ̃	

Laxing of high vowels and diphthongisation of the vowels occurring in Canadian French have not been taken into account because they are allophonic variations (Walker, 1984).

Presented below is the summary of the information the distribution of consonants, using the information provided in Wioland (1985) for the information on French phonemic distribution.

Table 14. Distribution of the consonant per test version, and comparision with French

Consonants	Version A	Version B	French
voiceless stops /p t k/	24%	26%	23%
voiced stops /b d g/	13%	12%	11%
voiceless fricatives /f s ʃ ɥ/	13%	14%	14%
voiced fricatives /v z ʒ l ʁ w j/	39%	39%	40%
nasal stops /m n ɲ/	11%	9%	12%

The 20 consonantal sounds are represented in both test versions in similar proportions. All sounds, apart from the exceptions discussed in the following lines, are present at least once for the onset-initial, onset-internal and coda-final positions. Only some sounds are represented at the coda-internal position. However, as mentioned above, there is already an over-representation of coda for both test versions. It was thus considered sufficient to have all sounds represented at the coda-final position, and only a few sounds at the coda-internal position to ensure that the child has the ability to produce consonants at that position. There are no exemplars of / ɥ w/ as coda, because these sounds never occupy that position (Ayres-Bennett & Carruthers, 2001; Walker, 1984). Furthermore, since the semi-vowels are usually considered as part of a branching nucleus (Ayres-Bennett & Carruthers, 2001), and due to the low frequency of /ɥ w/, it has been considered sufficient to have only one exemplar for these sounds for all positions. Because /j/ is more frequent as a consonant than the other glides, it as been included in the other positions. The absence of /ɲ/ at the word-initial position is due to the extremely low frequency of that phoneme at that position. Indeed, there is no occurrence of a word using that phoneme word-initially in the database NOVLEX, and only 26 are present in the database OMNILEX, which has 102000 entries. There are more variations for the content of the consonant clusters. However, the two tests are still similar on the number and variety of consonants.

Presented below is the summary of the information on the distribution of vowels, using the information provided in Wioland (1985) for the information on French phonemic distribution.

Table 15. Distribution of the vowels per test version, and comparision with French

Vowels	Version A	Version B	French
unrounded front	59%	55%	56%
rounded front	6%	5%	7%
unrounded back	1%	1%	-
rounded back	18%	23%	13%
central (shwa)	2%	3%	8%
nasal front	5%	3%	4%
nasal back	10%	11%	12%

These tables also show that the two test versions are highly similar regarding vowel distribution, and that both are also highly similar to French distribution. The main difference consists of an under-representation of the shwa (6% and 5% variation for version A and B respectively). However, this difference is likely due to the fact that shwa is most often deleted in 'casual' speech, even though it is maintained in formal speech (Casagrande, 1984). Words that might have been pronounced with a shwa, (eg, *cheval)*, have been exclude from the lists because of this optional pronunciation.

Word lists

Each test version is composed of a list of 54 words. The words ‘oui’ (*yes*) and ‘huit’ (*eight*), are present in both test versions, but they are prompted using a different elicitation question. The use of the same words in both versions allows to test the sounds [ɥ w] at the word-initial onset position. These sounds are rare in that position, since the glide usually is part of a branching nuclei, and from the possible words only these two were likely to be known by young children. It has been judged better to have the same word in both versions than to have words children would not know. Provided below are the two word lists.

Table 16. Word list, test version A

1	album	19	enveloppe	37	nuage
2	amoureux	20	escalier	38	oui
3	aquarium	21	feuille	39	parapluie
4	araignée	22	fleur	40	peinture
5	avion	23	framboise	41	rapetisser
6	beigne	24	garde-robe	42	serpent
7	bibliothèque	25	gardien	43	singe
8	brun	26	géant	44	soleil
9	camion	27	girafe	45	spectacle
10	carte	28	glissade	46	table
11	chapeau	29	graffigner	47	tomber
12	château	30	hélicoptère	48	tournevis
13	clown	31	huit	49	train
14	cochon	32	langue	50	traineau
15	crayon	33	lunettes	51	vaisselle
16	cuisine	34	manger	52	vélo
17	doigt	35	marionnette	53	yogourt
18	élève	36	niche	54	zoo

