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**THE ROLE OF ARTICULATION IN PHONOLOGICAL DEVELOPMENT
AND PHONOLOGICAL AWARENESS**

by

ELEANOR M. THOMAS

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of the requirements for
the degree of
Doctor of Philosophy

Department of Psychology
Carleton University
Ottawa, Ontario
October, 1997

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**THE ROLE OF ARTICULATION IN PHONOLOGICAL DEVELOPMENT
AND PHONOLOGICAL AWARENESS**

submitted by **Eleanor M. Thomas**
in partial fulfilment of the requirements for
the degree of Doctor of Philosophy

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October, 1997

Abstract

This paper presents a theoretical model of the development of phonological representations during language learning. The model links the development of phonological representation networks with articulation. It is argued that articulation and phoneme awareness depend on underlying networks of phonological representations, and that the link between articulation and these representations is one of bidirectional causality. The paper reports on the first two stages of a longitudinal study examining this theoretical model.

Two key questions arising from the model were addressed in the present report: First, are early articulation patterns associated with corresponding specific phoneme awareness patterns in very young pre-readers? Second, does early articulation quality predict later specific phoneme awareness in young pre-readers? These questions were addressed by studying articulation and phoneme awareness of single specific phonemes.

Eighty normally-developing 3-year-old children (mean age = 36.7 months) participated in Stage 1 of the study. Their articulation and phoneme awareness of the target phoneme /r/ and of control phonemes were assessed, and cognitive abilities were measured. Three simple, age-appropriate tasks with low cognitive demands were developed

to assess phoneme awareness, and a simple elicitation task was created to assess articulation of the target and control phonemes. Seventy-four of the children were reassessed nine to ten months later (mean age = 46.1 months) in Stage 2.

In the cross-sectional analysis, at both Stage 1 and 2, articulation of /r/ was positively related to phoneme awareness of /r/ relative to a control phoneme on two of the three tasks, after controlling for important cognitive variables. In the longitudinal analysis, on one of the tasks articulation quality of /r/ at Stage 1 predicted phoneme awareness of /r/ relative to control phonemes at Stage 2, after controlling for relevant cognitive variables and for the effects of Stage 1 phoneme awareness and Stage 2 articulation, consistent with the prediction. Results were less clear for the other tasks due to ceiling effects for one and non-linear trends in the data for the other. The findings were interpreted as evidence for the theoretical model.

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The Role of Articulation in Phonological Development and Phonological Awareness

Chapter 1. Introduction

The purpose of this dissertation is to investigate the relation between articulation and phonological awareness.

A new conceptual model, the Language Learning and Articulation Model, is presented. This model traces the development of phonological representations during language learning. The model, which was developed from a review of the literature on oral language, links the growth of phonological representation networks with both speech perception and speech production. The model is unique in that it ascribes a causal role to speech production quality, or articulation, in the development of phonological representations. It includes three different routes by which articulation quality feeds back to reinforce or modify phonological representations in memory. Since phonological awareness depends on stored phonological representations, a causal role for articulation in phonological awareness is implied. Another implication of the model is that early representation patterns may persist after articulation has normalized, and may have lingering effects on phonological awareness. The long-term implication is that these persisting patterns may continue to undermine phonological

awareness and ultimately reading acquisition in the early school years.

A longitudinal research project was designed to study language development, using the Language Learning and Articulation Model as a framework. The first two phases of the project, which investigated language development in the fourth year of life, are reported in this dissertation. The purpose of the study was to test two hypotheses arising from the model: The first phase of the study examined the hypothesis that a positive association exists between early articulation quality and concurrent specific phoneme awareness quality in young pre-readers. The second phase examined the hypothesis that early articulation quality predicts later phoneme awareness in young pre-readers.

The literature on phonology and reading acquisition is characterized by inconsistent terminology. In this paper definitions similar to those of Wagner and Torgesen in their 1987 review paper will be used. *Phonological awareness* will refer to knowledge and understanding of and access to the sounds and sound system of the language. *Phonological processing ability* will refer to the ability to use the sounds of the language to understand and produce speech. The term *phonemic awareness* has been used by some investigators in the sense that phonological awareness is used here (e.g., Byrne & Fielding-Barnsley, 1995). However, in this paper, the terms *phoneme* or *phonemic awareness* will refer to a more

specific awareness: that is, these terms will refer to knowledge and understanding of and access to specific language sounds at the level of the phoneme. Both phonological processing ability and phoneme awareness are considered to be specific dimensions of the more general concept, phonological awareness in this paper.

Chapter 2. Literature Review

Several fields that involve research, theory, and clinical practice are relevant to a study of the relation between articulation and the growth of phonological awareness and reading acquisition. Some of the major findings within these fields of investigation are presented below, with an indication of how each contributes to the overall rationale for the theoretical model and the research project presented in this paper.

Overview of Phonological Development

Development of Phonological Representations

Recent theories of language learning have proposed that early phonological representations are holistic in nature (Ferguson, 1986; Fowler, 1991; Jusczyk, 1986, 1993; Studdert-Kennedy, 1987; Walley, 1993), in contrast to the traditional view that phonological representations are organized phonemically from an early stage of development (e.g., Eimas, Siqueland, Jusczyk & Vigorito, 1971) and that children's phonological systems are the same as those of adults (Shriberg & Kwiatkowski, 1983; Stampe, 1969). The more recent models claim that early in phonological development lexical items are stored as high level units such as phrases or words, and that representation becomes

increasingly segmental over time, with words, then syllables, then sub-syllabic units, and eventually individual phonemes being represented, as phonological development advances (Walley, 1993). Consistent with this view, Stemberger (1992, Leonard, 1992) has proposed that these phonological representations are encoded as sets of interconnected units in memory. He has proposed that these phonological units are organized in a series of interconnected levels, including word, syllable, phoneme, and feature levels, and that information is fed down from the highest to the lowest levels for input into the motor programming system, which controls speech. Lower level activation patterns likewise reverberate back, and can modify representations at higher levels in the system. A recent series of experiments designed to test the theory of increasing segmentation of lexical storage (Gerkin, Murphy & Aslin, 1995) found evidence for segmental storage among 47- to 57-month-old children, as would be expected at this age.

In the present paper, phonological awareness is seen as emerging over time in response to the increasingly segmental nature of these phonological representations, according to the scheme presented by Fowler (1991). Therefore, in order to understand the development of phonological awareness and the subsequent acquisition of reading ability, it is necessary to understand the processes involved in the evolution of accurate phoneme structures, and to identify

factors that may facilitate or disrupt this evolution. The thesis of the present paper is that articulation quality is one such factor.

Acquisition of Speech Sounds

Normal speech sound development has been documented and described in detailed case studies of individual children as they acquire language (e.g., Vihman, 1993a), and large-scale cross-sectional studies have been undertaken to develop normative data bases to aid in language assessment (see Ingram, 1989; Smit, 1993; Smit, Hand, Freilinger, Bernthal, & Bird, 1990). While considerable variability is consistently found among children, certain normal sequences of acquisition of sounds in English have been identified, and typical as well as atypical error patterns have been described (e.g., Creaghead, 1989; Vihman, 1993a, 1993b). Researchers and clinicians have found that the articulation error patterns of children with expressive phonological disorders frequently resemble those of younger children whose oral language is developing normally (Leonard, 1992; Smit, 1993a). This pattern is consistent with the view that some articulation problems arise either from delays in the maturation of representational segmentation or from failure to self-correct typical non-standard early representations. Another relevant body of literature has proposed that phonological representations may be constructed incorrectly

by children as a result of their own perceptual biases, environmental experience, or cognitive characteristics, and that these erroneous representations may underlie some articulation problems (Dinnsen & Elbert, 1984; Winitz, 1989). Thus a child's expressive phonology would reflect not only the level of phonological development reached, but also the accuracy of his or her phonological representations.

Development of Phonological Awareness

Most of the experimental literature on the development of language has found evidence of only limited phonological awareness much before school age when formal reading instruction normally begins (e.g., Bryant, Bradley, Maclean & Crossland, 1989; Byrne & Fielding-Barnsley, 1991), although observational information suggests that children as young as two or three years of age are capable of making basic judgements about sounds in language (Chaney, 1992). These observational studies have demonstrated that children monitor and correct their own speech and that of others at a very young age, that they engage in word play of various kinds, and that they ask about word structure and segmentation (see Chaney, 1992), all of which indicate an elementary awareness of phonological structure. Some researchers have developed simplified phonological awareness tasks in an attempt to study emerging phonological awareness in very young children. Such tasks include word awareness

(Chaney, 1992; Fox & Routh, 1975; Tunmer, Bowey & Grieve, 1983), rhyming judgement and production (Bradley & Bryant, 1983, 1985; Chaney, 1992, 1994; Smith & Tager-Flusberg, 1982; Webster & Plante, 1992, 1995), speech sound recognition (Smith & Tager-Flusberg, 1982; Strange & Broen, 1980; Velleman, 1988), speech discrimination (Scarborough, 1990), alliteration detection (Webster & Plante, 1995), and partial word segmentation (Fox & Routh, 1975). These studies have established that children as young as three or four years of age demonstrate at least some phonological processing ability.

It is important to study the relation between articulation and phonological awareness in the early years, before reading instruction has begun. It is now well-established that phonological awareness and reading acquisition are causally linked, and that this relation is reciprocal (Vellutino & Scanlon, 1988; Wagner & Torgesen, 1987; Wagner, Torgesen & Rashotte, 1994; but see Wagner et al., 1997): phonological awareness supports early reading progress, and learning to read teaches phonological awareness. Evidence comes from studies showing strong relations between children's ability to recognize and manipulate the sounds in words and the ease with which they learn to decode words (e.g., Vellutino & Scanlon, 1988; Wagner et al., 1994); from studies that demonstrate deficits in phonological awareness and phonological processing

abilities among children with reading disabilities (e.g. Fletcher, Shaywitz, Shankweiler, Katz, Liberman, Stuebing, Francis, Fowler & Shaywitz, 1994; Mann & Brady, 1988; Rack, Snowling & Olson, 1992; Scarborough, 1989, 1990); and from studies indicating that training in phonological processing improves progress in reading acquisition (e.g., Bradley & Bryant, 1983; Byrne & Fielding-Barnsley, 1991; Castle, Riach & Nicholson, 1994).

Articulation and Phonological Awareness

Speech Pathology and Phonological Awareness

The relation between early expressive phonology and phonological awareness has received considerable attention in the clinical literature on speech pathology, where articulation disorders and problems with the perception of speech sounds have been found to occur together. Interactions between the production and perception of speech in young children have been reported by both clinicians and researchers (e.g., Bernthal & Bankson, 1993; Creaghead, 1989; Dinnsen & Elbert, 1984; Leonard, 1992; Winitz, 1989). Problems with speech discrimination, the ability to discriminate between speech sounds, have been attributed to both perceptual and phonological mechanisms in this literature. On the one hand, there may be an inability to distinguish between the acoustic features of sounds or to

focus on the relevant acoustic features (Locke, 1980a, 1980b; Winitz, 1989). In this case, the problem is a perceptual one that may undermine the development of phonological representations and hence both phonological awareness and articulation. On the other hand, the phonological system itself may bias the perception of sounds such that the sound perceived reflects the idiosyncracies of the underlying phonological system (Winitz, 1989). In this case the primary problem resides not in the perceptual system but in the phonological system, at the level of the phonological representations. Non-standard representation systems would undermine not only discrimination of speech sounds (and other phonological awareness skills), but also articulation. Whether the source of a difficulty with speech discrimination lies in the perceptual or phonological spheres or in both, a corresponding difficulty with articulation would be anticipated.

While many clinicians have failed to detect differences between children with articulatory disorders and those without in their performance on auditory or speech discrimination tests (Locke, 1980a, 1980b), major reviews of the literature (Weinir, 1967; Winitz 1989) have concluded that when children are tested appropriately using relevant items involving their own specific misarticulations in the context that they are produced, the relation between discrimination and articulation is strong, whether for

perceptual or phonological reasons. This important dimension of phoneme specificity in the assessment of both articulation and phonological awareness was incorporated into the methodology of the present study.

Misarticulation and Reading Disabilities

Similarly, misarticulation is one of many language impairments that have been linked to reading disabilities (Bird, Bishop & Freeman, 1995; Stackhouse & Snowling, 1992), but studies have failed to show consistent or reliable relations between articulation and reading problems (Catts, 1993). One cause of the inconsistent findings might be the failure to focus on specific articulation problems in these studies. The need for relevant and specific tests for assessing articulation has been recognized in the field of speech pathology (e.g., Newman & Creaghead, 1989; Weiner, 1967; Winitz, 1989), a procedural innovation that can be extended to assessing speech-language impairments as they relate to reading disabilities. Another problem is the largely cross-sectional nature of these studies. Few of them are longitudinal, and most of those that are assess language, phonological awareness and literacy rather late, in kindergarten (e.g., Bishop & Adams, 1990; Menyuk, Chesnick, Liebergott, Korngold, D'Agostino & Belanger, 1991). One longitudinal study (Scarborough, 1990) assessed the language skills of a group of very young children to

examine the hypothesis that early language deficits would be found for children who were later graded as disabled readers at the end of Grade 2. Consonant pronunciation error rate at age 30 months was one of the language measures in this study. The group of children who later became disabled readers had higher rates of consonant pronunciation errors at 30 months than those who became normal readers, although controlling for the other language measures, such as productive vocabulary and productive syntax, a measure of grammatical complexity, reduced the magnitude of this relation somewhat. Because later consonant pronunciation was not assessed in these children, it is unclear whether the disabled readers continued to exhibit articulation problems in grade 2. The possibility that very early misarticulations may have lasting effects on phonological representations that underlie phonological awareness and reading ability, even after articulation problems have been overcome, has not been addressed, and is a focus of the present research project.

Articulation and Phonological Awareness

The relation between the production and perception of speech sounds in young children has been examined by researchers who are interested in links between very early language deficits and later pre-reading and reading skills (Scarborough, 1990), and by those studying the extent to

which perception determines production in children (Vihman, 1996). Various studies (e.g., Locke, 1980b; Strange & Broen, 1980; Velleman, 1988) have shown that perception and production errors often occur together, and that for some children, difficulties with perception may resolve before difficulties with production for some phonemes. Some important studies that examined these questions, are reviewed briefly below.

Studies using clinical samples. Among the limited number of recent reports on research that has examined directly the relation between early articulation and phonological awareness is one by Magnusson (1991), who reported on a series of studies comparing children with normal and deviant speech production. Magnusson used mostly rhyme detection and rhyming judgement tasks, as well as phoneme segmentation and phoneme identification tasks, to assess phonological awareness. Most of the children in these studies were preschool children when first assessed. She reported that over several investigations, language disordered children consistently managed the phonological awareness tasks less well than children with normal speech production, even when matched for age and non-verbal cognitive level.

Bird, Bishop and Freeman (1995) studied 31 phonologically impaired 5- to 7-year-old boys, who were matched on age and nonverbal ability with control groups

whose articulation was normal. They found that the impaired group scored well below controls on tests of phonological awareness, including rime matching, onset matching, and onset segmentation and matching, whether or not they had other language problems, and that these differences endured for at least 1 or 2 years.

Webster and Plante (1995) assessed the productive phonological ability of 45 3-year-old children, using a test that ranked them on a five point scale of phonological process usage. Phonological processes can be defined as systematic strategies children use to simplify their oral language production, such as consonant or syllable deletions, reduction of consonant clusters, assimilations, and various substitutions. Their study sample included 29 children who were identified as phonologically delayed based on their developmental process rating derived from this test, and who were being seen at a communication disorders clinic. The remaining 16 children in the sample were developing normally according to the test. Using rhyme and alliteration detection tests, they found that children with more impaired productive phonology, that is, those who ranked higher in process usage, scored lower in phonological awareness than those with more standard articulation patterns. They also found that changes in articulation coincided with changes in phonological awareness.

Studies using normally developing samples. The studies

of articulation and phoneme awareness discussed above involved clinical samples of children with articulation problems. Very young children whose oral language is developing normally often exhibit misarticulation patterns as well but unlike the clinical samples, these are temporary and they disappear with development. Two studies that examined articulation and phoneme awareness in normally developing young children were reported in 1976. Eilers and Oller (1976) used minimal and non-minimal contrasts to test the discrimination ability of 2-year-old children on a limited set of phonemes, and compared their performance on this task with their imitated productions of the same sounds. Their findings were mixed in that for some contrasts that children discriminated reasonably well, production accuracy was low, while the opposite was true for other contrasts. Despite the fact that trends were found in both directions, the researchers concluded only that perceptual differences contributed to some production errors. Zlatkin and Koenigsknecht (1976) found similarly ambiguous relations between production and perception in their study of voice onset time, using four synthesized minimal pairs contrasting voiced and unvoiced initial consonants. They examined these contrasts in several age groups, including 3-year-olds. They found that the perception of voice onset time was more advanced than production in some of these 3-year-olds, attributing this difference at least partly to a lack of

consistent motor control over articulation.

Another study that examined articulation and phoneme awareness in normally developing children was that of Strange and Broen (1980). These researchers examined the perception and production of /r/, /l/, and /w/ by 3-year-olds. They taught 21 children aged 2;11 to 3;5 the labels for pictures whose names were sets of minimal pairs, with the initial phonemes contrasted (/r/ vs /l/; /w/ vs /r/; /w/ vs /b/). They used a simple forced-choice task to assess recognition of the stimulus words. They found that children with highly accurate articulation of the targeted phonemes showed better recognition of those phonemes than did those with highly inaccurate articulation. Similarly, when they used synthetic stimuli contrasting interpolated phonemes, the good articulators outperformed the poor articulators somewhat. Although their task was highly constrained, and the extensive training before testing may have biased their findings in unknown ways by focussing the attention of the children on the phonemic contrasts under study, these findings support links between phoneme awareness and articulation.

In 1988, Velleman reported a study of perception and production of voiceless fricatives (/s/, /θ/, /f/) in 12 normally developing children aged 3;2 to 5;6. Children were taught labels, and later pointed to pictures to indicate their discrimination of minimal pairs. Acoustic data were

collected to assess their articulation. Velleman found a correlation between /θ/ production and perception, but not between /s/ production and perception, and attributed this to the fact that substitutions for /s/, assessed acoustically, seemed to be based on production difficulties, while for /θ/ they were based on limitations at the perceptual or representational level. Velleman found evidence that for some children, acquisition of the phoneme /θ/ follows a progression from being neither perceived nor produced, through being perceived but not produced, to full mastery.

