Underlying and surface manifestations of developmental phonological disorder in French-speaking preschoolers aged 4 to 6 years

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À mes parents,
Diane Brosseau Lapré et André Lapré,
pour votre amour et votre support

To Raymundo Munguia Vazquez,
Sophie and Laura Munguia-Lapré
for making me happy

Abstract

Many children misarticulate more sounds than expected for their age and present with a Developmental Phonological Disorder (DPD). Children with DPD are at risk for later academic and socio-emotional difficulties; in order for clinicians to maximize positive outcomes for these children, they need to accurately identify children who are performing below expectations for their age, select appropriate treatment goals, and provide effective intervention. Successful intervention for these children is dependent on a good understanding of the underlying nature of their disorder (Stackhouse & Wells, 1997). Whereas speech-language pathologists have been assessing the surface manifestations of communication disorders for many decades, knowledge of the underlying causes of speech and language impairments is more limited but growing. In addition, while there is a large body of research on the surface manifestations of DPD in English-speaking children, there is currently a paucity of information regarding the surface manifestation of the disorder in French-speaking children.

The purpose of the research described in this dissertation was to investigate the underlying psycholinguistic profiles and the surface manifestations of DPD in a large group of French-speaking preschoolers. More precisely, Study one aimed to determine whether the psycholinguistic profiles of French-speaking children with DPD are similar to those of English-speaking children with DPD as reported in the literature. Seventy-two French-speaking children with DPD, aged 4 to 6 years, were assessed on measures of articulation accuracy, receptive vocabulary, nonverbal intelligence, phonological processing (phonological

awareness, speech perception, syllable repetition test) and structure and function of the oral-speech mechanism. Ten typically developing French-speaking children completed the articulation accuracy, receptive vocabulary, phonological awareness, and syllable repetition tasks. Results indicated that the vast majority of French-speaking children with DPD presented with phonological processing difficulties; furthermore, measures of phonological processing explained significant variance in speech production accuracy after controlling for individual differences in receptive vocabulary skills and maternal education.

Study two aimed to determine whether surface speech errors are manifested differently in French-speaking children with DPD in comparison to a very similar group of English-speaking children with DPD. Twenty-four French-speaking children with DPD were matched on percentage of consonants correct in conversation, age, and receptive vocabulary to English-speaking children with DPD. By comparing these children's productions of consonants on a single-word test of articulation, we found that the surface manifestations of DPD are different in these two languages. The French-speaking children obtained low match ratios for the major sound class features [+consonantal] and [+sonorant], reflecting a high frequency of omission errors. In contrast, English-speaking children obtained high match ratios for the major sound class features [+consonantal] and [+sonorant] and produced more substitution errors.

The results of Study one add to the growing body of literature supporting a core deficit in phonological processing in children with DPD. In English-speaking children, this underlying deficit in phonological processing remains present regardless of environmental changes and/or the child's maturation, whereas the

surface speech errors produced by young children with DPD change as they get older and in response to environmental changes. In the studies described here, a similar core deficit in phonological processing was found in children speaking French, whereas the surface speech errors were different than those of English-speaking children, due to the differences in the phonological systems of these two languages. These findings point to the importance of assessing the phonological processing skills of children with a current or past history of DPD, as well as to the need to use test instruments with French-speaking children that reflect the phonological characteristics of the language at multiple levels of the phonological hierarchy.

Résumé

Beaucoup d'enfants ont plus de difficultés à prononcer clairement les sons que les autres enfants de leur âge, et présentent un trouble phonologique (TP). Les enfants qui ont un TP sont à risque de présenter des difficultés académiques et socio-émotives; afin que les cliniciens puissent maximiser les résultats positifs pour cette population, ils doivent pouvoir identifier précisément les enfants qui performent en deçà des attentes pour leur âge, choisir des buts d'intervention appropriés, et leur fournir une intervention efficace. Une bonne compréhension de la nature sous-jacente de leur trouble phonologique est nécessaire afin de fournir une intervention efficace (Stackhouse & Wells, 1997). Tandis que les orthophonistes évaluent les manifestations de surface des troubles de la communication depuis plusieurs décennies, la connaissance des causes sous-jacentes des TP et des troubles de langage est plus limitée, mais grandissante. De plus, alors qu'il y a un large corpus de recherche au niveau des manifestations de surface des TP chez les enfants anglophones, il y a actuellement très peu de données au niveau des manifestations de surface de ce trouble chez les enfants francophones.

Le but des études décrites dans cette thèse était d'examiner les profils psycholinguistiques sous-jacents et les manifestations de surface du TP chez un grand nombre d'enfants francophones d'âge préscolaire. Plus précisément, l'Étude un avait pour but de déterminer si les profils psycholinguistiques d'enfants francophones avec un TP sont semblables à ceux des enfants anglophones avec un TP, tel que rapporté dans la littérature. Soixante-douze

enfants avec un TP, âgés de 4 à 6 ans, ont été évalués à l'aide de mesures de précision de l'articulation, du vocabulaire réceptif, de l'intelligence non-verbale, du traitement phonologique (conscience phonologique, perception de la parole, répétition de syllabes) et de la structure et de la fonction du mécanisme oral-périphérique. Dix enfants avec un développement typique ont également complété les mesures de précision de l'articulation, du vocabulaire réceptif, de la conscience phonologique, et de répétition de syllabes. Les résultats ont indiqué que la vaste majorité des enfants francophones avec un TP présentaient des difficultés au niveau du traitement phonologique; en outre, les mesures de traitement phonologique ont expliqué une portion significative de la variance au niveau de la précision de l'articulation, même en tenant compte de l'effet de la variation du vocabulaire réceptif et du niveau d'éducation maternelle.

L'Étude deux avait pour but de déterminer si les erreurs de production des sons de la parole se manifestent différemment chez les enfants francophones avec un TP, en comparaison à un groupe très semblable d'enfants anglophones. Vingt-quatre enfants francophones avec un TP ont été jumelés au niveau du pourcentage de consonnes correctes en conversation, de l'âge, et du vocabulaire réceptif, à des enfants anglophones avec un TP. En comparant la production de consonnes de ces enfants, obtenues à l'aide d'un test d'articulation de mots simples, nous avons trouvé que les manifestations de surface du TP sont différentes dans ces deux langues. Les enfants francophones ont obtenu de bas ratios de jumelage des traits phonologiques pour les classes majeures de traits [+consonantique] et [+sonant], reflétant une haute fréquence d'omission de consonnes. Au contraire, les enfants anglophones ont obtenu des ratios élevés de jumelage des traits phonologiques

pour les classes [+consonantique] et [+sonant], et ont produit plus d'erreurs de substitutions de consonnes.

Les résultats de l'Étude un viennent s'ajouter à un nombre croissant d'études qui appuient un déficit principal au niveau du traitement phonologique chez les enfants avec un TP. Chez les enfants anglophones avec un TP, le déficit sous-jacent au niveau du traitement phonologique demeure stable malgré des changements environnementaux et/ou la maturation de l'enfant, alors que les patrons d'erreurs de production de sons produits par les jeunes enfants avec un TP changent lorsqu'ils deviennent plus vieux, et en réponse à des changements environnementaux. Dans les études décrites dans cette thèse, nous avons trouvé un déficit principal au niveau du traitement phonologique chez des enfants francophones avec un TP, alors que les erreurs de prononciation des sons qu'ils ont produites sont différentes des erreurs produites par des enfants anglophones avec un TP puisque les systèmes phonologiques de ces deux langues diffèrent l'une de l'autre. Ces conclusions mettent en évidence l'importance d'évaluer les habiletés de traitement phonologique des enfants avec des antécédents courants ou antérieurs de TP, ainsi que l'importance d'utiliser des outils d'évaluation qui prennent en compte les caractéristiques du français à tous les niveaux de la hiérarchie phonologique pour les enfants francophones.

Preface & Contribution of Authors

I (Françoise Brosseau-Lapré) was responsible for the hypotheses and rationale for the two studies described in this thesis under the guidance of Dr. Rvachew. The data described here are derived from the intake assessments conducted with children enrolled in a randomized controlled trial of interventions for speech in francophone children, the Essai Clinique Randomisé sur les Interventions Phonologiques (ECRIP). The research design of ECRIP was conceptualized and developed by both Dr. Rvachew and myself. I was responsible for the recruitment of participants. I collected the data described in the thesis, with help from undergraduate and graduate student research assistants who were responsible for blinded assessments and data coding as well as data entry. I trained and supervised these students who are acknowledged in the Acknowledgements section. In some cases I co-supervised their summer research projects leading to joint poster presentations and publications based on these data as listed below. Furthermore I developed several of the test instruments used in this research, specifically the French version of the Speech Assessment and Interactive Learning System to test speech perception and the Test de Conscience Phonologique to test phonological awareness. I also collected and analyzed data to establish reliability and validity of the primary measure of speech accuracy used in this study (Test Francophone de Phonology; Paul and Rvachew, unpublished) and contributed to the norming of the short-form of this test, leading to the publication of three other manuscripts related to but not included in this thesis, as listed below.

I drafted and revised the manuscripts. Dr. Rvachew, the second author on both manuscripts, assisted in the interpretation of the data, and provided guidance and editorial suggestions throughout manuscript writing and revisions. The studies described in this dissertation present a novel investigation to better understand developmental phonological disorders (DPD) in French-speaking children. More specifically, Study 1 represents the first description of the underlying phonological processing skills of French-speaking preschoolers with DPD in comparison to a small group of typically developing children. Study 2 consists of the first cross-linguistic comparison of the consonant errors produced by similar groups of French- and English-speaking children with developmental phonological disorders, using both a spontaneous and an elicited data collection procedure.

Some of the results described in this thesis were presented at the *Language Lunch Series* of the *Center for Research on Language, Mind and* Brain in Montreal in March 2010; the *78e xiiecherch de l'Association Francophone pour le Savoir* in Montreal in May 2010; the *Annual Convention of the American Speech-Language-Hearing Association* in Philadelphia in November 2010; the *Canadian Association of Speech-Language Pathologists and Audiologists Conference* in Montreal in April 2011; the *International Child Phonology Conference* in York, England in June 2011; the *International Clinical Phonetics and Linguistics Association Conference* in Cork, Ireland, in June 2012; and the *Annual Convention of the American Speech-Language-Hearing Association* in Atlanta in November 2012. Publications that describe some of the raw data that underpin this thesis and the assessment methods that were developed for the

purpose of this investigation of French phonology have also been accepted for publication, specifically: Rvachew, S. Marquis, A., Brosseau-Lapré, F., Paul, M. Royle, P. & Gonnerman, L. (accepted). Speech articulation performance of Francophone children in the early school years: Norming of the Test de Dépistage Francophone de Phonologie, *Clinical Linguistics and Phonetics*; Rvachew, S., Leroux, É., & Brosseau-Lapré, F (accepted). Production of Word-Initial Consonant Sequences by Francophone Preschoolers with a Developmental Phonological Disorder. *Canadian Journal of Speech-Language Pathology and Audiology;* Rvachew, S. & Brosseau-Lapré, F. (accepted). Pre- and post-treatment production of syllable initial /ʁ/-clusters by French-speaking children. In M. Yavas (Ed.), *Unusual productions in phonology: universals and language-specific considerations.* Psychology Press/Taylor Francis.

At the time of the official submission of the dissertation to McGill University, Study 2 was in press in *The International Journal of Speech-Language Pathology.* Study 1 will be submitted for review before the oral examination.

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General Introduction

Most children learn how to speak effortlessly, and do so essentially by listening (Van Riper, 1939). Although the acquisition of intelligible speech is gradual (Ingram, 1976), children rapidly become competent oral communicators. While typically developing children make many speech errors at a young age (Kehoe, Hilaire-Debove, Demuth, & Lleó, 2008, French; Saaristo-Helin, Kunnari, & Savinainen-Makkonen, Finnish; Stoel-Gammon, 1987, English; Zanobini, Viterbori, & Saraceno, 2012, Italian), they achieve intelligible speech by the age of 4 years (Coplan & Gleason, 1988, English) and adult-like levels of speech accuracy at or before the age of 9 years (Austin & Shriberg, 1997, English; Fox & Dodd, 1999, German; Goldstein, 1995, Spanish; To, Cheung, & McLeod, 2013, Cantonese). Unfortunately, many children do not become competent communicators and fail to achieve intelligible speech, with an estimated prevalence of speech impairments of 11% in 5-year old English-speaking children (Beitchman et al., 1986). Children who misarticulate more sounds than other children of the same age represent the largest group of children receiving speech-language pathology services in school (ASHA, 2010). Developmental phonological disorder (DPD), also called speech delay (SD) or speech sound disorder (SSD), is the most common diagnosis made by speech-language pathologists working with the pediatric population (Broomfield & Dodd, 2004a; Mullen & Schooling, 2010).

In a small proportion of children with DPD, their speech sound production impairment is secondary to a known cause such as craniofacial anomalies,

sensorineural hearing loss, cerebral palsy, or cognitive impairment. Most children with DPD do not present with overt structural, sensory, psychological or neurological conditions (Gierut, 1998), and the cause of their DPD is unknown (Broomfield & Dodd, 2004b). In this thesis I focus on these children with primary DPD, who as preschoolers are misarticulating more sounds than other children of the same age. These children are at considerable risk of later literacy and academic difficulties, especially when concomitant language impairment is present (Baker & Cantwell, 1982; Bishop & Adams, 1990; Snowling, Bishop, & Stothard, 2000), which is the case for approximately two thirds of these children (Baker & Cantwell, 1982). Nonetheless, children with isolated DPD remain at risk for literacy problems, particularly if the speech difficulties persist past school entry (Bird, Bishop, & Freeman, 1995; Larrivee & Catts, 1999; Leitão, Hogben, & Fletcher, 1997; Nathan, Stackhouse, Goulandris, & Snowling, 2004; Raitano, Pennington, Tunick, Boada, & Shriberg, 2004; Rvachew, Ohberg, Grawburg, & Heyding, 2003). High rates of social difficulties and psychiatric disorder are also common in children with DPD with or without concomitant language delay (Beitchman et al., 1996). Children with DPD are frequently teased and bullied (McLeod, Daniel, & Barr, 2013), and their limited communication skills impair their abilities to solve social conflict verbally (Zadeh, Im Bolter, & Cohen, 2007).

Most children with DPD face negative long-term impacts of their disorder, which are aggravated if their speech is not remediated by school entry. Currently, some children with DPD fail to normalize their speech sound production abilities, even with intervention (Cantwell & Baker, 1987; Rvachew, Chiang, & Evans, 2007; Shriberg, Gruber, & Kwiatkowski, 1994). “Children with speech difficulties

are heterogeneous, differing in severity, underlying cause, speech error characteristics, profile of associated abilities and response to treatment" (Dodd, 2011, p. 98). Appropriate identification of children with DPD at a young age is crucial in order for clinicians to provide intervention and mitigate the risks of later academic and socio-emotional difficulties. However, successful intervention for children with DPD is dependent on knowledge of the underlying nature of their phonological disorder (Stackhouse & Wells, 1997). In other words, a better understanding of the underlying skills which are disrupted in DPD may lead to increased efficacy and efficiency of interventions and improvements in the rates of short-term normalization of children with the disorder.

Prior to the 1960s/1970s, children with unintelligible speech were considered to present with articulation disorders arising from the inability to execute motor programs (e.g. Waring & Knight, 2013). In 1976, Ingram's seminal book *Phonological Disability in Children* fundamentally changed the focus from the child's mouth to the child's mind (Grunwell, 1983). Children with unintelligible speech were no longer seen as having difficulties articulating individual phonemes, but rather, as having a problem at the level of their underlying system of phonological rules. Recently, a growing body of behavioral studies, genetic studies, and studies investigating the comorbidity of DPD with other neurodevelopmental disorders have provided support for a deficit in phonological processing as the etiological cause in the vast majority of children with DPD. These three main perspectives will be discussed in turn in terms of the knowledge they provide regarding the relationships between surface speech

errors, underlying psycholinguistic profiles, and possible etiological causes of DPD.

Statement of Purpose

The purpose of the research described in this dissertation was to investigate the underlying psycholinguistic profiles and the surface manifestations of DPD in a large group of French-speaking preschoolers, with the goal of helping clinicians better identify DPD in French-speaking children and provide insight as to which intervention approaches are better suited for children with the disorder. More precisely, study one aimed to determine whether the psycholinguistic profiles of French-speaking children with DPD are similar to those of English-speaking children with DPD as reported in the literature. No study has yet described the profiles and characteristics of a large group of French-speaking children with DPD. Similar profiles of underlying skills in children with DPD speaking a different language would enhance the evidence base for the validity of models developed with English-speaking children. On the other hand, differences in French-speaking children may lead to the development of models that take into account cross-linguistic differences, and/or to the development of more appropriate assessment measures in French.

Study two aimed to determine whether speech errors are manifested differently in French-speaking children with DPD in comparison to a very similar group of English-speaking children with DPD, due to differences between the phonological systems of these two languages. In order to mitigate the negative long-term outcomes of DPD, clinicians need to accurately identify French-speaking children with DPD, select appropriate treatment goals, and provide

intervention to preschool age children to maximize their chances of normalizing their speech skills before school entry. There is currently a paucity of normative tools to diagnose phonological disorders in French-speaking children, and clinicians often rely on English normative data to do so. Moreover, French test instruments have been developed based on English tests. The comparison of the manifestation of DPD in the speech errors produced by French-speaking children provides essential background for the development of assessment practices better suited to the phonological characteristics of French, allowing clinicians to more accurately identify DPD in children speaking this language.

A detailed description of these two studies is preceded by a review of the literature, organized into two chapters. Chapter 1 describes current knowledge about the underlying skills that are disrupted in DPD and their relationship to possible etiological causes and to surface speech errors. Chapter 2 highlights the contribution of cross-linguistic research to the understanding of DPD, and describes differences between French and English phonology that may lead to differences in the surface manifestations of DPD in French-speaking children.

Chapter 1: Developmental Phonological Disorders

There is an increasing body of research on the relationships between the surface speech errors and the underlying skills that are disrupted in children with DPD. A historical change in focus on production accuracy for individual sounds, to system-wide variations in phonological knowledge indexes increased recognition that for many children with DPD, their difficulties are not solely related to speech (McCormack, McLeod, McAllister, & Harrison, 2009). This chapter describes the evolution of knowledge about the underlying skills disrupted in DPD and their relationship to possible etiological causes and surface speech errors.

Articulation Perspective

Prior to the 1960s/1970s, assessment practices were fairly straightforward: speech difficulties were described by the number of individual phonemes the child distorted, substituted, omitted, or added (Baker, 2006). Intervention targeted the accurate articulation of individual phonemes, following the assumption that the children's speech errors arose from "faulty habits of articulation" (Morley, 1957, p.232; see also Scripture & Jackson, 1927; Van Riper, 1939). As cited in Baker (2006), Bleile noted that clinicians working with the pediatric population treated mostly school-age children before the 1960s and 1970s. Most of the speech errors found in school-age children are distortions, usually of rhotics and sibilants (Shriberg, 2009). Children with distortion errors or who misarticulate only a few sounds make progress with traditional, articulation approaches that target one

sound at a time (Hodson, 1998). Distortions are usually considered to be due to lack of articulatory precision and thus be motoric in nature (Shriberg et al., 2005). However, research findings with school-age children with residual speech errors did not support the assumption that distortion errors are simply related to children's abilities to execute the articulatory movements associated with the phonemes they misarticulate. For instance, Shuster (1998) found that children of an average age of 11 years who were unable to pronounce the phoneme /ɹ/ despite having received at least two years of speech therapy performed at chance level only when asked to identify correct and incorrect productions of the phoneme in their own speech. In addition, Preston and Edwards (2007) showed that children age 10 to 14 years with residual speech errors affecting rhotics obtained significantly lower scores on measures of nonword repetition, multisyllabic word repetition, spoonerisms, and phoneme elision than the children with typical speech abilities.

Speech-language pathologists began to assess and treat younger children in the 1960s and 1970s. Examination of the surface errors of preschoolers with DPD further challenged the assumption that speech sound production difficulties are due to a motor deficit. First, distortion errors would be expected to be more frequent if children with DPD misarticulated speech sounds due to difficulties executing motor programs (Pennington & Bishop, 2009). However, substitution errors are most frequently found in the speech of English-speaking preschoolers with DPD (e.g. Grunwell, 1988; Hodson, 2007; Rvachew et al., 2007). If substitution errors reflect a lack of knowledge of the requisite articulatory gestures, these errors should be produced consistently. However, English-

speaking children with DPD often produce such errors inconsistently (Forrest, Dinnsen, & Elbert, 1997; Forrest, Elbert, & Dinnsen, 2000). Sometimes children's inconsistent use of a given phoneme can be predicted by phonological rule (e.g., constraint against the [+continuant] feature in the onset position of syllables, Leonard & McGregor, 1991); in other cases the error might depend upon the phonetic environment of the target (e.g., labialization of [ɹ] in the onset of syllables containing a rounded vowel versus correct production in word initial /gɹ/; /s/ more likely to be produced accurately in syllable final position than syllable initial position, Kent, 1982). The frequent observation that such error patterns were predictable and apparently rule-governed, even if sensible from the perspective of articulatory principles, undermined the notion that children's errors are solely articulatory in nature (Hodson, 1998).

More direct examinations of the motor skills of children with DPD also failed to support the hypothesis that speech articulation errors are caused by difficulties with the speech articulation system. The most commonly used measures of speech motor ability involve asking the child to repeat syllables as quickly as possible. There are two different types of repetition rates: diadochokinetic rate (DDK) for repetition of monosyllables, most commonly /pə/, /tə/, and /kə/; and alternate motion rate (AMR) for repetition of syllable sequences, /pətəkə/ and at times also /pətə/. For each trial, the number of repetitions per second is calculated. Performance below the norm on repetition of monosyllables is a valid indicator of difficulties with motor execution; in this case weak muscle tone is usually present, affecting phonation, resonance, and prosody as well (e.g. Ozanne, 2005). On the other hand, poor performance on the

repetition of syllable sequences is a valid indicator of motor planning difficulties (e.g. Thoonen, Maassen, Gabreels, & Schreuder, 1999; Thoonen, Maassen, Wit, Gabreels, & Schreuder, 1996). Children who have difficulties with motor planning also perform worse than other children on another common task to assess oral-motor skills, the execution of nonverbal oral-motor movements. Similarly to their performance with DDK and AMR, these children have difficulties performing combinations of volitional movements such as "smile and pucker the cheeks" but perform within the norm on the production of isolated volitional movements (e.g. Aziz, Shodi, Osman, & Habib, 2010). Notwithstanding the fact that some children with DPD present with difficulties with motor planning or motor execution, only a very small percentage of these children (5% or less) have been found to present with a true motor speech disorder (e.g. Ozanne, 1995; Shriberg, 1994).

Phonological Perspective

A major paradigm shift from articulation to phonology occurred in the 1970s: children who were not as intelligible as their age peers were no longer seen as presenting with an articulatory problem, but rather, as having difficulties arising from "breakdowns at the cognitive level of linguistic knowledge and organization" (Grunwell, 1981, p. 5). Instead of describing children's speech errors in terms of individual phonemes, the errors are grouped in categories or patterns of difficulties both related to classes of similar sounds, and to syllable shapes. The intervention goal was to reorganize the child's phonological system through phonological generalization to similar, untreated sounds (Baker, 2006). The shift from a motor/articulation focus to a linguistic/phonological focus lead to

the development of numerous phonological intervention approaches for children with DPD. While preschoolers with unintelligible speech had been reported to become intelligible in 5 or 6 years with the traditional articulation intervention, the use of phonological approaches typically result in intelligible (but not error-free) speech in less than two years (Hodson, 1982, 1998; Klein, 1996).

Phonological processes became the most widely used analysis method for clinicians to describe children's error patterns (Edwards, 1997). This analysis is based on Natural Phonology theory (Stampe, 1973), which assumes that children's underlying phonological representations are adult-like and that innate processes reduce the difficulty for young children to accurately produce the targets. In other words, adults achieve a more complex phonological system than young children because they have learned to suppress these phonological processes such as deletion of final consonants and stopping of fricatives. Although Natural Phonology theory failed to explain why children's speech errors occur, SLPs commonly use phonological processes to describe speech errors (e.g. Fey, 1992; Kamhi, 1992). Lof (2002) argued for the need to modify the phonological process analysis, not only because other contemporary theories of phonology have since been developed, but also because the processes are not descriptive enough. For instance, "cluster reduction" is often used to describe very different error patterns, such as producing both consonants of the cluster but simplifying liquids, omitting the second consonant of the cluster, or coalescence (merging the consonants).