Table 17. Word list, version B

1	assiette	19	éléphant	37	œuf
2	autobus	20	emballage	38	oignon
3	autruche	21	escargot	39	orangeade
4	biberon	22	étoile	40	oui
5	bleuet	23	fourchette	41	parfum
6	bouteille	24	fromage	42	poisson
7	catalogue	25	garde-manger	43	pomme
8	céréales	26	gâteau	44	robot
9	chaise	27	genoux	45	soulier
10	chien	28	grenouille	46	spaghetti
11	ciseau	29	huit	47	téléphoner
12	congélateur	30	lapin	48	tortue
13	crabe	31	lune	49	(il) traverse
14	crocodile	32	maison	50	trompe
15	cuiller	33	montagne	51	vache
16	dehors	34	nappe	52	valise
17	détective	35	noyau	53	yo-yo
18	élastique	36	nuit	54	zèbre

Appendix 3: Transcription reliability

Table 18. PCCs per subjects for every syllable position and target sounds

	Opp.	1101 MDG	1102 MDG	1103 PDG	1104 MDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG	Average
Per syllable position (all consonants in the TFP)										
A	82	93%	99%	100%	98%	91%	93%	93%	94%	95%
Ab	26	85%	100%	92%	92%	92%	96%	100%	100%	95%
C	36	78%	100%	100%	94%	89%	92%	100%	86%	92%
Cb	6	83%	100%	100%	100%	100%	83%	100%	100%	96%
PCC	161	87%	99%	99%	96%	92%	93%	96%	93%	94%
Per target sound (only the sounds used in the study, all syllable positions)										
p	9	89%	100%	100%	100%	100%	100%	100%	78%	96%
k	12	75%	100%	92%	92%	92%	100%	92%	83%	91%
b	9	100%	100%	100%	100%	100%	100%	100%	100%	100%
g	6	83%	100%	100%	100%	83%	100%	100%	100%	96%
s	9	100%	100%	100%	89%	100%	89%	89%	100%	96%
ʃ	4	100%	100%	100%	100%	75%	75%	100%	75%	91%

Appendix 4: Detailed results per subject

MDG = motor Difficulty Group; PDG = Perceptual Difficulty Group

O = onset; C =coda

Table 19. Source of the target words for each subject, the corresponding target sounds and syllable position and the child's pronunciation.

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
Probes	jupe	/p/	C	p		p		p			
Probes	pêche	/p/	O		p		p		p		
Probes	pied	/p/	O	-	p	p					
Probes	poule	/p/	O			p				p	
Probes	puits	/p/	O	g	p	p					
Probes	ampoule	/p/	O			p				p	
TFP-Probes	chapeau	/p/	O	p	p; p	p	p; p	p	p; p	p	p

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
Probes	espace	/p/	O				p	p			
Probes	lapin	/p/	O			p				p	
Probes	panier	/p/	O	p	p	p					
TFP	peinture	/p/	O	p	p	p	p	ʔ	p	p	p
Probes	pilule	/p/	O			p				-	
Probes	pingouin	/p/	O	p	p	p					
Probes	poignée	/p/	O			p		p			
Probes	poisson	/p/	O	ʔ	p	p					
Probes	poubelle	/p/	O			p				p	
TFP- Probes	serpent	/p/	O	p	p	p	p; p	p; p	p	p	p
Probes	capuchon	/p/	O	p	p	p	p				
Probes	champignon	/p/	O			p					

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
TFP-Probes	parapluie	/p/	O	p; p	p	p	p; p	-	p	p	p
Probes	parasol	/p/	O			p				p	
Probes	pyjama	/p/	O	p		p		-			
Probes	épouvantail	/p/	O	p							
Probes	crêpes	/p/	C		p				p		
Probes	lampe	/p/	C			p				p	
TFP	enveloppe	/p/	C	p	p	p	p	p	p	p	p
Probes	capturer	/p/	C				-	-			
Probes	éruption	/p/	C				-	-			
TFP	rapetisser	/p/	C	-	p	-	p	-	p	-	p
TFP	hélicoptère	/p/	C	-	-	-	-	-	-	p	ʔ
Probes	balle	/b/	O			b				b	