Scarborough (1990) undertook a longitudinal study of a sample of children from normal families and from families with a history of dyslexia. She measured various language skills at age 30 months, including consonant pronunciation and speech discrimination, a phoneme awareness measure. Consonant pronunciation was assessed based on the accuracy of word production in a language sample drawn from mother-child play sessions. Speech discrimination was reassessed at 36 months, and phoneme awareness was assessed at 60 months, using a different task. Scarborough found that consonant pronunciation skill was not correlated with speech discrimination at 30 months of age, but that pronunciation at 30 months was correlated with speech discrimination six months later, at 36 months of age. Furthermore, this very early pronunciation measure was correlated with phoneme

awareness at age 60 months. Several early language measures, including pronunciation ability, were related to pre-reading skills in this sample, as well as to later reading status.

A final recent study that examined normally-developing children was that of Chaney (1992, 1994), who investigated metalinguistic skills and print awareness in 3-year-olds. As part of the investigation, she tested the phonological awareness of 43 normally-developing children using various tasks, including judgement and correction of phonemes, identification of initial sounds and rhymes, phoneme synthesis, and three production tasks. She included an assessment of the quality of consonant articulation. Chaney failed to find an articulation-phonological awareness link. However, because she did not identify specific articulation patterns and then assess specific awareness of those same specific phonemes, but used the total number of correct items as the articulation quality measure and awareness of multiple phonemes as her measure of phonological awareness, her data do not rule out an articulation-awareness link.

Conclusion. These studies of the interaction between the production and perception of speech sounds in both clinical and normally developing samples have demonstrated that errors in articulation and perception tend to occur together. Two of the studies found limited evidence that for some children, difficulties with the perception of some phonemes may resolve before difficulties with production.

All of these findings have been interpreted as evidence that errors in perception contribute to errors in phonological representations and hence lead to production errors in some children. In none of these studies was the possibility considered that the effects might be reciprocal, and that production errors have an effect on the underlying phonological representation system.

Articulation as a causal factor in phonological representations

The evidence in the literature that bears directly on the question of a causal role for articulation in the development of phonological representations is limited. The 1995 study of Bird, Bishop and Freeman that was discussed earlier found that the articulation problems of children with serious expressive phonological impairments predicted both later phonological awareness and later literacy problems in this population. Although the findings of this study were based on a clinical sample that was undergoing speech-language therapy and therefore cannot be generalized to a normally developing population, the results are consistent with the predictions of a causal role for articulation in phonological representations and subsequent awareness.

Compelling indirect evidence that articulation quality may influence phonological representations comes from the

field of phonological disorders and speech therapy, where repeated practice pronouncing target material is one therapeutic technique used (Hodson, 1991). It has been found that when children with impairments are required to practice producing words containing sounds that are difficult for them, the improvements sometimes generalize to untrained sounds, indicating that changes occurred at a higher level than the motor programming or motor output systems, presumably at the level of phonological representations (Creaghead, 1989; Gierut, 1986).

Studdert-Kennedy (1987) theorized that articulation contributes to the development of stable and accessible phonemic structures in memory. According to his theory, the spoken word is represented as an articulatory routine, a sequence of face, mouth, and larynx movements, that is linked with the associated acoustic signal the movements produce. The production sequence of these routines is believed to be stored in memory as part of the phonological representation of the word. Studdert-Kennedy's theory is consistent with Stemberger's (1992) interactive activation model discussed earlier, which proposed that lower level activation patterns within phonological networks reverberate back and modify representations at higher levels in the system. Leonard (1992) applied the Stemberger model to language data from a phonologically disordered child, and found that it predicted the pattern of anomalies well. Both

of these theoretical positions propose that the influence of articulation on phonological representation networks operates through internal, structural mechanisms.

The evidence provided by Studdert-Kennedy for his model was anecdotal, and few studies bearing directly on the question have been reported in the literature. However, his view and that of Stemberger (1992) and Leonard (1992) are consistent with clinical studies that have shown the importance of practicing production to bring about improvements in phonological awareness (e.g., Creaghead, 1989; Gierut, 1986; Lewkowicz, 1980).

Stemberger (1992) proposed that children's speech affects their representations in a less direct way than the interactive activation model described previously. He contended that children evaluate their own productions, comparing their output with perceived adult output, with the result that changes come about in the connections among representational units in memory. As a result, the likelihood is increased that pronunciation will be correct next time. Thus the phonological representations are modified, and to the extent that articulation anomalies are phonologically based, articulation will be modified as well. Stemberger's evidence for this idea was anecdotal, but the notion of self-monitoring as an important mechanism in articulation-representation interactions is consistent with some other reports. For example, a case study by Vihman

(1982) presented the idea of a "relexification route", a process whereby the child's own spoken language provided input to the lexicon and appeared to modify lexical representations. Similarly, Speidel (1989) proposed that early articulation problems can lead directly to phonological memory limitations and hence to limitations in phonological representations stored in long term memory, basing his proposal on a single case study. Adams and Gathercole (1995) examined this notion as part of a broad study of speech production and phonological working memory in young children, and found some weak correlational evidence in support.

Conclusion. No reports have been found in the literature of studies that directly consider the idea that articulation plays a causal role in the development of phonological representations. A limited amount of information from the speech therapy field and from one study involving a clinical sample supports the hypothesis. In addition, some theoretical papers in the literature are consistent with a causal role for articulation.

Chapter 3. Theoretical Framework: The Language Learning and Articulation Model

The literature on phonological development and on the relations between articulation competence and phonological awareness demonstrates that these two aspects of language are closely linked during development. The theoretical model presented here, the Language Learning and Articulation Model, was built on insights derived from the various fields of research, theory and clinical practice described above. Most writers have taken the perspective that perception builds the phonological representations on which both phonological awareness and articulation are based. Some aspects of the literature suggest that articulation may also play a causal role in the development of phonological representations. The model incorporates such a causal role for articulation during language learning.

The Language Learning and Articulation Model is presented in Figure 1. According to this model, language learning is a process whereby the child builds a network of linked phonological and semantic representations in memory, and begins to both understand and produce speech. Phonological representation networks develop as a result of exposure to spoken language, beginning in early infancy, and these are translated into increasingly consistent, accurate speech. Evidence comes from the literature on early word

production (e.g., Vihman, 1993a, 1993b) and speech perception (e.g., Jusczyk, 1993) showing that early phonological systems depend in part on the language to which the infant has been exposed. Figure 1 shows the processes involved in learning to understand and produce speech, according to this theoretical framework. When an acoustic signal in the environment that corresponds to speech, such as a spoken word, is perceived, it is encoded and held active in phonological memory (Baddeley, Pagano & Vallar, 1988) while working memory processes the input. This processing involves the activation by the short term memory trace in working memory of sound-meaning networks in long term memory. As a result of this activation, new connections may be established among units in the phonological and semantic pools in long term memory, or existing networks may be modified (see Seidenberg, 1992, Stemberger, 1992). In this way, phonological representations develop and become linked to semantic representations.

Speech comes about when semantic signals activate meaning-sound networks in long term memory. These activation patterns are processed by working memory, and the phonological information is encoded and held in an output buffer (see Adams & Gathercole, 1995). The motor programming system is recruited by working memory, and the stored phonological codes are then translated into motor system routines, producing speech.

The framework in Figure 1 includes three feedback cycles whereby the output patterns produced during speech may act to strengthen or modify the phonological representations in long term memory. These three feedback cycles constitute the mechanisms by which articulation quality is believed to modify phonological representations and therefore phonological awareness during development. A brief description of the processes in this model follows.

Internal feedback cycle

The internal feedback cycle begins with the activation of the networks in the motor programming system that give rise to the articulatory routines that comprise speech. Activation at this lower level is believed to reverberate back by way of internal connection networks to modify directly higher level representations, as suggested in the interactive activation model of Stemberger (1992; Leonard, 1992). Early in language development, when the child has a limited repertoire of output patterns in the motor programming system, he or she will produce many articulation errors. This erroneous activation at the motor programming level will feed back to higher levels of representation in long term memory, to distort activation patterns there. Not only will the stored representation be distorted, undermining phonological awareness, but the inaccurate articulation pattern will be more likely to recur when that

representation network is next activated for speech. In a similar way, accurate articulation patterns will feed back, and improve or strengthen higher level activation patterns. The other two feedback cycles may over-ride the effects of internal feedback. This internal feedback cycle is consistent with the proposal of Studdert-Kennedy (1987) that the spoken word is represented as an articulatory routine, a sequence of face, mouth, and larynx movements, that is linked with the associated acoustic signal that the movements produce. Studdert-Kennedy proposed that these routines are stored in memory as part of the phonological representation of the word.

Self-monitoring cycle

The second feedback cycle is the self-monitoring cycle, whereby the speech output itself constitutes an acoustic signal that may be perceived and processed by the speaker, resulting in modified representations. If the speaker attends to the acoustic signal, encodes it, and compares it to the representation in long term memory of the intended pronunciation, the stored long term phonological representation may be either modified or reinforced as a result. This process may bring about modifications of stored representations directly, or may operate indirectly by over-riding the effects of internal feedback. Consistent with this mechanism is the idea of a "relexification route" which

was first proposed by Vihman (1982), a process whereby the child's own spoken language provides input to the lexicon, and appears to modify lexical representations. Vihman (1993a, 1993b) has proposed that this process begins with the child's earliest vocalizations. When the child begins to attend to his or her own babbling, he or she discovers what motor acts produce what sounds. This awareness of the gesture-sound link gives rise to an "articulatory filter", whereby sounds for which the child already has established a motor system will be highly salient for that child, presumably because these auditory stimuli will already be strongly represented in memory (Vihman, 1982, 1993a, 1993b). Elbers and Wijnen (1992) proposed a similar mechanism, making the point that the child's own productions would be more influential than external input in establishing phonological representations because of the extra effort and attention involved.

The self-monitoring cycle is activated when an acoustic signal produced by the child's own speech is perceived and processed by the child. Three possible outcomes may result from this process, depending on the child's attention and motivation. First, the acoustic signal may be attended to, then encoded and rehearsed in phonological memory, while the short term trace and the long term trace of the intended pronunciation are compared. The stored representation may then be modified or reinforced as a result of this

comparison, whether or not the child attempts to correct the pronunciation. If the child does attempt to correct the pronunciation, the effort of production will produce a stronger effect (e.g., Elbers & Wijnen, 1992). Furthermore, the comparison process would be expected to override the effects of the internal feedback cycle, and lead the system towards more accurate representations and articulation. Second, the acoustic signal may be attended to, encoded and rehearsed, and then stored in long term memory without further processing, thus bringing about or strengthening erroneous representation networks directly. This failure to process may also affect representations indirectly by failing to over-ride the internal feedback cycle, which would continue to distort both representations and articulation. Misarticulations would be expected to persist, and representation networks would become increasingly faulty. Third, the acoustic signal may not be attended to or perceived by the child. In this case no change in phonological representations would be expected as a direct result of self-monitoring, but the internal feedback cycle would operate unchecked, influencing both representations and articulation, to an extent determined by the level of activation of lower level representations.

Environmental feedback cycle

The environmental feedback cycle is the third mechanism by which articulation may influence phonological representation networks, in that the nature and quality of the responses of people in the environment to early speech would be expected to affect the phonological representations underlying that speech. The environmental feedback cycle recognizes the influence of societal reactions to misarticulations on the developing phonological representation system of the child. Three reaction patterns and their potential effects on articulation and representations are possible. First, erroneous reinforcing feedback may be provided, as when the child's mispronunciation is repeated back to the child or used in other situations by the listener. If the child attends to this feedback but does not process it, the environmental cycle would operate like the equivalent process in the self-monitoring cycle, with encoding, rehearsal, storage of faulty representations, and persistence of misarticulations. If processing does take place, the detrimental influence of this cycle might be more powerful than self-monitoring, since the erroneous comparison trace would be immediately available in short term memory for comparison with the trace of the child's speech, the demands on working memory capacity would be reduced as a result, and inaccurate modifications may be made more easily to the phonological

representations. Second, corrective feedback may be provided by the listener. If this feedback takes the form of a simple recasting of the child's pronunciation, without attention being drawn to the error or the correction, its influence will depend on the child's own attention and interest, as with the self-monitoring cycle. If the child attends to and processes the input, the correct short term trace and his or her own spoken trace will be compared, the representation may be modified, and activation from the internal feedback cycle may be suppressed. Both the phonological representation network and articulation may improve. If the child does not attend or attends but does not process the recast item, the effects will correspond to those of the analogous self-monitoring situation. Third, corrective feedback may be provided, with the child's attention being drawn to the corrected pronunciation. The child may process the corrective input. If the listener has repeated the child's mispronunciation and provided the correct version, the effect may be particularly powerful, since the traces of the correct and faulty versions will be equally strong in short term memory for comparison, reducing the demands on working memory capacity. However, even without repetition, if the feedback is immediate then remnants of the child's trace will still be available for comparison with the correction. The phonological representation networks may be modified, articulation may improve as a result, and

activation from the internal feedback cycle may be suppressed, supporting the corrective changes.

There appears to be no information available in the literature about patterns of environmental response to early misarticulation and how they affect phonological development.

The present study

The three feedback cycles constitute the mechanisms by which articulation quality is believed to modify phonological representation networks and therefore phonological awareness during development. If the theoretical model in Figure 1 reflects reality, a statistical relation between articulation quality and phonological awareness should be evident at an early age. Furthermore, articulation quality should predict later phonological awareness. The study reported here was designed to investigate these two predictions.

The present study incorporated two important dimensions that have been identified as critical to an assessment of links between articulation and phonemic awareness: First, the sample included only normally developing children drawn from a non-clinical population; and second, specific articulation patterns were identified, and phonological awareness was studied for these specific patterns.

Specific phonemes in the study. The phonemes selected

for study in the present research included the frequently misarticulated liquids /r/ and /l/, and the well-articulated nasal /m/. These were drawn from tables of errors in consonant singletons in the word-initial position, tabulated by age and frequency, which were produced by the Iowa-Nebraska Articulation Norms Project (Smit, 1993). The relevant articulation patterns for these three phonemes in word-initial position, as determined by the Norms Study, are presented in Table 1. The phonemes /r/ and /l/ were chosen because of their high misarticulation rates among children at age three, and the fact that articulation of these phonemes improves between the ages of three and four, /l/ more so than /r/ (Smit, 1993). Furthermore, when they are misarticulated in the word-initial position, a single error type predominates, reflecting the phonological process of gliding; that is, substitution of [w] for /r/ or /l/. Two other misarticulation processes affecting /r/ that are relevant to this study are derhotacization, which involves reducing or removing the r-colouring of the sound produced, and labialization, wherein the sound is produced with the lips rounded. Both of these processes were infrequent in the Norms Study (Smit, 1993), but both have the effect of producing a sound that is more glide-like, that is, more [w]-like, for /r/. Deviation of pronunciation of the liquids, /l/ and /r/, has been identified as one of the three phonological processes that consistently distinguish

phonologically disordered children from their normally-developing peers (Hodson, 1991), the others being 1) consonant cluster reduction, which occurs when a consonant cluster is deleted, reduced by one or more consonants, or simplified with a substitute phoneme (e.g., *drum* becomes [um], [dum], or [dwum], respectively), and 2) stridency deletion, which occurs when a consonant that normally involves air being forced through an opening is produced with no air flow (e.g., *sail* becomes [tail]).

The control phoneme /m/ was selected because it demonstrates an extremely high rate of accurate articulation from a very early age, as demonstrated in the Iowa-Nebraska Norms Study (Smit, 1993). Furthermore, it shares at least some phonetic features with the other two phonemes, and the frequency with which it occurs in spoken English is roughly equivalent to that of both /r/ and /l/ (Shriberg & Kwiatkowski, 1983).

Research questions. Two key questions arising from the model were addressed in this research. First, are early specific articulation patterns associated with corresponding specific phoneme awareness patterns in very young pre-readers? Second, does early articulation quality predict later specific phoneme awareness in young pre-readers, over and above its relation with early phoneme awareness and the contribution of early to later awareness? A path diagram representing the hypothesized links among the relevant

variables is presented in Figure 2.

Research design. A short-term longitudinal study was undertaken to consider these questions. Three phoneme awareness tasks were developed to measure awareness of the target phoneme, /r/, relative to a control phoneme, and a simple articulation task assessing these same phonemes was prepared. Using these tools, the articulation and specific phoneme awareness of a sample of 80 children were assessed at Stage 1, when they averaged 36.7 months of age (range 35 to 39 months). Weighted articulation quality scores were calculated for each child, based on the nature of his or her productions of the target phoneme in the articulation task. The phoneme awareness measures used were scores that contrasted performance on the target and control phoneme items in each phoneme awareness task. Measures of vocabulary knowledge, phonological short-term memory, analytic intelligence and letter knowledge were taken. The children were reassessed nine months later at Stage 2 when they averaged 46.1 months of age (range 44 to 49 months), using the same tasks. Cross-sectional analyses were undertaken on the Stage 1 and Stage 2 data using fixed order hierarchical regressions, to assess whether specific articulation quality and phoneme awareness were related at these ages, after accounting for important cognitive variables. Longitudinal analyses were undertaken using fixed order hierarchical regressions to assess whether specific articulation quality

at Stage 1 predicted specific phoneme awareness at Stage 2, after accounting for Stage 1 phoneme awareness and Stage 2 articulation. Relevant Stage 1 cognitive variables were controlled.

Chapter 4. Method

Participants

Stage 1

Eighty three-year-old children (mean age = 36.7 months, range 35 to 39 months), 38 boys and 42 girls, from English-speaking homes, participated in Stage 1 of this study. The children were recruited from 28 day care centres and nursery schools in an urban area in Ontario, Canada. The centres and nursery schools served children from neighbourhoods that varied widely in socioeconomic status.

Parental permission to participate was obtained for 117 children. Of these, 23 were excluded because the home was not predominately English-speaking, 5 children refused to cooperate with the experimenters, 3 were unavailable during the testing period, 3 were found to be too old for the study at the time of initial testing, and 3 were excluded because of behavioural problems or developmental delays that seriously interfered with assessment.