The multilinear (or nonlinear) phonological approach has been used by Bernhardt and colleagues for the assessment and treatment of children with DPD since the 1990s (e.g. Bernhardt, 1990; 1992; Bernhardt & Stemberger, 1998). Multilinear analysis provides a more systematic description of the child's underlying representation at all levels of the phonological hierarchy (i.e. prosodic phrase, word, syllable, segment, individual features), as well as the relationships among these levels (Bernhardt & Stoel-Gammon, 1994). Contrary to the phonological process analysis, multilinear phonology does not assume that the child's underlying phonological representation is identical to the adult's representation. Two operations explain mismatches between the child's phonological knowledge in relation to the adult system: delinking, the deletion of association lines; and spreading of features, the addition of association lines (Bernhardt & Stemberger, 1998). Generally speaking, phonological approaches propose that children have difficulties abstracting linguistic rules. Although they do not necessarily propose specific causes for these difficulties abstracting the rules that govern phonology, the shift from an articulatory deficit, as well as the recognition that the quality of children's underlying phonological representations is important for the development of accurate speech, both considerably influenced intervention for children with DPD.

Dodd and colleagues have conducted many studies in an effort to test the hypothesis that some children with DPD have difficulties abstracting the linguistic rules governing phonology (e.g. Crosbie, Holm, & Dodd, 2009; Dodd, 2011; Dodd & McIntosh, 2008). Although Dodd interprets the data as supporting the notion that inaccurate speech is associated with central processing difficulties,

Waring and Knight (2013) point out that in these studies, PA skills, rule abstraction and cognitive flexibility were not assessed in the same children. More importantly in these studies the children's performance on the phonological processing tasks was not corrected for verbal intelligence or vocabulary knowledge, yet "vocabulary has proven to be the most robust language measure when predicting PA, both for children with and without speech and language impairments" (Preston & Edwards, 2010, p. 45).

Munson, Edwards, and Beckman (2005a) aimed to determine whether the speech production difficulties of children with DPD are related to deficits in "lower level knowledge of how sounds are instantiated and perceived in the physical world" and/or higher level phonological knowledge, or abstract knowledge about "how sound categories are used to code meaning in the language, and how they can be combined with other sounds to form words" (Munson et al., 2005b, p. 193). In order to do so, they measured three different types of phonological knowledge in 40 children with DPD and 40 children matched on age with typical phonological development. Picture naming tasks were used to assess articulatory knowledge. To measure perceptual knowledge, a gated-word recognition task was used with two sets of similar words (*tap/tack* and *cap/cat*). Three gated stimuli were created for each target: the entire word; the stop burst removed; and the burst and most of the final formant transition removed. The children were instructed to identify the word they heard by pointing to one of two pictures of the set. Although nonword repetition tasks are usually used as a measure of phonological memory, in this experiment the task was designed to tap the children's underlying knowledge of the English language

sound system. The stimuli consisted of 11 pairs of disyllabic and 11 pairs of trisyllabic nonwords in which the phonotactic probability was systematically manipulated. Within each pair, one nonword contained high probability phonotactic sequences that occur in many words known to young children, and the other nonword contained low probability phonotactic sequences that occur in few or no words known to young children. When repeating low frequency sequences, children would not be able to rely on knowledge from representations already in their lexicon, but rather, would need to have abstracted knowledge of phonemes. A larger magnitude of the difference between performances on the high-frequency nonwords as compared to the low-frequency nonwords for children with DPD, compared to the controls, would provide support for a deficit in abstract knowledge of the phonemic structure of words in children with DPD. As expected, the authors found that children with DPD, who by definition have difficulties accurately articulating speech sounds, were less accurate than typically developing children in repeating nonsense words. Children with DPD also performed less well than the controls on the speech perception task. Both groups of children were more accurate at repeating high frequency than low frequency phoneme sequences. Interestingly, the children with DPD did not have a greater effect of phonotactic probability, meaning that they did not seem to have a deficit in higher-level phonological knowledge. Using regression analyses, Munson et al. (2005a) found that vocabulary size was the only significant predictor of phonotactic frequency, with larger vocabulary sizes leading to smaller effects of phonotactic frequency. The authors also found that there was no interaction between the frequency effect and articulatory knowledge and perceptual

knowledge, indicating that the underlying difficulties of children with DPD is in the more primary perceptual/phonetic domain and not in higher-level phonological knowledge.

Core Deficit in Phonological Processing

In the past, DPD, language impairment and reading disability were generally believed to be different disorders with distinct etiologies and genetic bases (Lewis et al., 2006). Since they do at times occur in pure form, researchers attempted to find unique underlying cognitive and etiological causes for each of these neurodevelopmental disorders (Pennington & Bishop, 2009). However research findings in the past several decades revealed that these three disorders overlap at the symptomatic, cognitive, and etiological levels (Pennington, 2006). For instance, a significant proportion of children with DPD (in these studies, referred to as the 'proband') have a positive family history of speech, language, and/or learning disabilities, as indicated by several reports on the aggregation of speech and language delay in families (Campbell et al., 2003; Choudhury & Benasich, 2003; Tallal et al., 2001; and Stromswold, 1998, for a review). Between 20% and 60% of the family members of the probands presented with speech-language difficulties, as opposed to less than 10% of family members of control children. Several studies demonstrated that DPD is co-familial (e.g. Lewis, Elkelman, & Aram, 1989), and twin studies have demonstrated that the disorder is also heritable (e.g. Tunick & Pennington, 2002). To better understand the causes of DPD, studies have attempted to identify the genes that influence speech development and linkages with genes that influence reading development. Several chromosome regions and candidate genes have now been identified for DPD, such

as 1p34-36, 3p12-q13, 6p22, and 15q21 (McGrath, Smith, & Pennington, 2006; Newbury & Monaco, 2008), and a growing number of studies have found that DPD and reading disability are linked on these chromosome regions (e.g. Rice, Smith, & Gayan, 2009). In addition, in a large population-based twins study, Bishop and Hayiou-Thomas (2008) found that high heritability of language impairment was a function of the presence of speech impairment, with group heritability estimates increasing as the criteria for a diagnosis of speech impairment was stricter.

Phenotypes result from the interaction between genes and the environment, and consist of the observable characteristics of the disorder (Gottesman & Gould, 2003). In the case of children with DPD, speech error types such as omissions, distortions, and substitutions are phenotypes of the disorder. Many phenotypes may be related to a single gene, and conversely one phenotype may be linked to several genes. Moreover, phenotypes change in response to environmental changes and the child's maturation. For instance, Rvachew et al. (2007) found that speech error types did not remain constant as children aged, and varied with the severity of their DPD. In contrast, endophenotypes are more closely related to the underlying genotype of the disorder, and are measurable parameters associated with specific behaviors (Gottesman & Gould, 2003); verbal short-term memory, speeded naming, and repetition of multisyllables are examples of endophenotypes. Candidate chromosome regions for DPD have recently been linked to measures of phonological awareness (PA), phonological memory, vocabulary, oral motor skills, and processing speed (Miscimarra et al., 2007; Smith, Pennington, Boada, & Shriberg, 2005; Stein et al., 2004, 2006). In

addition, using a linkage analysis in a multigenerational family, Peter, Matsushita, and Raskind (2012) found that a deficit in motor sequencing abilities was an endophenotype of a subtype of speech sound disorder. Although one endophenotype may be related to more than one condition, it is a core determinant of the disorder and manifests itself regardless of the child's maturation or environmental changes. Adults with a history of DPD in childhood, who no longer produce surface speech errors, would nonetheless present with deficits in endophenotypes associated with DPD. For example, deficits in PA have been found in adults with a history of DPD as preschoolers (Lewis & Freebairn, 1992) as well as in children with resolved DPD (Raitano et al., 2004).

Pennington and Bishop (2009) have contended that the comorbidity observed in DPD, language impairment, reading disability, and attention deficit with hyperactivity disorder may result from shared deficits in endophenotypes or underlying cognitive skills, including memory, processing speed, or attention (McGrath et al., 2007; Pennington & Bishop, 2009; Peterson, Pennington, Shriberg, & Boada, 2009). Quite likely, these endophenotypes may be influenced by genes that have broad effects on neural development and processing (Lewis et al., 2011). For example, Castellanos and Tannock (2002) have suggested that endophenotypes such as a delay in temporal processing or working memory deficits appear to underlie ADHD, with the same endophenotypes contributing to DPD and language impairment. According to the multiple deficit view of developmental disorders (Pennington, 2006), more than one etiological cause results in the disorder, and various protective and risk factors, both genetic and environmental, interact with each other and with the etiological causes of the

disorder. In turn, the etiological risk and protective factors affect the development of cognitive processes, producing the symptoms used to define the disorders. For example, only a few, but more than one etiological factors may be necessary for a child to develop a DPD. As different developmental disorders will share risk factors at both the etiological and cognitive levels, it is expected to have comorbidity between the disorders. Finally, as each developmental disorder has a set of risk factors of which some may be shared with other developmental disorders, the distribution of children presenting with a given developmental disorder is continuous, not discrete, and quantitative, not categorical.

There is now increasing theoretical and empirical support for a core deficit in phonological processing in children with DPD, and more specifically at the level of acoustic-phonetic representations that are incomplete, immature, or specified with the wrong acoustic cues. For children with DPD, subtle problems in perceiving speech, leading to inaccurate or incomplete acoustic-phonetic representations, prevent the child to compare his own productions against the target and achieve consistent, accurate production of the target (Rvachew & Grawburg, 2006). The relationships between a proposed etiological factor of a deficit with encoding of acoustic-phonetic representations, endophenotypes of phonological processing (PA, verbal short-term memory, retrieval of lexical representations), and surface speech errors will be discussed in turn.

As a group, children with DPD have significant difficulties with perception of their own speech and that of other talkers (Broen, Stange, Doyle, & Heller, 1983; Hoffman, Daniloff, Bengoa, & Schuckers, 1985; Rvachew & Jamieson, 1989). Word identification tasks are more appropriate to assess speech

perception, and the assessment measure should mirror the child's speech errors since children's speech perception difficulties are specific to their misarticulations (Locke, 1980). Early studies investigating the relationship between speech perception skills and DPD typically used discrimination tasks and well-produced exemplars of adult words. Although some studies using this methodology found that children with DPD presented with deficits in speech perception compared to their peers with typical speech abilities (Cohen & Diehl, 1963; Sherman & Geith, 1967), many did not. Using identification tasks and synthetic speech continua, studies have demonstrated that children with DPD present with speech perception difficulties identifying words in which acoustic information was manipulated in order to create minimal contrasts such as "rake-lake" (e.g. Broen et al., 1983; Hoffman et al., 1985; Rvachew & Jamieson, 1989). Some of the children were not aware of the phonemic contrast while others defined the phonemic contrast based on the wrong acoustic cues. As mentioned earlier, Shuster (1998) also found that children with persistent SSD have difficulties perceiving the target sounds they misarticulate.

Internal phonological representations contain information regarding the phonological characteristics of lexical items (Edwards, 1995; Rvachew, 2006; Stackhouse, 1997). Phonological representations are immature in young children; as children age, the representations become more fine-grained and accurate (Nathan et al., 2004; Sutherland & Gillon, 2005). In fact, Metsala and colleagues found that receptive vocabulary, and not age, was correlated with better PA abilities and proposed that as the size of the child's lexicon increases, their phonological representations become more adult-like (Metsala, 1999; Walley,

Metsala, & Garlock, 2003). In other words, as the developing lexicon expands, the child organizes words based on increasingly smaller units across different tiers (word, foot, syllable, onset and rime, nuclei and coda, phonemes), which will in turn be organized into a hierarchically organized set of features. Studies using gated speech stimuli aim to determine whether the acoustic-phonetic representations for words of typically developing children and children with DPD are sufficiently detailed for word recognition in degraded listening conditions. Several studies demonstrated that compared to older children and adults, young children require longer portions of the gate in order to identify words (e.g. Elliott, Hammer, & Evan, 1987). Researchers also investigated the performance of children with DPD with gated-speech stimuli. For instance, Edwards, Fourakis, Beckman, and Fox (1999) compared the perception of natural recordings of similar words with no final consonants or with final consonants that differed in place of articulation (for example, le letter *P, Pete, peak, peep*) in children age 3;7 to 5;4 with DPD and children with typical development. Four gated stimuli were created for each target: the entire word; the portion after the stop burst removed; the stop burst removed; and part of the final formant transitions removed. The children were instructed to identify the word they heard by pointing to one of four pictures. Children with DPD performed as well as typically developing children when identifying a live-voice production of the word, and all participants had difficulty for the two gating conditions with the least amount of acoustic information. However, children with DPD performed significantly worse with recordings of entire words and words where only the portion after the stop burst was removed. The acoustic-phonetic representations of children with DPD were

not sufficiently detailed and mature to allow them to recognize words with slightly less redundancy of acoustic information.

The development of PA skills relies on well-specified underlying acoustic-phonetic representations (e.g. Elbro, Borstrom, & Peterson, 1998; Rvachew, 2006; Snowling, 2000; Sénéchal, Ouellette, & Young, 2004). In turn, numerous studies have demonstrated a stable and robust relationship between PA and reading abilities (Bradley & Bryabt, 1983; Calfee, Lindamood & Lindamood, 1973; Lonigan, Burgess, & Anthony, 2000; Menyuk et al., 1991; Pennington & Lefty, 2001; Torgesen, Wagner, & Rashotte, 1994; Wagner et al., 1997). Children with DPD are at risk for PA deficits, as well as deficits in spelling and reading (e.g. Anthony et al., 2011; Lewis et al., 2011; Nathan et al., 2004; Preston & Edwards, 2007). However, not all children with DPD will later develop reading disability (e.g. Lewis, Ekelman, & Aram, 1989; Lewis, Freebairn, & Taylor, 2000). Several researchers have examined the surface speech errors of children with DPD in order to determine which children are more likely to present with weak phonological representations, and therefore deficits in PA skills.

Leitão, Hogben, and Fletcher (1997) found that 5 to 6 year olds with moderate to severe DPD who produced atypical speech errors obtained significantly lower scores on the measure of PA than children who produced speech errors that are often found in younger, typically developing children. Rvachew et al. (2007) investigated the relationship between performance on a PA test and the types of speech errors produced on the Goldman-Fristoe Test of Articulation, Second Edition (Goldman & Fristoe, 2000) by 58 children with

DPD. The prekindergarten children who failed the PA measure did not produce more atypical consonantal errors than children who passed the PA test, but they did produce more omission errors, altering the word shape of the target. One year later, the kindergarten age children who presented with weak PA skills did, as a group, produce significantly more atypical segment errors than children who obtained a PA score not less than one standard deviation below the mean. Preston and Edwards (2010) aimed to determine whether the profile of speech sound errors could explain variance in PA skills above the contribution of age and vocabulary. Forty-three children with DPD, age 4 to 5 years, participated in the study. Speech errors on a 125-word picture-naming task, which assessed each consonant at least twice, were coded as either distortions, typical sound changes, or atypical sound changes. All participants produced at least a few atypical sound changes, and children who produced more atypical speech errors obtained significantly lower scores on the PA measure. Atypical speech errors accounted for 13% of the variance in PA performance, and approximately 6% of the unique variance in PA once the contribution of age and vocabulary were taken into account. Recently, Preston, Hull and Edwards (2013) re-examined the relationship between atypical speech errors and PA skills in 25 of the 43 children they had seen almost four years earlier. The only preschool speech production variable which was associated with school-age PA scores was atypical speech errors. Children who produced more distortion errors in preschool obtained lower scores on the GFTA-2 administered 4 years later. Preston and colleagues (Preston & Edwards, 2010; Preston, Hull, & Edwards, 2013) noted that Rvachew et al. (2007) had not found a significant relationship between PA skills and unusual speech

errors in their participants in the spring of their prekindergarten year, but did find such a relationship one year later. Possible explanations for this difference provided by Preston and colleagues include the possibility that the relationship between atypical speech errors and weak PA skills may be stronger only beyond kindergarten, and/or differences in statistical analysis, size of the sample of consonants analyzed, and differences in how speech errors were classified as typical or atypical. While both the Rvachew et al. (2007) and Preston and Edwards (2010) used a PA task adapted from the Bird et al. (1995) study and assessed rhyme matching, onset matching, and onset segmentation and matching, Preston and Edwards also adapted a task from Larrivee and Catts (1999) to test onset-rhyme blending and CVC phoneme blending. Notwithstanding differences in methodology, taken together these studies support the finding that children who have difficulties with PA skills produce more omission and atypical speech errors. Children with an increased genetic load for DPD were also found to be significantly more likely to omit later developing consonants as opposed to substituting or distorting these consonants (Shriberg et al., 2005), providing further support for a genetic etiological cause affecting speech perception for the vast majority of children with DPD. These difficulties, in turn, give rise to an endophenotype of a deficit in PA skills, and manifest themselves at a young age as phenotypes of increased omission and atypical speech errors.

Munson, Baylis, Krause, & Yim (2010) further examined the nature of deficits in phonological knowledge in children with DPD aged 3 to 7 years by comparing their abilities on measures of lexical access, phonological encoding, and perceptual learning to those of children with typical speech and language

development matched on age. Both groups of children performed similarly on the delayed picture naming task which assessed lexical access and on the picture-word interference task which assessed phonological encoding of lexical items. Differences between the two groups of children were found on a long-term repetition priming task, which assessed the ability to learn perceptual representations for new words. The children were first presented with nonwords auditorily, and asked not to respond. Following an oral motor examination (distracter task), the children repeated 52 nonwords; 26 of had not been previously presented to them (unprimed words), 13 had been presented to them (identical primed words) and 13 were presented before, but by a different talker (form-primed word). While the typically developing children repeated the identical primed words more accurately than the unprimed and form-primed nonwords, children with DPD did not show a priming effect. In terms of response latencies, a difference was also found between both groups of children: children with typical language skills repeated both types of primed words more rapidly than unprimed words, whereas the children with DPD repeated the form-primed words more rapidly, although there was considerable variation within the group with regards to response latency for identical primed words. The authors concluded that "together, these findings suggest that children with phonological impairment may have a deficit in encoding acoustic-perceptual information, but that they are able to use this acoustic perceptual information to form abstract phonological categories" (p.399). Munson and colleagues noted that the conclusion that children with DPD have difficulties with lexical representations in the more primary perceptual domains is in contrast with most phonological approaches,

which posit that children with DPD have difficulties abstracting higher-level phonological knowledge.

Kamhi and colleagues (Kamhi & Catts, 1986; Kamhi, Catts, Mauer, Apel, & Gentry, 1988) first reported that children with SLI have difficulties with nonword repetition tasks, and particularly for target words that have more syllables. While children with SLI often perform less well than typically developing children on target words that are one- or two-syllables long, the differences in performance between the two groups of children increase with targets of three- and four-syllables (e.g. Graf Estes, Evans, & Else-Quest, 2007; Dispaldro, Leonard, & Deevy, 2013). Although phonological short-term memory plays a major role in performance on nonword repetition tasks, differences between groups with one- and two-syllable words suggest that poor performance on these items could be due to difficulties with the discrimination and/or encoding requirements to complete the task (e.g. Gathercole, 2006). In fact, performance on standard nonword repetition tasks factors with articulation accuracy more clearly than memory (Colledge et al., 2002) and therefore these measures are of questionable validity for use with children who produce many misarticulations (for discussion, see Rvachew & Grawburg, 2008). The Syllable Repetition Task (SRT; Shriberg et al., 2009) was developed specifically for young children with limited inventories of speech sounds and for children of any age with mild to severe DPD. The primary goal of the measure is to study the underlying speech processes of nonword repetition while limiting or eliminating the measurement confounds that occur when administering and scoring a nonword repetition task to

children who misarticulate speech sounds and/or omit consonants in more complex syllable shapes. The target words contain only one vowel and four early-acquired consonants (/a/, /b/, /d/, /m/, /n/) and simple syllable structures (CVCV, CVCVCV, and CVCVCVCV), with equal stress on each syllable. The administration time is less than two minutes, minimizing the risk of fatigue effects. The SRT could also be useful in cross-linguistic research, since the vowel target is not scored, and many languages have the four consonantal targets in their inventories (Shriberg et al., 2009).

The errors that participants make on the items of the SRT can be used to quantify three speech processes: auditory-perceptual encoding of segmental features; memory processes to store and retrieve the representations; and transcoding processes (planning and programming). Shriberg et al. (2009) administered the SRT to children with: typical language and typical speech; typical language and speech delay; expressive language impairment and typical speech; expressive language impairment and speech delay. Children with speech delay (with or without typical language skills) obtained lower scores of auditory-perceptual encoding than children with typical speech and language skills. In terms of memory constraints, as reported in other studies, the participants were less accurate in repeating consonants as the target words increased in length, pointing to a memory capacity limitation. However, approximately one quarter of the children obtained accuracy scores between 0% and 50% on the 2-syllable stimuli, pointing to the role of a constraint other than phonological short-term memory in poor performance on these items. While the authors found support for

a constraint in auditory-perceptual encoding, and mixed support for a constraint in memory processes, they did not find support for a constraint in motor planning and programming underlying the errors children made on the SRT.

Several researchers have now provided evidence for a core deficit in speech perception in children with DPD, and more specifically at the level of inaccurate or incomplete acoustic-phonetic representations. This deficit in the encoding of acoustic-perceptual information prevents the child from comparing his own productions against the target to achieve consistent, accurate production of the target. Rvachew (2007) concluded that children with DPD who present with difficulties with encoding of acoustic-phonetic representations are particularly at risk for reading disability. Many children with DPD also have co-occurring disorders: as proposed by the multiple deficit view of developmental disorders (Pennington, 2006), DPD shares a phonological processing deficit with other disorders such as reading disability and language impairment. For children with DPD, the risk of later presenting with reading and spelling disability is moderated by additional risk factors such as low nonverbal intelligence (Peterson et al., 2009) and protective factors such as speech-language therapy, high quality language input, and reading instruction (Rvachew, 2007). Preston et al. (2013) found that children with DPD and histories of preschool DPD had weak PA scores at age 8 years, however their reading and spelling performance was overall within normal limits. The oral language scores of these children, and particularly vocabulary, were relatively strong and may have acted as a protective factor against literacy difficulties. While the endophenotype of weaknesses in PA skills is very likely to continue to be present over time, some children may continue to

compensate for their phonological processing deficit and not show phenotypes of reading and spelling deficits, or may make progress less quickly than their peers with regards to reading and spelling abilities.

In conclusion, several endophenotypes and speech processes have been associated with DPD, such as measures of phonological processing (phonological memory, phonological awareness, speech perception), vocabulary, and oral motor skills. Although DPD is a complex neurodevelopmental disorder, research regarding the underlying psycholinguistic abilities of children with DPD continues to clarify the relationships between the etiological processes and the surface manifestations of the disorder. Endophenotypes are closely related to the genotype of the disorder and manifest themselves regardless of environmental changes; I therefore expect that the same cognitive-linguistic skills identified in English-speaking children with DPD will be associated with DPD in monolingual speakers of French. In contrast, I hypothesize that the surface speech errors of French-speaking children with DPD will be different than in English, since phenotypes vary in response to the environment, such as a different ambient language. The following chapter describes the importance of cross-linguistic studies and the ways in which French phonology could impact the phenotypes of DPD.

