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The effects of motor practice on coarticulatory interactions in the speech of children and adults

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THE EFFECTS OF MOTOR PRACTICE ON COARTICULATORY INTERACTIONS IN THE SPEECH OF CHILDREN AND ADULTS

by

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ABSTRACT

The Effects of Motor Practice on Coarticulatory Interactions in the Speech of Children and Adults

by

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The current study was designed to elucidate the role of practice on speech production. Specifically, this investigation examined the effects of a distributed practice schedule on speech productions in young children and adults. Unlike the practice period used in previous studies, the practice session utilized in this investigation was spread out over one week (distributed over time), in which participants were required to practice on three different occasions before being retested. Therefore, the purpose of this investigation is to examine the notion of a developmental trend of coarticulation in children by verifying whether or not speech production strategies as exhibited by coarticulatory interactions are influenced by a distributed practice schedule. Participants were three-year olds, eight-year olds, and adults who were pre-tested, trained for one week, and post-tested. The data substantiates the developmental coarticulatory effects across age groups and demonstrated that this coarticulation can be affected by practice.

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CHAPTER I

INTRODUCTION

In the course of the first few years of life, a child becomes transformed from a callow, obstreperous, and impetuous creature into an intellectual, speaking human being. The story of this development has all the qualities of a good drama. As in the sequencing of scenes on the stage, every major change in functioning has been prepared for by antecedent events. For example, canonical babbling serves an important function in the preparation for language (Sussman, Duder, Dalston, & Cacciatore, 1999).

In 1951, Lashley pointed out that speech is the ultimate exemplar of complex motor skills. If this is true, then how is it that children in their first few years of life acquire speech with such apparent ease when they struggle with other, apparently simpler tasks such as catching a ball. Linguists and psycholinguists have searched for these answers for decades. The preeminent question in much of the recent speech development research today has been concerned with how children's utterances come to demonstrate mature phonetic structure. That is, in recent developmental studies, investigators have focused on when and how children learn to produce individual segments in a fashion similar to mature adult speakers (Nittrouer, 1993). One way of approaching this question is to investigate a specific aspect of speech production commonly termed coarticulation. Coarticulation is the fact that any one phonetic segment is highly influenced by the production of phonetic segments occurring both before and after the target segment

(Green & Gerdeman, 1995). The influence of phonetic segments occurring after the target segment is referred to as perservatory coarticulation and will not be addressed in this paper. Rather, anticipatory coarticulation, the influence of phonetic segments on a segment occurring before the target segment will be the focus. More specifically, the acoustic influence of the following vowel on consonantal onset is of primary interest.

The study of anticipatory coarticulation has been useful for explaining the difficulty in finding acoustic invariance in the speech signal and the inappropriateness of taking acoustic segments to correspond to linguistic segments (Lieberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Lieberman & Mattingly, 1985). In addition, studying coarticulation is useful for investigating the difference between language-universal and language-specific constraints in speech production (e.g., Flege, 1988; Katz, Kripke, & Tallal, 1991; Repp, 1986) and for establishing a more accurate basis for evaluating speech motor disorders (Smith, 1992). There is ample evidence that listeners are sensitive to the information coarticulation provides (Nittrouer & Whalen, 1989). Analyses of the extent to which speakers prepare for upcoming sounds in the speech stream have generated data about planning utterances and the exact nature of the speech motor programming units that comprise utterances (Katz et al., 1991).

A widely studied form of anticipatory coarticulation is spectral lowering for consonants preceding [u] relative to [I] (Katz et al., 1991). That is, in a visual display of speech productions (sound spectrogram) the section of the waveform associated with the vowel [u] reflects a decrease in the peak frequencies of the wave. This lowering or the decrease in wave peak frequencies in vowels is a result of lengthening of the front cavity of the mouth and of the lips and determines the second formant frequency (F2). In

vowels, the size and shape of the oral cavity determines F2 (Soli, 1981). Bell-Berti and Harris (1979) noted that lip rounding might precede the vowel by as much as 250 ms lowering the frequency of the spectral prominence in all sibilant fricatives by 300 to 500 Hz. In addition, Soli (1981) reported the entire noise spectrum for the [z(I)] spectra in the region of the second formant was 100 to 300 Hz higher than for the [z(u)] spectra. This shift in spectral energy corresponds chiefly with coarticulatory gestures of the lips and tongue (Katz et al., 1991). The increase seen in the frequency of the [I] stimuli is due to anticipatory tongue movements toward a more open articulatory configuration evidenced by increased airflow. Conversely, the decrease in the amplitude of the [u] stimuli arises because of lip rounding in anticipation of the vowel.

The coarticulatory gestures of the lips are referred to as labial coarticulation. For example, before pronouncing the word "tulip" the lips round before production of the [t] in anticipation of the [u]. Lingual coarticulation, in contrast, is a change in the height of the tongue body as a result of anticipation of an upcoming vowel. For example, it is well known that in English, the velar stop consonant [k] has two distinct allophones as a result of the tongue configuration in producing the following vowel. Allophones are distinct phones, but are not distinct phonemes and therefore, do not convey meaning (Rosenbaum, 1991). One allophone, before front vowels ([i, e]), has a relatively anterior vocal tract constriction, like in the syllable [ki] and the other, before back vowels ([a, u, o]), has a relatively posterior vocal tract constriction, like in the syllable [ka] (Sereno & Lieberman, 1987).

Determining the exact patterns of anticipatory lingual and labial coarticulation present in children's speech is particularly important in establishing when and how the

child develops differential motor control of the gestures responsible for consonantal occlusions and at the same time, tongue body shapes for forming the vowel (Sussman et al., 1999). In addition, determining the exact patterns of anticipatory coarticulation in children's speech is important because such data have been used to address a recent controversy concerning development and speech motor programming units. In anticipatory coarticulation, a speaker may initiate the production of selected features of a phoneme in advance of its target attainment (Lubker & Gay, 1982).