The children were given a series of tasks, including ability and knowledge assessments, a simple articulation task, and four tests of phoneme awareness. Notes were kept on behaviour during the testing sessions. The 80 children included in Stage 1 of the study are those who completed the receptive vocabulary test, the articulation assessment, and

at least one phoneme awareness test, the phoneme recognition task.

Stage 2

Seventy-four of the original sample of 80 children participated in Stage 2 of this study. The six children lost to the study included five who had moved out of the region, and one who had participated in Stage 1 but refused to take part in Stage 2. Stage 2 testing was undertaken from nine to eleven months after the initial session of Stage 1, with 63 children being seen between nine and ten months later, and eleven between ten and eleven months later. The Stage 2 sample included 34 boys and 40 girls, with a mean age of 46.1 months (range 44 to 49 months).

Tasks and Measures

Articulation Assessment, Stage 1 and 2

A simple elicitation procedure for collecting articulation data was developed for this study. Children were asked to name a set of familiar objects whose names normally fall within the vocabulary of the age range under study. If the child did not know the word, or if a non-target word was produced by the child (e.g., "bunny" instead of "rabbit"), the tester encouraged the child to try again. The tester told the child the target word (e.g., "It's a

rabbit.") if the child still did not produce the word. If the child repeated the word immediately after the tester said it, that response was not recorded, but all missed items were presented once more at the end of the set, and responses were recorded. The articulation test consisted of six items beginning with /r/V (V = vowel), six with /m/V, six with /l/V, two with /z/V, and two with /dz/V (e.g., jacket). An additional eight items were included (two /r/V, two /m/V, three /l/V, and one /dz/V) as substitutes for items the child failed to respond to in the original set. The maximum number of items scored was six for /r/, /m/, and /l/, and two for /z/ and /dz/. Two training items were presented, followed by the test items in a counterbalanced order, which was the same for all children. A list of items used in the articulation task is presented in Appendix 1. Only results for /r/, /m/ and /l/ are dealt with in the present report.

The objects were presented one at a time, and the tester wrote down each response as the child said it, representing the child's production using letters of the alphabet. For words beginning with /r/, the tester represented the production as either r, in the case of a clearly accurate pronunciation of that phoneme, w in the case of a clear [w] substitution, or wr where the production appeared intermediate between the two. The wr productions would include any children who substituted [wr] for /r/, and

a small number of children who exhibited derhotacization and labialization processes, as discussed above. The perception of the examiner determined the transcription. All responses were tape recorded so that items could be checked later in cases of doubt. A minimum of three /r/ items were required to establish /r/-articulation quality for each child. At Stage 1, all but one child successfully produced at least three /r/ items. The remaining child, who produced two, was retained in the sample because he displayed the same articulation pattern on both, and it was felt that his two productions were a fair representation of his typical pronunciation of initial /r/. All children produced at least three /r/ items at Stage 2.

Articulation quality for /r/. In order to quantify /r/-articulation quality, weighted scores were calculated. These scores were derived from the elicited productions for the six items that began with /r/ in the articulation task. Each accurate production of /r/ was scored as three, each [w] substitution was scored as one, and each intermediate [wr] production was scored as two. Thus, the more similar to /r/ that each production was perceptually, the higher its weighted score. The six scores for each child were combined to produce a total /r/-articulation quality score, which was labelled RQUALITY1 at Stage 1 and RQUALITY2 at Stage 2. Where fewer than six responses had been elicited, the child's score was adjusted to be equivalent to a six-item

score. This weighting scheme for the various productions of /r/ was based on the perceptual value of the child's pronunciations. The rationale here was that the actual sound produced by the child and perceived by others would be the signal that fed back via the three feedback cycles in the Language Learning and Articulation Model to influence phonological representations. No assumptions were made about the factors underlying the misarticulations or about the developmental course of the articulation of /r/. The [wr] productions, whatever the stage of development of the child, were perceived as intermediate between /r/ and /w/ by the examiners. That is, the acoustic signal was more similar to /r/ than was [w]. The weighting scheme used here reflects these perceptual values.

Phoneme Awareness Tasks, Stage 1 and 2

Four tests of phoneme awareness were developed for this study. They were intended to represent a range of difficulty, based on the ranking of phonological tasks developed by Chaney (1992), although only the simplest task here, the phoneme judgement task, corresponded exactly to any of her procedures. Like Chaney's, the tasks were characterized by simple vocabulary, simple linguistic structures, avoidance of linguistic terminology, and the use of demonstration and practice (Chaney, 1992). To ensure that words chosen as stimuli fell within the typical vocabulary

of children this age, they were selected from three published checklists of words likely to be understood or produced by children well before they turn three (Gilhooly & Logie, 1980; Rescorla, 1989; Reznick & Goldsmith, 1989). Furthermore, as emphasized in the clinical literature on testing and treating language-impaired children (e.g., Locke 1980a, 1980b; Winitz, 1989), the words were chosen to represent as wide a phonetic range as possible for the phoneme, with different vowel sounds following the initial target consonant. Also, words were selected that lent themselves to pictorial representation. The reliability of each task was assessed separately for Stage 1 and 2, using Cronbach's alpha. Reliability analysis was not undertaken on the scores of children who failed to complete the task with some variability, a consideration discussed in detail in the Results section below.

Phoneme recognition task. A task was developed to test whether children whose misarticulation involves using a common substitution for a target phoneme are able to correctly identify the target phoneme when it is presented to them, even though they do not produce it in everyday speech. Eight sets of three pictures were shown to the children twice. Each set included two pictures that represented a rhyming minimal pair, one beginning with either /r/ or /l/ and the other /w/, along with a non-rhyming foil to control for guessing. The child's task was

to point to the picture named by the experimenter. For example, the child was shown a picture of a rock, a child walking and a book, and was asked "Show me rock" or "Show me walk". Owing to the great difficulty finding minimal pairs of words that both fall within the normal vocabularies of children in the age group at Stage 1 of this study and can be represented pictorially, this test was a limited one, including four minimal pairs involving /r/ and /w/ in the initial position, and four involving /l/ and /w/. The list of stimuli sets used in the phoneme recognition task is presented in Appendix 2. The scores on the task considered here were the number correct for the four /r/ items (*rock, ring, write, a rake*), and the number correct for the four /l/ items (*a lake, lock, letter, light*), with maximum = 4 for each set. The reliability of this task at Stage 1 was relatively low, with Cronbach's alpha equal to .20 for the /l/ subscale and .40 for the /r/ subscale. The reliability at Stage 2, for children 9 to 10 months older, was low for the /l/ subscale, with Cronbach's alpha equal to .42, and was slightly negative for the /r/ subscale, with alpha equal to -.17.

Phoneme judgement task. A task based on one described by Chaney (1992) was used to assess children's ability to detect articulation errors involving the phonemes /r/, /l/ and the control phoneme /m/ in the speech of others. An appealing animal puppet, Bombom, was shown a set of 16

pictures, one at a time, and named them correctly or incorrectly. The incorrect pronunciation was identical to the correct one except that the initial phoneme /r/, /l/ or /m/ was replaced by the phoneme most often substituted for the target phoneme by misarticulating children, that is, /w/. For example, the puppet was shown a picture of rain and named it "wain". The child's task was to tell the puppet if its pronunciation was correct or not. A set of six pictures using non-target phonemes was used to train the children before testing. Because the purpose of the training was to focus the child's attention on the initial phoneme of the pronunciation produced by the puppet, words were chosen that began with phonemes that were well-articulated by three-year-olds, and that exhibited low rates of substitution errors in the Norms Study (Smit, 1993). It was expected that these phonemes would be well-discriminated overall by this age group, and that training based on such phonemes would be relatively efficient. A list of the stimulus pictures used in the phoneme judgement task are presented in Appendix 3. The score on the task was the number correct for each phoneme (maximum=4).

At Stage 1, a small number of children refused or failed to respond to one or a few of the items on the phoneme judgement task for some extraneous reason such as being distracted briefly (n=5 for /m/ subscale; n=8 for /r/ subscale). Another small group indicated that their response

to the occasional item was based on the content rather than the sound of a stimulus word; for example, indicating that the item wope was incorrect because it was a snake (n=6 for /m/ subscale; n=6 for /r/ subscale). At Stage 2, refusal or failure to respond was rare (n=2 for /m/ subscale; n=0 for /r/ subscale). Content-based incorrect responses were somewhat more frequent than at Stage 1 (n=8 for /m/ subscale; n=13 for /r/ subscale), possibly because of increased vocabulary levels. Where an item was missed for these reasons, the score for the phoneme was weighted to reflect accuracy out of four. Only results for the control phoneme /m/ and the target phoneme /r/ are dealt with in the present report. The reliability of this task was good, with Cronbach's alpha equal to .68 for the /m/ subscale and .77 for the /r/ subscale at Stage 1, and .63 for the /m/ subscale and .66 for the /r/ subscale at Stage 2.

Speech discrimination task. A task was developed to determine whether children who misarticulate by substitution can distinguish between the target and substitute phonemes when they are presented together. The children were shown twelve pairs of animal sticker pictures, one pair at a time, and were told the 'names' of the two animals. The child's task was to indicate whether the animals had the same name. The 'names' included eight pairs of syllables that were rhyming minimal pairs, one beginning with /r/ or /l/ and one with the substitution phoneme /w/, and four pairs that were

the same. For example, the child was shown a set of two animal stickers and told "This is ruh and this is wuh. Ruh. Wuh. Do they have the same name?" Care was taken to select syllables that were not words normally found in the vocabularies of young children, to ensure that the discrimination was made on the basis of phoneme-level representations rather than word-level representations. A set of four pairs starting with non-target phonemes was used for training the children before testing. Stimulus items used in the speech discrimination task are presented in Appendix 4. The score on the task was the number correct for each phoneme (maximum=4). A small number of children refused or failed to respond to one of the items for some extraneous reason such as being distracted briefly (at Stage 1, n=1 for /l/ subscale; n=2 for /r/ subscale; at Stage 2, n=2 for /l/ subscale; n=2 for /r/ subscale). Where an item was missed for these reasons, the score was weighted to reflect accuracy out of four. The reliability of this task was good at Stage 1, with Cronbach's alpha equal to .71 for the /l/ subscale and .69 for the /r/ subscale. At Stage 2 Cronbach's alpha was .35 for the /l/ subscale and .74 for the /r/ subscale.

Phoneme identification task. A task was developed to assess the ability of children to identify words that start with the same phoneme as another word. The task was a simplified version of the initial sound comparison tasks

reported in the literature for older children (e.g., Wagner et al., 1994), but it proved to be beyond the capacities of the children in Stage 1 of this study, and is not reported on here.

Cognitive and Behavioural Measures

Cognitive abilities and knowledge were assessed at Stage 1 only, with the exception of letter knowledge and letter-word identification, which were tested at Stage 2.

Vocabulary. Receptive vocabulary was assessed using the Peabody Picture Vocabulary Test-Revised (PPVT-R, Dunn & Dunn, 1981), and expressive vocabulary using the Expressive One-Word Picture Vocabulary Test-Revised (EOWPVT-R, Gardner, 1990). Standard scores were used in the analyses.

Short-term phonological memory. An auditory digit span test like that used by Adams and Gathercole (1995) in their study with preschool children was used to assess phonological working memory. Children were asked to repeat back sequences of digits spoken by the tester, beginning with a single digit. If two of three sequences at one length were repeated correctly, the number of digits was increased by one. Testing continued until the child failed to repeat two of three sequences at one length. Two scores were calculated: the maximum length at which one of the three lists was repeated correctly, and the maximum at which two were repeated correctly. The scores for one repetition were

used in the analyses reported here.

Analytic intelligence. The Animal Pegs subtest of the WPPSI-R (Weschler, 1989) was used as a measure of non-verbal intelligence. Age-standardized scaled scores were used in the analyses.

Letter and word identification. To determine whether the children had any knowledge of printed letters, they were shown seven brightly coloured plastic upper case letters, one at a time, and were asked to name them. The letters included the child's first initial, followed by A L B R M H, with D being used if the child's initial was one of the original six. The child's score was the number correct (maximum=7). This test was administered at Stage 1 and 2. In addition, early reading ability was assessed at Stage 2 using the Letter-Word Identification subtest of the Woodcock-Johnson Psycho-Educational Battery-Revised (Woodcock & Johnson, 1989, 1990).

Behaviour during testing. The examiners noted on the response sheets any major characteristics of each child's behaviour during Stage 1 testing that might have affected performance on the tests. The behaviours that were noted fell into six categories: 1) positive behaviours, 2) no problems or minor problems, 3) very short attention span, 4) very distractible, 5) resistant or defiant, and 6) shy or reluctant.

ProcedureStage 1

The children were seen individually at their day care centres by either the experimenter or a trained research assistant, both of whom were experienced in working with young children. For the most part, the children were seen three times within a 2 week period, with each session lasting 20 to 30 minutes. Tasks were administered in the same order for most children, as follows. Session 1 included the PPVT, the EOWPVT, the digit span test, and the articulation assessment. Session 2 included the phoneme recognition task, the first half of the phoneme identification task, and Animal Pegs. Session 3 included the phoneme judgement task, the letter knowledge test, the second half of the phoneme identification task and the speech discrimination task. The testers found it necessary to maintain flexibility in scheduling and ordering tasks and items when dealing with such young children. For some children, because of attentional or behavioural idiosyncracies, or scheduling problems at the day care centre, four (n=15), five (n=3) or even six (n=1) sessions were required to complete all of the tasks. For a few children, the order of presenting tasks was varied somewhat in order to retain or regain their attention. However, most children completed the tasks in three sessions and in the indicated order.

Responses for all tasks were recorded on detailed response protocols, and 20% of these were scored by both testers to establish reliability of the scoring procedures. Interrater reliability was 100% on all tasks. The articulation test was hand scored and tape recorded, and recordings were checked by both testers only in cases where an articulation item was in doubt.

Stage 2

At Stage 2, children were seen individually by the same experimenter or research assistant who had assessed them initially. Of the 74 children who were available, 63 were seen at the same day care centre as at Stage 1. The remainder were seen in their homes, or at their new centres. At Stage 2, most of the children were seen in a single session lasting 25 to 35 minutes. Tasks were administered in the same order for most of the children, as follows: the Letter-Word Identification Subtest, the phoneme recognition task, the articulation assessment, the phoneme judgement task, the letter knowledge test, and the speech discrimination task. Flexibility in ordering tasks was required for a small number of children, and two or three sessions were required to complete all the tasks for a small number of children ($n=2$). Responses were recorded on detailed response protocols. Both the scored protocols and taped articulation assessments were checked as for Stage 1.

Chapter 5. Results

The findings of this study are presented in three sections. First, the cross-sectional analyses of the Stage 1 data are described, and the findings presented. Second, the corresponding Stage 2 data and findings are presented. The Stage 1 and 2 cross-sectional results are relevant to the question of whether a concurrent statistical relation exists between articulation quality and phonological awareness at 36 and 45 months of age. In the third section, the longitudinal analyses are presented. These results are relevant to the question of whether early articulation quality predicts later phoneme awareness.

Stage 1 Analyses

Articulation Patterns and Cognitive Variables

Articulation. Children's production errors in this study were consistent with the phonologic error distributions found by Smit (1993) in the Iowa-Nebraska Articulation Norms Project, as presented in Table 1. The present study found 34% of the children at Stage 1, who were aged 3;1 on average, producing /r/ accurately, compared with Smit's finding of 22% for the children aged 2;0 to 4;0, increasing to 65% for ages 4;6 to 6;0. The present study also found that 48% of these children always substituted [w]

or [wr] for /r/ and that an additional 19% of them sometimes did. Smit found that between 30% and 80% of children aged 2;0 to 4;0 made this substitution, which suggests that, by interpolation, that approximately 55% of children aged 3;0 would produce this error in her sample, consistent with the present finding. Similarly, the present study found 96% accuracy for /m/, while Smit found 98% accuracy. In the present study, two of the 80 children at Stage 1 produced the denasalization error, [b], for /m/, while one substituted [n].

Articulation quality, Stage 1 (RQUALITY1). As described earlier, weighted /r/-articulation quality scores were calculated for each of the 80 children in the Stage 1 sample, based on their productions in the articulation task. As shown in Appendix 5, the mean of RQUALITY1 was 12.3 for this sample, with a standard deviation of 4.9. Fifteen children scored at the minimum of 6.0, these being the children who produced [w] for all items. Twenty-seven children scored at the maximum of 18.0, these being the children who produced /r/ accurately for all items. The remaining 38 children had scores ranging from 7.0 to 17.0. RQUALITY1 was the articulation measure used in the following analyses of the Stage 1 data.

Demographic and cognitive variables. The Stage 1 participants included 38 boys (47.5%) and 42 girls (52.5%). Forty (50%) were 35 to 36 months of age (younger group), and

40 (50%) were 37 to 39 months of age (older group). Boys and girls did not differ in RQUALITY1, with means of 13.0 and 11.6 respectively, $t(78) = 1.26$, $p = .210$. Age was not related to RQUALITY1, with means of 11.6 for the younger group and 12.9 for the older, $t(78) = -1.17$, $p = .244$.

The overall sample did not differ from established norms for three-year-olds on the PPVT-R, EOWPVT-R, Animal Pegs, or the digit span test (Gathercole & Adams, 1993). Means and standard deviations for the cognitive measures are presented in Table 2. As shown in Appendix 6, none of the cognitive measures was significantly correlated statistically with /r/-articulation quality, RQUALITY1.

Phoneme Awareness Stage 1

Stage 1 task completion. At Stage 1, data were available for all 80 children on the phoneme recognition task, 63 children on the phoneme judgement task, and 46 children on the speech discrimination task. Data were missing for two reasons: A small number of the children for whom data were not available refused to attempt the task in question. A larger number willingly completed or nearly completed the task, but showed no response variability; that is, they responded either "yes" or "no" to all items in the set. Lack of response variability was taken to indicate that the child had failed to understand the response requirements of the task, or that the child was responding on the basis

of considerations other than those of the task requirements. Such children were excluded from the analyses of results for that task, because it was assumed that all of their responses would reflect factors other than their phoneme awareness.