Chapter 2: Cross-Linguistic Studies and French Phonology

"The multilingual study of phonological acquisition and disorders provides insights not as easily noted if only focusing on the acquisition of a single language" (Ingram, 2012, p. 10). For example, a few decades ago Locke (1983) proposed a maturational explanation for children's productions of early consonants, which would be constrained by the acoustic and or/articulatory complexity of the segments. In other words, the order of consonant acquisition would be similar across languages, with consonants that are easier to articulate being produced first, regardless of the ambient language of the child. The linguistic environment of the child would only have an impact on phonological development at a later point, proposed by Locke to be at some time after the child is producing 50 words. However, investigation of the order of acquisition of consonants in languages other than English challenged this claim. For instance, although [v] is acquired quite late in English (e.g. Ingram, Christensen, Veach, & Webster, 1980; Shriberg, 1993), it is acquired quite early in other languages, such as Swedish (Magnuson, 1983, cited in Locke, 1983) and Italian (Bortolini, Bonifacio, Zmarich, & Fior, 1996). Similarly, the dental fricatives [θ] and [ð] are among the latest acquired consonants in English (e.g. Shriberg, 1993; Templin, 1957) but are acquired early in Greek (e.g. Mennen & Okalidou, 2007). Kent (1992) also proposed a universal and implicational hierarchy of articulatory difficulty of phonemes, which would account for the order of acquisition of sounds in every language. The four-level scale of articulatory complexity reflects the increased physiological characteristics and motor requirements to produce

consonants. Other researchers proposed that the order of acquisition of consonants would be influenced by elements specific to the ambient language, such as the frequency of the phoneme within the language (e.g. Amayreh & Dyson, 2000) or the functional load of the phoneme (e.g. Amayreh, 2003), which represents the cost to the language should the contrast between the target consonant and a similar consonant be lost. For instance, few English words are distinguished only by the consonants /ð/ and /d/, and therefore the functional load of /ð/ is low, since there would be little consequence to English if it should merge with other similar consonants such as /d/. Using cross-linguistic research, Stokes and Surendran (2005) teased apart the contribution of input frequency, functional load, and articulatory complexity on the order of acquisition and accuracy of production of consonants. They found that functional load was the best predictor of the age of emergence of consonants in young speakers of English; in contrast, frequency of the consonants in the input was the best predictor for Cantonese, a finding that probably reflects the smaller and less complex consonant inventory of Cantonese relative to English. Articulatory complexity was the main factor to account for accuracy of consonant production in English-speaking children, but input frequency explained most of the variance for children speaking Dutch, a language that has a smaller initial consonant inventory than English. Altogether this study revealed several important principles of phoneme acquisition; first, explanatory factors for the order in which sounds emerge in the inventory may differ from variables that explain the age at which children master accurate production of a given phoneme; secondly, these factors depend upon the size and complexity of

the phoneme inventory of the input language. Therefore, there can be no universal order of phoneme acquisition and cross-linguistic differences are to be expected even at the earliest stages of phonological acquisition.

In Chapter 1 I argued that most children with DPD have difficulties with phonological processing. In English this deficit results in an excessive number of speech errors relative to age peers. These errors appear to reflect the absence of phonological knowledge or partial phonological knowledge of misarticulated phonemes and phoneme classes. The way in which this phonological processing deficit manifests itself in English and French can be expected to differ however, given the differences in the linguistic inputs to children learning either one of these languages.

As mentioned in Chapter 1, multilinear phonology provides a more systematic description of the child's underlying representation at all levels of the phonological hierarchy, as well as the relationships between these levels (Bernhardt & Stoel-Gammon, 1994). A hierarchical organization is proposed, with one level of representation for segmental components, and another for prosodic components. In the following section I will first describe the characteristics of the segmental level of the phonological hierarchy and highlight differences between the Canadian English and Québec French phonological systems at the segmental tiers (for consonants only, since vowels were not considered in Study 1 or Study 2). I will then do the same for the prosodic tiers of the phonological hierarchy.

Differences Between English and French Phonology at the Segmental Level

Phonemes contain sets of features, which encode abstract phonetic

similarities and differences between segments. The feature is the basic unit of analysis in multilinear phonology (Bernhardt & Stemberger, 1998). I am assuming that features are binary; I am also assuming underspecification where only one value of any feature is marked. The hierarchical representation of features used to describe consonants, as proposed by Bernhardt and colleagues (Bernhardt & Stemberger, 1998; Bernhardt Stemberger, & Major, 2006; Bernhardt & Stoel-Gammon, 1994), is shown in Figure 1.

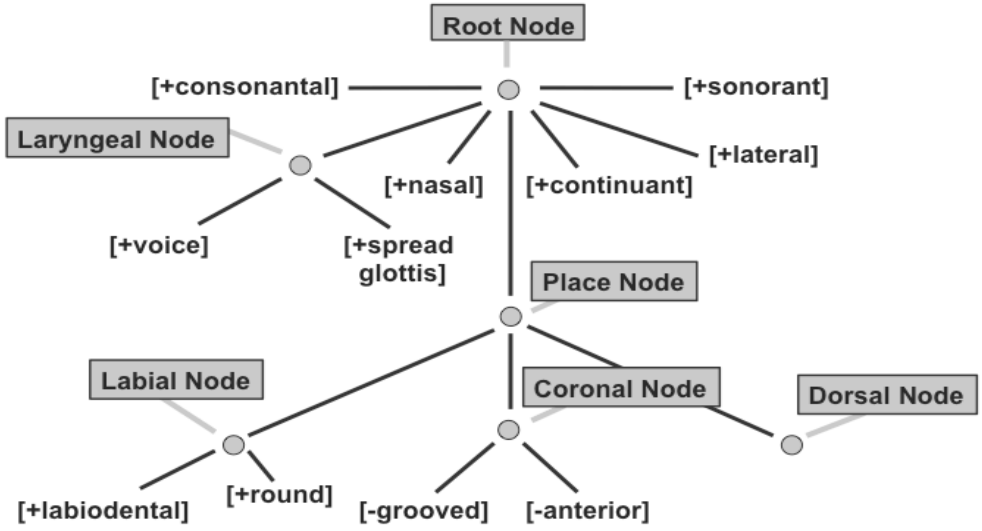

Figure 1. Feature hierarchy for consonants (Bernhardt & Stemberger, 1998; Bernhardt et al., 2006; Bernhardt & Stoel-Gammon, 1994). [1]

The root node organizes all features. There are two 'major sound classes': oral stops, fricatives, and affricates are [+consonantal], while liquids, glides and glottals are [+sonorant]. Nasals were classified by Bernhardt & Stoel-Gammon

[1] : The values are independent of the organization of features. Features shown are generally assumed to be the marked values although default versus marked options can vary with the learner, the language input, and syllable position.

(1994) as being [+consonantal], and were coded as such in Study two, although Bernhardt and colleagues have since classified them as [+sonorant] (e.g. Bernhardt et al., 2006). The feature [+nasal] applies to nasal consonants; [+continuant] applies to fricatives, liquids and glides; and [+lateral] applies to lateral fricatives and the liquid [l]. The liquids [l] and [ɹ] are specified for both [+consonantal] [+sonorant] simultaneously. The Root node also branches out to two additional nodes: Laryngeal, and Place. The Laryngeal node has two features: [+voice] for voiced obstruents; sonorants are voiced by default. The feature [+spread glottis] covers aspirated stops; and voiceless fricatives by default. The Place node branches to the three major place features: (1) Labial, for all consonants produced with the lips; [+labiodental] applies to [f] and [v], and [+round] applies to consonants produced with rounded lips, such as [w] in English; (2) Coronal, for consonants produced with the tongue tip or tongue blade; [-grooved] concerns the interdentals, and [-anterior] concerns the postalveolars; (3) and Dorsal for velar consonants. Bernhardt and colleagues have made small changes to the feature specifications throughout the years, in particular to the specification of /h/, affricates, and liquids. These changes reflect issues in the field of linguistics as to the appropriate specification for certain phonemes. These issues are not of primary concern in this thesis since I do not presume that the feature specifications are universal and since I also expect there can be individual variation among children.

Table 1 presents the consonantal inventory for Québec French. Consonants at the left of the slash are voiceless; consonants at the right are

voiced. The velar nasal [ŋ] was not included; although it is present in English loan-words, it is not usually considered part of the French inventory (Rose & Wauquier-Gravelines, 2007), it was not assessed on the single-word articulation test used in this thesis, and very rarely found in the spontaneous speech of the participants. In Québec, [ʁ] is most frequent rhotic (Rose & Wauquier-Gravelines, 2007); although variations of the pronunciation such as [r, ɾ, ɹ] have also been documented, they are often not considered phonemic due to their lower frequency and specificity to certain regions of the province (Ostiguy, Sarrasin, & Irons, 1996; Martin, 1996). In Québec French /t, d/ are affricated [t^s, d^z] before the high front vowels /i, y/, such as in *tigre* [t^sigʁ] ('tiger') and *dur* [d^zyʁ] ('hard'). These affricates are not represented in the inventory since they are allophones of the alveolar stops /t, d/.

Table 1: Phonemic inventory of Québec French consonants and glides (adapted from Martin, 1996 and Walker, 1984).

	Bilabial	Labiodental	Alveolar	Postalveolar	Palatal	Velar	Uvular
Stop	p / b		t / d			k / g	
Fricative		f / v	s / z	ʃ / ʒ			/ ʁ
Nasal	/ m		/ n		/ ɲ		
Approximant	/ w				/ j ɥ		
Lateral approximant			/ l				

Table 2. Consonant inventory for North American English (adapted from Edwards, 1992).

	Bilabial	Labiodental	Dental	Alveolar	Postalveolar	Palatal	Velar	Glottal
Stop	p / b			t / d			k / g	
Fricative		f / v	θ / ð	s / z		ʃ / ʒ		h
Affricate					tʃ /dʒ			
Nasal	/ m			/ n			/ ŋ	
Approximant	/ w			/ ɹ		/ j		
Lateral approximant				/ l				

While several consonants are common to both French and English, a few segments are unique to French ([ɲ, ʁ, ɥ]) and several English segments are absent from the French inventory: [ŋ, ɹ] as well as [tʃ, dʒ, θ, ð, h]. Although many segments are common to both French and English, the frequency of occurrence of common phonemes differ (Crystal, 1995; Malécot, 1974). For example, the phoneme /ʒ/ has a high frequency of occurrence in French relative to English and is present in many early acquired words such as 'juice' (*jus*, /ʒy/) and 'play' (*jouer*, /ʒue/).

The features associated with each consonant are presented in Table 3 (page 36). Importantly, multilinear phonology only specifies unpredictable information in the underlying representation. For instance, since stops can be either voiced or voiceless, [+voice] will be specified for voiced stops, while the

feature will not be specified for sonorants which are voiced by default. Features are also underspecified when they are not required in order to distinguish two phonemes from one another. For example, although /f/ is labiodental no other consonant in English would be specified by the combination of features [+consonantal] Labial [+continuant] and therefore [+labiodental] is not specified. Finally, Coronal is considered the default place of articulation.

Several studies have investigated the ages at which individual consonants are acquired by English-speaking children by using single-word picture naming procedures to elicit every English consonant in the initial and final position of words, and sometimes in the medial position as well. Large data sets collected by Templin (1957) and Wellman, Case, Mengert, and Bradbury (1931) were summarized in a chart by Sanders (1972), which to this day is often used by speech-language pathologists. Since then, four additional cross-sectional studies of English consonant acquisition in large numbers of children have been published (Arlt & Goodban, 1976; Dodd, Holm, Hua, & Crosbie, 2003; Prather et al., 1975; Smit et al., 1990). While there is a wealth of published evidence about the normal course of speech development in English, there are few studies regarding typical phonological development in Canadian or European French. Most of the studies on French phonological development include small numbers of participants, such as Grégoire's (1937) diary study of his two sons, longitudinal studies including one or two children (dos Santos, 2007; Rose, 2000; Yamaguchi, 2012), and studies of 4 to 25 children (Demuth & Kehoe, 2006; MacLeod & McCauley, 2003; Martinet, 1974; Vinter, 2001).

Table 3. Features for adult English and French consonants.

Segment	Root node	Laryngeal node	Place node
/p/	[+consonantal]		Labial
/b/	[+consonantal]	[+voice]	Labial
/t/	[+consonantal]		
/d/	[+consonantal]	[+voice]	
/k/	[+consonantal]		Dorsal
/g/	[+consonantal]	[+voice]	Dorsal
/f/	[+consonantal] [+continuant]		Labial
/v/	[+consonantal] [+continuant]	[+voice]	Labial
/θ/	[+consonantal] [+continuant]		Coronal: [-grooved]
/ð/	[+consonantal] [+continuant]	[+voice]	Coronal: [-grooved]
/s/	[+consonantal] [+continuant]		
/z/	[+consonantal] [+continuant]	[+voice]	
/ʃ/	[+consonantal] [+continuant]		Coronal: [-anterior]
/ʒ/	[+consonantal] [+continuant]	[+voice]	Coronal: [-anterior]
/tʃ/	[+consonantal] branching [+cont]		Coronal: [-anterior]
/dʒ/	[+consonantal] branching [+cont]	[+voice]	Coronal: [-anterior]
/m/	[+consonantal] [+nasal]		Labial
/n/	[+consonantal] [+nasal]		
/ŋ/	[+consonantal] [+nasal]		Dorsal
/ɲ/	[+consonantal] [+nasal]		Coronal: [-anterior]
/w/	[+sonorant]		Labial: [+round]
/j/	[+sonorant]		
/ɥ/	[+sonorant]		Labial: [+round]
/h/		[+spread glottis]	
/l/	[+cons] [+sonorant] [+lateral]		
/ɹ/	[+cons] [+sonorant]		Coronal: [-anterior] Labial: [+round]
/ʁ/	[+cons] [+sonorant]		Dorsal

An exception is the recent cross-sectional study by MacLeod, Sutton, Trudeau, and Thordardottir (2011). They described the consonant acquisition of 156 francophone children age 20 to 53 months using a picture-naming task targeting all consonants of Québec French in initial, medial, and final position. Consonants were considered acquired when 75% or more of the children accurately produced the segment in the initial, medial, and final word positions. Results indicated that /p, b, t, m, ɲ, f, z/ were acquired prior to 36 months; /d, k, g, v, ʁ, l, w, ɥ/ between 36 and 41 months; /n, ʃ, ʒ/ between 42 and 47 months; and /j/ between 48 and 53 months. The consonant /s/ was not acquired by 53 months but was nonetheless correctly produced by at least 50% of the children in two out of three word positions between 48 and 53 months. Comparison of French data to English is complicated because differences in methodology such as the length and segment sequences of the target words, elicitation procedure, and scoring can have a considerable impact on the results (Edwards & Beckman, 2008). Nonetheless, the results overall indicate earlier acquisition of consonants by monolingual children speaking Québec French compared to monolingual English-speaking children, particularly so for /v, z, l, ʁ/.

Differences Between English and French Phonology at the Prosodic Level

Prosodic tiers are also organized hierarchically; utterances are composed of progressively smaller units including phonological phrases and words, which are themselves composed of smaller intra-word units. Each unit is represented on its own tier, or level. Figure 2 (on page 38) depicts the prosodic hierarchy for the utterance ‘the baby is sleeping’. As shown at the bottom of the figure, the root

node of the segmental hierarchy attaches to the lowest level of the prosodic hierarchy, the skeletal tier. Continuing from the bottom up, consonants I and vowels (V) are grouped together into syllables. Strong (s) syllables are more prominent than others; weak (w) syllables are unstressed. The only obligatory component of the syllable is the syllabic nucleus (N), which is the peak in sonority and usually consists of a vowel. The onset (O) of the syllable consists of the longest permissible sequence of consonants to the left of the nucleus. The coda (Co) is made up of the remaining consonants to the right of the nucleus. Finally, the rime I consists of the nucleus and the coda (O'Grady & Dobrovolsky, 1997).

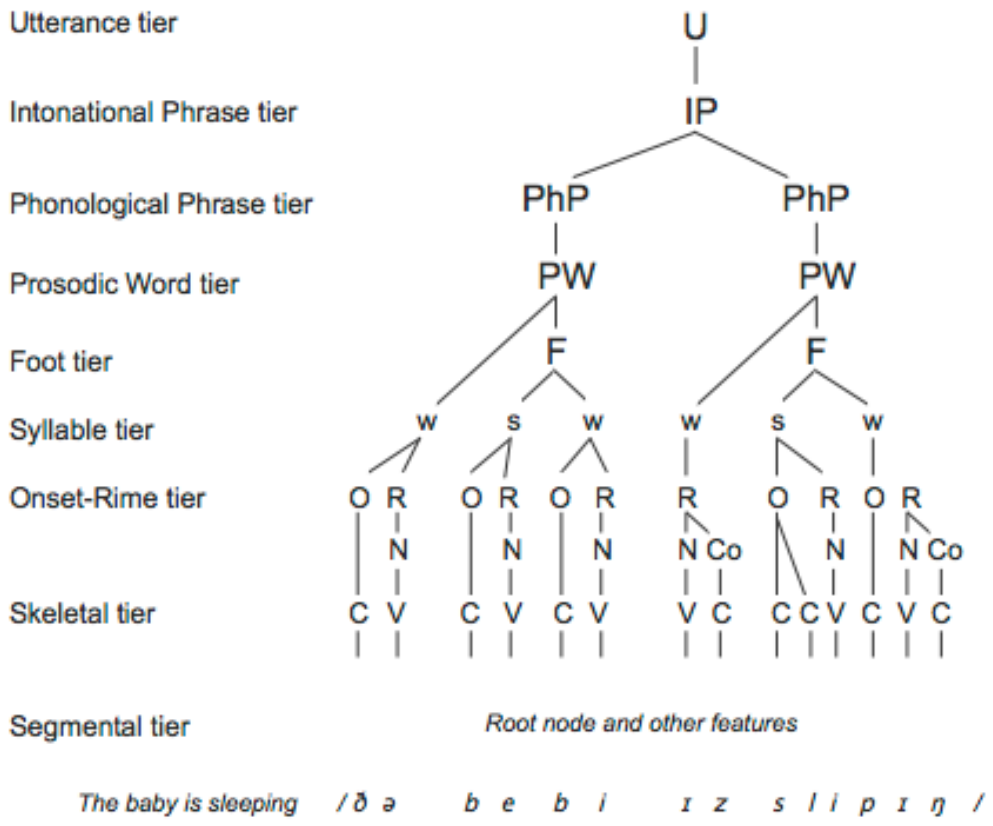

Figure 2. Illustration of the prosodic hierarchy for the sentence "the baby is sleeping".

As many as three consonants are allowed in the onset or coda position in French (Rose & Wauquier-Gravelines, 2007), as in English. However, there are several differences between the French and English phonological systems with regards to syllables. For instance, young French-speaking children tend to produce CV syllables first, and then VCV and CVCV word shapes, where the CV is often reduplicated or where the consonants are different but harmonized for place (Wauquier & Yamaguchi, in press). In contrast, whereas early words produced by English-speaking children also tend to be of the word shape CV, the forms VC and CVC are also very common, as are the two-syllable CVCV and CVCVC (Ingram, 1978). Young French-speaking children therefore produce very few CVC words in comparison to English-speaking children (e.g. Vihman & Velleman, 1989). In the speech of adult speakers of French, about 80% of syllables are open, meaning they do not contain a coda, and the most common syllable shape (55%) is CV (Adda-Decker, Boula de Mareüil, Adda, & Lamel, 2005). The difference regarding syllable shapes between the two languages is also reflected in the proportion of consonants to vowels per syllables, 1.6 in French compared to 2.1 in English (Delattre, 1965).

Although the individual syllable shapes are generally simpler in French than in English, French has a smaller proportion of monosyllable words than English. While 61% of items on the MacArthur-Bates Communication Development Inventory (Fenson et al., 1993) are monosyllabic words, only 33% of the items on its Québec French adaptation (Inventaires MacArthur-Bates du développement de la communication; Trudeau, Frank, & Poulin-Dubois, 1997)

contain only one syllable. Sixty-seven percent of the French items contain two syllables or more.

The French and English phonological systems are also markedly different at the next level up of the prosodic hierarchy, the foot tier. In English, most two-syllable words are trochaic, meaning that they have a strong syllable followed by a weak syllable; most trisyllabic words consist of a "strong-weak-weak" stress pattern and are also trochaic (e.g. Gerken, 1994). The prominence therefore falls on the initial syllables of disyllabic and trisyllabic words, as shown in examples [1]-[2]. Some researchers have proposed that French is an iambic language in which two-syllable words consist of a weak syllable followed by a strong syllable (e.g. dos Santos, 2007; Goad & Buckley, 2006; Rose, 2000). In support for this account, French stress is predictable, falling on the last syllable of a word, or on the penultimate syllable if the word-final syllable contains a schwa (Walker, 1984), as shown in examples [3]-[4].

[1] *baby* → [ˈbebi]

[2] *elephant* → [ˈɛləfənt]

[3] *bébé* ('baby') → [beˈbe]

[4] *éléphant* ('elephant') → [eleˈfɑ̃]

However, French stress predictably falls on word-final syllables only when words are spoken in isolation (Wauquier & Yamaguchi, in press), which is how the productions of the participants in Study 1 and Study 2 were elicited. Contrary to English, French does not have lexical stress; rather, the accentual unit is the phrase (Dell, 1985; Di Cristo, 1999). In conversational French, stress

placement falls on the last full syllable of a group, such as the utterance or a syntactic or semantic phrase, with a counter-accent on the first syllable of the group (Fonagy, 1980), as shown in [5]. In English, stress falls on each lexical word of the sentence as if they occurred in isolation, as shown in [6].

[5] *le bébé fait dodo* → [ˌlə bebe fɛ dɔˈdo]
‘the baby is sleeping’

[6] *the baby is sleeping* → [ðə ˈbebi ɪz ˈslipɪŋ]

To describe French stress, Di Cristo (1999) used the term “accentual arc”, in which the initial syllable and final syllable of a group are prosodically strong and are the pillars of the arc, as shown in examples [7]-[10].

[7] *le ballon* → [ˌlə baˈlɔ̃]
‘the ball’

[8] *le ballon rouge* → [ˌlə balɔ̃ ˈʁuʒ]
‘the red ball’

[9] *Sophie joue avec le ballon rouge* → [ˌsɔfi ʒu avɛk lə balɔ̃ ˈʁuʒ]
‘Sophie is playing with the red ball’

[10] *Sophie et Laura jouent avec le ballon* → [ˌsɔfi e loˈʁa ˌʒu avɛk lə baˈlɔ̃]
‘Sophie and Laura are playing with the ball’

The counter-stress may fall on the determiner, as shown in these examples, or on the initial syllable of the first word following the determiner; acoustic studies are needed in order to clarify in which contexts stress falls on the determiner or on the initial syllable of the left-most lexical word. Examples provided in Wauquier and Yamaguchi (2012) show that children preserve a proto-determiner but truncate the

initial syllable of the first content word in the context of a short phrase consisting of a proto-determiner and one content word.

French is classified as a syllable timed language, meaning that every syllable would be of approximately the same length, whereas English is stress-timed and would have syllables of unequal durations but fairly constant durations between consecutive stressed syllables (Roach, 1982). Investigation of the length of syllables in languages classified as either one of these timing categories has shown that syllable duration in stressed-timed languages are not very different than in syllable-timed languages, and that the perception of a distinction between stress- and syllable-timed languages is related to differences with regards to syllabic structures, vowel reduction, and the realization of stress (Dauer, 1983). While heavy syllables are more regular and prominent in English, in French the perception of syllable timing has been associated with a decreased prominence of stressed syllables in comparison to unstressed syllables, the dominance of CV syllables, and the fact that vowel deletion is common, as opposed to vowel lengthening which induces stress (Adda-Decker et al., 2005; Fant, Kruckenberg, & Nord, 1991).

All levels of the phonological hierarchy are connected and interact with each other. Interactions between prosodic stress and constraints at the syllabic level explain several patterns seen in the speech of young French-speaking children. For instance, according to Vihman, young children select preferred word templates from salient characteristics of the segments and prosody of their ambient language. They then adapt new words to their small number of preferred

templates. While omission of word initial consonants would be considered atypical in English-speaking children, children speaking languages with phrase-final prominence, such as French, commonly exhibit this error pattern (Vihman, 2010; Vihman & Croft, 2007). Vihman (2010) proposed that children learning French or other languages with similar phonological systems pay more attention to the second syllable of two-syllable words due to their increased prominence. This, in turn, may decrease the amount of attention these children pay to the initial consonant of the first syllable, increasing the likelihood that they will omit this particular consonant. Wauquier and Yamaguchi (in press) further explained that the prosodically strong positions are first established by children, who do not truncate them and rarely modify them. In French, unlike in English, single nouns rarely occur without a determiner (e.g. Bassano, Maillochon, & Mottet, 2008). French-speaking children are therefore rarely exposed to single words, and often to short noun phrases. Although there is a counter-stress on the first syllable in French, in the context of a short phrase containing a determiner and a noun, the counter-stress may fall on the determiner and not on the initial syllable of the lexical word, as shown in examples [11]-[13]. In English, on the other hand, stress falls on the first syllable of di- and trisyllabic words whether the adult produces them in isolation or in a short phrase. Initial consonants are therefore less vulnerable to deletion in English.

[11] *la balle* → [ˌla ˈbal]
‘the ball’

[12] *un mouton* → [ˌœ̃ muˈtɔ̃]
‘a sheep’

[13] *les crocodiles* → [ˌlɛ kʁɔkɔˈdil]
‘the crocodiles’

Wauquier and Yamaguchi (in press) further note that word-final codas in French are prominent when words are produced in isolation or in combination with determiners, and that in addition there are several high frequency CVC words in the French input to young children, such as *jambe* (‘leg’), *vache* (‘cow’), and *balle* (‘ball’). However, French-speaking children rarely produce CVC words. They propose that French’s children early word templates are influenced by the dominance of CV syllables in the input, and to the fact that CVC words are frequently resyllabified as CV words in continuous speech (Adda-Decker et al., 2005), as shown in example [14].