It is generally believed that in children consonants and vowels gradually emerge as independently controllable entities within the syllable (e.g., Davis & MacNeilage, 1990; Goodell & Studdert-Kennedy, 1993, Menn, 1986; Nittrouer, Studdert-Kennedy, & McGowan, 1989; Nittrouer, Studdert-Kennedy, & Neely, 1996; Studdert-Kennedy, 1987; Vihman, 1996). To obtain empirical evidence that the child has refined its minimal domain of articulatory organization from syllable sized to segment-sized entities, researchers have examined the acoustic influence of vowel contexts on spectral properties of a preceding consonant (e.g., Katz et al., 1991; Kent, 1983; Nittrouer, 1993; Nittrouer et al., 1989; Repp, 1986; Sereno & Lieberman, 1985; ;). If intrasyllable motor control has been achieved in phonological development, then "we might expect spatiotemporal overlap of gestures to diminish as children come to segregate consonantal from vocalic gestures and to coordinate them into the precise temporal patterns typical of adult speech" (Goodell & Studdert-Kennedy, 1993, p. 707). Reduced consonant vowel coarticulatory effects with advancing age (usually measured in the interval between the ages of 3 and 7 years) have been interpreted as indicating emergence of segmental independence of the consonant and vowel. Younger children who have not yet developed

intrasyllablic control of separate consonant and vowel segments should evidence greater acoustic influences of a vowel on the preceding consonant than older children and adults (Sussman et al., 1999). A sizeable literature exists describing the acoustic (primarily F2 related) effects of vowels on syllable initial consonants as a function of age. Unfortunately, the results are contradictory, with some studies showing that children show (a) more coarticulation than adults (Nittrouer, Studdert-Kennedy, McGowan, 1989; Nittrouer, Studdert-Kennedy, & Neely, 1996; Repp, 1986; Siren & Wilcox, 1995;), (b) less coarticulation than adults (Hodge, 1990; Kent, 1983; Sereno & Liberman, 1987), and (c) the same coarticulation as adults (Katz et al., 1991; Sereno et al., 1987; Turnbaugh, Hoffman, Daniloff, & Absher, 1985). The nonuniformity of the speech acquisition process and the lack of methodological consistency across studies provide some explanations for the equivocal results (Nittrouer, 1993). Such methodological factors as the articulator examined (e.g., lips versus tongue), consonant class studied (e.g., fricatives versus stops), and extent of vowel contexts analyzed contribute to the lack of agreement across studies (Sussman et al., 1999). The way in which coarticulation was measured also provides an explanation for the inconsistencies found. Researchers have used different points of F2 as their measure. For example, many researchers have looked at 30 ms prior to VO, as well as VO. Other investigators have taken a measure for VO and the offset of the vowel and averaged them. This measure is referred to as the centroid.

Given the conflicting findings of recent studies, additional information is needed to confirm or reject the notion of a developmental trend of coarticulation in children's speech productions. Investigators such as Siren and Wilcox (1995) have suggested that some motoric factor is accounting for the differences among coarticulatory interactions in

children's speech when compared to adults. They hypothesized that it may be children's limited repertoire of articulatory routines (Nittrouer et al., 1989) or gestural routines (Goodell & Studdert-Kennedy, 1991) that account for the coarticulatory interactions that have been observed. That is, Siren and Wilcox (1995) hypothesized that less practiced articulatory (or gestural) routines would exhibit more coarticulation due to less well-differentiated and contrasted sounds (Goodell & Studdert-Kennedy, 1993; Nittrouer et al., 1989). In their investigation, participants were given a practice period during which participants repeated the reduplicated syllables (/sisi/, /susu/, /sisi/, /susu/) 15 times. Only the sixteenth production of each disyllable target item was recorded and analyzed. Although they found that recent motor practice did not have an effect on fricative vowel coarticulation, the investigators suggested that their findings were not sufficient to reject motor practice as a possible factor accounting for developmental differences in speech production strategies. The degree of difference between children's limited articulatory experience with articulatory routines and adults more extensive and more practiced routines is far greater than that tested in their experiment.

Current Study

Siren and Wilcox (1995) used a particular type of practice protocol in their study known as massed practice. "Massed practice," means running work periods close together with either no rest between trials or very brief rest intervals between trials (Guadagnoli, 2001). Contrarily, "distributed practice" means spacing work intervals so that there are longer periods of rest. There is ample literature in both the fields of motor learning (e.g., Lee & Genovese, 1988; Bourne & Archer, 1956) and verbal learning (e.g.,

Dempster, 1988) that indicates the structure of practice has very important influences on learning. Moreover, this literature shows that distributing practice often yields better long-term retention of the material to be learned. Therefore, the finding of Siren and Wilcox (1995) could have been the result of the practice schedule used rather than actual lack of developmental differences.

The purpose of this investigation was to examine the effects of a distributed practice schedule on coarticulation in children and adults. The practice session entailed three days of practice spread out over a one-week period. Within the practice bouts, participants practiced five repetitions of five nonsense words. Two working hypotheses were generated. These hypotheses were developed based on two assumptions. First, that there is a finite ability as to the degree of coarticulation possible in the English language. Secondly, that by the time one has achieved adulthood they have reached this ability to coarticulate. One hypothesis was: If children develop coarticulation gradually with age, and thus, as a result of practice and experience, then practice should make their coarticulation more adult-like. That is, with practice one would expect to see greater spectral lowering in F2 for words containing the vowel [u] and a spectral increase in words containing the vowel [I]. This hypothesis suggests that certain aspects of coarticulation are learned. The alternate hypothesis was: If children possess similar coarticulatory abilities to that of adults, there would be no expected change in coarticulation measures between the pre-test and post-test, as a result of practice. This hypothesis implies that coarticulation is "hard-wired."

Hypotheses

Hypothesis I: Coarticulation is hardwired into the system and practice does not influence it.

Hypothesis II: Coarticulation is not hardwired into the system and practice does influence it.

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CHAPTER II

REVIEW OF LITERATURE

Apart from the rote miming of parrots, no animal can speak a human-like language. Many animals make complex sounds, among them dolphins and chimpanzees, but only in humans do these sounds represent objects and events in an arbitrary yet symbolic way. Though the words vary from dialect to dialect, they have specific meanings in each case and are solely the inventions of the human mind (Panati, 1984).

While there is anthropological evidence to suggest that humans possessed speech capabilities over 1.5 million years ago (Cartmill, 1998), researchers are assiduously investigating exactly how humans have come to acquire this grand invention. There are various ways to approach this question, however, this paper will focus on one particular aspect of speech production termed coarticulation. Coarticulation is the temporal overlap or coproduction of consonants and vowels in running speech. Moreover, the study of coarticulation has been used as a means of investigating the temporal and spatial organization of speech motor control patterns and the units comprising those patterns. The review of literature presented in this chapter is devoted to addressing the investigations pertaining to coarticulation. More specifically, this chapter highlights evidence supporting the presence of coarticulation and contrasting evidence surrounding the notion of a developmental trend of coarticulation in speech. In addition, this section

discusses the speech anatomy and how the role each anatomical part plays in the mechanics of speech production.