The differing response rates for the three tasks reflect, in part, their differing cognitive demands. The phoneme recognition task was a word recognition task, requiring a simple pointing response. All 80 children who were included in the study at Stage 1 successfully completed this task. The phoneme judgement task was more demanding cognitively, requiring the children to remember a spoken word and to indicate whether it had been said the "right way". In all, 63 children successfully completed this task, 6 did not attempt it, and 11 showed no variability in their responses. The speech discrimination task was the most demanding of the three, requiring the children to remember two spoken names, and to judge whether they were "the same". On this task, 46 children were successful, 6 did not attempt it, and 28 showed no variability in their responses. The analyses of individual phoneme awareness tasks reported below included all children who completed that particular task with at least some variability.

Control phonemes. Because /m/ shows a high rate of articulation accuracy from a very early age, it was assumed that articulation has no effect on /m/ phoneme awareness,

and /m/ was included as a control phoneme for /r/ on the phoneme judgement task. For the phoneme recognition and speech discrimination tasks, /l/ was used as the control phoneme for /r/. The phoneme /l/ is itself often misarticulated by young children. However, if a relation exists between /l/-articulation and /l/-phoneme awareness, as would be predicted from the model underlying the present study, that relation would tend to depress /l/-awareness scores. Therefore, using /l/ as a control phoneme for /r/ was a conservative approach in the analyses reported here, in that it would tend to underestimate awareness differences. In this study, the control phoneme awareness scores were used to control for the effects of general phonological awareness and processing ability on phoneme awareness of /r/.

Phoneme awareness contrast scores. Because the level of phoneme awareness of /r/ relative to that of the control phoneme was the dependent variable of interest in this study rather than the absolute level of phoneme awareness of /r/, the measures used to represent phoneme awareness of /r/ were contrast scores. These were calculated by subtracting the score for /r/ on each phoneme awareness task from the score for the control phoneme. Thus, if the contrast score was positive, awareness of /r/ was lower than awareness of the control phoneme, while a negative value would indicate that awareness of /r/ was higher.

Phoneme awareness task means. Means and standard deviations for the three individual phoneme awareness tasks are presented in Table 3. The statistics are presented for the control phonemes (/m/ or /l/), for /r/, and for the contrast score, that is, the difference between them. This table shows that for the phoneme recognition task, the mean score for the control phoneme and for /r/ did not differ statistically, $t(78) = -.64$, $p > .50$. The mean score was significantly higher statistically for the control phoneme than for /r/, as predicted, for both the phoneme judgement task, $t(61) = 4.00$, $p < .001$, and the speech discrimination task, $t(44) = 5.67$, $p < .001$.

Task Completion, Cognitive Abilities and Articulation

Analyses described earlier found no relation between any of the cognitive variables and /r/-articulation quality for the sample of 80 children at Stage 1, but this might not be so for the subgroup of children who either refused to attempt a phoneme awareness task or who responded with no variability. These would be the children who found the tasks too challenging, and they would be expected to differ considerably in their cognitive abilities from those who completed the tasks. Therefore, it was necessary to test the possibility that articulation quality of /r/ was related to the cognitive abilities for the subgroups of children who completed each of the tasks. If such a relation existed,

relations found in subsequent analyses between articulation quality and phoneme awareness of /r/ might be attributable to the cognitive variable, rather than to articulation. The correlation coefficient for each of the cognitive variables and /r/-articulation quality was calculated for the subsamples that completed each of the three phoneme awareness tasks. Cognitive variables that were significantly correlated statistically with /r/-articulation quality were to be included as predictor variables in the analyses of phoneme awareness and articulation reported later. Despite the high overall error rate expected when testing 45 correlation coefficients for statistical significance, an alpha level of .05 was set for testing each of the hypotheses of no correlation, to ensure that important cognitive trends would be detected.

The phoneme recognition task was completed by all 80 children. The correlation coefficients for this task, therefore, are those presented in Appendix 6 for the total sample. There was no statistically significant correlation between RQUALITY1 and any of the cognitive measures for this group. The figures for the phoneme judgement task, which was completed by 63 children, are presented in Appendix 7. A statistically significant negative correlation was found between RQUALITY1 and receptive vocabulary ($r = -.28$, $n = 63$, $p = .024$); that is, /r/-articulation quality decreased with increasing receptive vocabulary scores. Therefore, receptive

vocabulary was included as a predictor in the analysis of phoneme judgement scores. The figures for the speech discrimination task, which was completed by 46 children, are presented in Appendix 8. No statistically significant correlation was found between RQUALITY1 and any of the cognitive measures for this task.

Articulation and Phoneme Recognition

The simple correlation coefficient between phoneme recognition of /r/ and /r/-articulation quality at Stage 1 was $r = -.259$, as shown in Appendix 6.

The relation between articulation and phoneme recognition at Stage 1 was examined using a simple regression analysis. The dependent variable in this analysis was the contrast between the phoneme recognition score for the control phoneme, /l/, and for /r/ at Stage 1, labelled PR.CONTRAST.STG1. If PR.CONTRAST.STG1 was positive, recognition of /r/ was lower than recognition of the control phoneme, while a negative value for PR.CONTRAST.STG1 would indicate that recognition of /r/ was higher. The predictor variable was RQUALITY1. The results of the regression are shown in Table 4. Articulation quality accounted for 6.7% of the variance in the contrast score, PR.CONTRAST.STG1, with a negative regression coefficient as predicted, $t(78) = -2.40$, $p = .010$ (one-tailed test), indicating that as articulation quality increased, the phoneme recognition contrast

decreased; that is, as articulation quality increased, recognition of /r/ also increased.

Articulation and Phoneme Judgement

The simple correlation coefficient between phoneme judgement of /r/ and /r/-articulation quality was $r = -.257$, as shown in Appendix 7.

The relation between articulation and phoneme judgement at Stage 1 was examined using a fixed order hierarchical regression analysis. Similar to the phoneme recognition analysis, the dependent variable in this analysis, PJ.CONTRAST.STG1, was the contrast between the phoneme judgement score for the control phoneme, /m/, and for /r/ at Stage 1. A higher value for PJ.CONTRAST.STG1 would indicate lower phoneme judgement of /r/. Two predictor variables were included in this analysis: receptive vocabulary, which had been identified previously as an important control variable for this analysis, was entered first, followed by RQUALITY1. This fixed order approach allowed the unique contribution of articulation quality to phoneme judgement to be assessed, after accounting for the contribution of receptive vocabulary. The results of the regression are shown in Table 4. Receptive vocabulary alone accounted for 11.5% of the variance in PJ.CONTRAST.STG1, $t(61) = 2.82$, $p = .007$ (two-tailed test). After controlling for vocabulary, articulation quality accounted for a further 2.8% of the variance, with a

negative regression coefficient as predicted, $t(60)=-1.40$, $p=.083$ (one-tailed test).

Articulation and Speech Discrimination

The simple correlation coefficient between speech discrimination of /r/ and /r/-articulation quality was $r=-.323$, as shown in Appendix 8.

The relation between articulation and speech discrimination at Stage 1 was examined using a simple regression analysis. Similar to the previous two tasks, the dependent variable in this analysis, SD.CONTRAST.STG1, was the contrast between the discrimination score for the control phoneme, /l/, and for /r/ at Stage 1. As for the other tasks, a higher value for SD.CONTRAST.STG1 would indicate lower discrimination of /r/. The predictor variable was RQUALITY1. The results of the regression are shown in Table 4. Articulation quality accounted for 10.4% of the variance in the contrast score, SD.CONTRAST.STG1. The regression coefficient for RQUALITY1 was negative as predicted, $t(44)=-2.26$, $p=.014$ (one-tailed test), indicating that as articulation quality increased, the discrimination of /r/ also increased.

Stage 2 AnalysesArticulation Patterns and Cognitive Variables

Articulation. As at Stage 1, children's production errors at Stage 2 were consistent with error rates in the Iowa-Nebraska Articulation Norms Project (Smit, 1993) reported earlier, which are summarized in Table 1. At Stage 2, 51% of the children, who were aged 3;10 on average (range: 3;8 to 4;1), produced /r/ accurately. Also, 34% of the children always substituted [w] for /r/, and an additional 15% of them sometimes did so. The present study found 100% accuracy for /m/ at this age.

Articulation quality, Stage 2 (RQUALITY2). As described earlier, weighted /r/-articulation quality scores were calculated for each of the 74 children in the Stage 2 sample, based on their productions in the articulation task. This /r/-articulation quality variable for Stage 2 was labelled RQUALITY2. As shown in Appendix 5, the mean for RQUALITY2 was 13.8, with a standard deviation of 5.1. Ten children scored at the minimum of 6.0, 38 scored at the maximum of 18.0, and the remaining 26 had intermediate scores. RQUALITY2 was used as the /r/-articulation measure at Stage 2 in the analyses reported below.

Demographic and cognitive variables. The Stage 2 participants included 34 boys (45.9%) and 40 girls (54.1%). Twenty-six (35.1%) were aged 44 or 45 months (younger

group), and 48 (64.9%) were 46 to 49 months (older group). Boys and girls did not differ in RQUALITY2, with means of 13.4 and 14.1 respectively, $t(72) = -.57$, $p = .572$. Age was not related to RQUALITY2, with means of 14.0 for the younger group and 13.6 for the older, $t(72) = .32$, $p = .749$.

Two cognitive variables were measured at Stage 2, letter knowledge, measured by asking children to name seven letters, and letter-word identification, measured with the Letter-word Identification subtest of the Woodcock-Johnson Psycho-Educational Battery-Revised (Woodcock & Johnson, 1989, 1990). The mean number of letters identified at Stage 2 was 1.92 ($SD = 2.36$, $n = 71$). The sample, whose mean age was 46.1 months, did not differ from established norms on the letter-word identification test (mean age-equivalent score = 45.6 months, $SD = 8.96$, $n = 72$). Neither letter knowledge nor letter-word identification was significantly correlated statistically with /r/-articulation quality, RQUALITY2, at Stage 2.

Phoneme Awareness Stage 2

Stage 2 task completion. Of the 74 Stage 2 children, data were available for 73 on the phoneme recognition task, 70 on the phoneme judgement task, and 66 on the speech discrimination task. As described earlier, data were missing for two reasons: A small number of children refused to attempt the task in question, while others completed the

task, but showed no response variability. A greater number of children at Stage 2 than at Stage 1 completed the phoneme judgement and the speech discrimination tasks, as would be expected given the greater cognitive processing abilities of these children when they were nine to ten months older.

Phoneme awareness task means. Means and standard deviations for the three individual phoneme awareness tasks at Stage 2 are presented in Table 5. The statistics are presented for the control phonemes (/m/ or /l/), for /r/, and for the contrast score, that is, the difference between them. This table shows that the mean score was significantly higher statistically for the control phoneme than for /r/ for the phoneme recognition task, $t(71)=1.67$, $p=.049$, the phoneme judgement task, $t(68)=4.51$, $p<.001$, and the speech discrimination task, $t(64)=6.86$, $p<.001$.

Ceiling effects. General phonological awareness had increased substantially between Stage 1 and Stage 2, as illustrated by comparing Table 3 and Table 5. Table 3 shows that at Stage 1, the mean control phoneme scores for the three tasks were 2.7 (phoneme recognition), 2.9 (phoneme judgement), and 2.4 (speech discrimination) out of a possible maximum of 4.0, while Table 5 shows the corresponding scores at Stage 2 to be 3.5, 3.6 and 3.5. Although scores for /r/ were lower than the control phoneme scores, ceiling effects clearly reduced the range of results at Stage 2. On the phoneme recognition task, 65.8% scored at

ceiling for the control phoneme, and 41.1% did so for /r/. On the phoneme judgement task, the corresponding figures were 78.6% for the control phoneme and 48.6% for /r/, and on the speech discrimination task, 65.2% for the control phoneme and 30.3% for /r/.

Task Completion, Cognitive Abilities and Articulation

As for Stage 1, it was necessary to test the possibility that articulation quality of /r/ at Stage 2 was related to Stage 1 and 2 cognitive abilities for the subgroups of children who completed each of the tasks. If such a relation existed, relations found in subsequent analyses between articulation quality and phoneme awareness of /r/ might be attributable to the cognitive variable, rather than to articulation. The correlation coefficient for each of the cognitive variables and /r/-articulation quality, RQUALITY2, was calculated for the subsamples that completed the three phoneme awareness tasks. Cognitive variables that were found to be significantly correlated statistically with /r/-articulation quality were included as predictor variables in the analyses of phoneme awareness and articulation reported later. As for Stage 1, an alpha level of .05 was set for testing each of the hypotheses of no correlation, to ensure that important cognitive trends would be detected.

The phoneme recognition task was completed by 73 of the

74 children who participated in Stage 2. The correlation coefficients for this task are presented in Appendix 9. A statistically significant negative correlation was found between RQUALITY2 and expressive vocabulary ($r = -.23$, $n = 72$, $p = .050$); that is, /r/-articulation quality decreased with increasing expressive vocabulary scores. Therefore, expressive vocabulary was included as a predictor in the analysis of phoneme recognition scores at Stage 2. The figures for the phoneme judgement task, which was completed by 70 children, are presented in Appendix 10. Again, a statistically significant negative correlation was found between RQUALITY2 and expressive vocabulary ($r = -.25$, $n = 69$, $p = .035$); that is, /r/-articulation quality decreased with increasing expressive vocabulary scores. Therefore, expressive vocabulary was included as a predictor in the analysis of phoneme judgement scores. The figures for the speech discrimination task, which was completed by 66 children, are presented in Appendix 11. No statistically significant correlation was found between RQUALITY2 and any of the cognitive measures for this task.

Articulation and Phoneme Recognition

The simple correlation coefficient between phoneme recognition of /r/ and /r/-articulation quality at Stage 2 was $r = -.120$, as shown in Appendix 9.

The relation between articulation and phoneme

recognition at Stage 2 was examined using a fixed order hierarchical regression analysis. The dependent variable in this analysis was the contrast between the phoneme recognition score for the control phoneme, /l/, and for /r/ at Stage 2. To calculate this variable, which was labelled PR.CONTRAST.STG2, the score for /r/ was subtracted from the score for the control phoneme. Thus, if PR.CONTRAST.STG2 was positive, recognition of /r/ was lower than recognition of the control phoneme, while a negative value for PR.CONTRAST.STG2 would indicate that recognition of /r/ was higher. Two predictor variables were included in this regression analysis. Expressive vocabulary, which had been identified previously as an important control variable for this analysis, was entered first, followed by RQUALITY2. This fixed order approach allowed the unique contribution of articulation quality to phoneme recognition to be assessed, after accounting for the contribution of expressive vocabulary. The results of the regression are shown in Table 6. Expressive vocabulary alone accounted for less than 1% of the variance in PR.CONTRAST.STG2. After controlling for expressive vocabulary, articulation quality accounted for a further 2.4% of the variance, with a negative regression coefficient as predicted, $t(69) = -1.30$, $p = .099$ (one-tailed test). These limited findings reflect ceiling effects in the data, as discussed later.

Articulation and Phoneme Judgement

The simple correlation coefficient between phoneme judgement of /r/ and /r/-articulation quality at Stage 2 was $r = -.314$, as shown in Appendix 10. [Note that the n for this correlation differs from that of the regression which follows because of missing data for one child on expressive vocabulary in the regression analysis.]

The relation between articulation and phoneme judgement at Stage 2 was examined using a fixed order hierarchical regression analysis. Similar to the phoneme recognition analysis, the dependent variable in this analysis, PJ.CONTRAST.STG2, was the contrast between the phoneme judgement score for the control phoneme, /m/, and for /r/ at Stage 2. As for phoneme recognition, a higher value for PJ.CONTRAST.STG2 would indicate lower phoneme judgement of /r/. Two predictor variables were included in this analysis. Expressive vocabulary, which was identified previously as an important control variable for this analysis, was entered first, followed by RQUALITY2. This fixed order approach allowed the unique contribution of articulation quality to phoneme judgement to be assessed, after accounting for the contribution of expressive vocabulary. The results of the regression are shown in Table 6. Expressive vocabulary alone accounted for 3.4% of the variance in PJ.CONTRAST.STG2, $t(67) = 1.53$, $p = .130$ (two-tailed test). After controlling for expressive vocabulary, articulation quality accounted for a

substantial 7.9% of the variance, with a negative regression coefficient as predicted, $t(66) = -2.42$, $p = .009$ (one-tailed test), indicating that as articulation quality increased, judgement of /r/ also increased.

Articulation and Speech Discrimination

The simple correlation coefficient between speech discrimination of /r/ and /r/-articulation quality at Stage 2 was $r = -.278$, as shown in Appendix 11.

The relation between articulation and speech discrimination at Stage 2 was examined using a simple regression analysis. Similar to the previous two tasks, the dependent variable in this analysis, SD.CONTRAST.STG2, was the contrast between the speech discrimination score for the control phoneme, /l/, and for /r/ at Stage 2. As for the other tasks, a higher value for SD.CONTRAST.STG2 would indicate lower discrimination of /r/.

The predictor variable was RQUALITY2. The results of the regression are shown in Table 6. Articulation quality at Stage 2 accounted for a substantial 7.7% of the variance in the contrast score, SD.CONTRAST.STG2. The regression coefficient for RQUALITY2 was negative as predicted, $t(64) = -2.32$, $p = .012$ (one-tailed test), indicating that as articulation quality increased, the speech discrimination of /r/ also increased.

Longitudinal Analyses

Framework for Longitudinal Data Analysis

The theoretical model in Figure 1 predicts that early articulation quality is causally linked to later phoneme awareness, after accounting for Stage 1 phoneme awareness and Stage 2 articulation. These relations are presented in the path diagram in Figure 2. A preliminary assessment revealed that for this path diagram the structural equation model featuring reciprocal causation was not identified, so that a simultaneous estimation of model parameters, as in a standard LISREL analysis, was not feasible (Long, 1983). Therefore, the model was evaluated using a series of fixed order hierarchical regression analyses, as reported below.

As for the cross-sectional analyses reported earlier, cognitive variables that might be related to phoneme awareness and that were found to be related to Stage 1 articulation quality were included in these analyses, to rule out the possibility that later phoneme awareness differences were attributable to early cognitive variables rather than to early articulation.

Longitudinal Subsamples

The longitudinal analyses were designed to assess whether early articulation quality predicted specific phoneme awareness nine to ten months later in the young pre-

readers in this sample. Three sets of analysis were undertaken, one for each of the three phoneme awareness tasks. Phoneme recognition scores at Stage 1 and 2 were available for 73 children, phoneme judgement scores for 58, and speech discrimination scores for 41. These were the longitudinal subsamples examined in the main analyses reported below.