[14] *ta jambe* → [ta/ʒɑ̃b] => *ta jambe est cachée* → [ta/ʒɑ̃/bɛ/ka/ʃe]
‘your leg’ ‘your leg is hidden’

In terms of the segments, normative studies suggest earlier acquisition of consonants in French compared to English, which implies greater accuracy of consonant production by young French learning children. Perhaps this is not surprising because in French, target syllable shapes are simpler on average than those that must be mastered by English speaking children. At the same time however, French learning children are exposed to longer word and phrase lengths in the input, which may complicate the acquisition of French phonology at the prosodic levels of the phonological hierarchy. Furthermore, research with other language learners (e.g., African American English; Pearson, Velleman, Bryant, and Charko, 2009) has reported trade-offs between accuracy of production between the segmental and prosodic tiers. Therefore, due to differences between

the French and English phonological systems at the segmental and prosodic levels, I hypothesize that the surface speech errors of French-speaking children with DPD will be different than those of English-speaking children with DPD of similar severity. More precisely, I expect French-speaking children with DPD will achieve greater segmental accuracy but have more difficulty at the prosodic level than English-speaking children with DPD. As young, typically developing French-speaking children have been shown to omit onsets and codas, and to prefer CV and CVCV syllable shapes, I expect French-speaking preschool-age children to omit more codas, onsets, and branching onsets than a comparable group of English-speaking children with DPD. On the other hand, when French-speaking children with DPD do not omit the target consonant I expect they will show greater segmental accuracy than English-speaking children. Study two will investigate whether surface speech errors are indeed manifested differently in French-speaking children with DPD by comparing them to a very similar group of English-speaking children with DPD. First, however, Study one aims to determine whether the same underlying psycholinguistic skills which have been shown to be disrupted in English-speaking children with DPD are also disrupted in French-speaking children with DPD, as hypothesized at the end of Chapter 1.

Chapter 3

Study 1

Psycholinguistic profiles of French-speaking preschoolers with developmental phonological disorders.

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Abstract

This study examined the psycholinguistic profiles of French-speaking children with developmental phonological disorders (DPD). Seventy-two children with DPD, aged 4 to 6 years, were assessed on measures of articulation accuracy, receptive vocabulary, nonverbal intelligence, phonological processing (phonological awareness, speech perception, syllable repetition test) and structure and function of the oral-speech mechanism. The articulation accuracy, receptive vocabulary, phonological awareness and syllable repetition test were also administered to a small group of 10 typically developing children. The majority of the children with DPD presented with a psycholinguistic profile indicative of difficulties with phonological processing. Measures of phonological processing also explained significant unique variance in speech production accuracy. The results of this study indicated that French-speaking children with DPD are very similar to English-speaking children with DPD with regards to their underlying psycholinguistic skills and offered support for a multiple deficit view of DPD.

Introduction

Children who misarticulate speech sounds that should be mastered at their age represent the largest group of children receiving speech-language pathology services in school (ASHA, 2010). In the preschool population, developmental phonological disorder (DPD) is also the most common communication disorder (McLeod & Harrison, 2009; Mullen & Schooling, 2010). As a group, children with DPD are at increased risk of presenting with later academic and socio-emotional difficulties (McCormack, McLeod, McAllister, & Harrison, 2009). The provision of effective and efficient intervention before formal reading instruction begins is essential in order to maximize their chance of success (Bishop & Adams, 1990; Leitao & Fletcher, 2004; Nathan, Stackhouse, Goulandris, & Snowling, 2004). However, successful intervention for children with DPD is dependent on knowledge of the underlying nature of their phonological disorder (Stackhouse & Wells, 1997). For nearly a century, speech-language pathologists (SLPs) have been skillfully assessing the surface manifestations of communication disorders; understanding of the underlying neurobiological mechanisms that explain delayed speech and language development is more limited but growing with recent advances in neurolinguistics and genetics research (Morgan, 2013).

Phenotypes result from the interaction between genes and the environment, and are the observable characteristics of the disorder (Gottesman & Gould, 2003), such as omission, distortion, and substitution errors in the speech of children with DPD. Phenotypes change as the child matures, and in response to

the environment. For instance, speech error types vary with the severity of the DPD and the age of the child (Rvachew, Chiang, & Evans, 2007). Endophenotypes, on the other hand, are measurable parameters associated with a behavior that are more closely related to the genetic underpinnings of the disorder (Gottesman & Gould, 2003). The endophenotype is a core determinant of the disorder; it remains present notwithstanding changes in the environment or the child's maturation. For example, children with a history of DPD but who no longer present with surface speech errors nonetheless continue to present with deficits in phonological awareness (Raitano, Pennington, Tunick, Boada, & Shriberg, 2004). In the past decade, a small but growing number of studies have attempted to understand the neurobiological mechanisms of DPD by investigating the underlying speech processes that are disrupted by the disorder. These studies provide increasing support for a core deficit in phonological processing in the vast majority of children with DPD, and more specifically a deficit with encoding acoustic and articulatory variation in speech.

Oral-Motor Abilities

Prior to the 1960s/1970s, it was believed that the speech errors of children with DPD were due to their inability to execute the articulatory movements associated with the phonemes they misarticulate (Baker, 2006). Despite the fact that only a small percentage of children with DPD, approximately 5%, have been found to present with difficulties with a true motor disorder (e.g. Ozanne, 1995; Shriberg, 1994), the use of motorically-based intervention approaches remains quite popular with SLPs working with preschool and school-age children with

DPD. One example is nonspeech oral-motor exercises (NSOMEs), such as blowing horns or whistles, puffing the cheeks, and elevating the tongue (Forrest, 2002). These exercises do not require the child to speak, but are believed to improve the child's abilities to do so by breaking down the complex task of articulating into smaller movements, and by increasing the tone and strength of the articulators (Forrest, 2002; Lof & Watson, 2008). Although research findings do not support the use of NSOMEs to improve speech production abilities (e.g. Lass & Pannbacker, 2008; Ruscello, 2008), studies have reported that between 71.5% and 85% of practicing SLPs in the US, Canada, and the United Kingdom are using NSOMEs to improve children's speech sound production abilities (Hodge, Salonka, & Kollias, 2005; Joffe & Pring, 2008; Lof & Watson, 2008). Many clinicians indicated that they believed speech development was related to early oral motor movements such as sucking and chewing, and were using NSOMEs to, among others, increase the strength and the awareness of the articulators (Lof & Watson, 2008). Research has indicated, however, that from a very young age the motor patterns involved in non-speech oral movements are distinct from those involved in speech (Kent, 2000). Furthermore, very little articulator strength is required to speak (Forrest, 2002).

Another possibility for the widespread use of NSOMEs is that clinicians may believe that children with DPD present with concomitant difficulties with motor planning or motor execution, especially so if the child is producing inconsistent speech errors, as these are often considered to be a symptom of a motor speech disorder (Betz & Stoel-Gammon, 2005). However, two studies

demonstrated that the presence of difficulties with motor planning and/or programming could not be determined without direct measurement of speech motor control. Goffman, Gerken and Lucchesi (2007) compared the movement trajectory variability, segment accuracy, and segment variability of strong and weak syllables in various foot structures of ten young adults, ten young children with typical speech and language development, and ten children with language impairment. One of the findings of the study was that segmental variability, as measured by phonetic transcription, was not always aligned with movement trajectory variability. Using both phonetic transcription and acoustic measures, Preston & Koenig (2011) investigated the phonetic variability of 20 children aged 9 to 15 years with residual speech errors. They also found that transcription-based measures did not correlate with acoustic measures. In other words, it is not possible to determine whether a child has a motor planning and/or motor programming deficit from transcription of their speech alone.

Ozanne (2005) completed a cluster analysis of symptoms of motor involvement in 100 children aged 3 to 5 years with suspected motor speech disorder. Four clusters emerged, including one cluster of children who produced inconsistent and atypical speech errors with little or no motor involvement. Direct investigation of possible deficits with regards to oral-motor skills as well as to other speech processes is required for these children, since many children who present with a true motor deficit also have difficulties with encoding acoustic-perceptual information from the speech input (Shriberg, Lohmeier, Strand, & Jakielski, 2012).

Phonological Processing

Phonological processing refers to one's abilities to represent, manipulate, store, and retrieve phonological information of words (Snowling, 2000; Wagner & Targesen, 1987). In other words, phonological processes "require cognitive operations on the sound system of the language" (Metsala, 1999, p. 3) and include processes such as phonological awareness (PA), encoding of phonological representations, access to and retrieval of phonological representations, and phonological short-term memory. PA refers to the ability to attend to the sound structure of spoken language; tasks tapping into PA skills commonly involve sensitivity to similarities between words in terms of rimes, onsets, or number of syllables. PA assessment tasks may involve implicit awareness of these phonological units (as in matching words with similar structure) or explicit manipulation of the sound structure of words, as in blending or elision of phonemes or syllables. Numerous studies have demonstrated a stable and robust relationship between PA and reading abilities (Bradley & Bryant, 1983; Calfee, Lindamood & Lindamood, 1973; Lonigan, Burgess, & Anthony, 2000; Menyuk et al, 1991; Pennington & Lefty, 2001; Torgesen, Wagner, & Rashotte, 1994; Wagner et al, 1997). Children with DPD are at risk for future reading difficulties (e.g. Bird, Bishop, & Freeman, 1995; Nathan et al., 2004; Raitano et al., 2004; Rvachew, 2006). In fact, the probability that a child with DPD will later present with reading disorder (RD) is the same as a child with a family history of RD (Carroll & Snowling, 2004). A growing number of studies have found that these two disabilities are linked to several common chromosome regions and candidate

genes (e.g. Rice, Smith, & Gayan, 2009). As a group, children with a history of DPD, resolved or not, have lower PA abilities than children without a history of DPD (Raitano et al., 2004).

As the size of the child's lexicon increases, the child's phonological representations become more adult-like (Metsala, 1999). According to the Lexical Restructuring Hypothesis, the pressures associated with rapid lexical access within an increasingly large lexicon in which neighborhoods of similar words are becoming denser leads to the need for greater organization within that lexicon; therefore, lexical expansion leads to organization of words based on increasingly smaller units across different phonological tiers: word, foot, syllable, onset and rime, nuclei and coda, phonemes, which will in turn be organized into a hierarchically organized set of features. The development of PA skills relies on increasingly accurate and distinct internal phonological representations (Elbro & Pallesen, 2002; Fowler, 1991; Snowling, 2000) as well as the cognitive ability to access those representations explicitly. While PA tests do not assess speech perception directly, performance on PA tasks is strongly linked to the speech perception abilities of the child (Lyytinen et al., 2004), since acoustic-phonetic representations need to be sufficiently detailed and mature to allow the recognition of words with less redundancy of acoustic information.

Children with DPD have considerable difficulties with the perception of their speech and that of other talkers (e.g. Broen, Stange, Doyle, & Heller, 1983; Hoffman, Daniloff, Bengoa, & Schuckers, 1985; Rvachew & Jamieson, 1989). Using synthetic speech continua, studies have shown that children with DPD have

difficulty identifying words in which specific acoustic information was manipulated in order to create minimal contrasts such as “rake-lake” (Broen et al, 1983; Hoffman et al, 1985; Rvachew & Jamieson, 1989). Some of the children were not aware of the phonemic contrast while others defined the phonemic contrast based on inappropriate cue weighting strategies. For example, in typical development, perceptual and productive knowledge of the F3 cue permits accurate /ɹ/ production before age 5 years (Idemaru & Holt, 2013) whereas children with DPD appear to ignore F3 and manipulate F2 instead (Hoffman, Stager & Daniloff, 1983). Shuster (1998) also found that children with persistent speech sound disorder have difficulties perceiving the target sounds they misarticulate, even after many years of speech therapy. In a series of well-controlled studies, Munson and colleagues (Munson, Baylis, Krause, & Yim, 2010; Munson, Edwards, & Beckman, 2005; Munson, Kurtz, & Windsor, 2005) investigated the articulatory knowledge, perceptual knowledge, and phonological knowledge of children with DPD and children with typical language skills. The results of these studies showed that in the vast majority of children with DPD, their speech production difficulties are due to deficits encoding acoustic-perceptual information from the speech input. These encoding difficulties, in turn, lead to inaccurate or incomplete acoustic-phonetic representations for words, which prevent the child from comparing his or her own productions against the target to achieve consistent, accurate production of the target (Shiller, Rvachew, & Brosseau-Lapré, 2010).

Recently, Anthony et al. (2011) compared the phonological, language, and literacy skills of three groups of 68 children age 3;5 to 5;6: children with DPD,

children with typical speech matched on receptive vocabulary, and children with typical speech and language skills. Several weaknesses in phonological processing were found in the children with DPD, who obtained significantly lower scores than the other two groups of children on PA and speech perception tasks. Among others, children with DPD had more difficulty producing a complete word after hearing an incomplete target. As noted by Anthony and colleagues, this result is similar to previous results obtained several years before by Edwards and colleagues (Edwards, Fourakis, Beckman, & Fox, 1999; Edwards, Fox, & Rogers, 2002). Using gated speech, they found that children with DPD performed significantly worse than TD children when instructed to identify the word they heard by pointing to one of four pictures. The acoustic-phonetic representations of children with DPD were not sufficiently detailed and mature to allow them to recognize words with slightly less redundancy of acoustic information. In the study conducted by Anthony and colleagues, TD children, who had the largest vocabulary sizes, performed better than the other two groups of children. However, children with DPD performed worse than children with identical vocabulary sizes but better articulation accuracy scores. Taken together, these results indicate that children with DPD have a core deficit in phonological processing and are at increased risks for deficits in PA and reading acquisition independently of their language abilities. However, concomitant language impairment increases their risk of reading disability (e.g. Nathan et al., 2004; Raitano et al., 2004; Snowling, Bishop, & Stothard, 2000).

Studies investigating the phonological processing abilities of children with DPD often use receptive PA and speech perception tasks, which have the advantage of avoiding scoring confounds when the examiner does not understand what the child said. Nonword repetition taps into many speech processes, such as encoding of the phonological representation, phonological memory and motor planning (e.g. Coady & Evans, 2008). Many studies have shown that it is a reliable endophenotype associated with heritable language impairment (e.g., Bishop, Adams, & Norbury, 2006; Bishop & Hayiou-Thomas, 2008) and reading disability (e.g. Bishop, Adams, & Norbury, 2004; Smith, Pennington, Boada, & Shriberg, 2005). However, until recently it was difficult to assess the nonword repetition abilities of unintelligible children since these tests include phonemes that are commonly misarticulated by children with DPD. In fact, even when testing TD children, nonword repetition strongly indexes speech production accuracy (e.g., Colledge et al., 2002; for further discussion, see Rvachew & Grawburg, 2008). In response to this problem, Shriberg et al. (2009) developed the Syllable Repetition Task (SRT) for individuals with mild to severe DPD. The test items contain only sounds that are produced by young children and speakers with speech sound production deficits (specifically, /b/, /d/, /m/, /n/, /a/). There are eight CVCV items (e.g. *dama*), six CVCVCV items (e.g. *bamana*) and four CVCVCVCV items (e.g. *manabada).*

A competence score as well as three speech processing scores (encoding, memory, and transcoding) can be derived from the SRT, as described by Lohmeier & Shriberg (2011) and Shriberg et al. (2012). The competence score

consists of the number of consonants that were accurately produced by the child; cognate substitutions on the voiced stops are scored as correct (i.e. p/b, t/d), and additions errors are not taken into account as long as the target consonant is produced in the correct position. Encoding of auditory-perceptual representations is measured by calculating the percentage of substitution of sounds that belong to the same manner as the target, which presumably indicates partial knowledge of the target. The ratios of accurately repeated consonants in longer words compared to shorter words allow quantifying the contribution of phonological memory in the speaker's performance on the SRT. The ratios are transformed using the formula 100*(1+natural log of the ratio); values above 100 or below 0 are truncated. Finally, the transcoding score is the percentage of items containing one of more addition errors such as /bada/ → [banda], subtracted from 100 so that higher scores denote higher competence in transcoding. Addition errors are considered to reflect motor planning and/or programming deficits.

In addition to the fact that the SRT target words only contain sounds that are unlikely to be mispronounced, the target consonants are also generally present in the inventories of other languages, providing an opportunity to assess these endophenotypes of phonological processing and oral-motor ability in children with DPD speaking languages other than English. Shriberg et al. (2009) concluded that this test supported the hypothesis of encoding and/or memorial constraints for most English-speaking children with speech delay. In contrast, children with motor speech disorders, in particular childhood apraxia of speech,

have difficulty with transcoding when assessed with the SRT (Shriberg et al., 2012).

Purpose of the Study

To our knowledge no study has described the psycholinguistic profiles of French-speaking children with DPD. Endophenotypes, being core determinants of a disorder, remain stable despite environmental variation, such as the characteristics of the child's ambient language. We believe it is important to determine whether the same endophenotypes that have been identified in English-speaking children with DPD (measures of phonological processing, vocabulary, and oral motor skills) are also involved in French-speaking children with DPD. This may lead to a better understanding of the underlying speech processes that are disrupted in DPD and ultimately improve intervention for these children.

We hypothesized that, as a group, French-speaking children with DPD would have significantly worse phonological processing skills than French-speaking children with typically developing speech accuracy, as measured by tests of speech perception, phonological awareness, and syllable repetition. Only a very small proportion of children were expected to present with a motor speech disorder. We further hypothesized that articulation accuracy would be predicted by vocabulary and phonological processing skills, while motor speech abilities would not explain speech deficits in French-speaking children.

Methods

Participants

The children with DPD were recruited in six cohorts and were referred to the study by speech-language pathologists (SLPs) at the Montreal Children's Hospital. Each child was assessed by the first author, a certified SLP, or by graduate students in speech-language pathology under the supervision of the first author. The assessments were conducted in a testing room at the Montreal Children's Hospital or in a research laboratory at McGill University. A total of 72 eligible children completed the intake assessment over one visit of 60-90 minutes. During this time most parents completed questionnaires about their child's development and medical and family history; a few families asked to complete the questionnaires at home with their spouse. One to six weeks later, the children were seen for a second assessment visit lasting 40 to 50 minutes, during which time a language sample was collected and measures of speech perception and syllable repetition skills were administered. The selection criteria were: native and dominant speaker of French (at least 75% exposure to French as reported by the parents); age 4;0 to 5;11 on the first planned day of intervention; primary diagnosis of DPD; hearing within normal limits as documented before referral to the study; and standard score of at least 80 on measures of receptive vocabulary and non-verbal intelligence. Children were excluded from the study if their DPD was secondary to other conditions such as sensory-neural hearing loss, cerebral palsy, cleft palate, global developmental delay, or autism spectrum disorder. Concomitant receptive and/or expressive language impairment and suspected

childhood apraxia of speech were not exclusionary criteria. Two identical twins and two siblings participated in the study; one child from each pair was removed from certain analyses, as described below.

French is the majority language of the approximately 7.9 million residents of the province of Québec, Canada. While 51.8% of the population of Québec is monolingual French, only 37% of the residents of the city of Montreal and its region do not speak other languages: 53.7% speak both French and English, and the most common mother tongues in this city, following French and English, are Arabic, Spanish, Italian, Creole, and Greek (Statistics Canada, 2012). Table 1 presents the linguistic environments of the participants.

Insert Table 1 about here.

Ten typically developing (TD) children also participated in the study and were assessed at their house by the first author. Parents of the TD children completed the same questionnaires about their child's development and medical and family history, and four tests which will be described below were administered to these children: receptive vocabulary, phonological awareness, articulation accuracy in single words, and syllable repetition. The language exposure of the TD children is shown in Table 1.

Table 2 presents descriptive information for the two groups of participants. With regards to the children with DPD, there were 52 males and 20 females, a 2.6 male:female ratio which is very similar to the 2.75:1 ratio reported for English-speaking children with speech sound disorders by Shriberg (1994). In terms of past or current family history of speech, language, or reading difficulties, the data

are presented for 65 of the 72 children with DPD since two children had been adopted, the parents of three additional children did not complete the questionnaires, and one member of each sibling pair was randomly removed from the family history analyses.

Insert Table 2 about here

Procedures

EVIP. The Échelles de Vocabulaire en Images de Peabody (Dunn, Theriault-Whalen, & Dunn, 1993) is a Canadian-French adaptation of the Peabody Picture Vocabulary Test-Revised (Dunn & Dunn, 1981). The children were shown black and white plates with four pictures and asked to point to the word named by the examiner. The five practice items were given before the test.

K-BIT-2. The Matrices subtest of the Kaufman Brief Intelligence Test, 2nd Edition (Kaufman & Kaufman, 2004) measures non-verbal intelligence. Children were presented color plates with a target picture at the top, and six pictures at the bottom. They were asked to point to the picture among the six choices that went with the target. The practice items of each section were administered according to the instructions in the test manual.

TFP. The Test Francophone de Phonologie (Paul & Rvachew, unpublished) is a test of articulation accuracy that mirrors the phoneme distribution, syllable shapes, and word length characteristics of Quebec French, as described in Paul (2009). In brief, a total of 54 words are elicited using 20 full color photographs, targeting 161 consonants and 107 vowels. Twenty-eight percent of the elicited words are monosyllabic, 50% disyllabic, and 23% contain

at least three syllables. In addition, 36% of syllables contain a coda, and 15% contain a consonant cluster. Examiners used carrier phrases to elicit spontaneous productions of the target words; if the child did not answer, delayed imitation techniques such as asking a choice question with the target as the first choice was used. Immediate imitation was used as a last resort to ensure data sets that were as complete as possible for each child. Nonetheless, three children each refused to produce one target word, and one child did not produce two target words. Administration of the TFP was video-recorded using a Sony Handycam HDR-XR520 or a JVC Everio GZ-MG360 videocamera. The audio files were extracted and saved as .wav files.

OSMSE-3. The Oral Speech Mechanism Screening Examination, Third Edition (St. Louis & Ruscello, 2000) evaluates the structure and function of the lips, tongue, jaw, teeth, palate, pharynx, velopharyngeal mechanism, breathing, and DKRs and AMRs. The screening tool was administered according to the manual and was video-recorded. Repetition rates were calculated from waveform displays of the children's responses and rounded to the nearest tenth of a second. Two children refused to complete most of the test items and therefore the structure and function scores could only be derived for 70 of the children. The DKR and AMR rates are only available for 67 of the children, since the video recording was missing for two children and an additional child refused to complete the repetition tasks. Finally, the repetition of the disyllable /pata/ was not administered by mistake to 8 children. Many of the children who participated in this study were younger than 5;0, the minimum age to use the OSMSE-3

norms. Younger children had more difficulty completing the required number of repetitions (16 for single syllables, 12 for [pata] and 8 for [pataka]) but age was not correlated with performance with regards to repetition rates in syllable/seconds for any of the isolated syllables or syllable sequences. We therefore calculated the repetitions/second for each child, and prorated the pass criteria for the required number of repetitions. Pass standards were 2.9; 2.3; 2.7; 1.7; 0.95 repetitions/second for [pa], [ta], [ka], [pata] and [pataka] respectively for children up to the age of 55 months, and 3.2; 2.5; 2.9; 1.7; 1.0 for children aged 66 to 71 months.

TCP. The Phonological Awareness Test was developed by Bird, Bishop, and Freeman (1995) for research purposes and consists of three subtests: rime matching, onset matching, and onset segmentation and matching. In the rime matching subtest, the child is shown a puppet, told its name, and told that the puppet "likes things that sound like his name." The child is presented with four pictures (target and three distracters). The examiner names each of the four pictures while pointing at them and then asks the child to point to the correct answer. In the onset matching subtest, the child is told the puppet likes "everything he owns to start with the same sound." The clinician produces the sound the puppet likes, names each picture while pointing at them, and then asks the child to point to the correct picture among four items. In the onset and segmentation subtest the child is told the puppet's name, and that the puppet "likes things that start with the same sound as his name", without hearing the target sound in isolation. The examiner names each pictures and then asks the

child to select the correct answer among four pictures. There are five practice items at the beginning of each subtest during which corrective feedback can be provided as necessary. The rime matching subtest has 14 test items and the remaining two subtests each have ten test items.

The Test de Conscience Phonologique (TCP; Brosseau-Lapré & Rvachew, 2008, unpublished), a French adaptation of the Bird, Bishop, and Freeman task, was created for this study. While the number of practice and trial items remained the same for each subtest, the target phonemes and syllable structures of the words were modified to better represent the phonology of Quebec French. A laptop was used to present the pictures and audio stimuli, although the examiner pointed to each picture and named them live-voice. The test stimuli, items and instructions are available under "Clinical software and tools" at http://www.medicine.mcgill.ca/srvachew.