Mechanics of Speech Production

When we talk, we use our tongues and lips and other vocal organs to produce the different speech sounds. For every sound, there must be a corresponding movement of a source of sound. In the majority of speech sounds, the vibrations of the air in the passages of the mouth, throat, and nose, collectively known as the vocal tract, serves as the movements that initiate the sound waves. The vocal tract is comprised of vocal folds, a larynx, pharynx, nasal tract, velum, lips, and tongue (see Figure 1.2). At one end of the vocal tract the larynx houses the vocal folds or more commonly referred to as vocal cords. The larynx serves four main functions: it regulates the pitch of the voice, it modulates aspiration, it allows for whispering, and it creates a buzzing sound known as voicing. Voicing is controlled by adjusting the distance between the vocal cords, two folds that lie across the roof of the larynx. During production of voiced consonants such as [v] and [b], the distance between the cords is small, but during production of unvoiced consonants such as [f] and [p], the distance increases to the point where air flowing between the cords does not cause vocal cord vibration. The cavity lying between the larynx and the oral cavity is the pharynx. The shape of the pharynx constrains the vowels that can be made. Due to the fact that adult humans have long necks, low larynxes, and large, mobile throats, their pharynxes have resonance properties suitable for production of certain vowels such as [a], [i], and [u]. The resonance of a body is the frequency at which it vibrates with the greatest amplitude for each unit of energy supplied. The

throats of human infants and of apes do not have these characteristics. The resonances for human infants and apes are higher than for human adults. Thus, these resonances would not permit matching the formant frequencies that reflect resonances in common with adult production of [a], [i], and [u].

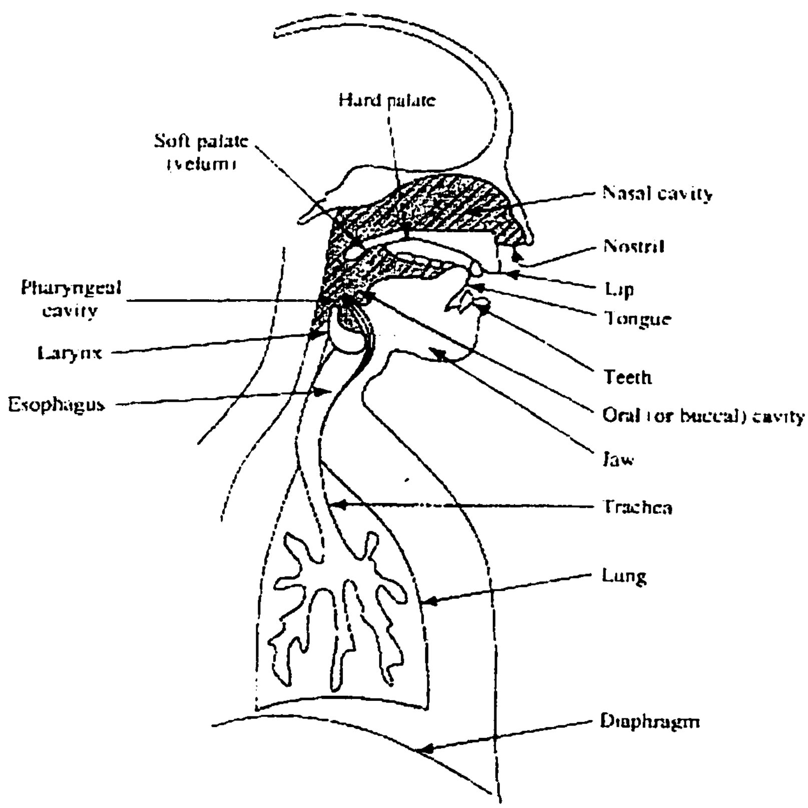

Figure 1.2 Schematic view of human speech production mechanism.

Ascending up the vocal tract, the movable flap connecting the nasal tract and the oral cavity is the velum. The positions of the velum along with the other parts of the

vocal tract (lips and tongue) affect the production of consonants. For example, a consonant is assumed either to be or not to be nasal. That is, consonants are either produced with the velum closed or open. When the velum is open, such as in the consonant [n], air passes through the nasal cavity producing a distinctive sound.

The positions and activities of the tongue and lips also affect consonant production. These structures make up the remaining components of the vocal tract. The tongue, a movable organ on the floor of the mouth is responsible for both the productions of vowels and consonants. The position of the tongue body, either high or low in the mouth and toward the front or back of the mouth determines what type of vowel is produced. For example, to produce the vowel in “sin”, the tongue body is placed high in the mouth and toward the front. This is termed a high-front vowel. The vowel in “get” requires placement of the tongue body low in the mouth and toward the front, hence a low-front vowel.

The production of consonants, like the production of vowels, depends on where the tongue is placed. That is, the tongue moves about the oral cavity narrowing the air stream. Similarly, the lips work in conjunction with the tongue to interrupt airflow and produce distinct consonants. For example, the word “forth” is produced as a result of narrowing the air stream by the lips and tongue.

The vocal tract forms a resonating chamber of complex shape. When the air in this chamber is set in motion by a sharp tap, it vibrates in a complex way. It is these vibrations that cause the sound waves that we hear. The taps that set the air in the mouth and throat in vibration are due to the actions of the vocal folds. The vocal folds are literally small folds of muscle supported by cartilage in the larynx. In speech, the folds

are brought loosely together. If air is being pushed out of the lungs, pressure will be built up beneath them until they are blown apart. But as soon as they have been blown apart, there is less pressure beneath them, and they come together again (termed the Bernoulli effect), which results in the pressure being built up so that they are blown apart again. This cycle of events is repeated rapidly until air is no longer being pushed out of the lungs or the position of the vocal folds is adjusted. The rush of air between the vocal folds actually causes them to be sucked together, so that they close very sharply. The abrupt changes in air pressure that occurs when the vocal folds come together acts like a blow on the air in the vocal tract and sets it vibrating.