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
TFP	beigne	/b/	O	b	b	p	b	b	b	b	b
Probes	bol	/b/	O			b				b	
Probes	bûche	/b/	O		b		b		b		
Probes	bulle	/b/	O			b				b	
TFP	album	/b/	O	b	b	b	b	d	b	b	b
Probes	balcon	/b/	O				b	b			
Probes	baleine	/b/	O			b				b	
Probes	ballon	/b/	O			b				b	
Probes	batterie	/b/	O		b				b		
Probes	berceau	/b/	O	b; b			b; b	b			
Probes	bijoux	/b/	O	b		b		b			
Probes	biscuit	/b/	O	g	b	b					

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
TFP-Probes	framboise	/b/	O	b; -	b; b	b; b	b	b	b	b	b
Probes	poubelle	/b/	O			b				b	
Probes	tambour	/b/	O	b			b				
TFP	tomber	/b/	O	b	b	b	b	b	b	b	b
Probes	bicyclette	/b/	O						b		
TFP-Probes	bibliothèque	/b/	O	-	b	b	b	b	b; b	-	b
Probes	jambe	/b/	C			b		b			
Probes	robe	/b/	C	b			b				
TFP	garde-robe	/b/	C	b	b	b	b	b	b	b	b
TFP	carte	/k/	O	k	k	k	k	k	k	k	t
Probes	cœur	/k/	O	k			k				

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
Probes	cor	/k/	O	k			k				
Probes	balcon	/k/	O				k	k			
Probes	biscuit	/k/	O	g	k	k	k	k			
Probes	cactus	/k/	O				k	k			
Probes	cadran	/k/	O				k	k			
Probes	cafetière	/k/	O	k	k	k					
TFP	camion	/k/	O	k	k	k	k	k	k	k	k
Probes	canard	/k/	O	k			k				
Probes	caniche	/k/	O		k		k		k		
Probes	cassette	/k/	O	k							
TFP-Probes	cochon	/k/	O	k;k	k;k	k;k	k;k	m;k	k;k	k	k
Probes	coiffeur	/k/	O	ʔ	k	k					

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
TFP	cuisine	/k/	O	-	k	k	k	b	k	k	k
Probes	flocon	/k/	O						k		
Probes	raquette	/k/	O	k			k				
TFP	aquarium	/k/	O	-	k	k	k	-	k	-	-
Probes	arc-en-ciel	/k/	O	-	k	k					
Probes	capturer	/k/	O				k	k			
Probes	capuchon	/k/	O	k	k	k	k				
TFP	escalier	/k/	O	k	k	k	k	k	k	k	k
TFP	hélicoptère	/k/	O	k	k	-	k	-	k	t	t
Probes	cactus	/k/	C				k	k			
Probes	facteur	/k/	C				k	-			
TFP	spectacle	/k/	C	-	k	k	-	-	-	-	-
Probes	tracteur	/k/	C				k	-			

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
Probes	saxophone	/k/	C	-							
TFP-Probes	bibliothèque	/k/	C	t	k	k	k	k	k; k	k	k
Probes	dragon	/g/	O		g				g		
Probes	garçon	/g/	O	g			g				
TFP	gardien	/g/	O	g	g	g	g	g	g	g	g
Probes	gorille	/g/	O	g			g				
Probes	guitare	/g/	O	g			g				
Probes	légumes	/g/	O			g				g	
Probes	pingouin	/g/	O	-	g	g					
TFP	yogourt	/g/	O	g	g	g	g	g	g	g	g
TFP	garde-robe	/g/	O	g	g	g	g	-	g	g	g
TFP	langue	/g/	C	g	g	g	g	g	g	g	g

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
Probes	sel	/s/	O	ʔ							
Probes	selle	/s/	O			s̩				s	
TFP	singe	/s/	O	-	s	s̩	s	s	s̩	s̩	t
Probes	soupe	/s/	O	ʔ							
Probes	berceau	/s/	O	ʔ; s			s; ʃ	b			
Probes	cassette	/s/	O	s							
Probes	citron	/s/	O		s				s		
Probes	garçon	/s/	O	ʔ			s				
TFP	glissade	/s/	O	-	s	s̩	s	s	s̩	s	s
Probes	glissoire	/s/	O						s		
Probes	poisson	/s/	O	ʔ	s	s̩					
Probes	racines	/s/	O	s			s				
Probes	sapin	/s/	O	s; p							