Supplementary subsamples. In addition, in an effort to reduce variability and clarify patterns in the data, supplementary analyses were undertaken using only those children whose behaviour during Stage 1 testing was stable, as indicated by notes about behaviour made during the testing sessions. These were children for whom positive behaviours, no problems, or minor problems were recorded by the examiners. Excluded from the subsample were those whose behaviour during testing had been classified as extreme in at least one of the following areas: short attention span; distractibility; resistance or defiance; shyness or reluctance. The subsamples with stable behaviour included 52 children for the phoneme recognition task, 47 for the phoneme judgement task, and 34 for the speech discrimination task.

Cognitive measures for the longitudinal analyses

In order to test the hypothesis that /r/-articulation quality at Stage 1 predicted phoneme awareness of /r/ at

Stage 2 after controlling for relations among the articulation and phoneme awareness variables, it was necessary to first assess the possibility that Stage 1 /r/-articulation quality was related to any of the cognitive abilities, for the longitudinal subsamples. If such a relation existed, relations found in subsequent analyses between Stage 1 articulation quality and Stage 2 phoneme awareness of /r/ might be attributable to the cognitive variable, rather than to early articulation. Correlation coefficients were calculated for each of the cognitive variables and /r/-articulation quality at Stage 1, for the longitudinal subsamples; that is, for the subsamples that had completed the phoneme awareness tasks at both Stage 1 and 2. Cognitive variables that were significantly correlated statistically with Stage 1 /r/-articulation quality for these longitudinal subsamples were to be included as predictor variables in the analyses of phoneme awareness and articulation reported later. As for the Stage 1 and 2 cross-sectional data, an alpha level of .05 was set for testing each of the hypotheses of no correlation, to ensure that important cognitive trends would be detected.

The phoneme recognition task was completed by 73 children in the longitudinal subsample. This is the same group of children who were assessed at Stage 2 for the phoneme recognition task. The correlation coefficients for the cognitive variables and RQUALITY1 for this subsample are

presented in Appendix 12. No statistically significant correlations were found between any of the cognitive variables and RQUALITY1 for these children.

The figures for the phoneme judgement task, which was available for 58 children in the longitudinal subsample, are presented in Appendix 13. A statistically significant negative correlation was found between RQUALITY1 and receptive vocabulary ($r = -.31$, $n = 58$, $p = .017$); that is, /r/-articulation quality decreased with increasing receptive vocabulary scores. Therefore, receptive vocabulary was included as a predictor in the longitudinal analyses of phoneme judgement scores.

The figures for the speech discrimination task, which was completed by 41 children, are presented in Appendix 14. No statistically significant correlation was found between any of the cognitive measures and RQUALITY1 for this task.

Articulation and Phoneme Recognition

The simple correlation coefficient between phoneme recognition of /r/ at Stage 2 and /r/-articulation quality at Stage 1 for the longitudinal subsample was $r = -.064$, as shown in Appendix 12.

The relation between Stage 1 articulation and Stage 2 phoneme recognition was examined using a fixed order hierarchical regression analysis. As for the cross-sectional analyses reported earlier, the dependent variable in this

analysis was a contrast score, in this case the contrast between the phoneme recognition score for the control phoneme, /l/, and for /r/ at Stage 2, PR.CONTRAST.STG2. A higher value for PR.CONTRAST.STG2 would indicate lower phoneme recognition of /r/. Three predictor variables were included in this analysis: The contribution of early phoneme recognition was represented by the contrast between the phoneme recognition scores for the control phoneme, /l/, and the target phoneme, /r/, at Stage 1, PR.CONTRAST.STG1. The contribution of later articulation was represented by the articulation quality score at Stage 2, RQUALITY2. These two predictors were entered as a block before the predictor variable of interest, the articulation quality score at Stage 1, RQUALITY1. This fixed order regression was used to allow the unique contribution of RQUALITY1 to be assessed after accounting for the contribution of the first two variables. The results of this analysis are shown in Table 7 in the section labelled *Main Analysis*. The first two predictor variables together accounted for approximately 1.6% of the variance in PR.CONTRAST.STG2, $F(2,70) = .55$, $p = .579$. When Stage 1 articulation, RQUALITY1, was entered in the regression subsequently, there was no increase in explained variance for /r/ phoneme recognition, PR.CONTRAST.STG2. The final regression equation is shown in Table 8 in the section labelled *Main Analysis*.

The impact of the RQUALITY1 variable on the equation

can be presented visually using an added variable plot (Cook & Weisberg, 1982). This is implemented by plotting the residuals of the regression of the dependent variable, PR.CONTRAST.STG2, on all of the predictor variables except RQUALITY1 against the residuals of the regression of RQUALITY1 on these same predictor variables. The added variable plot appears in Figure 3. The standardized residuals of the regression of PR.CONTRAST.STG2 on the predictor variables form the Y-axis of the plot. The standardized residuals of the regression of RQUALITY1 on the predictor variables form the X-axis of the plot. Thus, the plot represents the effect of RQUALITY1 on PR.CONTRAST.STG2 after accounting for the effects of the other two predictor variables. The line graph in Figure 4 presents the observed distribution of residuals, and the linear and quadratic trends in that distribution. As can be seen, and consistent with the fixed order hierarchical regression described above, no systematic relation appears in these data.

These negative findings may be partly attributable to the ceiling effects in Stage 2 phoneme recognition scores that were noted in the cross-sectional analysis both for the control phoneme and for /r/. Overall, 65.8% of the children scored at ceiling on the control phoneme at Stage 2, and 41.1% did so for /r/. For those children who scored at ceiling on both phonemes, the PR.CONTRAST.STG2 score was zero, and for at least some of those who scored at ceiling

on only the control phoneme, the contrast also would have been understated. Hence, the distribution of the outcome variable was constrained.

Supplementary analysis. The fixed order hierarchical regression described above was run a second time, this time for the subsample of 52 children whose behaviour during Stage 1 testing was stable, as indicated by clinical notes during the testing session. The dependent and predictor variables were identical to those used in the analysis on the main longitudinal subsample for the phoneme recognition task. The results of this analysis are shown in the section of Table 7 labelled *Supplementary Analysis*. For this subsample, the first two predictor variables accounted for 14.1% of the variance in Stage 2 /r/ phoneme recognition, PR.CONTRAST.STG2, $F(2,49)=2.64$, $p=.060$. When RQUALITY1 was entered in the regression subsequently, there was no increase in explained variance in PR.CONTRAST.STG2. The final regression equation is shown in Table 8 in the section labelled *Supplementary Analysis*.

Articulation and Phoneme Judgement

The simple correlation coefficient between phoneme judgement of /r/ at Stage 2 and /r/-articulation quality at Stage 1 for the longitudinal subsample was $r=-.370$, as shown in Appendix 13.

The relation between Stage 1 articulation and Stage 2

phoneme judgement was examined using a fixed order hierarchical regression analysis. As for phoneme recognition, the dependent variable in this analysis was a contrast score, in this case the contrast between the phoneme judgement score for the control phoneme, /m/, and for /r/ at Stage 2, PJ.CONTRAST.STG2. A higher value for PJ.CONTRAST.STG2 would indicate lower phoneme recognition of /r/.

Four predictor variables were included in this analysis: The contribution of early phoneme judgement was represented by the contrast between the phoneme judgement scores for the control phoneme, /m/, and the target phoneme, /r/, at Stage 1, PJ.CONTRAST.STG1. The contribution of later articulation was represented by the articulation quality score at Stage 2, RQUALITY2. Receptive vocabulary score was also included. These three predictors were entered as a block before the predictor variable of interest, the articulation quality score at Stage 1, RQUALITY1. This fixed order regression was used to allow the unique contribution of RQUALITY1 to be assessed after accounting for the contribution of the first three variables. The results of this analysis are shown in Table 9 in the section labelled *Main Analysis*. The first three predictor variables together accounted for 15.0% of the variance in PJ.CONTRAST.STG2, $F(3,54)=3.18$, $p=.031$. When Stage 1 articulation, RQUALITY1, was entered in the regression subsequently, there was a non-

negligible increase of 3.5% in explained variance for /r/ phoneme judgement, PJ.CONTRAST.STG2. The regression coefficient for RQUALITY1 which corresponded to this increase was negative, as predicted, $t(53)=-1.52$, $p=.068$ (one -tailed test). The final regression equation is shown in Table 10 in the *Main Analysis* section.

The impact of the RQUALITY1 variable on the equation can be presented visually using the added variable plot procedure of Cook & Weisberg (1982). The residuals of the regression of the dependent variable, PJ.CONTRAST.STG2, on all of the predictor variables except RQUALITY1 were plotted against the residuals of the regression of RQUALITY1 on these same predictor variables. The added variable plot for the phoneme judgement task appears in Figure 5. The standardized residuals of the regression of PJ.CONTRAST.STG2 on the predictor variables form the Y-axis of the plot. The standardized residuals of the regression of RQUALITY1 on the predictor variables form the X-axis of the plot. Thus, the plot represents the effect of RQUALITY1 on PJ.CONTRAST.STG2 after accounting for the effects of the three other predictor variables. The line graph in Figure 6 presents the observed distribution of residuals, and the linear and quadratic trends in that distribution. As can be seen, and consistent with the fixed order hierarchical regression described above, the linear trend in the data indicates decreasing PJ.CONTRAST.STG2 residuals as RQUALITY1 residuals

increased, consistent with the prediction of increasing /r/ phoneme awareness with increasing /r/ articulation quality.

While the contribution of Stage 1 articulation quality to Stage 2 phoneme judgement, after accounting for other potentially important predictor variables, was sufficiently large to be of interest, and approached statistical significance ($p=.068$, Table 9), ceiling effects in the Stage 2 phoneme judgement scores may have reduced the strength of these regressions somewhat. Overall, 78.6% of the children scored at ceiling on the control phoneme at Stage 2, and 48.6% did so for /r/. As discussed above for the phoneme recognition scores, these patterns would have constrained the distribution of the outcome variable.

Supplementary analysis. The fixed order hierarchical regression described above was run a second time, this time for the subsample of 47 children whose behaviour during Stage 1 testing was stable, as indicated by clinical notes during the testing session. The dependent and predictor variables were identical to those used in the analysis on the main longitudinal subsample for the phoneme judgement task. The results of this analysis are shown in the section of Table 9 labelled *Supplementary Analysis*. For this subsample, the first three predictor variables accounted for a considerable 35.2% of the variance in Stage 2 phoneme judgement of /r/, $PJ.CONTRAST.STG2$, $F(3,43)=7.79$, $p<.001$. When $RQUALITY1$ was entered in the regression subsequently,

there was a substantial increase of 5.1% in explained variance in PJ.CONTRAST.STG2. The regression coefficient for RQUALITY1 was negative, as predicted, $t(42)=-1.90$, $p=.033$ (one-tailed test). The final regression equation is shown in Table 10 in the section labelled *Supplementary Analysis*.

Articulation and Speech Discrimination

The simple correlation coefficient between speech discrimination of /r/ at Stage 2 and /r/-articulation quality at Stage 1 for the longitudinal subsample was $r=-.053$, as shown in Appendix 14.

The relation between Stage 1 articulation and Stage 2 speech discrimination was examined using a fixed order hierarchical regression analysis. As for the other two phoneme awareness tasks, the dependent variable in this analysis was a contrast score, in this case the contrast between the speech discrimination score for the control phoneme, /l/, and for /r/ at Stage 2, SD.CONTRAST.STG2. A higher value for SD.CONTRAST.STG2 would indicate lower discrimination of /r/.

Three predictor variables were included in this analysis: The contribution of early speech discrimination was represented by the contrast between the speech discrimination scores for the control phoneme, /l/, and the target phoneme, /r/, at Stage 1, SD.CONTRAST.STG1. The contribution of later articulation was represented by the

articulation quality score at Stage 2, RQUALITY2. These two predictors were entered as a block before the predictor variable of interest, the articulation quality score at Stage 1, RQUALITY1. This fixed order regression was used to allow the unique contribution of RQUALITY1 to be assessed after accounting for the contribution of the first two variables. The results of this analysis are shown in Table 11 in the section labelled *Main Analysis*. The first two predictor variables together accounted for 16.2% of the variance in SD.CONTRAST.STG2, $F(2,38)=3.69$, $p=.034$. When Stage 1 articulation, RQUALITY1, was entered in the regression subsequently, there an increase of 3.5% in explained variance for /r/ speech discrimination, SD.CONTRAST.STG2. The regression coefficient for RQUALITY1 was not in the predicted direction, $t(37)=1.27$, $p>.50$ (one-tailed test). The final regression equation is shown in Table 12 in the section labelled *Main Analysis*.

The impact of the RQUALITY1 variable on the equation can be presented visually using the added variable plot procedure of Cook & Weisberg (1982). The residuals of the regression of the dependent variable, SD.CONTRAST.STG2, on all of the predictor variables except RQUALITY1 were plotted against the residuals of the regression of RQUALITY1 on these same predictor variables. The added variable plot for the speech discrimination task appears in Figure 7. The standardized residuals of the regression of SD.CONTRAST.STG2

on the predictor variables form the Y-axis of the plot. The standardized residuals of the regression of RQUALITY1 on the predictor variables form the X-axis of the plot. Thus, the plot represents the effect of RQUALITY1 on SD.CONTRAST.ST2 after accounting for the effects of the other two predictor variables. The line graph in Figure 8 presents the observed distribution of residuals, and the linear and quadratic trends in that distribution. As can be seen, and consistent with the fixed order hierarchical regression described above, the linear trend in the data, though slight, is in the opposite direction to that predicted by the model. A small quadratic trend also appears in this graph, as discussed below.

Supplementary analysis. The fixed order hierarchical regression described above was run a second time, this time for the subsample of 34 children whose behaviour during Stage 1 testing was stable, as indicated by clinical notes during the testing session. The dependent and predictor variables were identical to those used in the analysis on the main longitudinal subsample for the speech discrimination task. The results of this analysis are shown in the section of Table 11 labelled *Supplementary Analysis*. For this subsample, the first two predictor variables accounted for a substantial 25.5% of the variance in Stage 2 /r/ speech discrimination, SD.CONTRAST.STG2, $F(2,31)=5.32$, $p=.010$. When RQUALITY1 was entered in the regression

subsequently, there was an increase of 6.3% in explained variance in SD.CONTRAST.STG2. The regression coefficient for RQUALITY1 was not in the predicted direction, $t(30)=1.67$, $p=>.50$ (one-tailed test). The final regression equation is shown in Table 13 in the section labelled *Supplementary Analysis*. The results for this subsample with stable Stage 1 behaviour during testing, were the same as for the complete longitudinal subsample for this task.

The sign of the beta weights for RQUALITY1 in both the main analysis and the supplementary analysis indicated that in these equations, the relation between Stage 1 articulation quality and Stage 2 discrimination of /r/ was in the direction opposite to the prediction.

Assessment of non-linear trends. The tendency in the data for higher RQUALITY1 scores to be associated with greater contrast scores, that is, with lower discrimination of /r/, was inconsistent with the findings for the other two tasks, and with the findings of the cross-sectional analyses. In an attempt to understand this pattern in the data, quadratic trends were examined, as suggested by the added variable plot described earlier. When the SD.CONTRAST.STG2 scores were plotted against RQUALITY1, without including any covariates, a strong negative quadratic trend was revealed in the relation between these two variables, as shown in Figure 9. Children in the middle range of the RQUALITY1 scale had higher SD.CONTRAST.STG2

scores than those at the lower and upper ends of the scale. In other words, children in the middle range of the articulation quality scale at Stage 1 demonstrated lower discrimination of /r/ at Stage 2 than those in the lower and higher articulation ranges.

To investigate whether this strong non-linear trend was masking the predicted negative relation between RQUALITY1 and SD.CONTRAST.STG2, a second set of fixed order hierarchical regression analyses was undertaken, first for the original sample and next for the sample with stable behaviour. These two analyses incorporated as an additional predictor variable the quadratic term, RQUALITY1.SQ, the square of RQUALITY1. The dependent variable in this analysis was SD.CONTRAST.STG2, as before, with the other three predictor variables remaining the same. SD.CONTRAST.STG1 and RQUALITY2 were entered first as a block. RQUALITY1 and RQUALITY1.SQ were then entered together as a second block, to allow the joint contribution of the linear and quadratic trends in articulation quality at Stage 1 to be assessed after accounting for the contribution of the first two variables. The results of these analysis are shown in Table 11 as *Alternative Block 2*. For the main sample, when RQUALITY1 and RQUALITY1.SQ were entered together in the regression, an increase of 12.4% was found in explained variance for SD.CONTRAST.STG2, $F(2,36)=3.21$, $.05 < p < .10$. The final regression equation is shown in Table 12 in the

section labelled *Alternative Predictors*. The results were similar for the supplementary analysis, which involved the subsample with stable behaviour. When RQUALITY1 and RQUALITY1.SQ were entered together in the regression, an increase of 10.4% was found in explained variance for SD.CONTRAST.STG2, $F(2,29)=2.25$, $.05 < p < .10$. The final regression equation is shown in Table 13 in the section labelled *Alternative Predictors*.

The nature of the joint contribution of RQUALITY1 and RQUALITY1.SQ to SD.CONTRAST.STG2, after accounting for the covariates, is illustrated in Figure 10 for the main sample. This figure plots the joint contribution of the linear and quadratic terms, that is, $(.898 \cdot \text{RQUALITY1}) - (.034 \cdot \text{RQUALITY1.SQ})$, against RQUALITY1, which ranges in value from 6.0 to 18.0. The point at which the sum of the linear and quadratic terms attains its maximum, the critical point on the curve, is 13.21. The plot shows that in the upper part of its range, from the critical point of RQUALITY1 = 13.21 to RQUALITY1 = 18.0, RQUALITY1 is related to the adjusted speech discrimination contrast score in the predicted direction, while below that point it is not.