The air in the vocal tract will vibrate in different ways when the vocal organs are in different positions. The way in which a body of air vibrates depends on its size and shape. Largely the movements of the tongue, the lips, and the soft palate determine the variations in the shape of the vocal tract. By changing the position of the articulators, one is changing the resonant frequencies of the vocal tract, which gives rise to formants once the source sound spectrum is passed through the filter of the vocal tract. It is the presence of formants that enables us to recognize the different vowels that are associated with the different positions of the vocal organs (Ladefoged, 1996). For example, research (e.g., Nearey, 1990; Ziegler & von Cramon, 1985) has determined that the first formant (F1) reflects vowel height or overall constriction of the vocal tract, while the second formant (F2) reflects front-back distinctions and lip rounding (Nittrouer & Whalen, 1989).

In general, formant frequencies depend on three factors. One of those factors is the position of the point of maximum constriction in the vocal tract, which is controlled by the backward and forward movement of the tongue. Another factor is the size or

cross-sectional area of the maximum constriction, which is controlled by the movements of the tongue toward and away from the roof of the mouth and the back of the throat. Lastly, formant frequencies depend on the position of the lips (Ladefoged, 1996). The common modeling approaches purposefully ignore the contributions from the teeth (on constrictions) and other components to maintain a simpler determination of the size of the tubes that air is being passed through.

Speech Sounds

Speech sounds can be described in terms of their physical properties such as frequency and amplitude. Speech sounds can also be described in terms of how they are produced. Research on phonological development makes reference to both sorts of descriptions, but it relies more on the latter, known as articulatory phonetics. Using articulatory phonetics, it is possible to describe the 40 plus sounds of English as combinations of a smaller number of features of the articulatory mechanism that produces those sounds. These features are called phonetic features. For example, [z] and [s] differ in terms of voicing (i.e., presence of vocal fold vibration) but are the same in terms of every other feature. As you produce [z] and [s], you can feel that your teeth, lips, and tongue stay in the same place. The only thing that changes is what you do with your vocal cords. Many other pairs of consonants differ only in voicing, such as [d], [t], [k], and [g]. Voicing is not the only feature that differentiates speech sounds.

A basic distinction among speech sounds is between consonants and vowels. When a consonant is produced, the flow of air from the lungs through the mouth is obstructed somewhere along the line. In contrast, when a vowel is produced, the airflow

is unobstructed. There are also distinctions among sounds within the class of consonants and within the class of vowels that can be described in terms of how the sounds are produced.

Vowels differ on several articulatory dimensions (see Figure 2.2). One dimension is the position of the tongue body; either high or low in the mouth and toward the front or back of the mouth. To produce the vowel in "sin," for example, the tongue body is placed high in the mouth and toward the front; consequently this is a high-front vowel. To produce the vowel in "book," the tongue body is placed high in the mouth and toward the back. This is a high-back vowel. The vowel in "get" requires placement of the tongue body low in the mouth and toward the front; hence this is a low-front vowel. The vowel in "luck" requires placement of the tongue body low in the mouth and toward the back. This is a low-back vowel. There is also a vowel that requires an extremely low front tongue placement (the [a] in "ash"), and there is a vowel that requires an extremely low back tongue placement (the [augh] in "caught") (Rosenbaum, 1991).

	Front	⟷	**Back**
High	sin		book
↕	get		luck
Low	ash		caught

Figure 2.2 Vowel Articulatory Dimensions

The production of consonants, like the production of vowels, depends on where the tongue is placed. Linguists have categorized consonants according to their manner

and place of articulation. Manner of articulation refers to the way in which the air stream is constricted by the articulators, such as whether the air is momentarily stopped by closure of the lips. Place of articulation refers to the location where the constriction occurs. There are several manners and places of articulation.

The consonants used in this investigation were [f] and [s]. These consonants are referred to as fricatives. Fricatives are produced by turbulent airflow that is caused by a partial constriction in the vocal tract. The position of the constriction creates damped vibration modes with resonate frequency regions. The friction of the constriction produces a "hissing" sound that is characteristic of all fricatives. Fricatives like [f] are produced by a constriction at the front of the mouth; raising the lower lip until it nearly touches the upper front teeth. The air stream passes through some of the space between the upper teeth. This positioning acts to attenuate frequencies below 1500 Hz and above 7500 Hz; these fricatives are perceived as a noise "high" in pitch but weak in intensity. Fricatives such as [sh[in "shub" and [s] as in "sib" are produced by a constriction at the back of the mouth utilizing the root of the tongue. The air may then be forced over the sharp teeth edge (sib) or forced into a narrow beam due to grooving the tongue (shub). This positioning results in a greater contribution of low frequency sounds (down to 700 Hz) and results in peaks of energy much like vowel formants between 1000 Hz and 3000 Hz. For voiced fricatives (sub), the turbulent airflow is accompanied by a low frequency periodic component (around 700 Hz) because of the vibration of the vocal folds.

Coarticulation

During running speech neighboring phonetic segments affect each other in various ways (Hertrich & Ackermann, 1995). These contextual influences are termed coarticulation. More specifically, coarticulation is referred to as overlapping movements in the production of neighboring or near-neighboring phonetic segments (Nittrouer & Studdert-Kennedy, 1987). That is, the acoustic properties of certain sounds are changed based on the influence of adjacent sounds. These effects are categorized as anticipatory or "forward" coarticulation and carryover or "backward" coarticulation. Whereas carryover coarticulation is often attributed to the inertial properties of the articulators (Sereno et al., 1987), anticipatory coarticulation may extend beyond simple inertial factors. Anticipatory coarticulation may reflect planning in motor behavior (Sereno & Lieberman, 1987).

One of the most extensively studied anticipatory coarticulation effects has been the rounding of consonants preceding a rounded vowel, such as [u]. Many articulatory studies using a variety of techniques have demonstrated the existence of labial coarticulation in adults (Sereno et al., 1987). Daniloff and Moll (1968) and Lubker (1981), citing an earlier study by Lubker, McAllister, and Carson (1975), found that anticipatory rounding, measured by the amount of lip protrusion using cinefluorographic film and the amount of electromyographic (EMG) activity of the obicularis oris muscle, begins in the first consonant of a series of consonants that precede the rounded vowel [u]. This articulatory effect has also been corroborated in a study of French utterances, in which lip protrusion occurred in the first of a series of four to six consonants preceding a rounded vowel (Benguerel & Cowan, 1974). In addition, spectral analyses of fricative

segments have also clearly showed anticipatory coarticulation effects (Soli, 1981). The second formant frequencies of the entire sibilant fricatives were 100-300 Hz higher before the front vowel [I] compared to the back vowels [a, u]. These acoustic manifestations of anticipatory coarticulation were present in the frication segments about 30-60 ms before the vowel's first pitch period. It seems, then, that brief initial consonantal segments excised from both stop-vowel and fricative-vowel syllables display systematic acoustic differences in their spectral properties and provide sufficient cues for the appropriate perceptual identification of the following vowel.