SAILS. The Speech Assessment and Interactive Learning System (SAILS) is a computer-based tool, which was developed by Rvachew (1994) to treat speech perception deficits and has also been used as a speech perception assessment measure. It consists of a two-alternative, forced-choice word identification task. The child hears natural speech recorded from adults, typically developing children and children with phonological disorders. The child's task is to indicate whether or not the word that was presented consisted of the target. An experimental French version of the SAILS tool was developed for this study, which has not yet been submitted to testing for validity and reliability. The French test was modeled on the English version and using the Module Generator function

of SAILS. The stimuli consisted of single syllable words, without reference to the phonological error patterns commonly seen in French-speaking children with DPD as there were no studies in the literature on this topic. SAILS should be administered with headphones, however most of the time in this study the stimuli were presented through the computer's speakers, without headphones. Three treatment targets were selected for each child based on their performance on the TFP, the single-word articulation test; the children completed the SAILS modules associated with their individual error patterns and therefore the children did not all complete the same SAILS modules.

SRT. The Syllable Repetition Task was administered using the PowerPoint audio presentation and scored according to the instructions provided by Shriberg & Lohmeier (2008). Data is available for the ten TD participants and 52 of 72 children with DPD since the task was not administered to the first cohort of 12 children; we removed one child from each of the two pairs of siblings; and an additional six children did not complete the task by mistake.

Reliability

The first author completed narrow phonetic transcriptions of the participants' responses on the TFP based on the audio recordings. Audio files were reviewed at least three times for each child. In the case that a child produced the same target word more than once, the clearer recording was transcribed; if the productions were equally clear the first one was used. Two research assistants (one graduate student in speech-language pathology and one undergraduate student in Linguistics) independently transcribed 11% and 21% of the TFP

samples. The mean transcription agreement with the first author for narrow transcription of the target consonants was 93% (range = 87% to 97%). When the consonant transcriptions differed, the two transcribers listened to the video recording and reached consensus on the final transcription. Four graduate students in speech-language pathology completed narrow transcriptions of the language samples based on the audio recordings. Subsequently, a graduate student in speech-language pathology transcribed 12% of the samples. Transcription agreement for narrow transcription of the target consonants was 90% (range: 88% to 93%).

Results

Speech Sound Production Abilities

The children's performance on the TFP was summarized as percent consonants correct (PCC). Although the percentage of consonants correct on the picture-naming test of articulation accuracy ranged from 31.06 to 91.93 for children with DPD, as seen in Figure 1 very few children performed below 50% consonants correct, with the vast majority of children obtaining PCC values between 71 and 80.

Insert Figure 1 about here.

The PCC values obtained by the children with DPD were higher than we expected based on the proposed PCC values by Shriberg and Kwiatkowski (1982) of 50 to 64.5 for English-speaking children with moderate to severe DPD. Nonetheless, the PCC values of both groups of participants differed significantly from each other, and every child with DPD obtained a PCC value inferior to every

child in the TD group (compare mean values and range in Table 2 and distributions in Figure 1).

We examined the consonant inventories of the French-speaking children with DPD, as shown in Figure 2. For each child, consonants that were produced at least twice and consonants that were produced only once were identified from the transcriptions of their responses on the TFP. Consonants were included in the inventory whether or not they had been used correctly. As seen in Figure 2, the vast majority of French-speaking children in our study produced all consonants except for /ʃ/ and/or /ʒ/.

Insert Figure 2 about here.

Oral-Motor Abilities

Most children received a perfect score in terms of the structure of the mechanism on the OSMSE-3. The scores for oral mechanism function were more variable. Several children had difficulty performing certain tongue movements, especially elevating the tongue and moving the tongue along the palate, or puffing the cheeks. Many children had difficulty with regards to rhythm and accuracy of the DKRs and AMRs; Table 3 shows the repetition rates and the percentages of children who failed the criteria for rate, rhythm and accuracy of the DKRs and AMRs. With regards to the repetition rates, 52.9% of children passed all five tasks. With respect to the DKRs specifically, 7.4% of the children failed two of the three tasks, 19.1% failed one of the three tasks and no child failed all three tasks, suggesting that there were very few cases of subclinical dysarthria in our participants. On the other hand, 22.1% of the children failed one AMR task and

14.7% failed both tasks, revealing a higher proportion of cases with either motor or phonological planning difficulties. The proportion of children failing more than 3 tasks, indicating difficulties with the repetition of both single and multi-syllable sequences was small (5.9%), suggesting that the prevalence of true motor speech disorders was low in this sample.

Insert Table 3 about here.

The children who achieved slower than average DKRs performed similarly to children who obtained DKRs within normal limits on the measures of receptive vocabulary, nonverbal intelligence, consonant accuracy in single words, and phonological awareness. Similarly, there were no significant differences on any of the assessment measures between the children who achieved slower than average AMRs compared to the children who achieved AMRs within normal limits. The four children (5.9% of the sample) who failed multiple tasks likely present with a motor speech disorder. Finally, number of repetitions of [pataka] per second was not correlated with PCC ($r = .01$, $p = .93$).

Phonological Awareness

The children with DPD obtained significantly lower scores on the Test de Conscience Phonologique than TD children, as shown in Table 4. While the PA abilities of children with DPD varied greatly, all three implicit phonological awareness tasks proved quite difficult for the vast majority of the children with DPD: 11 children did not respond correctly to any test items and an additional 51 children obtained a score of one or two out of a maximum of 34, performing

below chance levels on every subtest. The rime matching subtest proved to be easier than onset matching or segmentation for both groups of children.

Insert Table 4 about here.

Syllable Repetition Task

Table 5 presents the competence and three processing scores (encoding, memory, and transcoding) for the DPD and TD groups. As expected, the competence scores decreased as the length of the target words increased: all TD children obtained scores of 100% for the 2-syllable target words, scores above 75% for the 3-syllable target words, and scores above 50% for the 4-syllable target words. Children with DPD also showed a similar word-length effect but obtained significantly lower competence scores. With regards to encoding of auditory-perceptual representations, notwithstanding the high within group variability of children with typical and delayed speech, 57% of the children with DPD obtained an encoding score for the total SRT stimuli that was more than one standard deviation below the mean of the TD children. In terms of phonological memory, the most sensitive ratio for our sample was the 4-syllable: 2-syllable ratio. A total of 51.9% of the children with DPD obtained a score more than one standard deviation from the mean of the TD children. Finally, additions of consonants only were rare in our French-speaking participants: 1 child added a single consonant to one 2-syllable word; 2 other children each added a consonant to one 2-syllable word and one 4-syllable word; and 2 other children each added one consonant to one 3-syllable word. None of the TD children added a consonant to the target words.

Insert Table 5 about here.

Figure 3 presents the proportion of children who failed one or more of the speech processing measures of the SRT. Eleven children (21% of the 52 children for whom we have SRT data) passed all three speech processing tasks on the test. Most children (69.3%) failed encoding only, memory only, or both encoding and memory.

Insert Figure 3 about here.

Predictors of Articulation Accuracy

Hierarchical linear regression was performed using SPSS for Windows to examine the contribution of phonological processing skills to articulation accuracy after controlling for two background variables, specifically receptive vocabulary skills and maternal education. Receptive vocabulary and maternal education were forced in the first step of the regression. To test for the contribution of phonological processing to articulation accuracy, three measures of phonological processing were entered in the second step: Test de Conscience Phonologique, encoding, and phonological memory. Speech perception as measured by SAILS was not entered in the regression analysis since the TD children did not complete the test, children with DPD did not complete the same modules of the test, and there was an unusual number of missing scores for this test since it was not administered to all children according to the protocol (the research assistants often failed to use headphones as instructed). The results of this analysis are shown in Table 6. This analysis indicates that phonological processing explains a significant unique portion of articulation accuracy and that

all three measures of phonological processing make a contribution.

Insert Table 6 about here.

Subgroups of Children Using Cluster Analysis

Qualitative inspection of the data suggested three subgroups of children with DPD based on their PCC values and performance on the receptive vocabulary and PA tests. A cluster analysis was completed using the K-means cluster function of SPSS for Windows. As shown in Figure 4, the resulting clusters were as follows: Cluster 1 (15 children; 20.8%) had the lowest PCC values, low receptive vocabulary (EVIP) scores and PA scores. Cluster 2 (33 children, 45.8%) obtained much higher PCC scores but low EVIP and PA scores. Cluster 3 (24 children, 33.3%) obtained high EVIP scores, and on average higher PA scores and PCC scores.

Insert Figure 4 about here.

The relationships between speech perception, receptive vocabulary, PA skills and speech accuracy found in these three clusters of children also point to the important role of phonological processing in achieving articulation accuracy. Although higher receptive vocabulary and PA performance were associated with higher speech accuracy in Cluster 3 children, Cluster 2 children achieved slightly higher speech accuracy levels despite lower receptive vocabulary and PA skills than Cluster 3 children. Comparison of the three clusters revealed that they did not differ in terms of nonverbal intelligence as measured by the KBIT-2, $F(2, 69) = 1.85$, $p = 0.165$; maternal education, $F(2, 65) = 1.17$, $p = 0.317$; or oral-motor skills as measured by the function score of the OSMSE-3, $F(2, 56) = 0.395$, $p =$

0.676 or their AMR performance, $F(2, 63) = 0.688$, $p = 0.506$. Differences were found, however, on measures of phonological processing, the speech perception measure (French version of SAILS), $F(2, 60) = 12.72$, $p < 0.001$ and on the competence score of the SRT, $F(2, 51) = 8.99$, $p < 0.001$. Significantly higher performance on SAILS was found for Cluster 3 children, and significantly better competence scores on the SRT were found for Clusters 2 and 3 children.

Discussion

Seventy-two French-speaking preschool-age children with DPD were assessed on measures of articulation accuracy, receptive vocabulary, nonverbal intelligence, phonological processing (phonological awareness, speech perception, syllable repetition test) and structure and function of the oral-speech mechanism. We hypothesized that the majority of children in our sample would present with a psycholinguistic profile that is indicative of a phonological processing endophenotype rather than an underlying problem in the articulatory domain. The children's patterns of performance across our battery of assessments support this hypothesis. First, very few children showed evidence of difficulties with motor planning and/or programming as evidenced by their performance on the oral-motor examination and the transcoding score derived from the SRT. With regards to the DKRs and AMRs, 5.9% of the children failed four or five tasks out of five. On the SRT, three children failed memory and transcoding, and one child failed encoding, memory, and transcoding; only one child failed the transcoding speech process of the SRT only. As found in other studies, most children in our study who did present with motor speech difficulties also had deficits in other

endophenotypes related to phonological processing skills, language skills, and literacy skills (e.g. Lewis, Freebairn, Hansen, Iyengar, et al., 2004; Lewis, Freebairn, Hansen, Taylor, et al., 2004; Shriberg et al., 2012).

Second, the majority of children showed marked difficulties with tasks indexing phonological processing. Only 10% of the children with DPD passed the PA test, with the vast majority of children (82%) obtaining a PA score more than two standard deviations below the mean of the TD children. In addition, a total of 76.9% of our sample presented with deficits in encoding and/or memorial processes as revealed by the SRT. Furthermore, phonological awareness, encoding, and memorial processes explained significant unique variance in speech production accuracy even after controlling for individual differences in receptive language and maternal education.

Ramus, Marshall, Rosen, and van der Lely (2013) recently completed a factor analysis of school-age children with language impairment (LI) and RD, children with LI only, children with RD only, and TD children. Three factors explained considerable variance in the language abilities of the participants: non-phonological language skills (e.g., vocabulary, grammar), phonological processing skills (e.g., rhyme awareness, rapid digit naming), and phonological representations (e.g., nonword repetition, nonword discrimination). The authors concluded that the relationship between LI and RD is best explained by a multiple-component model of language abilities. Children with both LI and RD had deficits in these three areas, which tended to be more severe than children with either only LI or only RD. Similarly, DPD overlaps with LI, RD, and

ADHD, and this comorbidity may result from shared deficits in endophenotypes and underlying psycholinguistic skills (Pennington & Bishop, 2009). According to the multiple deficit view of developmental disorders (Pennington, 2006), genetic risk and protective factors interact with environmental risk and protective factors as well as with the etiological causes of the disorder. In the case of children with DPD, it has been proposed that their risk of later presenting with literacy difficulties is moderated by protective factors such as high quality language input, high quality reading instruction, and speech-language therapy (Rvachew, 2007). With respect to speech sound disorders (i.e., DPD), Lewis et al. (2011) found an association with oral motor skills, phonological awareness, phonological memory and speeded naming when children who were receiving speech therapy were referred as preschoolers; subsequently these endophenotypes were linked to school-age literacy outcomes such as spelling deficits. Genetic linkage analyses in this study were consistent with previous studies that identified chromosomes 1, 3, 6 and 15 as playing a role in multiple aspects of spoken and written language.

Some of our participants with DPD had poor articulation accuracy and performed relatively well on the PA task, while some children had milder difficulties with articulation accuracy but performed poorly on the PA task, as previously described for English-speaking children with DPD (e.g. Hesketh, 2004; Holm, Farrier, & Dodd, 2008; Rvachew, Chiang, & Evans, 2007). Examination of these variations in profile between children can be helpful in illuminating the interactions that explain individual outcomes. Three clusters of children with DPD were found in our sample, with different strengths and

weaknesses with regards to phonological processing skills, receptive vocabulary, and articulation accuracy. Cluster 1 presented with low receptive vocabulary, low PA scores, and low PCC scores as well. Children in Cluster 2 presented with similarly low receptive vocabulary and PA scores, but on average achieved higher PCC values; this might be explained by a strong tendency for Cluster 2 children to have higher encoding abilities in comparison to the children in Cluster 1. The children in Cluster 3 presented with very high receptive vocabulary skills and, with two exceptions, higher PCC values and PA skills than the other children with DPD. The two outliers in this cluster obtained PCC values below 60 despite exceptional vocabulary knowledge and average phonological awareness skills; closer inspection of the data for these two children revealed that their nonverbal intelligence was in the higher average range and that their well-educated parents reported a high frequency of literacy activities such as reading books and going to the library. Language input provided to the child is the most important environmental influence in terms of language development (Hart & Risley, 1992; Hoff & Naigles, 2002);. Strong vocabulary scores, combined with strong nonverbal intelligence and rich language input likely allowed these two children to attain good PA skills despite the challenges associated with their severe DPD.

Cross-Linguistic Differences

Despite the finding that French and English speaking children with DPD are similar at the level of the endophenotype, there was an interesting difference in our sample's performance when repeating the 2-syllable target words of the SRT relative to the published literature for English speaking children. Few

French-speaking children with DPD (6%) obtained a score of 50% or less for the CVCV words, compared to 24% of the participants in Shriberg et al. (2009). One possible explanation for this difference is the age of the participants, as the French-speaking children were 4 to 6 years old, whereas the English-speaking children were 3 to 5 years old. Additionally, it is possible that French-speaking children with DPD repeat CVCV targets more accurately than English-speaking children since French words tend to be longer than words in English (MacLeod et al., 2011). A similar finding was found by Dispaldro, Leonard, & Deevy (2013) in Italian-speaking children with specific language impairment or typical development, using a nonword list composed of words with phonemes and syllable shapes that are mastered by young children. Italian words are also longer than English words, with most words in Italian being three- and four-syllables long (Mancini & Voghera, 1994). Dispaldro et al. (2013) proposed that familiarity with longer words "might enable Italian-speaking children to gain greater command of longer linguistic material" (p. 332). Further studies are required to determine whether the performance of children speaking languages with longer words than English on the 3-syllable targets of the SRT might indicate difficulties with encoding of acoustic-perceptual information, similarly to how English-speaking children perform with the 2-syllable words of the SRT.

Whereas incomplete phonetic inventories are common in the speech of preschool English-speaking children with DPD (Dinnsen, Chin, Elbert, & Powell, 1990; Schwartz, Leonard, Folger, & Wilcox, 1980), the consonant inventory of 70 out of the 72 French-speaking children with DPD contained at least the following

phonemes: /p, b, t, d, k, g, m, n, f, s, z, ʁ, l, j, w/. The results from MacLeod, Sutton, Trudeau, & Thordardottir (2011) indicated earlier acquisition of consonants by French-speaking preschoolers with typical speech and language development compared to typically developing children speaking English; in our study most French-speaking children with DPD accurately produced many if not all of the consonants in simple syllable shapes such as CV. Speech perception as measured by the experimental French version of SAILS was not correlated with articulation accuracy (although it was correlated with vocabulary skills and phonological awareness replicating previous findings for English in this respect; McBride-Chang, 1995; Rvachew & Grawburg, 2006). The French speech perception assessment measure was developed for this study in a similar manner as the English SAILS and assessed speech perception at the segmental level. However, the difficulties with speech sound production experienced by the French-speaking children with DPD were not predominantly present at the segmental level but rather at the prosodic level of the phonological hierarchy. Thus, there is a need for a French measure of speech perception better adapted to French phonology, and which more closely reflects the types of speech errors seen in French-speaking children.

Clinical Implications

While speech-language pathologists do not routinely assess the PA abilities and other phonological processing skills of preschoolers with DPD, it seems important that they do so since these children are particularly at risk of future literacy difficulties. Many of the children who participated in this study

obtained PCC values between 71 and 80, with a significant proportion of children also obtaining PCC values between 81 and 90. Several of the speech-language pathologists who referred them to our study were unsure they were appropriate candidates, since they considered their speech production abilities, as compared to English-speaking children, to be fairly strong. However, they were not as intelligible as other children of the same age. The parents of the participants with DPD reported that their children were not easily understood by strangers, peers, and often even close family members. In addition, these children's speech production abilities were significantly below those of the TD children, and their severe difficulties with phonological processing point to the need to examine endophenotypes as well as the surface manifestations of the disorder in order to plan appropriate speech-language remediation for these children.

Limitations

A major limitation of this study was that not all measures were obtained from all of the children. The measures of oral motor ability and non-verbal IQ were not administered to the TD group and not all children in the DPD group received the SRT. As mentioned previously the test of speech perception that was developed for this project was determined to be not well adapted to French phonology. Children received different modules of the test and some did not complete the test or completed it without headphones. Although the total sample was reasonably large at 82 children overall it was not large enough to permit modeling of the complex relationships among all the variables. Finally, when comparing the DPD and TD samples, the large difference in receptive vocabulary

skills and the smaller difference in maternal education were problematic. However, during the course of the study we developed measures of speech accuracy and phonological awareness that proved to be valid and reliable for French-speaking children and showed that the Syllable Repetition Task could be used with this population as well. Therefore, following modification of the speech perception test to reflect our improved understanding of phonological development in French, the tools are in place for continued investigation of the underpinnings of DPD in French and the linkages between the phonological processing endophenotype and later literacy outcomes.

Conclusion

This study represented the first description of the speech characteristics of a large group of French-speaking children with DPD. The results regarding the endophenotypes of PA, auditory-perceptual representations, and oral-motor skills, were very similar to the literature on English-speaking children with DPD. The vast majority of French-speaking children with DPD who participated in the study had difficulties with auditory-perceptual encoding of speech. When assessing children who were referred for a speech delay, SLPs should measure articulation accuracy, phonological processing skills (PA, speech perception, phonological awareness, phonological memory, rapid automatic naming), and language skills. The results of the current study add to a growing literature recommending that intervention for children with DPD do not focus solely on production accuracy, but rather, focus on perceptual and phonological knowledge (e.g. Munson et al., 2010).

Acknowledgements

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Table 1. Language Exposure of the Group with Developmental Phonological Disorder (DPD) and the Group with Typical Speech Development (TD) at Home and at Daycare.

Home Language		Daycare Language		DPD	TD
French	Other	French	Other	*n* = 72	*n* = 10
100%		100%		48	5
100%		75-95%	5-25%	3	2
75-99%	1-25%	100%		15	3
50 – 74%	26-50%	100%		2	
60-90%	10-40%	75-80%	20-25%	2	
25%	75%	100%		2	

Note. "Other" Language at home usually refers to English, although five children with DPD were exposed to one of these languages at home, in addition to French: Spanish, Arabic, Albanian, Lingala, or Bulgarian. "Other" language at daycare was always English.

Table 2. Demographic data and test scores for children with developmental phonological disorder (DPD) and children with typical development (TD).

		DPD (n=72)			*TD (n=10)*						
Measure		*M*	*SD*	Range	*M*	*SD*	Range	*t*	*df*	*p*	*d*
Age (months)		53.96	5.00	46-69	55.60	6.14	45-63	0.77	10.55	0.457	0.32
Gender	*n* girls	20			4						
	n boys	52			6						
Family	*n* negative	27			8						
history	*n* 1 nuclear	14			1						
	n 2+ nuclear	15			0						
	n extended	9			1						
Maternal education (years)		14.00	2.52	10-18	15.60	1.96	12-18	2.27	13.43	0.040	0.65
EVIP (standard score)		98.88	14.86	80-133	109.70	3.98	105-117	4.93	48.96	.000	0.77
KBIT-2 (standard score)		103.46	11.71	83-127	--	--	--	--	--	--	--
TFP (PCC)		71.84	11.91	31.06-91.93	94.60	1.71	92.55-98.14	14.93	79.40	.000	2.03

Note. EVIP = Échelle de vocabulaire en images de Peabody (Dunn, Theriault-Whalen, & Dunn, 1993), a French adaptation of the Peabody Picture Vocabulary Test-Revised; KBIT-2 = nonverbal matrices subtest of the Kaufmann Brief Intelligence Test, 2nd Edition (Kaufman & Kaufman, 2004); TFP = Test Francophone de Phonologie (Paul & Rvachew, unpublished); PCC = percentage of consonants correct.

Table 3. Performance of 65 French-Speaking Preschoolers with DPD on tasks to assess diadochokinetic and alternate motion rates.

Task	Repetitions/Sec			Rate	Rhythm	Accuracy
	M	*SD*	Range	Fail %	Fail %	Fail %
[pa]	3.8	0.8	2.3 – 5.6	15.2	4.5	1.5
[ta]	4.0	0.9	2.6 – 6.5	0.0	3.0	3.0
[ka]	3.7	1.0	2.2 – 6.0	12.3	6.0	13.4
[pata]	1.9	0.6	0.7 – 4.0	27.6	23.9	31.3
[pataka]	1.3	0.7	0.4 – 4.0	29.2	58.2	80.6

Note. Data obtained from the Oral Speech Mechanism Screening Examination, Third Edition (St. Louis & Ruscello, 2000). Data is available for 65 of the 72 children since we removed one child from each of the two pairs of siblings; three children refused to complete the repetition rate tasks; and the video recordings were missing for two additional children. The data for [pata] only includes 57 children as this specific task was not administered by mistake to eight of the children.

Table 4: Test de Conscience Phonologique scores obtained by the groups of French-speaking children with Developmental Phonological Disorder (DPD) and Typical Speech Development (TD).

	DPD Group $n = 72$			TD Group $n = 10$		95% Confidence Interval	t-test to Compare Means Between Groups			
PAT Subtest	*M*	*SD*	% passed	*M*	*SD*	$Mean_a - Mean_b$	*t*	*df*	*p*	*d*
PA Test	5.26	5.29	9.72	20.70	6.97	$\pm$ 5.37	6.42	10.34	.000	2.80
Rime matching	4.01	3.29	18.06	9.70	2.45	$\pm$ 1.95	6.29	13.41	.000	1.77
Onset matching	0.94	1.85	15.28	5.90	2.39	$\pm$ 1.84	6.01	10.40	.000	2.59
Onset segmentation and matching	0.31	1.10	8.33	5.10	2.34	$\pm$ 1.79	6.06	9.50	.000	3.68

Note: % passed is the percentage of children with DPD who obtained a score less than 1 SD below the mean obtained by the group of TD children.

Table 5. Competence and processing scores derived from Syllable Repetition Task performance by 52 children with developmental phonological disorder (DPD) and 10 typically developing (TD) children.