To further clarify the relation between SD.CONTRAST.STG2 and RQUALITY1, given the non-linear trend, the sample was divided into two groups, one whose RQUALITY1 scores fell below the critical point of RQUALITY1 = 13.21 ($n=24$), and one whose scores fell above ($n=17$). Regression

equations based on such small samples would not be expected to cross-validate well (Stevens, 1992), and the following results are presented as secondary information only. A fixed order hierarchical regression analysis was undertaken on each of these subsamples separately, with SD.CONTRAST.STG2 as the dependent variable, SD.CONTRAST.STG1 and RQUALITY2 as the predictor variables in the first block, and RQUALITY1 as the sole predictor variable in the second block. This is the same analysis that was undertaken for the original longitudinal subsample for this task. For the subsample with the lower RQUALITY1 scores, the first two predictors accounted for 6.9% of the variance in the outcome variable, $F(2,21)=.783$, $p=.470$. RQUALITY1 explained a further 10.2% of the variance, with a regression coefficient in the direction opposite to that predicted $t(20)=1.57$, $p>.50$ (one-tailed test). On the other hand, for the subsample with the higher RQUALITY1 scores, the first two predictors accounted for a considerable 51.4% of the variance in the outcome variable, SD.CONTRAST.STG2, $F(2,14)=7.406$, $p=.006$. RQUALITY1 explained substantial additional variance, 13.2%, with a regression coefficient in the predicted direction, $t(13)=-2.20$, $p=.023$ (one-tailed test).

Chapter 6. Discussion and Conclusions

This paper presents a theoretical model of the development of phonological representations during language learning. The model links the development of phonological representation networks with articulation. It is argued that articulation and phoneme awareness depend on underlying networks of phonological representations, and that the link between articulation and these representations is one of bidirectional causality. The paper reports on the first two stages of a longitudinal study examining this theoretical model.

Two key questions arising from the model, which is depicted in Figure 1, were addressed in the present report: First, are early articulation patterns associated with corresponding specific phoneme awareness patterns in very young pre-readers? Second, does early articulation quality predict later specific phoneme awareness in young pre-readers?

Concurrent Articulation and Phoneme Awareness

The answer to the first question was positive: articulation and phoneme awareness were found to be linked in this non-clinical sample, at both 37 and 46 months of age. Specific articulation accuracy of the target phoneme,

/r/, accounted for substantial variance in awareness of the target phoneme, /r/, relative to control phonemes, at Stage 1 and Stage 2. The percentage of variance accounted for by articulation quality was statistically significant on two of the three tasks at both stages of the study.

The role of cognitive variables

The cross-sectional findings reported here are consistent with the hypothesis of a causal link between articulation and phoneme awareness as proposed in the language learning model presented in Figure 1, but other interpretations are possible. The link between articulation and phoneme awareness may be an indirect one, mediated by a third variable, such as vocabulary knowledge, letter knowledge, phonological short-term memory or non-verbal intelligence. These cognitive factors would not be expected to have a direct differential influence on awareness of the target and control phonemes. However, indirect differential effects are possible if these variables influence articulation quality, because articulation quality is expected to be associated with target phoneme awareness but not control phoneme awareness. For example, phonological short-term memory has been directly linked to articulation (Adams & Gathercole, 1995), but there is no indication in the literature of a direct link between non-verbal intelligence or letter knowledge and articulation (e.g.,

Chaney, 1992). However, all three of these variables are related to vocabulary level in young children (e.g., Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie & Baddeley, 1992; Sénéchal, LeFevre, Thomas & Daley, in press), which in turn may be related to articulation. Some reports have suggested that young children select words they produce on the basis of their own articulation competence and comfort (e.g., Schwartz, 1988, 1991), leading to limitations in expressive vocabulary. The case for links between receptive vocabulary and articulation is less clear (Chaney, 1992), but because vocabulary tests focussing on specific phonemes are not available, the hypothesis of links between vocabulary and articulation has not been truly tested. The present study found links between general vocabulary knowledge and specific articulation quality that were the reverse of those predicted by the theoretical literature. Children with higher receptive and expressive vocabulary scores tended to have lower /r/ articulation scores. This finding is discussed in more detail later.

Conclusion

These cross-sectional results are consistent with several studies in the speech perception field involving non-clinical samples (e.g., Eilers & Oller, 1976; Zlatkin & Koenigsknecht, 1976; Strange & Broen, 1980; Velleman, 1988), in which specific phoneme awareness was related to

articulation of that phoneme among small samples of young, normally developing children. The present results are also consistent with the findings of researchers in the field of phonological development, who found that auditory or speech discrimination (Weinir, 1967; Winitz, 1989) and other phonological awareness measures (Bird et al, 1995; Magnusson, 1991; Webster & Plante, 1995) were related to articulation quality in clinical samples. Although only the phoneme /r/ was considered here, similar findings would be predicted for other phonemes that are frequently misarticulated by normally-developing young children, as found by Velleman (1988) for /θ/.

The cross-sectional findings do not rule out the possibility that a confounding variable determined both articulation and performance on these phoneme awareness tasks, and that the apparent relation between them was spurious. The potential role of vocabulary is of particular interest. As in Chaney's study (1992), the vocabulary tests used here were general ones that did not isolate the phonemes under study, so the possibility of a role for vocabulary in this relation was not adequately tested in the present study. Also, other variables that were not considered here may have contributed to the findings. However, the idea of a two-way causal link between articulation and phoneme awareness is strongly supported by the results for the phoneme recognition task and speech

discrimination task at Stage 1 and the phoneme judgement task and speech discrimination task at Stage 2. These findings are consistent with the links proposed in the theoretical model of language learning presented earlier.

Articulation Predicting Later Phoneme Awareness

The second question arising from the theoretical model asked whether early articulation quality predicts later specific phoneme awareness in young pre-readers. The answer to this question was qualified but positive. For one of the three phoneme awareness tasks, the phoneme judgement task, a positive link was found between early articulation on the one hand and later phoneme judgement on the other. Although this relation was only marginally significant statistically, children whose articulation quality was higher tended to have higher awareness of the target phoneme relative to the control phoneme than those whose articulation quality was lower, with articulation quality at Stage 1 accounting for 3.5% of the variance in phoneme judgement at Stage 2. This pattern was present in the data after controlling for earlier links between articulation and phoneme awareness, for concurrent links between these two variables, and for a key cognitive variable, receptive vocabulary. When only those children whose behaviour during Stage 1 testing was relatively stable were considered, articulation quality at

Stage 1 accounted for 5.1% of the variance in phoneme judgement at Stage 2, a statistically significant result.

The findings for the speech discrimination task were not so clear. The results did not support the hypothesis of a positive link between early articulation and later phoneme awareness when the data were analyzed using the planned fixed order hierarchical regression for the subsample. However, non-linear trends were identified in the data that appeared to mask a positive relation between articulation and speech discrimination for a subgroup of children whose articulation quality fell in the upper half of the range. A post hoc analysis using a subsample of children from the upper half of the articulation accuracy range found evidence supporting the hypothesis: among these children, those with articulation quality at the upper end of the upper half of the range tended to have higher speech discrimination of the target phoneme relative to the control phoneme than those whose articulation quality was at the lower end of this half of the range. This pattern was present after controlling for earlier links between articulation and phoneme awareness and for concurrent links between these two variables.

The longitudinal results for the phoneme recognition task do not contribute any information because of ceiling effects that were found for scores on both the control and target phonemes at Stage 2. The task was too easy for children at the Stage 2 age, and therefore did not

discriminate among different levels of phoneme recognition ability. The question of task design is discussed in detail below.

Conclusion

The longitudinal findings from the two tasks that were appropriate for the age group under study at Stage 2 are consistent with the conceptual model of language learning and articulation presented in Figure 1. They provide some evidence for the hypothesis of a causal link between early articulation and later phoneme awareness. The results for the phoneme judgement task, although not overly strong, clearly support the hypothesis, with early articulation accounting for non-negligible variance in later phoneme awareness. The post hoc analysis of the speech discrimination data provide further evidence that is consistent with the theoretical position under study here. The findings do not rule out the possibility that an unknown confounding variable linked early articulation and later performance on the phoneme judgement task and that the apparent relation between them was spurious. However, the findings are consistent with the theoretical model of language learning presented in Figure 1.

Measuring Phoneme Awareness in Young Children

This study confirmed the findings of Chaney (1992, 1994), Smith and Tager-Flusberg (1982), Webster and Plante (1995) and others that many children as young as three years old are able to demonstrate some phonological awareness when age-appropriate tasks are used. Locke's terminology (1980a, 1980b) is useful to describe what was going on in each of the tasks in this study. The phoneme recognition task showed that at Stage 1, when they averaged 36.7 months old, some children were able to contrast the adult surface form that was presented (e.g., lock) with two internal forms (lock and walk), and to indicate which was the better match. Children were significantly more likely to choose the correct match in the minimal pair than to choose an incorrect response, $t(79)=6.43$, $p<.001$. The phoneme judgement task, modelled on that of Chaney (1992), was intended to show that children were able to compare an adult surface form of a lexical item with their own internal form. In the present study, some of the children were able to recognize and report that the adult form presented (e.g., woon, watch) did or did not match their internal form (moon, watch), scoring above chance for the control phoneme, $t(62)=5.6$, $p<.001$. They were less successful on the speech discrimination task, in which they were required to compare two adult surface forms (e.g., lu and wu or le and le) and report whether they were the

same. The children scored above chance for the control phoneme, but the difference did not reach statistical significance, $t(46)=1.48$, $p=.145$. By Stage 2, when the children averaged 46.1 months old, they were considerably more successful, with over 65% of them scoring at ceiling for the control phoneme on all three tasks. In summary, it has been shown that not only do many young children possess a certain level of phonological awareness, but that this can be measured if appropriate tests are used.

Methodological and Measurement Issues

Characteristics of the Participants

The present study incorporated two important dimensions that are critical to an assessment of articulation-awareness links: First, the sample included only normally developing children drawn from a non-clinical population; and second, specific articulation patterns were identified, and phonological awareness was studied for these specific patterns. The present study focussed on specific phonemes that are commonly misarticulated by very young children rather than on general articulation quality in clinical samples, and it tested awareness of those specific misarticulated phonemes rather than general phonological awareness. The early misarticulations studied here are often developmental in nature, and resolve in most children before

they enter school.

Practical Measurement Issues

The difficulty of administering approximately 60 minutes of tests and tasks to eighty 37-month-old children in 28 different day care centres and nursery schools can hardly be overstated.

Variability of testing situation. The logistics of testing were challenging, but the staff of the day care centres and nursery schools were almost without exception enthusiastically supportive of the research effort. Appropriate facilities were available at most centres, but at some, a separate quiet area was not available for testing, and assessments had to be done in noisy, distracting settings. It was assumed that environmental influences were randomly distributed over the articulation groups, but where a quiet setting was not available, increased variability in responding would be expected. At one centre where testing was done in sight of the other children, a friend approached and told the child who was being assessed, "Hey, you don't have to do this you know. Come and play in the tent." The child returned to the task at hand only with considerable coaxing. At another, the examiner could barely hear the children's responses on the articulation task, and even on the tape the background noise made the articulation assessments difficult.

Behavioural variability. More challenging than the logistics of the testing settings was the behavioural variability of these very young children. Most of the children could be persuaded to participate, but for some, completion of the various tests and tasks was impeded by difficult behaviours. These included short attention span, distractibility, resistance or defiance, and extreme shyness or reluctance. Clinical notes taken during the testing sessions allowed for the identification of these children later, and for the longitudinal phase of the study, supplementary analyses that excluded them were undertaken for all of the tasks. Removal of the cases for whom the examiners recorded difficult behaviours that may have interfered with responding had a substantial stabilizing effect on the data. The identification procedure in this study was unstructured and highly subjective. The inclusion of a behavioural rating scale to systematically assess behaviour would control for these dimensions, and would allow for a more consistent identification of children whose performance limitations were related to behaviour rather than to cognitive or phonological capabilities.

Task Design

Phoneme recognition task. Despite its low reliability, especially for the control phoneme subscale, performance on the phoneme recognition task was significantly correlated

with articulation quality at Stage 1. Improving reliability of this task would greatly improve its predictive power. Observations during testing indicated that the stimulus pictures differed in clarity and inherent appeal for the children. Making the task more homogeneous on these dimensions would strengthen it considerably and increase its reliability. Reliability also would be improved if the unrelated foils were eliminated, and a choice were forced between the target or control phoneme on the one hand and the substitute phoneme on the other. The inclusion of unrelated foils to control for guessing was unnecessary for this task, because guessing patterns, whether the target phoneme or /w/ were chosen, should have been unrelated to articulation quality when phoneme recognition failed. Offering the third option may have increased response variability, since when a discrimination was difficult for the child, he or she was able to abstain by choosing the neutral option. Furthermore, in some cases children chose the foil because it was more appealing than the relevant pictures, and attracted their attention, again increasing variability on the task. This point is illustrated in Table 14, which presents the pattern of responding to the /r/ and /l/ items on this task at Stage 1: on four of the eight items, the rate of responding to the irrelevant foil approached or exceeded responding to the /w/ contrast.

While the phoneme recognition task was appropriate to

the abilities of children at Stage 1, at Stage 2 a high percentage of the children scored at ceiling, suggesting that the items were too easy for these older children. More challenging items could be included for testing this age group. This could involve adding more choices, including contrasts in the more difficult medial or final positions, or introducing a delay between stimulus and response.

To reduce the testing load on the children, the second target phoneme, /l/, which was also used as the control phoneme for /r/ for this task, was tested along with /r/ using the same /w/ contrasts. Because some children substitute [w] for both of these target phonemes, and others confuse the two (Smit, 1993), this intermingling might have increased variability on this task for both phonemes. A test that included only the /r/ items and some other control phoneme such as /m/, along with appropriate /w/ contrast items, would be more reliable than the one used here.

Phoneme judgement task. The phoneme judgement task was the one on which children were most successful at Stage 1, when they averaged 36.7 months of age, consistent with the findings of Chaney (1992). At Stage 1, performance on this task was not correlated with /r/ articulation quality once vocabulary knowledge had been taken into account, but it was significantly correlated with articulation quality at Stage 2. Conceptually, this task depended more on vocabulary ability than the other tasks in that the children could

respond using a word judgement rather than a phoneme judgement. Observations during testing indicated that some children did this for some items. For example, some responded "No, it's a snake" or "a daddy" for the picture of the coiled rope or the man. This feature of the task could bias the findings in unknown ways. Clarifying all the stimuli pictures and replacing ambiguous ones might improve the sensitivity of this task to phoneme awareness differences. As with the phoneme recognition task, there was a need here to limit the testing load on these young children. Therefore, no non-target items were included in the phoneme judgement task, with the result that all of the items included /w/ as the word-initial phoneme. It is possible that some children were sensitized to the phoneme /w/ and to the focus on /w/ substitution errors during the course of this task, which may have produced unknown biases in the results, and reduced reliability. Including items that begin with non-target phonemes in the stimulus set might improve this task by reducing attention to the phonemes of interest.

Speech discrimination task. The speech discrimination task showed good reliability at Stage 1 and fair or good reliability at Stage 2, despite being positioned at the end of the testing cycle when fatigue or boredom would be a factor for some children. Observations during testing suggested that the order in which items were presented was

not ideal, leading some children to develop a response set and a perseveration of 'yes' or 'no' responding. This task would be improved by reordering the early items in the stimulus set to encourage variable responding. Unlike the other two tasks, the speech discrimination task did not require children to look at the picture cues in order to respond. Pictures were presented, but they were not necessary for the task. Observations indicated that some children ignored the pictures and watched the examiner's mouth for visual cues as to which phoneme was being presented orally. The use of screening or a different seating arrangement to prevent this behaviour would improve this task. Like the phoneme recognition task, the speech discrimination task included /l/ as a control phoneme. If only /r/ items, control items using a phoneme such as /m/, and appropriate /w/ contrast items were included, reliability might be improved.

Cognitive Variables

Vocabulary

The vocabulary tests used in this study, the PPVT-R and the EOWPVT-R, are standardized tests that assess overall receptive and expressive vocabulary levels. Because vocabulary tests that focus on specific phonemes are not available, relations between vocabulary and specific

phoneme articulation could not be assessed in this study. In fact, the relations that were found between vocabulary and articulation were in the direction opposite to that suggested by the literature (e.g., Schwartz, 1988, 1991). In the present study, children with lower /r/-articulation accuracy tended to have higher vocabulary scores than those with higher articulation accuracy. Given the lack of specificity of the tests, it would not be surprising to find no links between the two variables, but this negative relation was unexpected. Post hoc speculation suggests the following possible explanation for this finding: This relation may reflect environmental factors that are represented by the environmental feedback cycle of the language learning model in Figure 1. Articulation inaccuracies might attract adult attention to the child's speech, and stimulate oral interaction as the caregiver either attempts to understand what the child has said, or presents an accurate version of the misarticulated production. Increased oral interaction with adults would be expected to accelerate all dimensions of language learning, including vocabulary development. Hence, for some children there might be an indirect causal link between misarticulation and vocabulary growth.

Phonological Memory, Analytic Intelligence and Letter Knowledge

Phonological short-term memory was assessed using an auditory digit span test. This assessment tool might not have been the best choice for these very young children. Number names are words, and the use of digit span to assess memory introduces a meaning element that might bias findings in unknown ways, depending on the child's familiarity with numbers and previous exposure to number concepts. The nonword repetition test developed by Gathercole and Adams (1993) has been found to be a highly stable and reliable measure of phonological working memory for children of this age (Adams & Gathercole, 1995), and might have worked better than digit span in the present study.

Analytic intelligence was assessed using the Animal Pegs subtest of the WPPSI-R (Weschler, 1989). Observations during testing suggested that success on this task depended rather heavily on fine motor control, a dimension on which these young children were highly variable. Another task, such as the Puzzle Solving subtest of the McCarthy Scales of Children's Abilities (McCarthy, 1970), which was used successfully by Gathercole and Adams (1993) with preschool children, might have allowed for a more valid assessment of analytic abilities.

Letter knowledge was tested at Stage 1 and letter knowledge and word identification at Stage 2, to establish

whether the children had developed any pre-reading skills that might contribute to phoneme awareness. It was considered important to test for this ability, since phonological awareness and reading are known to be causally linked, and reciprocal causation has been demonstrated by several researchers (Vellutino & Scanlon, 1988; Wagner & Torgesen, 1987; Wagner, Torgesen & Rashotte, 1994; but see Wagner et al., 1997). It is interesting to note that although many of the children demonstrated at least some phoneme awareness at Stage 1, as discussed earlier, few of them knew more than one letter, which was usually their first initial. At Stage 2, although phoneme awareness had increased considerably, letter knowledge had increased only slightly overall, and word identification ability was low. These tendencies suggest that at very young ages phoneme awareness develops without knowledge of the written symbols that represent those sounds. It was obvious during testing that most of the children were aware of what letters were, even if they were unable to name them. One child responded, when asked what one of the plastic letters was, "I don't know, but my mother knows them all." Such children may be aware of the symbolic relevance of letters, and this knowledge may contribute in some abstract way to the development of phonological awareness. Future research could consider this possibility.