There is substantial articulatory, perceptual, and acoustic evidence to support the presence of anticipatory coarticulation in adult speech. There is, however, significantly more variability in the literature demonstrating the existence of coarticulation in children's speech. For example, some studies have found that children tend to coarticulate more that adults (e.g., Nittrouer et al., 1989; Nittrouer et al., 1996; Repp, 1986; Siren & Wilcox, 1995;), whereas other studies indicate that children coarticulate less (e.g., Hodge, 1990; Kent, 1983; Sereno & Lieberman, 1987;). Subsequently, there is evidence to suggest that children coarticulate to the same degree as adults (e.g., Katz et al., 1991; Sereno et al., 1987; Turnbaugh et al., 1985) and in other investigations the presence of coarticulation has been found to be non-uniform (e.g., Goodell & Studdert-Kennedy, 1993; Nittrouer, 1993 Sussman et al., 1999). For example, Goodell and Studdert-Kennedy (1993) found for lingual stops [d, g], coarticulation decreased over a 10-month period in 22 to 32 month old children, whereas labials showed a nonsignificant trend of increasing coarticulatory overlap.

Speech Motor Programming

The phoneme-sized phonetic segment (Kent, 1983), the syllable (Nittrouer et al., 1989; Nittrouer & Whalen, 1989), and words and phrases (Ferguson & Farwell, 1975; Waterson, 1971) have all been considered the primary units used by children learning to produce speech. Determining the organization, however, has always presented serious challenges to linguists and psycholinguists because of extreme difficulty in identifying corresponding units in the physical structure of speech, (Das & Nadas, 1992; Elman & McClelland, 1986). Consequently, some investigators have abandoned these accounts as the basic unit of phonological organization and have begun looking for alternative approaches (Nittrouer, 1993). More recently, such terms as "phonetic gesture" (Liberman & Mattingly, 1985; Mattingly, 1990), "dynamically-defined articulatory gesture" (Browman & Goldstein, 1990), or more simply "gesture" (Browman & Goldstein, 1986, 1991; Saltzman & Munhall, 1989) have been used to represent a set of closely related concepts. Essentially, phonetic gestures are linguistically significant actions of structures of the vocal tract. Browman and Goldstein also support the notion that phonological structure is represented by the organization of the articulatory gestures produced over the course of an entire utterance. Furthermore, individual gestures are produced according to language-specific spatial and temporal rules, and then are combined in precise and consistent ways that the perceiver can recognize and can use to reconstruct the phonological structure intended by the speaker.

The Motor theory of speech perception (Lieberman & Mattingly, 1985) and the Direct-Realist theory of perception (Gibson, 1954) also fall in line with these alternative gestural approaches. According to Motor theory, there is a specialized phonetic module

that links perception and production. The phonetic module is specialized to do two things: (a.} to allow the talker to produce speech as a sequence of temporally overlapping, coarticulated units of movement referred to as phonetic gestures and (b.) to allow the listener to recover those elements from the coarticulated signal. Thus, speakers and listeners could conduct their linguistic business using the common currency of phonetic gestures. Similarly, the Direct-Realist approach holds that the gesture is the fundamental component a listener's uses to identify a speech sound.

In a different view, Nittrouer (1993) contends that even more than adults' speech, children's speech seems amenable to descriptions of structure, other than those based strictly on phonetic segments. Particularly in studies with babbling infants or toddlers acquiring their first few words, it seems more appropriate to think of children's speech as being organized over units that have been described as "articulatory routines" (Menn, 1983) or as "word recipes" (Vihman & Velleman, 1989). So, according to this view, children initially master a few simple patterns of articulatory movement. For example, a child in the pre-linguistic or initial word stage of development might show a preference for using the vocal tract opening gesture associated with moving from a complete occlusion near the alveolar ridge to a mid-open vocal tract, resulting in what a mature language user would judge to be a [de] syllable. As long as only a few words or phrases are required for communication, children can get by with a few modified forms of their basic patterns. These simple modifications can take the shape of reduplications [dede] (e.g., Schwartz, Leonard, Wilcox, & Folger, 1980), slight changes in vowel quality [dae] (e.g., Vihman & Velleman, 1989), or addition of a diminutive ending [dei] (e.g., French, 1989; Ingram, 1974). However, as articulatory skill improves and as need increases for

more vocabulary items, children diversify their articulatory routines (Menn. 1983). Diversification occurs because a wider range of articulatory gestures can now be produced, as well, variation occurs in the gestures that can be combined. Thus, the order in which gestures can be combined becomes less rigid. With diversification, the coordination among the various gestures becomes more precise and more consistent across productions of the same intended utterance until eventually the child's speech exhibits the stable relations among gestures evident in adults speech.

An alternative view of speech development is that speech coordination emerges from earlier from appearing oral motor behaviors, such as chewing (Moore & Ruark, 1996). Two lines of reasoning can be taken to address the coordinative framework of speech during the early stages of development. The first line draws on mechanisms of central pattern generation, which has directly been observed in animals (see Grillner, 1981), and from dynamical systems theory (e.g., Kent & Hodge, 1990). A dynamic pattern perspective suggests that speech movements emerge gradually through an interaction of context (i.e., external conditions) with intrinsically generated patterns stemming from the rhythmic movements of sucking, chewing, reduplicated babbling, and variegated babbling (Moore & Ruark, 1996). An alternative approach holds that speech develops independent of extant behaviors, emerging as a new and unique motor skill. Support for this position is drawn directly from observations of babbling rhythmicity and further relies on findings that the coordinative organization of mature speech is distinct from that of any of the postulated precursors (Moore, Smith, & Ringel, 1988). The established orofacial coordination available to children from these behaviors does not appear to be well suited to speech. For example, kinematics and positional control

characterizes speech coordination, whereas force generation is probably one of the primary goals of coordination for chewing.

These two approaches to speech development are not necessarily incompatible, as discontinuities in speech development can be modeled as expressions of different attractor states of the dynamical systems involved. In any case, the considerations raised by these two approaches may aid in organizing efforts, which at this stage rely heavily on the intuitive appeal of contemporary hypotheses (Moore & Ruark, 1996).