Score	Item Length	DPD Group		TD Group		t-Test to Compare Means			
		M	*SD*	*M*	*SD*	*t*	*df*	*p*	*d*
Competence	2 syllable	82.21	15.52	100.00	0.00	8.18	51.00	0.000	1.24
	3 syllable	67.31	16.51	90.56	8.26	6.47	24.06	0.000	1.49
	4 syllable	53.13	19.78	79.38	13.42	4.99	16.79	0.000	1.38
	total	67.54	13.75	90.00	5.93	8.14	29.47	0.000	1.74
Encoding	2 syllable	48.93	42.24	100.00	0.00	8.63	51.00	0.000	1.31
	3 syllable	47.08	29.89	77.42	21.21	3.16	9.07	0.011	1.04
	4 syllable	46.37	24.66	72.50	31.64	2.35	11.01	0.038	1.01
	total	49.60	15.80	76.35	23.80	3.25	10.44	0.008	1.55

Table continues

Table 5 continued

Memory	4:3	86.43	16.63	92.99	6.27	2.1	35.55	0.042	0.42
	3:2	89.46	9.69	95.51	4.04	3.16	30.89	0.003	0.67
	4:2	77.51	19.61	89.31	7.67	3.15	33.80	0.003	0.98
Transcoding	2 syllable	99.28	2.91	100.00	0.00	1.77	51.00	0.083	0.27
	3 syllable	99.36	3.21	100.00	0.00	1.43	51.00	0.159	0.22
	4 syllable	99.04	4.81	100.00	0.00	1.43	51.00	0.159	0.22
	total	99.25	2.45	100.00	0.00	2.19	51.00	0.033	0.33

Table 6. Hierarchical multiple regression analysis to examine contribution of phonological processing to speech production accuracy.

Step	Variable	*Final β*	R^2	ΔR^2	ΔF	*df*	*p*
1	Receptive vocabulary	-.037					
1	Maternal education	1.69					
			.122	.122	4.04	2,58	.023
2	Phonological awareness	.33					
2	Encoding	.25					
2	Phonological memory	.28					
			.433	.311	10.05	3,55	.000

Note. Receptive vocabulary was assessed with the Échelle de vocabulaire en images de Peabody (see Table 2 for descriptive statistics); maternal education was assessed in years; phonological awareness was assessed with the Test de Conscience Phonologique (see text for details and Table 4 for descriptive statistics); encoding and phonological memory scores were derived from performance on the Syllable Repetition Task (see text for details and Table 5 for descriptive statistics).

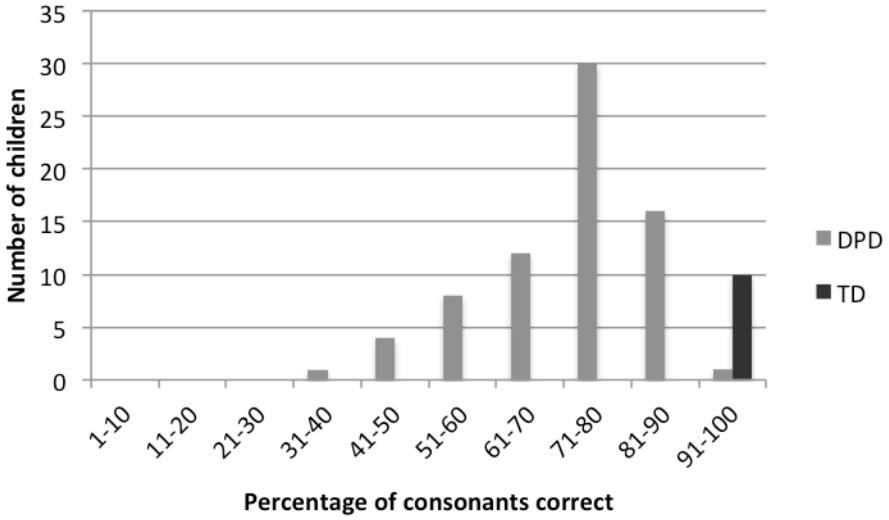

Figure 1. Distribution of the percentage of consonants correct for the 72 French-speaking children with DPD and the 10 TD children.

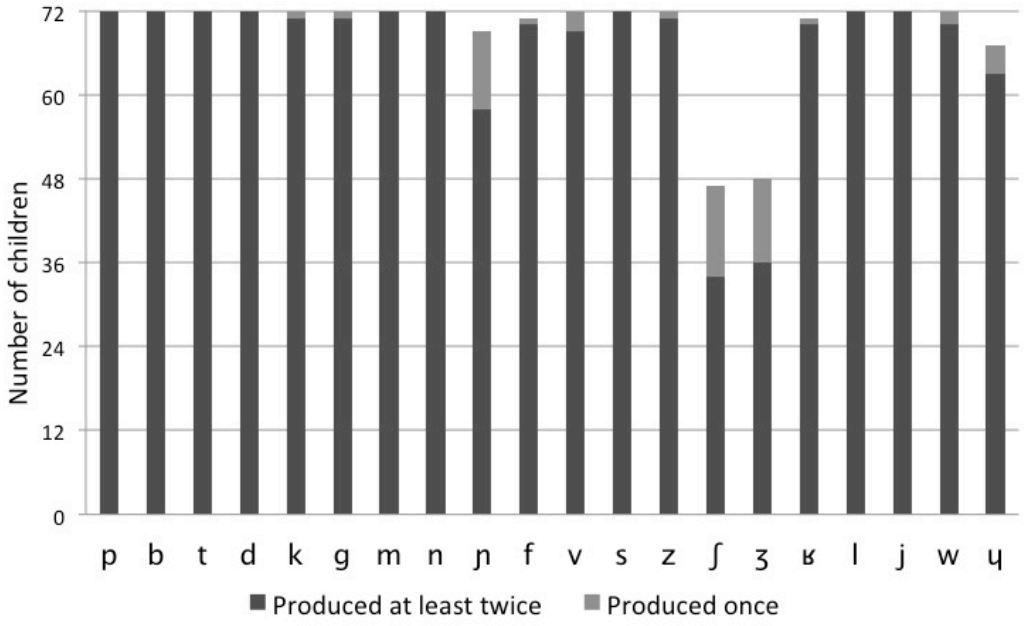

Figure 2. Consonant inventories of the 72 French-speaking children with DPD.

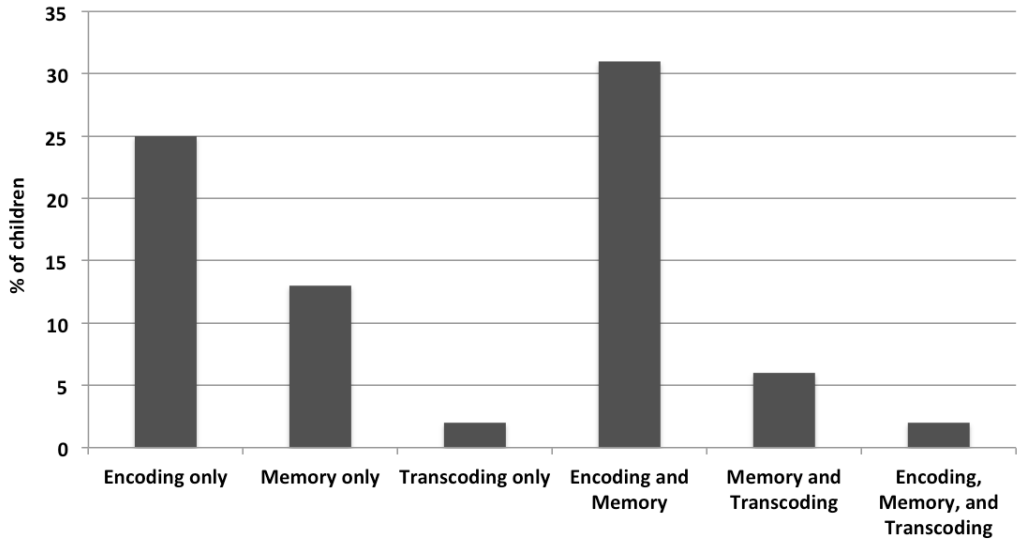

Figure 3. Percentages of children with DPD who failed at least one speech processing task on the SRT.

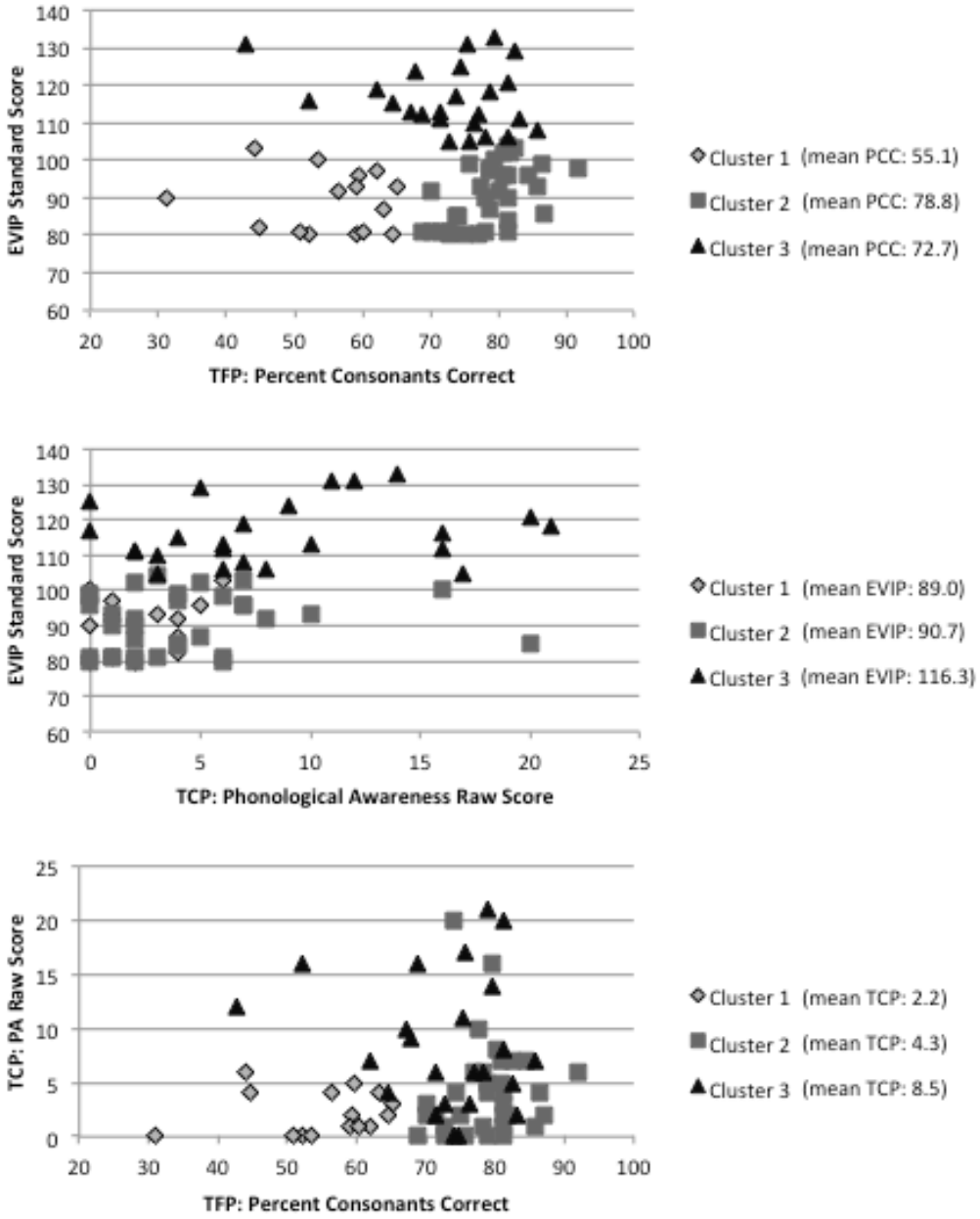

Figure 4. Cluster profiles of the 72 children with DPD.

Preface to Chapter 4

Study 1 aimed to determine whether the same endophenotypes that are associated with DPD in English-speaking children are associated with French-speaking children with DPD. Endophenotypes of phonological processing (phonological awareness, phonological memory, speech perception), vocabulary, and oral motor skills were indeed also associated with French-speaking preschoolers with DPD. More precisely, as in English-speaking children, the vast majority of French-speaking children with DPD had difficulties encoding acoustic-perceptual information from the speech input, leading to phonological processing difficulties.

Differences in the surface manifestation of DPD in French-speaking children were found in Study 1: the consonant inventories of the French-speaking children were larger, and their PCC values on a single-word articulation test were higher than what is reported in the literature on English-speaking children with DPD. I hypothesized that the surface manifestations of DPD would be different in French-speaking children due to differences in the phonological system at the segmental and prosodic levels. A subset of 24 children who participated in Study 1 was selected for Study 2. These children were matched on age, receptive vocabulary, and PCC in conversation to 24 English-speaking children with DPD who had participated in a study by Rvachew, Chiang, and Evans (2007) in order to directly compare the surface manifestations of DPD in these two languages.

Chapter 4

Study 2

Cross-linguistic comparison of speech errors produced by English- and French-speaking preschool-age children with developmental phonological disorders.

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Abstract

Twenty-four French-speaking children with developmental phonological disorders (DPD) were matched on PCC-conversation, age, and receptive vocabulary measures to English-speaking children with DPD in order to describe how speech errors are manifested differently in these two languages. The participants' productions of consonants on a single-word test of articulation were compared in terms of feature-match ratios for the production of target consonants, and type of errors produced. Results revealed that the French-speaking children had significantly lower match ratios for the major sound class features [+consonantal] and [+sonorant]. The French-speaking children also obtained significantly lower match ratios for [+voice]. The most frequent type of errors produced by the French-speaking children was syllable structure errors, followed by segment errors, and few distortion errors. On the other hand, the English-speaking children made more segment than syllable structure and distortion errors. The results of the study highlight the need to use test instruments with French-speaking children that reflect the phonological characteristics of French at multiple levels of the phonological hierarchy.

Introduction

Good clinical practice in the area of developmental phonological disorders (DPD) requires detailed knowledge about typical and atypical phonological development. While there is a wealth of published evidence regarding the normal course of phonological development in English, this essential information is largely unavailable to the speech-language pathologist (SLP) who is treating French-speaking children. Approximately 87 million people worldwide speak French as a mother tongue (Rose & Wauquier-Gravelines, 2007). In Canada, French is the majority language of the roughly 7.9 million residents of the province of Québec (Statistics Canada, 2012) and a minority language in the rest of the country. Since currently there are no standardized articulation and/or phonology tests for French-speaking children, clinicians in Québec typically compare the performance of French-speaking children to norms available for English, especially those reported by Sander (1972) and Smit et al. (1990), as well as various non-standardized and informal charts adapted for Québec French. This is problematic since French phonology is different from English with regards to segments, prosodic structures, and stress patterns.

In terms of segments, Québec French has 20 consonants and 16 vowels (Walker, 1984; Martin, 1996): the voiceless stops /p, t, k/; the pre-voiced stops /b, d, g/; the nasals /m, n, ɲ/; the voiceless fricatives /f, s, ʃ/; the voiced fricatives /v, z, ʒ/; the uvular fricative rhotic /ʁ/; the liquid /l/; and the glides /w, j, ɥ/. The vowel inventory consists of the 12 oral vowels /i, y, u, e, ø, o, ə, ɛ, œ, ɔ, a, ɑ/ and the 4 nasal vowels /ɛ̃, œ̃, ɔ̃, ɑ̃/. Common consonants between French

and English differ in their perceptual and motor characteristics (e.g., MacLeod & Stoel-Gammon, 2009; Sundara, Polka & Genesee, 2006), as does the frequency of occurrence of common phonemes between the two languages (Crystal, 1995; Malécot, 1974). French has a relatively complex syllable structure: although the minimal syllable shape in French is a single, open vowel (e.g., *eau* [o], 'water'), it can contain up to three consonants in the onset or coda of a syllable (Rose & Wauquier-Gravelines, 2007). Only certain combinations of three consonants are allowed in pre-vocalic position: /s/ + obstruent + liquid; and obstruent + liquid + glide. French-speaking children can syllabify consonant-glide-vowel clusters as rising diphthongs, i.e. with the glide being represented in the nucleus of the syllable with the vowel (Rose, 2000; Rose & Wauquier-Gravelines, 2007). In post-vocalic position, sequences of three consonants are allowed, although in colloquial speech one or more of the consonants in the final cluster can be omitted. For example, *trimester* could be realized as /tʁimɛstʁ/ → [tʁimɛst] or [tʁimɛs] ('trimester'). In addition to its relatively complex syllabic structure, French has a small proportion of monosyllabic words, as opposed to English. For instance, while the French version of the MacArthur-Bates Communication Development Inventory (Trudeau, Frank, & Poulin-Dubois, 1997) contains 33% monosyllabic words and 66% multisyllabic words, the English version contains approximately the opposite proportion, 61% monosyllabic words and 38% multisyllabic words (MacLeod, Sutton, Trudeau, & Thordardottir, 2011). Finally, French is a syllable-timed language: every syllable has roughly the same duration (e.g., Abercombrie, 1967; Delattre, 1965; Ladefoged, 1975; Smith, 1976).

Contrary to English, stress has no contrastive value in French and predictably remains on the last syllable of the word unless it contains a schwa, in which case stress falls on the penultimate syllable (Walker, 1984).

Given that French and English are different with regards to segments, syllable/word shapes, and stress, it is not surprising that differences in the order and rate of consonant acquisition and word shape acquisition have been documented between typically developing English and French-speaking children. For instance, Demuth and Kehoe (2006) investigated the acquisition of consonant clusters in 14 French-speaking children between the ages of 1;10-2;9 in France. Results showed that the French-speaking children acquired word-initial consonant clusters before word-final clusters, whereas English-speaking children acquired word-final consonant clusters first (Kirk & Demuth, 2005; McLeod, van Doorn, & Reed, 2001). Vinter (2001) analyzed the phonological processes present in the spontaneous word productions of 13 typically developing French-speaking children aged 1;11-2;1 in Belgium. At that age, 58% of the phonological processes observed affected the syllable and word structure. These processes involved syllable deletion, final consonant deletion, deletion of a coda inside a word, and simplification of a consonant cluster. Several processes affecting segments were also noted, such as stopping of fricatives, fronting of velars, and assimilations. Interestingly, phonological processes were only present in 30% of participants' word productions. A cross-sectional study was conducted the same year in Belgium with 61 typically developing French-speaking children aged 2;10 to 5;10 (Jamart, 2001). All children completed the same word-naming task. Only four phonological processes were occasionally observed in 3-year-old children:

consonant cluster simplification, consonant deletion, fronting of alveolars, and devoicing. At the age of 5 years, reduction of final consonant clusters and devoicing of final consonants were occasionally observed, processes that are also present in adult speakers (Schelstraete, Maillart, & Jamart, 2004). These findings were also in contrast to the English literature. For instance, cluster reduction, glottal replacement, labial assimilation, gliding of liquids, and weak syllable deletion are all commonly used by children age 3;0 and 3;6, and weak syllable deletion and consonant cluster reduction commonly occur in children age 4;6 and 5;0 (Haelsig & Madison, 1986). The greatest reduction in phonological process use occurred in the 3- to 4-year-old English-speaking children studied by Haelsig and Madison, whereas phonological processes were only occasionally used by the 2- and 3-year-old French-speaking children studied by Vinter and Jamart in Belgium.

Together these studies suggest earlier acquisition of segments in French. More recently, and in Canada, MacLeod et al. (2011) systematically described the consonant acquisition of 156 typically developing Québec French-speaking children aged 1;8 to 4;5. Participants produced 40 words containing each consonant in initial, medial and final position. All consonants were produced accurately by at least 75% of the children in all three word positions (age of acquisition) by 3;6 to 3;11, with the exception of /ʁ/ and /j/ which were acquired by 4;0-4;5. This large cross-sectional study provides a solid first step towards the development of norms for consonant acquisition in French-speaking children and pointed to earlier acquisition of /v/, /z/, /l/, /ʁ/, /ʃ/ and /ʒ/ compared to English.

A large body of evidence describing the speech of English-speaking children with DPD also exists. “It is a reduced sound system, however, which is the most striking feature of developmental phonological disorder” (Hewlett, 1988, p. 31). In other words, incomplete phonetic repertoires are common in the speech of English-speaking preschool children with DPD (Dinnsen, Chin, Elbert & Powell, 1990; Schwartz, Leonard, Folger & Wilcox, 1980). Late acquisition of the feature system of English provides further evidence of a reduced sound system: Rvachew, Chiang and Evans (2007) reported feature matches of 75% or less for [+continuant], Dorsal, [+distributed] and [–anterior] among 4- to 5-year-old English-speaking children with DPD. Information regarding the speech of French-speaking children with DPD is unfortunately not available to clinicians. A few studies other than the ones mentioned above also described monolingual French consonant acquisition (Deville, 1891; dos Santos, 2007; Rose, 2000; Yamaguchi, 2012). These studies are typically longitudinal and include small numbers of participants. Remarkably, to our knowledge all studies of French consonant acquisition have so far involved children with typically developing speech. Nonetheless, variables that have been proposed to explain differences in the order of segment acquisition across languages are helpful in making predictions as to how error types might differ between French-speaking and English-speaking children with DPD.

One factor that impacts the speech output of typically developing infants is the auditory environment. Some studies specifically investigated prosodic differences in the speech of infants learning French as compared to infants learning a different language. For instance, Levitt and Aydelott Utman (1992)

followed one French- and one English-learning infant from the ages of 5 to 14 months. Mirroring their respective speech input, the English-learning infant produced more closed syllables while the French-learning infant produced longer utterances and more lengthening of the final syllable. Hallé, de Boysson-Bardies, and Vihman (1991) found that compared to Japanese learners, 18-month-olds French-learning children preferred rising intonation contours and lengthening of the final syllable. Vihman (Vihman, 2010; Vihman & Croft, 2007) proposed that young children select word templates from their ambient language and then adapt new words to their restricted number of templates. The templates arise from salient characteristics of the segments and prosody of the language input and incorporate speech production constraints as well as factors relating to the individual speech output practice of the child.

Stokes and Surendran (2005) examined the individual impact of three factors on the order of acquisition and accuracy of production of consonants: input frequency, functional load, and articulatory complexity. Input frequency corresponded to the frequency of occurrence of the target initial consonant divided by the total number of initial consonants in the adult speech sample. Functional load represented the cost to the language should the contrast between the target consonant and similar consonants be lost; in other words, the relative importance of the target. For example, although /ð/ is very frequent in English, there would be little consequence to the language should it merge with other similar consonants such as /d/, since very few words are distinguished only by these two sounds. With regards to articulatory complexity, consonants were

ranked according to a four-level scale proposed by Kent (1992): level 1: [p, m, n, w, h]; level 2: [b, d, k, g, f, j]; level 3: [t, r, l], and level 4: [s, z, ʃ, ʒ, tʃ, dʒ, v, θ, ð]. Stokes and Surendran (2005) compared the ages of acquisition of initial consonants between English-speaking 8-25 months old children and Cantonese-speaking children age 15 to 30 months. English has an articulatory complex and larger consonant inventory than Cantonese. Functional load was the best predictor of the age of emergence of consonants in young English-speaking children, whereas frequency of the consonant in the input was the best predictor for Cantonese. In terms of the accurate production of consonants, the authors compared 25-month-old English-speaking children to 24-month-old Dutch-speaking children. While articulatory complexity explained most of the variance in accurate consonant production for the English-speaking children, input frequency was the main predictor for the Dutch-speaking children, who have a smaller initial consonant inventory.

Input frequency, functional load of the consonant, and articulatory complexity play different roles in the order of emergence and rate of consonant accuracy across languages depending on the characteristics of their segment inventory. Differences have also been documented between two dialects of the same language, and factors such as syllable structure and phonotactics likely play a role in explaining variance in consonant acquisition patterns. For instance, Pearson, Velleman, Bryant, and Charko (2009) found differences in the order and rate of consonant and word structure acquisition by typically developing children speaking African-American English (AAE) compared to speakers of General

American English (GAE). Children speaking AAE acquired several segments at earlier ages, and differences in their phonological system were mostly present at the prosodic level of the phonological hierarchy. In fact, Velleman, Pearson, Bryant, and Charko (2010, as described in Velleman & Pearson, 2010) further described a different trade-off between the segmental and the prosodic level in speakers of these two dialects: children acquiring AAE are more likely to simplify the phonotactic word structure, and these simplifications in turn allow them to achieve greater accuracy of later-developing consonants. Children acquiring GAE, on the other hand, do not tend to simplify complex word structures and are less accurate in producing segments. The differences seen between typically developing children acquiring AAE and GAE were also seen in children with DPD (Velleman & Pearson, 2010). Children with DPD were delayed in their mastery of many initial singleton consonants and consonant clusters compared to typically developing children speaking their dialect, but dialectal differences remained: AAE-speaking children with DPD had mastered several segments and consonant clusters at earlier ages than GAE-speaking children with DPD. Although input frequency, functional load of the consonant, and articulatory complexity have not been directly compared they are likely very similar in the case of AAE and GAE as they are dialects of the same language. Since typically developing French-speaking children acquire several consonants earlier than typically developing English-speaking children, and since French word shapes tend to be longer and more complex, we expected that French-speaking children with DPD would exhibit a similar trade-off between accuracy of segments and of prosodic structures seen between speakers of GAE and AAE. More specifically,

given that French-speaking children are known to achieve segmental accuracy earlier than English-speaking children, and taking into account the trade-off between segmental and prosodic accuracy, French-speaking children with DPD may produce a large proportion of errors in the prosodic domain.