Conclusion

This report presents the findings from the first two stages of a longitudinal study of articulation development and phonological awareness in young children. The long-term project was designed to investigate whether early articulation and phoneme awareness are linked, perhaps causally, and if so, whether distortions in awareness of specific phonemes linger after the articulation of those phonemes has normalized, to undermine later reading acquisition.

At Stage 1, when the children were 36.7 months old on average, a positive relation was found between articulation and early phoneme awareness. This relation persisted nine to ten months later at Stage 2. Several non-causal interpretations of the data were ruled out, lending some support to the causal hypothesis. A longitudinal analysis examined the hypothesis that articulation plays a causal role in the development of phoneme awareness. Evidence was found supporting this hypothesis: on one of the tasks, early articulation at Stage 1 predicted later phoneme awareness at Stage 2, after controlling for relevant cognitive variables and for concurrent links between articulation and phoneme awareness at Stage 1 and Stage 2. The results of a second task, while not conclusive, were consistent with this interpretation. In summary, the findings of this research

project offered qualified support for the theoretical model in Figure 1.

Future Research Directions

The Language Learning and Articulation Model presented in this dissertation provides a useful framework for a research program to study language development in young children. Several lines of research are suggested by this conceptualization.

The present study demonstrated links between articulation and phoneme awareness of one specific phoneme, the frequently misarticulated liquid /r/. If the theoretical model is valid, similar results should be found with other specific phonemes. Future research should extend the investigation to other phonemes, to establish whether the relations are more general. The findings for /r/ also need to be replicated, with improved tests and procedures. Thus, corroboration and extension of the findings reported here would be an important next step in this research effort.

While the research reported here was undertaken with a sample of normally developing children, few of whom had major articulation problems, the model has implications for children with more serious and pervasive articulation difficulties. Links between articulation and phoneme awareness that parallel those found here would be expected

for clinical populations. Research is needed to study whether the relations between articulation and phoneme awareness proposed in the model are found in children with serious speech disorders. Increased understanding of these relations potentially could lead to both effective prevention programs and new approaches to intervention.

Another important line of research that flows from the model concerns the links between early articulation patterns and later reading acquisition. The theoretical model predicts that early articulation influences underlying phonological representation networks, that distorted representations may be caused by early misarticulation, and that these may persist after articulation has normalized, to undermine reading acquisition and later reading ability. A longitudinal study that examined the reading acquisition and later reading ability of children with various early articulation histories would be needed to evaluate this prediction. An interdisciplinary research program to deal with this issue might include developing and testing intervention programs that attempted to modify early articulation, and assessing the effects of the programs on later phoneme awareness and reading.

A program of research could be designed to study the processes in the feedback cycles of the Language Learning and Articulation Model. The environmental feedback cycle is of particular interest. This cycle assumes that the nature

and quality of the responses of people in the environment to early speech affect the phonological representations underlying that speech. The discussion of this cycle in Chapter 3 suggested that feedback may take one of three forms: erroneous feedback, corrective feedback, and corrective feedback with emphasis. However, no information was found in the literature about actual patterns of environmental response to early misarticulation and how they affect phonological development. Nothing is known about how people typically respond to children's early oral productions. This would be the first question to address, using exploratory, qualitative methods involving mainly observation, in homes, day care centres, and possibly laboratory settings. Once typical patterns of response were documented, it might be possible to assess differential impacts of these patterns on both articulation and phonological awareness. Intervention ideas could also be developed. The possibility that articulation difficulties might have a beneficial effect on other aspects of language development via the environmental cycle, such as the growth of vocabulary knowledge as hinted at in the findings of the present study, should also be explored.

The self-monitoring cycle lends itself to scientific study. Researchers such as Chaney (1992) have reported very young children's self-correction of their own speech, suggesting that at times this self-monitoring is visible.

Studies are needed that document the extent and nature of such behaviour. Other studies might explore the question of whether children with different articulation patterns exhibit different patterns of this observable self-monitoring. The possibility of teaching children to self-monitor could be explored.

The model presented in this paper suggests several research directions to improve our understanding of the relations among oral language development, the growth of phonological awareness, and reading acquisition. The studies suggested here are just a few of the many possibilities arising from this conceptualization.

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APPENDICES

Appendix 1. Items in the Articulation Task

Training items: cat car

Test items: monkey, lion, rabbit, zebra, jellybeans,
motorbike, lamb, rock, man, leaf, rope,
ladder, red, mouse, lips, mitten, raisins,
marble, ladybug, ring, jacket, zipper

Substitute items: lamp, light, lemon, rat, ribbon, money,
mirror, jar

Appendix 2. Stimulus Sets in the Phoneme Recognition Task

	<u>Target word</u>	<u>Test pictures</u>
<u>Training items:</u>	deer	deer - zebra - bird
	moon	jacket - moon - dancer
<u>Test items:</u>	rock	rock - walk - book
	wetter	wetter - monkey - letter
	a lake	zipper - a lake - awake
	white	write - white - bike
	lock	mouse - walk - lock
	awake	boat - a rake - awake
	ring	wing - bed - ring
	white	man - white - light
	walk	rock - walk - book
	letter	wetter - monkey - letter
	awake	zip - a lake - awake
	write	write - white - bike
	walk	mouse - walk - lock
	a rake	boat - a rake - awake
	wing	wing - bed - ring
	light	man - white - light

Appendix 3. Stimuli in the Phoneme Judgement Task

	<u>Picture</u>	<u>Puppet says</u>
<u>Training items:</u>	Bed	Bed
	Knife	Kife
	Horse	Borse
	Hammer	Hammer
	Nose	Nose
	Bike	Yike
<u>Testing items:</u>	Rabbit	Wabbit
	Watch	Watch
	Lamp	Wamp
	Monkey	Wonkey
	Ribbon	Wibbon
	Wagon	Wagon
	Ladybug	Wadybug
	Mittens	Wittens
	Rope	Wope
	Witch	Witch
	Moon	Woon
	Rain	Wain
	Leaf	Weaf
	Worm	Worm
	Man	Wan
	Lion	Wion

Appendix 4. Stimulus Pairs in the Speech
Discrimination Task

Training pairs: Mip Mip Sub Mub
Hab Hab Kit Nit

Testing pairs: Names (pronunciation)
wo wo (woke)
ru wu (rude)
ruh ruh (rub)
la wa (lab)
rah wah (raw)
le le (let)
li wi (lip)
ra wa (rat)
lu wu (loon)
wuh wuh (won)
ri wi (rip)
lah wah (lawn)

Appendix 5. Articulation Quality for /r/ at Stage 1 and 2

RQUALITY1	Frequency	Percent	Cum Percent
6.00	15	18.8	18.8
7.00	1	1.3	20.0
7.20	3	3.8	23.8
7.50	1	1.3	25.0
8.00	5	6.3	31.3
8.40	4	5.0	36.3
9.00	4	5.0	41.3
10.00	2	2.5	43.8
10.80	1	1.3	45.0
11.00	3	3.8	48.8
12.00	6	7.5	56.3
14.40	3	3.8	60.0
16.00	2	2.5	62.5
16.80	1	1.3	63.8
17.00	2	2.5	66.3
18.00	27	33.8	100.0
Total	80	100.0	100.0

Mean = 12.3 Standard deviation = 4.9

RQUALITY2	Frequency	Percent	Cum Percent
6.00	10	13.5	13.5
7.00	5	6.8	20.3
7.20	1	1.4	21.6
8.00	4	5.4	27.0
8.40	1	1.4	28.4
9.00	4	5.4	33.8
10.00	2	2.7	36.5
11.00	1	1.4	37.8
13.20	2	2.7	40.5
16.00	2	2.7	43.2
16.80	2	2.7	45.9
17.00	2	2.7	48.6
18.00	38	51.4	100.0
Total	74	100.0	100.0

Mean = 13.8 Standard deviation = 5.1

RQUALITY1 and RQUALITY2 = /r/-articulation
quality at Stage 1 and 2

Appendix 6. Intercorrelations of /r/-Articulation Quality (RQUALITY1) and Phoneme Recognition Contrast (PR.CON.STG1) with Five Cognitive Variables, for the Total Sample (and Phoneme Recognition Subsample) at Stage 1

Measure	RQUALITY1	PR.CON.STG1
PR.CON.STG1	-.259*	1.000
Receptive vocabulary	-.131	.157
Expressive vocabulary	-.091	.140
Digit span	.067	.064
Analytic intelligence	-.207	.007
Letter knowledge	-.065	-.120

RQUALITY1 = /r/-articulation quality at Stage 1; PR.CON.STG1 = contrast between control phoneme and /r/ on the phoneme recognition task at Stage 1. Each correlation coefficient was computed based on the number of children completing each measure, ranging from n=69 to n=80.

* $p < .05$

Appendix 7. Intercorrelations of /r/-Articulation Quality (RQUALITY1) and Phoneme Judgement Contrast (PJ.CON.STG1) with Five Cognitive Variables, for the Phoneme Judgement Subsample at Stage 1

Measure	RQUALITY1	PJ.CON.STG1
PJ.CON.STG1	-.257*	1.000
Receptive vocabulary	-.285*	.340**
Expressive vocabulary	-.187	.318*
Digit span	-.087	.217
Analytic intelligence	-.171	.112
Letter knowledge	-.040	.049

RQUALITY1 = /r/-articulation quality at Stage 1; PJ.CON.STG1 = contrast between control phoneme and /r/ on the phoneme judgement task at Stage 1. Each correlation coefficient was computed based on the number of children completing each measure, ranging from n=55 to n=63.

* $p < .05$ ** $p < .01$

Appendix 8. Intercorrelations of /r/-Articulation Quality
(RQUALITY1) and Speech Discrimination Contrast
(SD.CON.STG1) with Five Cognitive Variables, for the
Speech Discrimination Subsample at Stage 1

Measure	RQUALITY1	SD.CON.STG1
SD.CON.STG1	-.323*	1.000
Receptive vocabulary	-.192	.083
Expressive vocabulary	-.223	.075
Digit span	.018	.146
Analytic intelligence	-.213	-.147
Letter knowledge	-.108	-.020

RQUALITY1 = /r/-articulation quality at Stage 1; SD.CON.STG1 = contrast between control phoneme and /r/ on the speech discrimination task at Stage 1. Each correlation coefficient was computed based on the number of children completing each measure, ranging from n=40 to n=46.

* $p < .05$

Appendix 9. Intercorrelations of /r/-Articulation Quality (RQUALITY2) and Phoneme Recognition Contrast (PR.CON.STG2) with Seven Cognitive Variables, for the Phoneme Recognition Subsample Stage 2

Measure	RQUALITY2	PR.CON.STG2
PR.CON.STG2	-.120	1.000
Receptive vocabulary	-.138	-.042
Expressive vocabulary	-.232*	-.076
Digit span	.039	-.224
Analytic intelligence	.062	.033
Letter knowledge Stage 1	.056	-.104
Letter knowledge Stage 2	-.028	-.034
Letter word identification	-.003	-.058

RQUALITY2 = /r/-articulation quality at Stage 2; PR.CON.STG2 = contrast between control phoneme and /r/ on the phoneme recognition task at Stage 2. Each correlation coefficient was computed based on the number of children completing each measure, ranging from n=64 to n=73.

* $p < .05$

Appendix 10. Intercorrelations of /r/-Articulation Quality (RQUALITY2) and Phoneme Judgement Contrast (PJ.CON.STG2) with Seven Cognitive Variables, for the Phoneme Judgement Subsample at Stage 2

Measure	RQUALITY2	PJ.CON.STG2
PJ.CON.STG2	-.314**	1.000
Receptive vocabulary	-.123	.197
Expressive vocabulary	-.254*	.184
Digit span	.040	.021
Analytic intelligence	.002	.226
Letter knowledge Stage 1	.054	-.099
Letter knowledge Stage 2	-.048	-.020
Letter word identification	-.002	.022

RQUALITY2 = /r/-articulation quality at Stage 2; PJ.CON.STG2 = contrast between control phoneme and /r/ on the phoneme judgement task at Stage 2. Each correlation coefficient was computed based on the number of children completing each measure, ranging from n=61 to n=70.

* $p < .05$ ** $p < .01$

Appendix 11. Intercorrelations of /r/-Articulation Quality
(RQUALITY2) and Speech Discrimination Contrast
(SD.CON.STG2) with Seven Cognitive Variables, for the
Speech Discrimination Subsample at Stage 2

Measure	RQUALITY2	SD.CON.STG2
SD.CON.STG2	-.278*	1.000
Receptive vocabulary	-.083	.014
Expressive vocabulary	-.224	.020
Digit span	.026	.072
Analytic intelligence	.030	-.088
Letter knowledge Stage 1	.050	-.004
Letter knowledge Stage 2	-.044	-.067
Letter word identification	-.006	-.010

RQUALITY2 = /r/-articulation quality at Stage 2; SD.CON.STG2 = contrast between control phoneme and /r/ on the speech discrimination task at Stage 2. Each correlation coefficient was computed based on the number of children completing each measure, ranging from n=58 to n=66.

* $p < .05$

Appendix 12. Intercorrelations of /r/-Articulation Quality
and Phoneme Recognition Contrast at Stage 1 and 2
with Seven Cognitive Variables, for the Longitudinal Phoneme
Recognition Subsample

Measure	RQUALITY1	RQUALITY2	PR.CON.STG1	PR.CON.STG2
RQUALITY2	.499***	-		
PR.CON.STG1	-.225	-.097	-	
PR.CON.STG2	-.064	-.120	-.021	-
REC VOCAB	-.189	-.138	.153	-.042
EXP VOCAB	-.185	-.232*	.185	-.076
DIGT SPAN	-.017	.039	.110	-.224
AN INTELL	-.226	.062	-.017	.033
LETTR KN1	-.083	-.056	-.083	-.104
LETTR KN2	-.118	-.028	-.030	-.034
LET WRD ID	-.121	-.003	.122	-.058

RQUALITY1 and RQUALITY2 = /r/-articulation quality at Stage 1 and Stage 2; PR.CON.STG1 and PR.CON.STG2 = contrast between control phoneme and /r/ on the phoneme recognition task at Stage 1 and Stage 2; REC VOCAB = receptive vocabulary; EXP VOCAB = expressive vocabulary; DIGT SPAN = maximum number of digits repeated correctly one time; AN INTELL = analytic intelligence; LETTR KN1 = number of letters correctly identified at Stage 1; LETTR KN2 = number of letters correctly identified at Stage 2; LET WRD ID = letter-word identification at Stage 2. Each correlation coefficient was computed based on the number of children completing each measure, ranging from n=64 to n=73.

* $p < .05$ *** $p < .001$

Appendix 13. Intercorrelations of /r/-Articulation Quality
and Phoneme Judgement Contrast at Stage 1 and 2
with Seven Cognitive Variables, for the Longitudinal Phoneme
Judgement Subsample

Measure	RQUALITY1	RQUALITY2	PJ.CON.STG1	PJ.CON.STG2
RQUALITY2	.539***	-		
PJ.CON.STG1	-.282*	-.467***	-	
PJ.CON.STG2	-.370**	-.316*	.263*	-
REC VOCAB	-.313*	-.154	.367**	.261*
EXP VOCAB	-.263	-.299*	.368**	.258
DIGT SPAN	-.123	.070	.267	.085
AN INTELL	-.231	-.042	.111	.246
LETTR KN1	-.044	.109	.039	-.087
LETTR KN2	-.118	-.025	.018	.025
LET WRD ID	-.065	.029	.069	.091

RQUALITY1 and RQUALITY2 = /r/-articulation quality at Stage 1 and Stage 2; PJ.CON.STG1 and PJ.CON.STG2 = contrast between control phoneme and /r/ on the phoneme judgement task at Stage 1 and Stage 2; REC VOCAB = receptive vocabulary; EXP VOCAB = expressive vocabulary; DIGT SPAN = maximum number of digits repeated correctly one time; AN INTELL = analytic intelligence; LETTR KN1 = number of letters correctly identified at Stage 1; LETTR KN2 = number of letters correctly identified at Stage 2; LET WRD ID = letter-word identification at Stage 2. Each correlation coefficient was computed based on the number of children completing each measure, ranging from n=51 to n=58.

* $p < .05$ ** $p < .01$ *** $p < .001$

Appendix 14. Intercorrelations of /r/-Articulation Quality and Speech Discrimination Contrast at Stage 1 and 2 with Seven Cognitive Variables, for the Longitudinal Speech Discrimination Subsample

Measure	RQUALITY1	RQUALITY2	SD.CON.STG1	SD.CON.STG2
RQUALITY2	.492***	-		
SD.CON.STG1	-.310*	-.198	-	
SD.CON.STG2	-.053	-.317*	.307*	-
REC VOCAB	-.150	-.102	-.018	-.101
EXP VOCAB	-.244	-.177	-.013	-.137
DIGT SPAN	-.029	.108	.147	.016
AN INTELL	-.215	-.023	-.211	-.086
LETTR KN1	-.084	.052	-.077	-.023
LETTR KN2	-.057	-.054	-.029	-.086
LET WRD ID	-.095	-.044	-.198	-.065

RQUALITY1 and RQUALITY2 = /r/-articulation quality at Stage 1 and Stage 2; SD.CON.STG1 and SD.CON.STG2 = contrast between control phoneme and /r/ on the speech discrimination task at Stage 1 and Stage 2; REC VOCAB = receptive vocabulary; EXP VOCAB = expressive vocabulary; DIGT SPAN = maximum number of digits repeated correctly one time; AN INTELL = analytic intelligence; LETTR KN1 = number of letters correctly identified at Stage 1; LETTR KN2 = number of letters correctly identified at Stage 2; LET WRD ID = letter-word identification at Stage 2. Each correlation coefficient was computed based on the number of children completing each measure, ranging from n=36 to n=41.