Studies of the structure of children's first meaningful utterances have generally used narrow transcription, and have shown that there are constraints on the vocal-tract constrictions (consonants) and open configurations (vowels) that can be combined within a syllable (e.g., Davis & MacNeilage, 1990; Stoel-Gammon, 1983), as well as constraints on the syllable position that certain gestures can occupy (Menyuk & Menn, 1979). Thus, new speakers are not able to control the internal components of the syllable independently, as adults can. That is, inexperienced articulatory systems may operate according to the "everything moves at once" principle, in which sets of articulatory gestures are produced in a largely synchronous manner (Kent, 1983). Then with maturation and practice, this operating mode gives way to greater phasing among individual gestures. In addition, young speakers may exhibit great variation in (perceived) phonetic structure across attempts at the same utterance even though the set of individual gestures executed in each attempt remains fairly constant and appropriate for the intended utterance (Nittrouer, 1993). This lack of consistency in phonetic structure is thought to arise from imprecise temporal coordination among the gestures (Ferguson & Farwell, 1975). Furthermore, there may be greater overlap among the

articulatory gestures of young speakers compared to what is observed for experienced speakers (Goodell & Studdert-Kennedy, 1993; Nittrouer et al., 1989). In other words, the curves sometimes used to depict the prominence of individual signal components or articulatory gestures, across time might be envisioned as being flatter, broader, and having more shared areas in children's than adults' productions. Based on these findings, some developmental psycholinguists (e.g., Ferguson, 1986; Menn, 1983; Studdert-Kennedy, 1990) are adopting the position that early productions are best described as largely undifferentiated entities, which become more tightly controlled sets of articulatory gestures as the child matures and gains experience with a native language.

Theories of Children's Speech Production

Investigations of children's abilities to coarticulate have yielded mixed results. One set of data supports the notion that early language learning involves a segment-by-segment process with coarticulation increasing in effect as speech and language develop (Kent, 1983). Thus, from this data, coarticulation appears as a skill that children learn after they have mastered the articulation of individual segments. That is, children learn the canonical patterns of production associated with each phoneme and then learn how to make the appropriate adjustments to accommodate neighboring segments (Katz et al., 1991; Kent, 1983, Sereno et al., 1987). From this perspective, the acoustic and articulatory records of children's speech reveal less evidence of coarticulation, thereby resulting in more segmental productions than adults' speech.

Data from other investigations has shown that children coarticulate more than adults. From this data, the phonetic segment is the endpoint rather than the starting point

of development (Studdert-Kennedy, 1987). Standard descriptions of babbling during the pre-meaningful speech period distinguish reduplicated babble, in which syllable margins and nuclei do not change across a syllable string (e.g., [mama], [daedae]) from variegated babble, in which margin and/or nucleus vary from one syllable to the next (e.g., [daedi], [dagi], and suggest that reduplicated patterns predominate early during this period with variegated patterns predominating later (Oller, 1980, 1986; Smith, Brown-Sweeney, & Stoel-Gammon, 1989; Stark, 1980). Thus, the holistic, undifferentiated syllable appears to be the initial unit of speech production, from which it is hypothesized segments gradually emerge, first by differentiation of the syllable into its gestural components, then by integration of those gestures into the recurrent articulatory-acoustic patterns known as consonants and vowels (Studdert-Kennedy, 1991). If this were the case, one would expect that children's speech would display more extensive (or at least different) patterns of coarticulation than adults' speech (Nittrouer et al., 1996).

Finally, data from still other investigations suggest that productions of children and adults are similar with respect to the magnitude and extent of anticipatory coarticulation. The pattern of results does not support the notion that two to three year old children exhibit speech char-acteristics reflecting a predominately syllable-based system of perceptuomotor organization (Menyuk & Menn, 1979; Nittrouer et al., 1989). Rather, the acoustic and video data show that children as young as three years of age plan speech much as older children and adults do. The perceptual data suggest either that coarticulation is produced with less regularity at age three, than at later ages or that three year old children produce regular coarticulatory cues that are more difficult to perceive because of a poorly produced preceding consonant (Katz et al., 1991).

In the following section, the findings from these investigations of children's coarticulation will be addressed. In order to elucidate the findings, the results are presented according to the type of coarticulation (i.e., lingual or labial) and by the theory to which they lend support (i.e., developmental trend, coarticulate more, or coarticulate the similarly.

Evidence Supporting a Developmental Trend in Lingual Coarticulation

The theory that children produce speech initially segment by segment with coarticulation gradually increasing with age was first presented after a preliminary investigation conducted by Kent (1983). He examined lingual coarticulation in three children's (4 year olds) and three adults' productions of the word "box." In his comparison of the wide-band spectrograms, he found that the adults' productions included a rising second formant (F2) in the vowel, in anticipation of tongue body elevation for the following [ks] cluster, while the children's productions exhibited a relatively steady-state F2 offset. From this, he concluded that children did not possess the motor skills needed to coarticulate.

An investigation conducted by Sereno and Lieberman (1987) on anticipatory lingual coarticulation, reported similar findings, in which children's speech varied greatly from speaker to speaker, with some children exhibiting little evidence of lingual coarticulation. These researchers measured three tokens of the velar stop consonants [ki] and [ka] produced by five adults and 14 child speakers. The children ranged in age from two years eight months to seven years one month. The acoustic analyses of the mean spectral peak values showed strong lingual coarticulatory effects for adults, and variable,

or sometimes non-existent, lingual coarticulatory effects in the children. The researchers also reported a high degree of intersubject variability in the children's speech patterns. That is, some of the children's spectra displayed the same pattern as the adults', a few of the children's spectra did not show these systematic differences between [k] spectra preceding [i] compared to [a]. This was interpreted as evidence that coarticulation develops gradually with maturation and that coarticulatory precision represents one form of fine-tuning speech motor patterns.

Similarly, Repp (1986) analyzed lingual coarticulation in the productions of the words "sea", "sand", "soup", "tea", "tan", and "tooth" in the carrier phrase "I like the ___" of one adult and two children (ages four and nine). He found a rising second formant (F2) in the adult and older child's productions of the word "sand". That is, the adult and older child anticipated the front-back tongue position of the stressed vowel transconsonantly, whereas the younger child did not (Goodell & Studdert-Kennedy, 1993). In addition, first formant (F1) estimates for the schwa showed that only the adult anticipated tongue height.

In a more extensive study of three, five, and nine year olds and adults (ten in each group), Hodge (1990) estimated F2 values in the word "bark". Only the nine year olds and adults displayed significant evidence of anticipating the stressed vowel.