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
Probes	savon	/s/	O	-							
Probes	sécheuse	/s/	O		s		s				
TFP-Probes	serpent	/s/	O	-	s	s̪	s; s	s̪; -	s̪	s	s
Probes	sifflet	/s/	O						ʃ		
TFP	soleil	/s/	O	-	s	s	s	-	s	s	s
Probes	sorcière	/s/	O	-; -	s	s	s				
Probes	sorcière	/s/	O	-; -	s; s	s	s				
Probes	sourire	/s/	O	-			s				
Probes	souris	/s/	O	ʔ			s				
TFP	vaisselle	/s/	O	-	s	s̪	s	s	s̪	s	s
Probes	arc-en-ciel	/s/	O	-	s	s					
Probes	bicyclette	/s/	O						s		

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
Probes	éruption	/s/	O				s	ʃ			
Probes	parasol	/s/	O			s̪				s	
TFP	rapetisser	/s/	O	-	s	s̪	-	-	s	s	s
Probes	saxophone	/s/	O	-							
Probes	vis	/s/	C	s							
Probes	biscuit	/s/	C	-	s	s	s	-			
Probes	cactus	/s/	C				s	s			
Probes	espace	/s/	C				ʔ	-			
Probes	espace	/s/	C				s	ʃ			
Probes	moustache	/s/	C		s		s; -	m	-		
TFP	escalier	/s/	C	-	s	s̪	s	-	-	s	s
TFP	tournevis	/s/	C	s	s	s	s	s	s̪	s	s
Probes	chaîne	/ʃ/	O		s̪	s̪	s	ʃ̪	ʃ		

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
Probes	chaise	/ʃ/	O		s		s		ʃ		
Probes	chat	/ʃ/	O	-	s	s̪	s	ʃ̪	ʃ		
Probes	chien	/ʃ/	O	-	s	s̪					
Probes	chou	/ʃ/	O	-	s	s̪	ʃ	ʃ̪	ʃ		
Probes	chute	/ʃ/	O		s		ʃ		ʃ		
Probes	brochette	/ʃ/	O		s				s		
Probes	chandelle	/ʃ/	O		s	s̪; s̪	s	-	ʃ	ʃ	
TFP-Probes	chapeau	/ʃ/	O	ʔ	s; s	s	s; s	t	ʃ̪; ʃ	ʃ	ʃ
TFP-Probes	château	/ʃ/	O	-; -	s; s	s̪; s̪	s; s	s; s	s̪; ʃ	ʃ	s
Probes	chemise	/ʃ/	O		s		s		ʃ		
Probes	chevreuil	/ʃ/	O		ʃ; s		ʃ		s; ʃ		
TFP-probes	cochon	/ʃ/	O	ʔ; ʔ	s; ʃ	s̪; s̪	ʃ; s	s; ʃ	s; ʃ	ʃ	s

Source	Words	Target Sounds	Syllable position	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG
Probes	échelle	/ʃ/	O		s		ʃ		ʃ		
Probes	fourchette	/ʃ/	O	ʔ	s	ṣ	ʃ; s	s; s	ʃ		
Probes	sécheuse	/ʃ/	O		ʃ		s				
Probes	capuchon	/ʃ/	O	ʔ	s	ṣ	s	s	ʆ		
Probes	champignon	/ʃ/	O			ṣ					
Probes	bûche	/ʃ/	C		s		ʃ		ʃ		
TFP	niche	/ʃ/	C	ʃ	s	ṣ	s	ʃ	s	ʃ	s
Probes	pêche	/ʃ/	C		h		j		ʒ		
Probes	tache	/ʃ/	C		ʃ		ṣ		-		
Probes	caniche	/ʃ/	C		s		s		ṣ		
Probes	moustache	/ʃ/	C		ʃ		s; s	ṣ	ʃ		

Appendix 5: Number of opportunity Graphs 8-9

Table 20. Number of opportunities for the Graphs 6-7 per subject and per subgroup, for the onset position