The purpose of this study was to compare the characteristics of speech errors produced by French-speaking children with DPD to a group of English-speaking children with DPD. Most studies investigating language-specific and cross-linguistic patterns of speech errors have focused on few sound classes and/or substitution errors (Goldstein & Cintrón, 2001). We therefore matched French-speaking children with DPD to English-speaking children with DPD on PCC-conversation, age, and receptive vocabulary and compared their feature match ratios for all sound classes and frequency of three error types: substitutions, omissions, and distortions. More specifically, we hypothesized that French-speaking children would produce more omissions (syllable structure errors) than English-speaking children. This, in turn, would lead to lower match ratios for the major sound class features [+consonantal] and [+sonorant] for the French-speaking participants.

Methods

Participants

Speech-language pathologists at the Montreal Children's Hospital were asked to refer 4- and 5-year old French-speaking children with suspected DPD for participation in a study investigating the effectiveness of interventions to improve the phonological skills of children with DPD. The children were assessed by the

first author, a certified SLP, or by graduate speech-language pathology students under the supervision of the first author. The assessment sessions took place either in a quiet room at McGill University or in a testing rom at the Montreal Children's Hospital. The selection criteria were as follows: age 4;0 to 5;11; native speaker of French (exposure 75% of the time or more); standard score of at least 80 on measures of non-verbal intelligence and receptive vocabulary; hearing within normal limits as documented prior to the referral to the study; primary diagnosis of DPD. Exclusionary criteria included the presence of sensory-neural hearing loss, cleft palate, global developmental delay, autism spectrum disorder, or other medical conditions that could lead to a secondary DPD. Children with suspected childhood apraxia of speech or with concomitant receptive and/or expressive language impairments were not excluded from the study. A total of 72 eligible children completed the assessment.

Twenty-four of these French-speaking children were matched on PCC-conversation, age, and receptive vocabulary with English-speaking children from the Rvachew, Chiang, and Evans (2007) study. As shown in Table 1, children were considered a match if: (1) the difference in PCC-conversation was no more than 3 percentage points, with most children having less than 1.5 percentage point difference; (2) the age difference was 6 months or less, and (3); the difference in standard points on the receptive vocabulary measure was 10 points or less. Table 2 presents the average of the two groups of participants on these measures. In terms of language exposure, 17 of the 24 children were exposed uniquely to French at home and daycare; two children were exposed uniquely to French at home and to both French and English at daycare; one child was exposed to French

(>75%) and to English (<25%) both at home and at daycare. Four children were exposed only to French at daycare, and to French (>75%) and other language(s) at home: two children were exposed to English (5%, 25%), one child to Cambodian (10%), and one child to both Lingala (8%) and English (2%). The study was conducted in accordance with the ethical standards of the Research Ethics Office of the Faculty of Medicine, McGill University.

Insert Table 1 about here.

Insert Table 2 about here.

Procedures

The Échelles de Vocabulaire en Images de Peabody, EVIP. (Dunn, Theriault-Whalen, & Dunn, 1993) is a normed Canadian-French measure of receptive vocabulary. The children were asked to point to the item among four black and white pictures that corresponded to the word named by the examiner. All five practice items were administered before the test; basal and ceiling rules followed the instructions in the test's manual.

The Test Francophone de Phonologie (TFP) (Paul & Rvachew, unpublished), as described in Paul (2009), was used to assess articulation accuracy. It contains 54 target words carefully selected to be representative of the phoneme distribution, syllable shapes, and word length characteristics of Québec French. Although a total of 161 consonants and 107 vowels are targeted, vowels were not considered for the analyses described below. In addition, only a subset of the targeted consonants was analyzed, such that one instance of each consonant common to English was included in each position (initial, medial and final), similarly to the GFTA-2 (Goldman & Fristoe, 2000). Initial consonant clusters

common to the GFTA-2 were also included in the analyses. Spontaneous productions of the targets were elicited using carrier phrases; alternatively delayed imitation and subsequently immediate imitation was used if necessary in order to collect full data sets from each participant. Administration of the test was recorded with a Sony Handycam HDR-XR520 or a JVC Everio GZ-MG360 videocamera. Audio files were extracted from the video recordings and saved as .wav files.

Conversational speech sample. The PCC-conversation was derived from language samples obtained using the wordless book Good Dog, Carl by Alexandra Day. The examiner presented the book to the child and asked open-ended questions about what was happening in the story. The amount of talking from the examiner was kept to a minimum; for children that were not talkative at first, the examiner provided choice questions, used fill-in-the-blank completion prompts, or remained silent to encourage the child to provide a response. The examiner did not comment on the accuracy of the child's speech. The speech sample was video recorded using a Sony Handycam HDR-XR520 or a JVC Everio GZ-MG360 camera; audio files were extracted from the audiovisual files and saved as .wav files.

Coding procedures – feature match ratios. The feature match ratios were calculated as described in Rvachew, Chiang, and Evans (2007). The features associated with selected target consonants on the TFP were compared to the features associated with the consonant produced by the child. Matches and mismatches were coded for the major sound class features [+consonantal] and [+sonorant]; for the manner class features [+nasal], [+continuant], and [+voice];

and for the place nodes Labial, Dorsal, and the place feature [-anterior]. A consonant produced accurately resulted in a match for all associated features and place nodes; an omission resulted in a mismatch for all features and place nodes associated with the phoneme. In the case of substitutions, only common features between the target and the child's production resulted in matches. Production of /ʁ/ → [w] resulted in matches for [+sonorant] and [+continuant], and mismatches for [+consonantal] and Dorsal. An example of a feature-match ratio is presented in Figure 1 for the production of *serpent* (/sɛʁpɑ̃/, 'snake') → [tɛpɑ̃]. The feature match ratio for each feature and place node was calculated for each child by averaging the proportion of matches to the total number of target consonants representing the feature or place node.

Insert Figure 1 about here.

Coding procedures – error type frequencies and proportions. This procedure was also similar to the one used in Rvachew, Chiang, and Evans (2007), in which production of each target consonant was classified as being correct or belonging to one of five different error types: typical segment errors, atypical segment errors, typical syllable structure errors, atypical syllable structure errors, and distortion errors. Since there is no available literature regarding typical and atypical errors produced by French-speaking children, inaccurate productions of consonants on the TFP were coded as one of three types: segment error; syllable structure error; or distortion error. *Segment errors* consisted of substitution errors that did not impact the syllable structure of the target word, such as *lunettes* /lynɛt/ → [nynɛt] ('glasses') and *train* /tʁɛ̃/ → [tlɛ̃] ('train').

Syllable structure errors consisted of omissions that modified the syllable structure of the target word, such as *peinture* /pɛ̃tyʁ/ → [pɛ̃ty] (‘paint’) and *fleur* /flœʁ/ → [fœʁ] (‘flower’). *Distortion errors* did not affect the phonemic category of the target consonant, such as *chapeau* /ʃapo/ → [ʃapo] (‘hat’). For each child, error type frequencies and error type proportions were calculated. Error type frequencies were obtained by dividing the number of errors of each type by the total number of target consonants. Error type proportions were obtained by dividing the number of errors of each type by the total number of consonants that were produced inaccurately by the child.

Reliability.

Transcription. Based on the audio recordings, narrow phonetic transcriptions of the participants’ responses on the TFP were completed by the first author, who reviewed each file at least three times. If a child produced the same target more than once, the clearer recording was transcribed; if productions of the same target were equally clear the first one was transcribed. One graduate student in speech-language pathology and one undergraduate student in linguistics each completed narrow phonetic transcriptions of 16% of the TFP samples independently. Transcription agreement with the first author for narrow transcription of the target consonants on the TFP was 94% (range = 89% to 97%).

Language samples. Four graduate students in speech-language pathology completed narrow transcriptions of the language samples based on the audio recordings. Subsequently, a graduate student in speech-language pathology

transcribed 21% of the samples. Transcription agreement for narrow transcription of the target consonants was 91% (range = 89% to 95%).

Coding procedures. The first author coded all target consonants for error type. The same research assistant coded all target consonants produced by five randomly selected participants (21% of the samples). Only one error type token was different and involved a consonant coded as a syllable structure error by the first author and coded as a segment error by the research assistant due to different syllabifications of the consonants produced by the child; the disagreement was resolved by consensus. Similarly, the first author calculated the feature match ratios for all target consonants produced by all participants whereas the research assistant did the same for 25% of the participants. The mean agreement for feature match ratios was 98% (range of 88% for [-anterior] to 100% for [+nasal] and Labial).

Data analysis.

T-test of two independent samples was used to assess the significance of the difference between the feature match ratios for the French- and for the English-speaking children. The Mann-Whitney test for two independent samples was performed to assess the significance of the difference between the types of consonant errors produced by the French- and by the English-speaking children. A p-value of less than 0.05 was considered significant.

Results

The goal of the present study was to compare the consonant errors produced by French-speaking preschool children with DPD to English-speaking children matched on PCC-conversation, age, and receptive vocabulary. The

children's productions of consonants on a single-word test of articulation were compared in terms of feature-match ratios for the production of target consonants, and type of errors produced. The results for the feature match ratios, as shown in Table 3, indicate that French-speaking 4- to 6-year-old children with DPD showed significantly lower proportion of matches to the major sound class features [+consonantal] and [+sonorant] than the English-speaking children with DPD. The French-speaking children also obtained significantly lower match ratios for [+voice]. Both groups of children had relatively low matches for [+continuant], Dorsal, and [-anterior].

Insert Table 3 about here

A total of 69 singleton consonants and clusters from the TFP were included in the analyses for the French-speaking children, and all 76 singleton consonants and consonant cluster targets from the GFTA-2 were included for the English-speaking children. Table 4 presents the percentages of correct production and error type frequencies by the French- and English-speaking children. The French-speaking children were significantly more likely to omit the target consonant (mean proportion of 57.03% of errors) than the English-speaking children (mean proportion of 21.89%) when making a consonant error ($z=5.6$, $p<.0001$). On the other hand, French-speaking children were significantly less likely to produce a segment error when misarticulating a consonant (mean proportion of 36.45% of errors) than English-speaking children (mean proportion of 59.73% of errors; $z=-4.27$, $p<.0001$). Distortion errors were rarely produced by the French-speaking children (proportion of 6.53%) but were significantly more common in English-speaking children (proportion of 18.20%; $z= -3.31$, $p=.0005$).

Insert Table 4 about here

The data for syllable structure errors produced by the French-speaking children indicate that certain syllable positions are particularly vulnerable to omission. As seen in Figure 2a, word-internal and word-initial onsets were least likely to be omitted (3.2% and 5.0% respectively). Examples of onsets include the target /p/ in *chapeau* (/ʃapo/, 'hat') for word-internal onsets and word-initial /k/ in *cochon* (/kɔʃɔ̃/, 'pig'). Codas, such as the target /t/ in *lunettes* (/lynɛt/, 'glasses'), were omitted in 9.7% of cases. In contrast, 45.1% of word-initial branching onsets were omitted (e.g., *clown* /klun/ → [kun], [tun], 'clown') and 54.2% of word-internal branching onsets were omitted (e.g., *parapluie* /paʁaplɥi/ → [paʁapɥi], 'umbrella'). Figure 2b shows that there is also a word-length effect with regards to consonant omissions. While 14% of consonants in mono- and disyllabic words were omitted, consonants in three-syllable words and four-syllable words such as *tournevis* (/tuʁ.nə.vis/, 'screwdriver') and *hélicoptère* (/e.li.kɔp.tɛʁ/, 'helicopter') were omitted 24.7% and 26.0% of the time.

Insert Figure 2 about here

As illustrated in Figure 3, further examination of the omission errors produced by the French-speaking children indicates that word length does not affect all syllable positions equally. When considering word-initial branching onsets specifically, omission errors were significantly more frequent in two- or three-syllable words than in monosyllabic words (p=.02). Word-internal branching onsets were statistically significantly more likely to be omitted in two-

and three-syllable words than in monosyllable words (p=.028). Although onsets of three-syllable words tended to be omitted more frequently than onsets of one- and two-syllable words, the difference was not statistically significant. Similarly, onsets within two- and three-syllable words were not omitted statistically more frequently than onsets within monosyllabic words. Word final codas were omitted with a similar frequency independently of word length, with 8% of codas omitted in one-, three-, and four-syllable words.

Insert Figure 3 about here

Only a subset of the consonants contained in the TFP were analyzed in this study, in order to mirror the GFTA-2's inclusion of initial consonant clusters and one instance of each consonant in initial, medial, and final positions. Table 5 provides the errors that the children produced for the target words *framboise* (/fʁɑ̃bwaz/, 'raspberry'), *parapluie* (/paʁaplɥi/, 'umbrella'), and *hélicoptère* (/elikɔptɛʁ/, 'helicopter'). The majority of the errors consisted of delinking of entire consonants. There were several mismatches involving delinking of features, especially so for [+consonantal] for /ʁ/ and /l/ (/ʁ, l/ → [j, w]), as well as Labial (/f/ → [s]), Dorsal (/k/ → [t]), and [+sonorant] (/l/ → [n]). A few mismatches involved spreading of Dorsal. Some error patterns which are present in English-speaking children with DPD were also observed in our French-speaking participants with DPD. For instance, consonant clusters were often reduced to one member of the sequence, either the first or second consonant. Inaccurate production of one or both consonants of the cluster was also observed on several occasions. On the other hand, the French-speaking children only occasionally

deleted weak syllables of trisyllabic words, and more frequently produced all three syllables, albeit inaccurately, or weakened one syllable, as in *parapluie* (‘umbrella’) /paʁaplɥi/ → [paipi], [paaplɥi], [pajaji], [pajapi]. Weak syllable deletion and/or weakening was frequently observed in two four-syllable targets of the test, *hélicoptère* (/elikɔptɛʁ/, ‘helicopter’) and *bibliothèque* (/bibliɔtɛk/, ‘book shelves’). While final consonant deletion is often present in the speech of English-speaking children with DPD, word-final coda deletion was relatively uncommon in French-speaking children for disyllabic words and words of three and four syllables, as seen in Figure 3 and Table 5. However, the word-internal coda /p/ was very frequently omitted in the target *hélicoptère* (/elikɔptɛʁ/ → [elikɔtɛʁ], ‘helicopter’). Omission of the glide in the rising diphthong as in *framboise* (/fʁɑ̃bwaz/ → [fʁɑ̃baz], ‘raspberry’) and *parapluie* (/paʁaplɥi/ → [paʁapli], ‘umbrella’) was also very frequent, an error pattern that seems more typical of Quebec French as opposed to English. Finally, initial consonant deletion was observed on several occasions in our sample, as seen for example in /paʁaplɥi/ → [aplɥi], which is not an uncommon pattern in typically developing toddlers acquiring French (Vihman, 2010).

Insert Table 5 about here.

Discussion

In this study we compared the speech errors produced by French- and English-speaking preschoolers with DPD. Although the two groups of children obtained similar PCC-conversation values, the French-speaking children obtained

low match ratios for the major sound class features [+consonantal] and [+sonorant] (83% and 66%), reflecting a high frequency of segment deletions. This in turn decreased their match ratios for all other features and place nodes. English-speaking children, on the other hand, obtained match ratios superior to 95% for the major sound class features [+consonantal] and [+sonorant]. While substitutions resulting from delinking or spreading of place features are more common in English as reported in the literature, omission errors are less frequent.

The difference in the manifestation of DPD in French speaking children could be due to differences at the supra-segmental level. French-speaking children with DPD frequently omitted segments that are accurately produced by very young children in simple contexts such as the CV, CVC, CVCV, and CVCVC words that comprised 65% of the test items used by MacLeod and colleagues (2011). Consonants were more likely to be omitted in three- and four-syllable words than mono- and disyllable words. Word length influenced the likelihood for consonants to be omitted depending on their syllable position. For instance, branching onsets were very likely to be deleted, and even more so for longer words. Interestingly, word-final codas were not influenced by word length: 8.3% of codas in one-, three-, and four-syllable words were omitted, and 10.9% in two-syllable words. In French, the final full vowel receives stress (Dell, 1984; Walker, 1984) and therefore word-final codas are particularly salient in the speech input. It is possible that from the ambient language, French-speaking children develop word templates that include a word-final coda: the French-speaking children with DPD in this study generally produced word-final consonants accurately, and produced segment errors only 6.1% of the time. In fact, consonants which were

classified as level 4 in terms of articulatory complexity by Kent (1992) and which were examined in this study, namely [s, z, ʃ, v] were produced accurately 78.9% of the time in the coda position.

Clinical implications

The main finding of this study, namely that French-speaking children with DPD produce significantly more omission errors than English-speaking children, indicates that speech-language pathologists should not rely on English normative data to diagnose phonological disorders in French-speaking children. The normative data from MacLeod et al. (2011) represents a solid first step towards the establishment of consonantal acquisition norms for French-speaking children. The development of normed assessment tools specifically designed to mirror the phonological characteristics of French would provide a better description of consonant acquisition among typically developing francophone children, and ultimately allow clinicians to more accurately diagnose DPD and select appropriate treatment targets. Although there are currently no normed test instruments that reflect the phonological characteristics of spoken French at multiple levels of the phonological hierarchy, clinicians can describe error patterns in relation to syllable structure rather than word position and analyze the child's phonological system from the perspective of multilinear phonological theory (Bernhardt & Stemberger, 1998). As illustrated by Bernhardt and Stemberger (2000), the analysis of the child's speech at multiple levels of representation focuses on what the child is able to produce, and what is absent from the phonological system for all levels of the phonological hierarchy (e.g., feature, segment, syllable, word, phrase, and relationships among these levels).

This in-depth analysis provides a detailed description of the child's underlying representations (Bernhardt & Stoel-Gammon, 1994).

Study limitations

One limitation of this study was the inclusion of imitated responses. There are very few studies of the impact of spontaneous versus imitated sampling procedures on the speech sound accuracy of preschool children with DPD. One exception is the study conducted by Goldstein, Fabiano, and Iglesias (2004). Twelve Spanish-speaking children age 3;1 to 4;9 with DPD (PCC values ranging from 65 to 85%) were asked to name pictures spontaneously. When the production was inaccurate a second response was obtained using delayed imitation. The spontaneous and imitated responses were identical in 62% of the words; imitated productions were more accurate than spontaneous productions 25% of the time; and spontaneous productions were more accurate than imitated responses 12% of the time. Differences between children pointed to the importance of child-specific factors such as age and whether or not the child had previously received speech therapy. In our study some of the children had previously received speech therapy and may have provided imitative responses that were significantly different from spontaneous responses. Furthermore, responses were at times obtained with direct imitation, which may also influence the speech accuracy of the children's productions. The effect of delayed and direct imitation may also be modulated by the lexical frequency and/or phonological complexity of the target words.

A second limitation of this study is that it focused on production of consonants only. Vowels are often not included in standardized

articulation/phonology tests and were not described in Rvachew, Chiang, and Evans, 2007. The Weighted Speech Sound Accuracy (WSSA, Preston et al., 2011) takes into account both consonant and vowel production. It consists of the multiplication of the global structural alignment score (proportion of the target's vowel and consonant slots which are filled by the child) by the featural agreement score (deductions for vowel and consonant substitutions). Different numerical values are assigned to different types of speech errors. WSSA values for transcribed speech samples recorded from typically developing toddlers and preschoolers and young adolescents with and without SSD are available in Preston et al. (2011). In the future, a similar scale developed for French could allow for a comparison of both consonant and vowel accuracy.

Another limitation of the study is that we did not include a full analysis of the impact of the syllable position and word length on consonant omission. The subset of target consonants selected for the French-speaking children mirrored the inclusion of each consonant in initial, medial, and final positions from the GFTA-2. However, as was seen in the French-speaking children's productions of the target *hélicoptère* (/elikɔptɛʁ/, 'helicopter'), codas inside the word were very often omitted, as were word-internal glides in a rising diphthong such as in *framboise* (/fʁɑ̃bwaz/, 'raspberry'). A complete analysis of where omissions occur in function of syllable position and word length would help shed light on the influence and interaction between stress patterns, word shapes, and segments in French.

Future directions

The results of this study demonstrate the importance of cross-linguistic studies of speech errors, ultimately allowing speech-language pathologists to better diagnose DPD and plan intervention for children who speak languages other than English. There is also a need for further cross-linguistic studies of speech errors, as well as studies of typical and atypical phonological development in French. In particular, collection of normative data using the same stimulus words would allow clinicians to more accurately diagnose DPD in French-speaking children. Another future direction is to analyze all consonants targeted in the Test Francophone de Phonologie with French-speaking children with DPD. We plan to conduct such an analysis with the sample of 72 children who completed the intake assessment for inclusion in a larger study investigating the effectiveness of interventions for children with DPD. To investigate the influence of and interaction between French stress patterns, word shapes, and segments, we will describe the consonant inventories of these children, calculate their feature match ratios, and compare error type frequencies by syllable position and word length.

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Table 1. French-speaking and English-speaking participants matched on age, PCC and receptive vocabulary.

French-speaking				*English-speaking*				*Difference*		
Participant	Age	PCC	EVIP	Participant	Age	PCC	PPVT	Age	PCC	EVIP/PPVT
5101	58	59.67	131	301	54	59.14	128	4	0.53	3
5112	49	64.97	105	209	54	66.92	106	-5	-1.95	-1
1110	58	66.54	115	32	54	66.89	114	4	-0.35	1
3107	54	69.46	80	18	58	69.75	81	-4	-0.29	-1
1101	61	69.85	116	14	63	69.98	113	-2	-0.13	3
5111	49	70.21	110	205	55	72.75	111	-6	-2.54	-1
3108	48	70.27	93	24	54	71.83	103	-6	-1.56	-10
5106	52	70.39	111	211	57	70.42	102	-5	-0.03	9
1106	49	72.30	96	09	47	72.73	89	2	-0.43	7
1104	59	73.03	131	224	57	73.80	123	2	-0.77	8
4107	55	73.90	87	40	61	73.14	95	-6	0.76	-8
2111	59	75.12	118	201	57	75.51	118	2	-0.39	0
3105	60	76.12	100	500	59	75.11	107	1	1.01	-7
1102	58	76.30	112	236	60	78.50	106	-2	-2.20	6
5110	61	76.72	92	215	64	77.24	101	-3	-0.52	-9
2109	49	77.10	97	235	54	76.77	106	-5	0.33	-9
5107	54	77.50	90	206	53	78.65	94	1	-1.15	-4
3102	51	79.02	102	212	57	78.95	111	-6	0.07	-9
5113	48	80.09	81	42	51	81.07	87	-3	-0.98	-6
5108	57	80.50	104	28	61	81.84	111	-4	-1.34	-7
3106	52	81.12	98	43	57	80.20	101	-5	0.92	-3
4108	55	82.32	81	38	55	82.63	80	0	-0.31	1
2105	57	85.79	112	34	58	84.59	112	-1	1.20	0
1111	54	94.39	99	302	58	91.64	102	-4	2.75	-3

Note: Age indicated in months; PCC is percent consonants correct in conversation; EVIP is the standard score on Échelle de vocabulaire en images de Peabody (Dunn, Theriault-Whalen, & Dunn, 1993), PPVT is the standard score on Peabody Picture Vocabulary Test-Third Edition (Dunn & Dunn, 1997.

Table 2: Descriptive statistics of the French- and English-speaking groups.

	French-speaking (n=24)		*English-speaking (n=24)*	
Measure	*M*	*SD*	*M*	*SD*
Age (months)	54.46	4.35	56.58	3.81
PCC-conversation	75.11	7.27	75.42	6.80
Receptive vocabulary	102.54	14.23	104.21	12.11

Note: PCC-conversation derived from language samples obtained with the wordless book *Good Dog, Carl,* by Alexandra Day; Receptive vocabulary: EVIP = Échelle de vocabulaire en images de Peabody (Dunn, Theriault-Whalen, & Dunn, 1993), a French adaptation of the Peabody Picture Vocabulary Test – Revised, and PPVT–III = Peabody Picture Vocabulary Test—Third Edition (Dunn & Dunn, 1997).

Table 3: Mean and standard deviation of feature match ratios for French- and English-speaking children.