Evidence of Greater Lingual Coarticulation in Children than Adults

In contrast to the evidence supporting the notion of a developmental trend of coarticulation, there is also research that lends support to the theory that children initially produce speech in syllable-sized segments, resulting in greater coarticulation.

In a two-year longitudinal study on gestural coordination using younger children (22 and 32 month olds), Goodell and Studdert-Kennedy (1993) found clear differences in speech gestural coordination between two and three year old children and adults during lingual coarticulation. More specifically, these investigators found for lingual stops [d] and [g], the coarticulatory effect of the vowel on the consonant decreased in the ten-month interval examined. This lead them to conclude that the two to three year old children showed a tendency to produce longer utterances with different degrees of overlap between neighboring gestures than adults.

Similarly, Nittrouer et al. (1989) found age-related differences for the coarticulatory effect of tongue position. Speech samples of the reduplicated syllables [sisi], [sisi], [susu], and [susu] were collected from eight adults and four groups of eight children each at the ages three, four, five, and seven years. Two measurements were made on each speech token: centroids and second formant frequencies. These researchers found greater coarticulation among the three and four year old productions. That is, they found increased spectral lowering for the reduplicated syllables containing [u] (i.e., [susu] and [susu]) and spectral increasing in the syllables containing [I] (i.e., [sisi] and [sisi]). Moreover, they found that the lingual coarticulatory effects significantly diminished with increasing age.

Siren and Wilcox (1995) replicated these results. They compared F2 measurements of three, five, and eight year old children with adults. The target productions were differentiated in terms of meaningful versus non-meaningful and practiced versus non-practiced. There were eight meaningful target items. Four of the target items were CV words ([si], [su], [Si], [Su]), while the other meaningful target items

were four CVC words ([sit], [sup], [ʃip], [ʃut]). In addition, there were four nonsense CVC words ([sib], [sub], [ʃib], [ʃud]). The final four target items consisted of reduplicated syllables ([sisi], [susu], [ʃiʃi], [ʃuʃu]). The data showed that a pattern of decreasing magnitude of difference in F2 values with increasing age. That is, three year olds displayed greater coarticulation or overlap than the five and seven year olds and adults.

Evidence of Similar Lingual Coarticulation Among Children and Adults

An additional body of evidence exists that has found no difference in the degree of lingual coarticulation in adults and children. This data indicates that anticipatory coarticulation in young children's speech is roughly similar to that of adults. For example, Turnbaugh et al. (1985) found less conclusive evidence of early segmental organization in their study of lingual coarticulation in children ranged in age from three to seven years old and adults. These researchers examined F2 onset in the stop-vowel syllables [si], [su], [ti], [tu], [di], and [du]. The results indicated similar degrees of coarticulation across age groups, thereby leading the authors to conclude that there was no indication in the data that children coarticulate less than adults.

Katz et al. (1991) confirmed these results in a cross age comparison, in which the results demonstrated similar patterns of lingual coarticulation for children (3, 5, and 8 year olds) and adults producing the consonant [c] in the carrier phrase "I said ____." The centroid frequencies and second formant frequencies of the productions were measured. Their results indicated no statistically significant differences between the amount of children and adults' coarticulation.

Evidence Supporting a Developmental Trend of Labial Coarticulation

With respect to labial coarticulation, there is some evidence supporting Kent's theory that coarticulation develops gradually with age. For example, in a comparison of children's (3 to 7 year olds) and adults F2 values using the stop consonant vowel [CV] syllables [si], [su], [ti], [tu], [di], and [du] Sereno et al. (1987) found strong coarticulatory effects for the adults and comparable, although less consistent, coarticulation in the speech stimuli of the children. These researchers concluded that their results supported a gradual developmental process and progressive fine-tuning of speech motor patterns.

Evidence of Greater Lingual Coarticulation in Children than Adults

In contrast, other investigations of labial coarticulation have yielded data that suggests young children show greater overlap among labial articulatory gestures compared to what is observed in more experienced speakers. In Goodell and Studdert-Kennedy's (1993) longitudinal study of 22 and 32 month old children mentioned earlier, these researchers found that labial coarticulation was greater at the initiation of the study and then decreased significantly as participants matured. Similar findings were obtained by Hodge (1989), in which he compared F2 trajectories at vowel onset in the syllable [du] and found more coarticulation in three year olds than in older children and adults.

Evidence of Similar Lingual Coarticulation Among Children and Adults

Finally, other researchers have found no age-related effects for labial coarticulation. These findings suggest children produce gestures similar in shape to those of adults. For

example, in the Katz et al. (1991) investigation mentioned earlier, labial coarticulation was also addressed. In order to determine the degree of lip rounding, participants produced the word [sue] in the carrier phrase “I said ___.” In comparing the mean centroid and mean F2 frequencies, these researchers found that like lingual coarticulation the magnitude and extent of labial coarticulation was similar between the children (three, five, and eight year olds) and adults.

Similarly, Nittrouer et al.’s (1989) comparison of the centroid and F2 of three, four, five, and seven year old children and adults productions of the reduplicated syllables [sisi], [SiSi], [SuSu], and [susu] revealed that three year old children already execute lip rounding and coordinate it with tongue and jaw action in an essentially adult fashion.

In a later study, Nittrouer (1993) examined ten adults and 30 children (ten each of the ages three, five, and seven years) productions of 15 consonant-vowel syllables consisting of the consonants [s], [S], [t], [k], and [d] and the vowel [u]. She concluded from her examination of F2 trajectories that children produced labial gestures similar to those of adults, but many movements were produced more slowly by the children than by the adults. This conclusion is based on the finding that the spectral structure of children and adults’ samples demonstrated similar patterns, but the time course of spectral change was often longer and more variable in children’s samples.

Practice

Practice is defined as repeated performance or systematic exercise for the purpose of acquiring proficiency. For example, if one wants to learn how to speak French, one

would need to practice speaking French words and sentences. The positive effects of practice and learning a particular task or skill have been well documented in the literature (e.g. Bourne & Archer, 1956; Dempster, 1988; Lee & Genovese, 1988). One area of practice that is of great importance to researchers, instructors, and therapists alike has been the scheduling of periods of work (i.e., time spent in actual practice) and rest (i.e., time not practicing the task). This scheduling can be considered within a short time frame, as when one selects the amount of work and rest within a 30-minute therapy session. Or the scheduling may be considered in terms of a longer scale, as when one chooses the length and frequency of sessions per week. The important issue is how the frequency and length of rest periods affect learning the skill being practiced in the work periods. In other words, what is the best way to distribute the time spent in work versus the time spent resting?