Word length	Target sounds	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG	Motor group	Perceptual group	All subjects
1 σ	p	3	3	3	1	0	1	1	0	9	3	12
2 σ	p	7	7	11	6	6	4	7	3	25	26	51
3 σ	p	4	2	5	3	2	1	2	1	11	9	20
4 σ	p	1	0	0	0	0	0	0	0	1	0	1
1 σ	b	1	2	4	2	1	2	4	1	7	10	17
2 σ	b	9	6	9	7	6	4	6	3	24	26	50
3 σ	b	0	0	0	0	0	1	0	0	0	1	1
4 σ	b	1	1	1	1	1	2	1	1	3	6	9
1 σ	k	3	1	1	3	1	1	1	1	5	7	12
2 σ	k	9	7	6	11	8	6	3	3	22	31	53
3 σ	k	5	5	5	4	3	2	2	2	15	13	28
4 σ	k	1	1	1	1	1	1	1	1	3	5	8

Word length	Target sounds	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG	Motor group	Perceptual group	All subjects
1 σ	g	0	0	0	0	0	0	0	0	0	0	0
2 σ	g	6	4	4	5	2	3	3	2	14	15	29
3 σ	g	1	1	1	1	1	1	1	1	3	5	8
4 σ	g	0	0	0	0	0	0	0	0	0	0	0
1 σ	s	3	1	2	1	1	1	2	1	6	6	12
2 σ	s	18	9	7	14	6	7	4	4	34	35	69
3 σ	s	3	2	3	2	2	2	2	1	8	9	17
4 σ	s	0	0	0	0	0	0	0	0	0	0	0
1 σ	ʃ	3	6	4	5	3	5	0	0	13	13	26
2 σ	ʃ	6	14	8	13	8	13	4	3	28	41	69
3 σ	ʃ	1	1	2	1	1	1	0	0	4	3	7
4 σ	ʃ	0	0	0	0	0	0	0	0	0	0	0

Table 21. Number of opportunities for the Graphs 6-7 per subject and per subgroup, for the coda position

Word length	Target sounds	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG	Motor group	Perceptual group	All subjects
1 σ	p	0	1	2	0	1	1	1	0	3	3	6
2 σ	p	1	1	1	1	1	1	1	1	3	5	8
3 σ	p	1	1	1	3	3	1	1	1	3	9	12
4 σ	p	1	1	1	1	1	1	1	1	3	5	8
1 σ	b	1	0	1	1	1	0	0	0	2	2	4
2 σ	b	0	0	0	0	0	0	0	0	0	0	0
3 σ	b	1	1	1	1	1	1	1	1	3	5	8
4 σ	b	0	0	0	0	0	0	0	0	0	0	0
1 σ	k	0	0	0	0	0	0	0	0	0	0	0
2 σ	k	1	1	1	4	4	1	1	1	3	11	14
3 σ	k	1	0	0	0	0	0	0	0	1	0	1
4 σ	k	1	1	1	1	1	2	1	1	3	6	9
1 σ	g	1	1	1	1	1	1	1	1	3	5	8
2 σ	g	0	0	0	0	0	0	0	0	0	0	0
3 σ	g	0	0	0	0	0	0	0	0	0	0	0
4 σ	g	0	0	0	0	0	0	0	0	0	0	0

Word length	Target sounds	1101 MDG	1102 MDG	1104 MDG	1103 PDG	1108 PDG	1110 PDG	1111 PDG	1113 PDG	Motor group	Perceptual group	All subjects
1 σ	s	1	0	0	0	0	0	0	0	1	0	1
2 σ	s	1	2	1	6	5	1	0	0	4	12	16
3 σ	s	2	2	2	2	2	2	2	2	6	10	16
4 σ	s	0	0	0	0	0	0	0	0	0	0	0
1 σ	ʃ	1	4	1	4	1	4	1	1	6	11	17
2 σ	ʃ	0	2	0	3	1	2	0	0	2	6	8
3 σ	ʃ	0	0	0	0	0	0	0	0	0	0	0
4 σ	ʃ	0	0	0	0	0	0	0	0	0	0	0