	French-speaking		*English-speaking*			
Feature or place node	*M*	*SD*	*M*	*SD*	*t(df)*	*p*
+ Consonantal	82.64	13.69	97.88	2.61	-5.25(46)	<.0001*
+ Sonorant	66.29	19.65	96.21	5.66	-7.03(46)	<.0001*
+ Nasal	92.44	14.88	98.38	4.48	-1.84(46)	.0361
+ Continuant	76.06	14.51	77.61	19.92	-0.31(46)	.3789
+ Voice	84.79	13.56	97.58	2.85	-4.43(46)	<.0001*
Labial	86.57	15.63	94.57	7.62	-2.22(46)	.0156
Dorsal	66.46	22.54	81.05	19.73	-2.36(46)	.0112
Anterior	42.71	40.35	58.23	25.64	-1.65(46)	.0528

Note: * denotes a statistically significant difference (p value less than 0.05/8 after applying the Bonferroni correction).

Table 4: Mean percentages and standard deviation of correct production and error type frequencies by the French- and English-speaking children.

	French-speaking		*English-speaking*			
Target consonant	*M*	*SD*	*M*	*SD*	*z*	*p*
Correct production	71.68	12.73	54.82	9.54	5.19	<.0001*
Segment error	9.53	4.26	27.41	10.32	-5.54	<.0001*
Syllable structure error	16.81	10.08	10.14	5.70	2.18	.0146*
Distortion error	1.98	3.73	7.62	6.85	-3.7	.0001*

Note: * denotes a statistically significant difference (p value less than 0.05).

Table 5: Types and tokens of the attempted targets /fʁ̃bwaz/ (*raspberry*), /paʁaplɥi/ (*umbrella*), and /elikɔptɛʁ/ (*helicopter*).

Type	Token	Type	Token	Type	Token
ã̃bwaz	2	aplɥi	1	atɛʁ	1
fã̃baz, faʁ̃baz	3	papɥi	4	tɔtɛʁ	1
fã̃bwaz	6	paipi	1	kɔtɛw	2
fã̃bʁaz	1	pajapi	3	kɔtɛʁ, katøʁ	4
sã̃bwaz	1	pajaji	1	etɔiti	1
ʁã̃bwa	1	palaʁi	1	etɔtɛʁ	2
ʁã̃bwaz	1	pajapɥi	1	ekɔtɛʁ, ɔkɔtɛʁ	2
kʁã̃bwaz	1	paaplɥi	2	nikɔtɛ	1
fʁã̃bʁaz	1	pawapɥi	1	nikɔtɛʁ	1
fʁã̃bʁaʒ	1	palapɥi	1	litɔptɛʁ	2
fʁɛbwaz	1	paʁapɥi	2	likɔptɛk	1
fʁã̃bwaz	5	pawaplɥi	1	etɔptɛʁ	1
		pakaplɥi	1	ejikɔtɛj	1
		paʁapli	2	elitɔtɛw	1
		paʁaplɥi	2	elikɔtɛʁ	1
				eitɔptɛʁ	1
				ezikɔtɛʁ	1

Figure 1. Visual representation of the feature matches for ‘serpent’ (snake) /sɛʁpã/ → [tɛpã]. For each feature or Place node a match is indicated with a checkmark whereas a mismatch is indicated with an ‘x’.

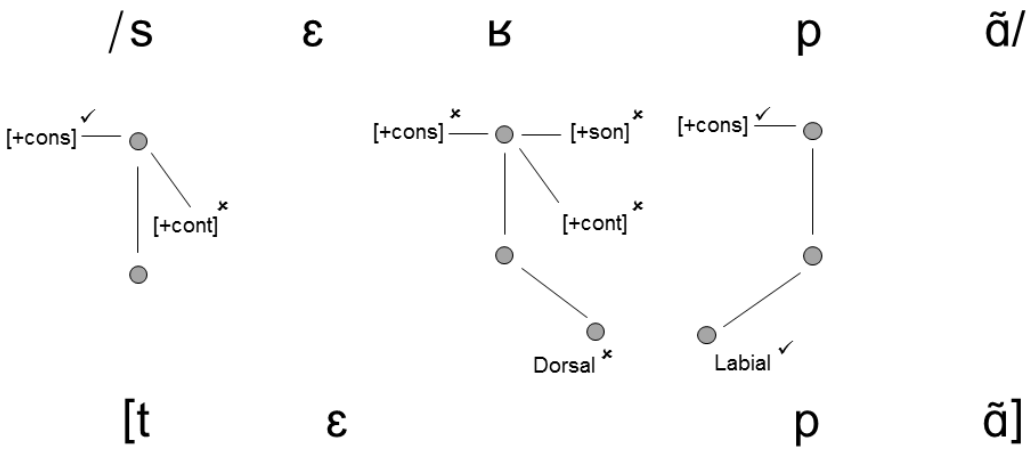


Figure 2. Percent omissions of consonants in French-speaking children with DPD by (A) syllable position and (B) word length. Abbreviations: O = onset; O(WI) = onset, word internal; BO = branching onset; BO(WI) = branching onset, word internal; C = coda.

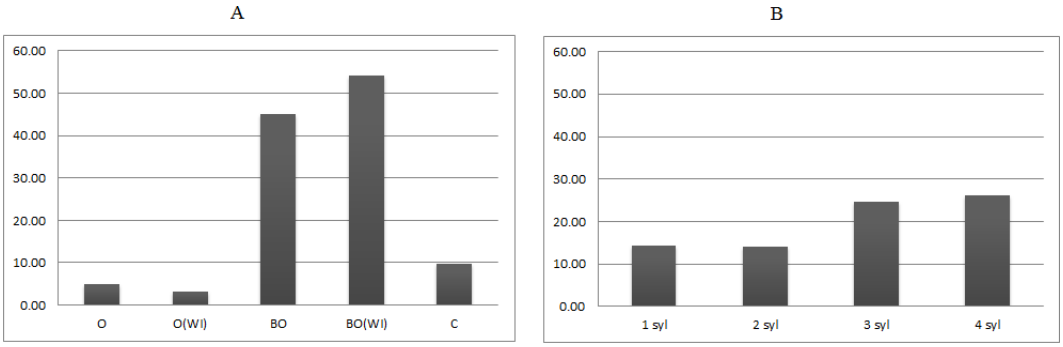
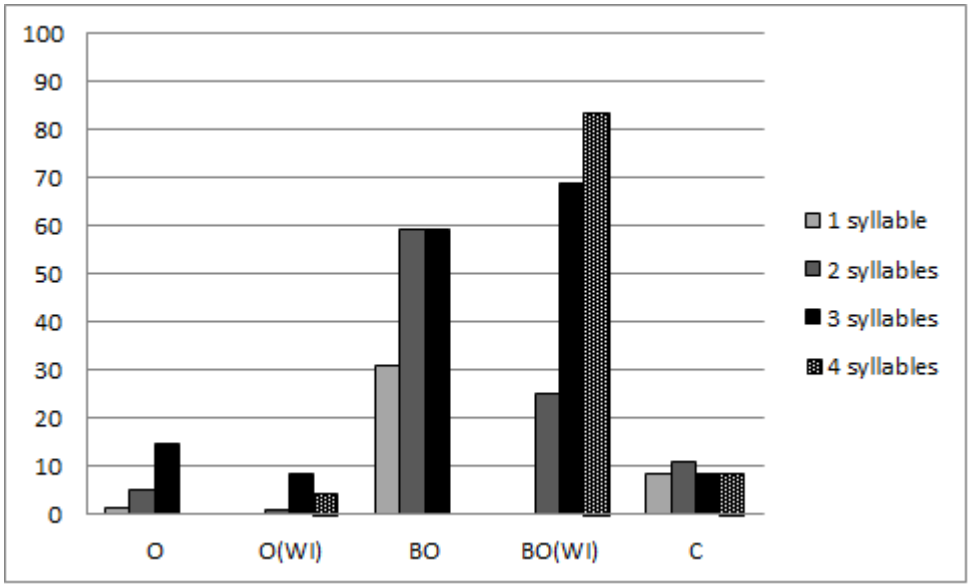


Figure 3. Interaction between syllable position and word length in percent omissions of consonants. Abbreviations: O = onset; O(WI) = onset, word internal; BO = branching onset; BO(WI) = branching onset, word internal; C = coda.



Chapter 5: General Discussion

Children who misarticulate more sounds than their same age peers and present with developmental phonological disorder (DPD) consist of the largest population on the caseloads of speech-language pathologists (SLPs) working with children (Broomfield & Dodd, 2004a; Mullen & Schooling, 2010). In the past few decades, findings from genetic, behavioral, and imaging studies have revealed that DPD, language impairment, and reading disability overlap at the symptomatic, cognitive, and etiological levels (Pennington, 2006). Children with DPD often present with concomitant language impairment (e.g. Baker & Cantwell, 1982), and are at risk for long-term academic difficulties, even if they present with isolated difficulties accurately producing speech sounds (e.g. Nathan et al., 2004, Raitano et al., 2004; Rvachew et al., 2003). Most children who have poor reading skills at the early stages of formal reading instruction are very likely to continue to have reading difficulties throughout their schooling (Francis, Stuebing, Sgaywitz, Sgaywitz, & Fletcher, 1996; Juel, 1988). As opposed to reading disability, which can only be identified once children have begun reading instruction, DPD can be identified early in life, with the conversational speech of children age 3 being expected to be 75%-100% intelligible to strangers, although not necessarily free of articulation errors (Coplan & Gleason, 1988).

Since DPD can be identified early, SLPs have the opportunity to improve the long-term outcomes of children with the disorder. However, in order to provide effective intervention which will lead to short-term normalization of the child's speech sound production abilities, as well as prevent the negative long-

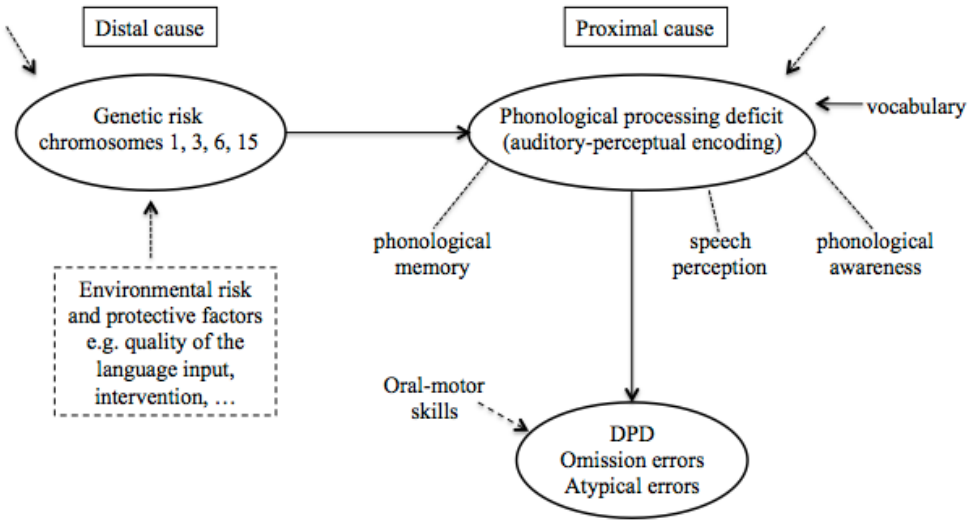
term academic outcomes for these children, a good understanding of the underlying nature of their DPD is required (Stackhouse & Wells, 1997). While SLPs are adept at defining and assessing the phenotypes of communication disorders (Morgan, 2013), namely difficulties with the accurate production of speech sounds in the case of DPD, there is a limited but expanding understanding of the underlying neurobiological mechanisms which underlie the disorder. In addition, although there is a wealth of published evidence regarding the surface manifestations of atypical speech development in English-speaking children, this essential information is largely unavailable to SLPs working with French-speaking children. This gap in knowledge is striking in view of the fact that the first clinical master's program in SLP in Canada was offered in 1956 at l'Université de Montréal, and therefore, French-speaking clinicians with formal training have been practicing in the province for more than 50 years.

The studies presented in this dissertation were completed to fill some of these knowledge gaps by investigating both the underlying psycholinguistic profiles and the surface speech errors of French-speaking preschoolers with DPD. Surprisingly, to our knowledge no previous study has described the psycholinguistic profiles or surface speech errors of French-speaking children with DPD. More precisely, the main goal of Study 1 was to investigate whether the vast majority of French-speaking children with DPD would present with phonological processing difficulties, with a small minority presenting with oral-motor difficulties. Since endophenotypes of phonological processing have been associated with the vast majority of English-speaking children with DPD in the past decade, and as endophenotypes manifest themselves regardless of

environmental changes, I expected that the same endophenotypes would be found in most French-speaking children with DPD. Study 2 compared the surface speech errors of very similar groups of French- and English-speaking children with DPD. Since phenotypes vary in response to the environment, such as the child's ambient language, and in view of differences in the French and English phonological systems I hypothesized that the surface speech errors in these two populations would differ.

As hypothesized, the first study found that the vast majority of French-speaking preschoolers with DPD presented with marked difficulties with phonological processing as measured by the Test de Conscience Phonologique and the encoding and/or phonological memory processes on the SRT. In both the participants with DPD and the smaller group of typically developing children, PA, encoding of acoustic-perceptual representations, and phonological memory explained significant unique variance in speech production accuracy once we had controlled for receptive language and maternal education. These results, taken together with the cluster analysis of the participants with DPD, offer support for the multiple deficits view of developmental disorders (Pennington, 2006) and the "common disease/common variant" model (Bishop, 2009). More precisely, while children with DPD present with a core deficit in phonological processing, this etiological cause of the disorder interact with genetic risk and protective factors as well as with environmental risk and protective factors, which further interact among each other. In other words, the etiological causes of DPD are multifactorial, with combinations between these many genetic and environmental factors explaining the range of performance on measures of endophenotypes

associated with the disorder, leading to heterogeneity at the surface level (phenotypes). A proposed model of the relationship between the distal causes and the proximal causes of DPD is shown in Figure 1.



In English-speaking children, there is increasing support for a genetic distal cause and core deficit in phonological processing as a proximal cause for the vast majority of children with DPD. This core deficit in phonological processing at the level of encoding of auditory-perceptual representations from the speech input is manifested as endophenotypes of phonological processing such as phonological memory, speech perception, and phonological awareness. The surface manifestations of the disorder, the phenotype, consist of speech errors such as omission of consonants and atypical substitutions; however, the surface characteristics of the child's speech are expected to change as language inputs accumulate and demands for more sophisticated speech increase while the child matures and interacts with an increasingly complex environment.

The results from the two studies reported here provide support for this model, this time in French-speaking children. Study 1 described pervasive deficits in phonological processing in French-speaking children with DPD and suggested that these difficulties with encoding speech input may be the proximal cause of the children's speech errors. Furthermore, as in other studies with English-speaking children, endophenotypes of oral-motor skills were also related to DPD in a very small number of children with the disorder.

Study 2 compared the surface manifestations of DPD in English and French-speaking children. Twenty-four French-speaking children were matched on the basis of PCC-conversation, age, and receptive vocabulary, to English-speaking preschoolers with DPD who had participated to the study by Rvachew, Chiang, and Evans (2007). Since the English and French phonological systems differ both at the segmental and prosodic levels of the phonological hierarchy, we hypothesized that the surface manifestations of the disorder would be different in these two languages. Despite matched severity of DPD, French-speaking children produced significantly more syllable structure errors than English-speaking children. In contrast, English-speaking children produced more errors involving segments while leaving the syllable structure of the word intact; specifically errors in the English sample were more likely to be distortions of a segment or substitution errors that resulted from delinking of place features. Omission errors were less frequent among the English-speaking children compared to the French-speaking children.

The French-speaking children frequently omitted consonants that they accurately produced in simple contexts such as CV, CVC, CVCV, and CVCVC.

While consonants were more likely to be omitted in longer words, the syllable position of the target greatly influenced the likelihood of being omitted. For instance, branching onsets were very likely to be omitted, especially in longer words. On the other hand, consonants in the word-final coda position were not very likely to be omitted, independently of the length of the target word. In French, stress falls on the final syllable of a group that does not contain a schwa, and therefore the final coda of single words is particularly salient in the speech input. In brief, while the difficulties of English-speaking children with DPD are predominantly present at the segmental level (incomplete phonetic inventories, many substitution errors), in French-speaking children difficulties are predominantly present at the prosodic level.

Clinical Implications

The findings from the two studies described in this dissertation are of clinical significance with regards to the identification and assessment of French-speaking children with DPD. For almost a century, SLPs have been assessing the surface manifestations of communication disorders (Morgan, 2013). With regards to English-speaking children with DPD, clinicians have access to a wealth of published evidence about normal speech development, providing them with the necessary knowledge to decide if a child is performing below expectations and requires intervention. There also exists a large body of evidence describing the surface speech errors of English-speaking children with DPD. In the case of French-speaking children, however, preliminary normative data regarding consonantal acquisition were published only very recently (MacLeod et al., 2011), and clinicians generally use English normative data with this population. As

pointed out by Thordardottir, Kehayia, Lessard, Sutton, and Trudeau (2010) there is a critical lack of normative data regarding language acquisition for French-speaking children in Québec, which impacts how clinicians assess and define language disorders for this population. The authors also explained that this gap in normative data on typical language development in French-speaking children prevents to quantify the severity of the disorder.

The situation is similar for DPD in French-speaking children: clinicians commonly assign severity levels for speech sound production difficulties based on expectations for English-speaking children. For instance, the PCC values and the consonant inventories of the 72 French-speaking children with DPD who participated to Study 1 were respectively higher and more complete than expected based on the English literature. Several of the SLPs who referred these children to the study considered their speech difficulties to be mild when compared to English normative data. However, while most participants with DPD in Study 1 obtained PCC values between 71 and 90, and would therefore be considered to have mild or mild to moderate speech difficulties according to English normative data, they obtained PCC values that were more than 2 standard deviations from the mean of the typically developing children, indicating they presented with more severe speech difficulties than previously believed based on English norms.

Moreover, so far published evidence regarding French consonant acquisition had only involved children with normally developing speech. Study 2 therefore represented the first description of the surface manifestations of DPD in French-speaking children by systematically comparing the consonant errors produced by similar groups of French- and English-speaking children with the

disorder. The findings from this study clearly demonstrate that speech errors are manifested differently in French-speaking children with DPD. More precisely, in two similar groups of children in terms of PCC, age, and receptive vocabulary, French-speaking children produced significantly more omission errors, and therefore obtained lower match ratios for the major sound class features [+consonantal] and [+sonorant] compared to the English-speaking children, who produced more substitution errors.

In addition to indicating the need to use normative data from the same population as the child being assessed, these findings point to the importance of assessing knowledge at multiple levels of the phonological hierarchy. Currently, assessment of children with DPD is usually one-dimensional, using a single-word articulation test to assess mastered consonants, calculate PCC and/or identify phonological processes present in the child's speech (Ingram & Dubasik, 2011). Ingram and Dubasik propose to use nine measures across four aspects of phonological development, proceeding from the word level to word shapes, to phonetic inventories, and to segments. Similarly, multilinear phonology provides a description of the child's phonological system at all levels of the phonological hierarchy as well as the relationships between these levels. While these multidimensional approaches to intervention are more appropriate for all children suspected of presenting a DPD, they are especially important for French-speaking children with DPD.

Current assessment practices for French-speaking children with DPD focus on the accuracy of the production of segments; however, French-speaking children with DPD were shown to make more prosodic than segmental speech

errors in Study 2. These findings point to the need for not only new analytical tools but also new approaches to speech sampling during the speech therapy assessment, in order to examine all levels of the phonological hierarchy. The *Test Francophone de Phonologie* was developed specifically to rapidly assess the child's speech sound production abilities following a multilinear framework. Specifically, the phoneme distribution, syllable shapes, and word length characteristics of the target words mirror the characteristics of Québec French phonology. For instance, at the moment clinicians often use word lists or informal tests which target each French consonant in initial, medial, and final word positions, usually in simple syllable structures (CVC, CVCV, CVCVC, CCV). In addition to simple syllable shapes, the TFP contains very similar proportions of longer words with more complex syllable shapes as is found in Québec French, such as *escalier* (/ɛskalje/, 'stair case'), aquarium (/akwaʁjɔm/, 'fish tank'), tournevis (/tuʁnəvis/, 'screwdriver'), parapluie (/paʁaplɥi/, 'umbrella'), and *hélicoptère* (/elikɔptɛʁ/, 'helicopter'). Therefore, single-word articulation tests such as the TFP or the Test de Phonologie du Français, developed very recently by Bérubé, Bernhardt, and Stemberger (2013) also following principles of nonlinear phonology, should be used. In connected speech, there is a need to assess phonology in view of the "accentual arc", in which the initial syllable and final syllable of a group are prosodically strong. Difficulties correctly producing phonemes in prosodically strong positions would be of particular concerns, especially so for segments that should be acquired at the child's age according to the recent normative data from MacLeod et al. (2011). On the other hand,

omission of the first syllable of a three- or four-syllable word that follows a determiner, such as *un dinosaure* /œ̃ dinozɔʁ…/ → [œ̃ nozɔʁ] would not be unusual in the speech of a French-speaking preschooler. Eventually, a measure of speech accuracy in connected speech, such as PCC, could be developed for French by weighing the prominence of the segment according to its syllable position.

The findings from Study 1 also revealed another, very important clinical implication with regards to assessment of French-speaking children with DPD. As noted in the literature regarding English-speaking children with DPD, their speech errors change as they get older and vary depending on the severity of the disorder (Rvachew et al., 2007). Difficulties with phonological processing, however, remain present in children with a history of DPD but who no longer misarticulate speech sounds (Raitano et al., 2004). Rvachew & Grawburg (2006) recommended that SLPs assess the speech perception, PA skills, and receptive vocabulary of English-speaking children with DPD. Skahan, Watson, and Lof (2007) surveyed the assessment procedures used by SLPs for children with suspected DPD. While the vast majority of clinicians consistently completed a hearing screening and assessed the intelligibility, single-word articulation accuracy, and oral motor skills of these children, only 12.9% and 12.6% of them consistently assessed the PA skills and speech perception skills of these children. Preston and Edwards (2010) also noted that SLPs do not routinely assess the PA skills of all children with DPD, and recommended that they do so to prevent the reading difficulties that these children are at increased risk of experiencing. A similar recommendation is

very pertinent for French-speaking children with DPD, especially in view of the fact that 82% of our sample obtained PA scores that were more than 2 standard deviations below the mean of the typically developing comparison group. Some children who participated in our study had mild difficulties with articulation accuracy but performed poorly on the PA task, as found in English-speaking children with DPD (e.g. Hesketh, 2004; Holm, Farrier, & Dodd, 2008; Rvachew et al., 2007). Therefore all French-speaking children with current, or resolved, difficulties accurately producing speech sounds should receive an assessment of their phonological processing skills.

Clinicians working with French-speaking children now have access to test instruments to assess their PA skills, such as the nonverbal task used in Study 1, as well as the *Épreuve Préscolaire de conscience phonologique* which has preliminary normative data for children aged 3 to 5 years (Lefebvre, Girard, Desrosiers, Trudeau, & Sutton, 2009). The *Syllable Repetition Task* (Shriberg et al., 2009) is also a promising tool to assess the encoding and phonological memory skills of children with DPD who speak languages other than English. At the moment, however, no speech perception tool is readily available for French-speaking children; the French version of the SAILS program we develop has not yet been submitted to testing for validity and reliability. When we first developed the tool, the speech error patterns of French-speaking children with DPD were unknown and we mirrored the task on the English version, which is a limitation of Study 1. Since Study 2 demonstrated that the speech errors of French-speaking children are predominantly at the prosodic level of the phonological hierarchy, and in view of the finding that French-speaking children with language

impairments have difficulties perceiving prosodic errors in multisyllabic words (Mailhart, Schelstraere, & Hupert, 2004), future studies need to determine whether the PA skills of French-speaking children with DPD are predicted by their speech perception of segmental errors in single syllable words and their receptive vocabulary, as was found for English-speaking children with DPD (Rvachew & Grawburg, 2006). It is possible that in French-speaking children, speech perception of prosodic errors in longer words will predict their PA skills.

Conclusion

In conclusion, "speech development is a multifaceted endeavor that involves the gradual accrual of knowledge and skills at multiple levels of representation" (Rvachew & Brosseau-Lapré, 2012, p. 569). Increased knowledge regarding the underlying speech processes which are disrupted in DPD, as well as the manifestations of the disorder at all levels of the phonological hierarchy, both in English-speaking children and children speaking other languages, will ultimately allow better identification of children with DPD, selection of more appropriate prevention and/or remediation approaches, and a better understanding of prognosis for these children (Stackhouse, 1993).

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