* $p < .05$ *** $p < .001$

TABLES

Table 1

Articulation Patterns for Selected Phonemes in the Word-initial Position (Derived from Smit, 1993)

Phoneme	Age range	Percent accurate	Usual substitution	Percent using substitution
/r/	2;0-4;0	22%	w	30%-80%
	4;6-6;0	65%	w	15%-30%
	7;0-9;0	92%	w	5%-15%
/l/	2;0-3;0	40%	w	30%-50%
	3;6-4;0	72%	w	15%-30%
	4;6-5;6	81%	w	5%-15%
	6;0-9;0	96%	-	<5%
/m/	2;0-9;0	98%	-	-

Table 2

Scores on Cognitive and Knowledge Measures at Stage 1

Measure	Mean	Standard deviation	<u>n</u>
Receptive vocabulary ^a	97.9	13.4	80
Expressive vocabulary ^b	103.4	11.7	79
Digit Span ^c	3.0	0.6	69
Letter knowledge ^d	0.8	1.5	78
Analytic intelligence ^e	11.0	2.0	74

^a Peabody Picture Vocabulary Test-Revised, standard score

^b Expressive One-Word Picture Vocabulary Test-Revised, standard score

^c Maximum number of digits repeated correctly, one task

^d Number of letters correctly identified (maximum = 7)

^e Animal Pegs subtest of the WPPSI-R, scaled score

Table 3

Scores on Three Phoneme Awareness Tasks for Control Phonemes (/m/ or /l/), for /r/, and for the Contrast Between Them at Stage 1

Task Phoneme	Mean	Standard deviation	<u>n</u>	<u>t</u>
<i>Phoneme recognition</i>				
Control /l/	2.7	1.0	80	-.64
/r/	2.8	0.9	80	
Contrast(l-r)	-0.1	1.0		
<i>Phoneme judgement</i>				
Control /m/	2.9	1.3	63	4.00***
/r/	2.2	1.6	63	
Contrast(m-r)	0.7	1.4		
<i>Speech discrimination</i>				
Control /l/	2.4	1.5	46	5.67***
/r/	1.2	1.4	46	
Contrast(l-r)	1.1	1.4		

Contrast = difference between the control phoneme and /r/
Maximum score = 4

*** $p < .001$, one-tailed

Table 4

Regression analyses at Stage 1 for the Three Phoneme Awareness Tasks

Task (Dependent variable) Predictor	Total R^2	$t(F)$	p	R^2 change	t	p
<i>Phoneme recognition (n=80)</i> (PR.CONTRAST.STG1)						
RQUALITY1	.067	-2.40	.010a	-	-	-
<i>Phoneme judgement (n=63)</i> (PJ.CONTRAST.STG1)						
Block 1 Receptive vocabulary	.115	2.82	.007	-	-	-
Block 2 RQUALITY1	.144	(5.03)	.010	.028	-1.40	.083a
<i>Speech discrimination (n=46)</i> (SD.CONTRAST.STG1)						
RQUALITY1	.104	-2.26	.014a	-	-	-

PR.CONTRAST.STG1 = contrast between control phoneme and /r/
on phoneme recognition task at Stage 1
PJ.CONTRAST.STG1 = contrast on phoneme judgement task
SD.CONTRAST.STG1 = contrast on speech discrimination task
RQUALITY1 = /r/-articulation quality at Stage 1

a one-tailed test

Table 5

Scores on Three Phoneme Awareness Tasks for Control Phonemes (/m/ or /l/), for /r/, and for the Contrast Between Them at Stage 2

<i>Task</i> Phoneme	Mean	Standard deviation	<u>n</u>	<u>t</u>
<i>Phoneme recognition</i>				
Control /l/	3.5	0.8	73	1.67*
/r/	3.3	0.6	73	
Contrast(l-r)	0.2	0.9		
<i>Phoneme judgement</i>				
Control /m/	3.6	0.9	70	4.51***
/r/	2.9	1.4	70	
Contrast(m-r)	0.7	1.4		
<i>Speech discrimination</i>				
Control /l/	3.5	0.8	66	6.86***
/r/	2.3	1.5	66	
Contrast(l-r)	1.2	1.4		

Contrast = difference between the control phoneme and /r/
Maximum score = 4

* $p < .05$, one-tailed *** $p < .001$, one-tailed

Table 6

Regression Analyses at Stage 2 for the Three Phoneme Awareness Tasks

Task (Dependent variable) Predictor	Total R^2	$t(F)$	p	R^2 change	t	p
<i>Phoneme recognition</i> (n=72) (PR.CONTRAST.STG2)						
Block 1 Expressive vocabulary	.006	-.63	.528	-	-	-
Block 2 RQUALITY2	.029	(1.05)	.357	.024	-1.30	.099a
<i>Phoneme judgement</i> (n=69) (PJ.CONTRAST.STG2)						
Block 1 Expressive vocabulary	.034	1.53	.130	-	-	-
Block 2 RQUALITY2	.113	(4.20)	.019	.079	-2.42	.009a
<i>Speech discrimination</i> (n=66) (SD.CONTRAST.STG2)						
RQUALITY2	.077	-2.32	.012a	-	-	-

PR.CONTRAST.STG2 = contrast between control phoneme and /r/
on phoneme recognition task at Stage 2
PJ.CONTRAST.STG2 = contrast on phoneme judgement task
SD.CONTRAST.STG2 = contrast on speech discrimination task
RQUALITY2 = /r/-articulation quality at Stage 2

a one-tailed test

Table 7

Fixed Order Hierarchical Regressions of PR.CONTRAST.STG2
on Three Predictor Variables for Two Samples

Analysis (Dependent variable) Predictor	Total R^2	F	p	R^2 change	t	p
<i>Main Analysis (n=73)</i> (PR.CONTRAST.STG2)						
Block 1 PR.CONTRAST.STG1 RQUALITY2	.016	.55	.579	-	-	-
Block 2 RQUALITY1	.016	.37	.778	<.01	-.10	.460a
<i>Supplementary analysis (n=52)</i> (PR.CONTRAST.STG2)						
Block 1 PR.CONTRAST.STG1 RQUALITY2	.141	4.03	.024	-	-	-
Block 2 RQUALITY1	.142	2.64	.060	<.01	.10	>.50a

PR.CONTRAST.STG1 = contrast between control phoneme and /r/
on phoneme recognition task at Stage 1

PR.CONTRAST.STG2 = contrast at Stage 2

RQUALITY1 = /r/-articulation quality at Stage 1

RQUALITY2 = /r/-articulation quality at Stage 2

a one-tailed test

Table 8

Regression Equations for Two Analyses for the Phoneme
Recognition Task: Regression of PR.CONTRAST.STG2 on Three
Predictor Variables

Analysis Predictor variables	Regression coefficient	Beta	<u>t</u>	<u>p</u>
<hr/>				
<i>Main analysis (n=73)</i>				
PR.CONTRAST.STG1	-.032	-.035	-.23	.387a
RQUALITY2	-.021	-.117	-.85	.200a
RQUALITY1	-.003	-.014	-.10	.460a
CONSTANT	.489	-	1.42	.160
 <i>Supplementary analysis (n=52)</i>				
PR.CONTRAST.STG1	-.174	-.175	-1.29	.101a
RQUALITY2	-.057	-.334	-2.23	.015a
RQUALITY1	.003	.016	.10	>.50a
CONSTANT	.934	-	2.60	.013

PR.CONTRAST.STG1 = contrast between control phoneme and /r/
on phoneme recognition task at Stage 1

PR.CONTRAST.STG2 = contrast at Stage 2

RQUALITY1 = /r/-articulation quality at Stage 1

RQUALITY2 = /r/-articulation quality at Stage 2

a one-tailed test

Table 9

Fixed Order Hierarchical Regressions of PJ.CONTRAST.STG2
on Four Predictor Variables for Two Samples

Analysis (Dependent variable) Predictor	Total R^2	F	p	R^2 change	t	p
<i>Main Analysis (n=58)</i> (PJ.CONTRAST.STG2)						
Block 1 PJ.CONTRAST.STG1 RQUALITY2 Receptive vocabulary	.150	3.18	.031	-	-	-
Block 2 RQUALITY1	.185	3.02	.026	.035	-1.52	.068a
<i>Supplementary analysis (n=47)</i> (PJ.CONTRAST.STG2)						
Block 1 PJ.CONTRAST.STG1 RQUALITY2 Receptive vocabulary	.352	7.79	<.001	-	-	-
Block 2 RQUALITY1	.403	7.09	<.001	.051	-1.90	.033a

PJ.CONTRAST.STG1 = contrast between control phoneme and /r/
on phoneme judgement task at Stage 1

PJ.CONTRAST.STG2 = contrast at Stage 2

RQUALITY1 = /r/-articulation quality at Stage 1

RQUALITY2 = /r/-articulation quality at Stage 2

a one-tailed test

Table 10

Regression Equations for Two Analyses for the Phoneme
Judgement Task: Regression of PJ.CONTRAST.STG2 on Four
Predictor Variables

<i>Analysis</i> Predictor variables	Regression coefficient	Beta	<u>t</u>	<u>p</u>
<hr/>				
<i>Main analysis (n=58)</i>				
PJ.CONTRAST.STG1	.090	.087	.58	.281 _a
RQUALITY2	-.037	-.129	-.80	.214 _a
Receptive vocabulary	.016	.137	.99	.329
RQUALITY1	-.067	-.232	-1.52	.068 _a
CONSTANT	.379	-	.21	.834
 <i>Supplementary analysis (n=47)</i>				
PJ.CONTRAST.STG1	.063	.074	.52	.302 _a
RQUALITY2	-.064	-.269	-1.79	.040 _a
Receptive vocabulary	.029	.304	2.35	.024
RQUALITY1	-.062	-.262	-1.90	.033 _a
CONSTANT	-.897	-	-.65	.521

PJ.CONTRAST.STG1 = contrast between control phoneme and /r/
on phoneme judgement task at Stage 1

PJ.CONTRAST.STG2 = contrast at Stage 2

RQUALITY1 = /r/-articulation quality at Stage 1

RQUALITY2 = /r/-articulation quality at Stage 2

a one-tailed test

Table 11

Two Fixed Order Hierarchical Regressions of SD.CONTRAST.STG2
on Three Predictor Variables for Two Samples

<i>Analysis</i> (Dependent variable) Predictor	Total R^2	F	p	R^2 change	$t(F)$	p
<i>Main Analysis (n=41)</i> (SD.CONTRAST.STG2)						
Block 1 SD.CONTRAST.STG1 RQUALITY2	.162	3.69	.034	-	-	-
Block 2 RQUALITY1	.197	3.03	.041	.035	1.27	>.50a
Alternative block 2 RQUALITY1 RQUALITY1.SQ	.286	3.61	.014	.124	(3.21)	<.10
<i>Supplementary analysis (n=34)</i> (SD.CONTRAST.STG2)						
Block 1 SD.CONTRAST.STG1 RQUALITY2	.255	5.32	.010	-	-	-
Block 2 RQUALITY1	.319	4.67	.008	.063	1.67	>.50a
Alternative block 2 RQUALITY1 RQUALITY1.SQ	.359	4.05	.010	.104	(2.75)	<.10

SD.CONTRAST.STG1 = contrast between control phoneme and /r/
on speech discrimination task, Stage 1

SD.CONTRAST.STG2 = contrast at Stage 2

RQUALITY1 = /r/-articulation quality at Stage 1

RQUALITY2 = /r/-articulation quality at Stage 2

a one-tailed test

Table 12

Regression Equations for the Main Analysis for the Speech
Discrimination Task: Regression of SD.CONTRAST.STG2 on Two
Sets of Predictor Variables

Analysis Predictor variables	Regression coefficient	Beta	<u>t</u>	<u>p</u>
<hr/>				
<i>Main analysis (n=41)</i>				
SD.CONTRAST.STG1	.326	.304	1.96	.029a
RQUALITY2	-.104	-.365	-2.15	.019a
RQUALITY1	.065	.221	1.27	>.50a
CONSTANT	1.570	-	2.01	.052
 <i>Alternative predictors</i>				
SD.CONTRAST.STG1	.306	.285	1.92	.031a
RQUALITY2	-.124	-.435	-2.63	.006a
RQUALITY1	.898	3.044	2.27	.030
RQUALITY1.SQ	-.034	-2.811	2.12	.041
CONSTANT	-2.423	-	-1.19	.240

SD.CONTRAST.STG1 = contrast between control phoneme and /r/
on speech discrimination task, Stage 1

SD.CONTRAST.STG2 = contrast at Stage 2

RQUALITY1 = /r/-articulation quality at Stage 1

RQUALITY1.SQ = square of RQUALITY1 measure

RQUALITY2 = /r/-articulation quality at Stage 2

a one-tailed test

Table 13

Regression Equations for the Supplementary Analysis for the
Speech Discrimination Task: Regression of SD.CONTRAST.STG2
on Two Sets of Predictor Variables

Analysis Predictor variables	Regression coefficient	Beta	<u>t</u>	<u>p</u>
<hr/>				
<i>Supplementary analysis (n=34)</i>				
SD.CONTRAST.STG1	.316	.315	1.97	.029a
RQUALITY2	-.142	-.529	-3.02	.003a
RQUALITY1	.082	.298	1.67	>.50a
CONSTANT	1.748	-	2.27	.031
 <i>Alternative predictors</i>				
SD.CONTRAST.STG1	.273	.272	1.69	.051a
RQUALITY2	-.156	-.572	-3.28	.002a
RQUALITY1	.676	2.465	1.52	.139
RQUALITY1.SQ	-.024	-2.167	-1.35	.188
CONSTANT	-1.027	-	-.47	.643

SD.CONTRAST.STG1 = contrast between control phoneme and /r/
on speech discrimination task, Stage 1

SD.CONTRAST.STG2 = contrast at Stage 2

RQUALITY1 = /r/-articulation quality at Stage 1

RQUALITY1.SQ = square of RQUALITY1 measure

RQUALITY2 = /r/-articulation quality at Stage 2

a one-tailed test

Table 14

Phoneme Recognition Task: Percentage (and Number) of
Children Giving the Correct Response (/r/or/l/), the Minimal
Pair Incorrect Response (/w/), and the Incorrect Foil
Response at Stage 1

Target word (n)	Response		
	Correct (/r/or/l/)	Incorrect (/w/)	Incorrect (foil)
rock (65)	80.0	12.3	7.7
ring (65)	86.2	10.8	3.1
write (64)	43.8	25.0	31.3
a rake (64)	59.4	26.6	14.1
a lake (63)	42.9	31.7	25.4
lock (65)	73.8	21.5	4.6
letter (64)	67.2	17.2	15.6
light (65)	83.1	13.8	3.8

Incorrect response words are presented in Appendix 2.

FIGURES

Figure 1. Language Learning and Articulation Model

Artic(r)T1 = Articulation of /r/ at Time 1

Artic(r)T2 = Articulation of /r/ at Time 2

PA(c)T1 = Phoneme awareness of control phoneme at Time 1

PA(c)T2 = Phoneme awareness of control phoneme at Time 2

PA(r)T1 = Phoneme awareness of /r/ at Time 1

PA(r)T2 = Phoneme awareness of /r/ at Time 2

Figure 2. Path diagram linking phoneme awareness and articulation at Time 1 and Time 2

X axis = Standardized residuals of the regression of
RQUALITY1 on the predictor variables:
PR.CONTRAST.STG1 and RQUALITY2

Y axis = Standardized residuals of the regression of
PR.CONTRAST.STG2 on the predictor variables:
PR.CONTRAST.STG1 and RQUALITY2

Figure 3. Added variable plot for the phoneme recognition task

X axis = Standardized residuals of the regression of
RQUALITY1 on the predictor variables:
PR.CONTRAST.STG1 and RQUALITY2

Y axis = Standardized residuals of the regression of
PR.CONTRAST.STG2 on the predictor variables:
PR.CONTRAST.STG1 and RQUALITY2

Figure 4. Added variable plot, with linear and quadratic trends, for the phoneme recognition task

X axis = Standardized residuals of the regression of RQUALITY1 on the predictor variables: receptive vocabulary, PJ.CONTRAST.STG1 and RQUALITY2

Y axis = Standardized residuals of the regression of PJ.CONTRAST.STG2 on the predictor variables: receptive vocabulary, PJ.CONTRAST.STG1 and RQUALITY2

Figure 5. Added variable plot for the phoneme judgement task

X axis = Standardized residuals of the regression of RQUALITY1 on the predictor variables: receptive vocabulary, PJ.CONTRAST.STG1 and RQUALITY2

Y axis = Standardized residuals of the regression of PJ.CONTRAST.STG2 on the predictor variables: receptive vocabulary, PJ.CONTRAST.STG1 and RQUALITY2

Figure 6. Added variable plot, with linear and quadratic trends, for the phoneme judgement task

X axis = Standardized residuals of the regression of
RQUALITY1 on the predictor variables:
SD.CONTRAST.STG1 and RQUALITY2

Y axis = Standardized residuals of the regression of
SD.CONTRAST.STG2 on the predictor variables:
SD.CONTRAST.STG1 and RQUALITY2

Figure 7. Added variable plot for the speech
discrimination task

X axis = Standardized residuals of the regression of
RQUALITY1 on the predictor variables:
SD.CONTRAST.STG1 and RQUALITY2

Y axis = Standardized residuals of the regression of
SD.CONTRAST.STG2 on the predictor variables:
SD.CONTRAST.STG1 and RQUALITY2

Figure 8. Added variable plot, with linear and quadratic trends, for the speech discrimination task

X axis = Stage 1 /r/-articulation quality (RQUALITY1)

Y axis = Stage 2 speech discrimination contrast scores
(SD.CONTRAST.STG2)

Figure 9. Distribution of Stage 2 speech discrimination contrast scores by Stage 1 /r/-articulation quality, showing quadratic trend

X axis = Stage 1 /r/-articulation quality (RQUALITY1)

Y axis = Joint contribution of RQUALITY1 and RQUALITY1.SQ
to Stage 2 adjusted speech discrimination
contrast score (SD.CONTRAST.STG2)

Figure 10. Variance in SD.CONTRAST.STG2, adjusted for two covariates (SD.CONTRAST.STG1 and RQUALITY1), explained by the joint contribution of RQUALITY1 and RQUALITY1.SQ, at different levels of RQUALITY1

IMAGE EVALUATION TEST TARGET (QA-3)

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