Research on practice-distribution effects has often used the terms massed practice and distributed practice. In one sense, "massing" means to put things together. In this case, running work periods very close together with either no rest at all or very brief rest intervals in between. In contrast, distributing practice means spacing these intervals of work apart with longer periods of rest. The terms "massed" and "distributed", however, are merely labels often used to describe two extremes of practice distributions. Many experiments used more than two distribution conditions. Thus these terms must be considered within the context of other conditions within any particular experiment. Even though practice-distribution experiments involved wide differences in methods, such as the length of work and rest periods and number of trials, the findings are remarkably

similar. That is, given constant periods of work, short rest periods depress performance relative to longer rest periods.

Findings from a study by Bourne and Archer (1956) are typical of the performance effects seen in experiments on practice distribution. The task was a pursuit rotor tracking. Five different groups of subjects were compared; all groups had work periods of 30 seconds. In one group (the zero second rest group), subjects practiced continuously for 21 trials, with no rest at all. For the other four groups, each of the work periods was interspersed with periods of rest. One group had rest periods of 15 seconds and the other three groups had rest periods of 30, 45, or 60 seconds. Bourne and Archer's findings were quite clear; the longer the rest period, the better the performance.

Perhaps of more direct significance to instructors and therapists are the effects of practice distribution when conducted on a much longer time scale than the single session experiments carried out. A few studies have been conducted and the results are generally similar to those of the studies done in a single session. In a very early investigation of this type, right-handed subjects were asked to throw javelins with their left hand (Murphy, 1916). All subjects practiced on 34 separate days. Massed practice subjects performed on consecutive days (Monday through Friday) for seven weeks. The distributed group practiced three times per week for 12 weeks. Results at the end of the 34^{th} day of practice and on a retention test performed three months later showed both performance and learning benefits for the distributed group. Similar findings were also reported by Baddeley and Longman (1978) for postal workers who were training to use a keyboard. In this study, separate groups of postal workers trained for 60 to 80 hours using one of four schedules: work periods were conducted either once or twice per day,

with the duration of each work period being one or two hours. The data for the practice period and for the retention tests showed that the condition that massed the practice the most resulted in the poorest performance and learning. These data appear to suggest that there is some generalizability of the results obtained in experiments of relatively short duration to studies involving practice and retention over much longer periods of time (Schmidt & Lee, 1999).

Clearly, the structure of practice has very important influences on learning. Distributed practice facilitates performance and learning, more than massed practice does.

CHAPTER III

METHODS AND PROCEDURES

Participants

The participants selected for inclusion in this study consisted of 15 volunteers: two groups of five children each, of the ages three years and eight years ($\pm$ six months), and one group of five adults (mean= 26 years, s.d.= 3 years).

All children who served as participants had normally developing speech, language, and hearing skills as reported by their parents and as judged by answers to a questionnaire administered upon arrival at the testing site. In addition to the questionnaire (see Appendix I), all volunteers and/or volunteer's parents completed an informed consent form.

Stimulus Materials

A Sony audiocassette player and headphones were used to present the speech tokens to participants. The tokens were the following five nonsense words: "shub", "sub", "sib", "shib", and "shud". Four of the five nonsense words were stimulus items used in Siren and Wilcox's study (1995). The purpose of the nonsense words was to simulate a first time at production and thus, ensure that all groups upon initiation of the study were equal. The fricative consonants were used for two reasons. One reason they

were used was to try to replicate the findings of the Siren and Wilcox study. Secondly, according to Whalen (1990), fricative productions produce a lot of noise, which makes it somewhat easier to discern between the fricative and vowel in a spectrogram. A single female speaker, at normal talking rate, was used to record the nonsense words. The words were recorded using an Aiwa audiocassette recorder. Participants' speech productions were recorded onto an IBM Laptop computer, using a Sony ECM-250 microphone and WinPitch Speech Analyzing Software (developed by Germain-Rutherford & Martin). The productions were analyzed using the Computerized Speech Research Environment (CSRE) (developed by Avaaz Innovations). For each token, three measurement points of the second formant frequency were located: (a) at vowel onset (VO)- the first full period of voicing, (b) 30 ms prior to vowel onset (VO-30 ms), and (c) the centroid- the average of F2 at vowel onset and at vowel offset. One or two of these measures have typically been used in the previous literature. This study used all three as a way to compare previous results with the results of this study.

Design

The experimental design was a 2 (Test) x 3 (Age) x 5 (Word) mixed design with repeated measures on the factors of Test and Word. The factor Test defined as the time at which coarticulation was measured was within-subject. There were two levels of Test: pre-test-before training and post-test-after training. The factor Age was a between-subject factor with three levels, three-year olds, eight-year olds, and adults. The factor Word, which was the various nonsense words to be uttered, was within-subject.

Procedures

Prior to testing, participants completed a general questionnaire (see appendix I.) The questionnaire addressed issues regarding speech and language disorders and hearing impairments. Only those individuals that reported never having had speech, hearing, or language disorders or abnormalities were chosen. An informed consent form was administered to all eligible participants. Following completion of the informed consent form, participants were assigned a participant number and pre-tested. The pre-test consisted of a pre-recorded audiocassette tape of five nonsense words, each produced five times with three seconds of silence between each word. The entire tape lasted approximately 90 seconds.

Participants were instructed to speak into the microphone and produce the nonsense words just as they were heard on the audiocassette tape. There were ten repetitions of each nonsense word on the audiocassette tape. The testing protocol was scripted so as to ensure that each participant received consistent instructions. Each of the participant productions was recorded on a laptop computer. The productions were digitized using WinPitch speech analyzing software. Following the pre-test, participants were given a copy of the audiocassette tape of the nonsense words presented in the pre-test and a practice log. Participants were instructed to practice the items on the audiocassette tape, producing each item, over three practice sessions. The participants had one week to complete the three practice sessions. In order to maintain that the practice sessions were completed, participants and/or their parents were asked to record each practice session on the log provided. Participants and/or their parents were

instructed to begin the practice session the day following the pre-test. After the practice period, the researcher returned to the testing site to conduct the post-test.

Analyses

The dependent measures of interest were three discrete points of the second formant frequencies (F2). The F2 values were measured at three discrete points across the age groups, organized by word, and by test: (a) at vowel onset (VO), (b) 30 ms prior to vowel onset (VO-30 ms), once the vowel onset time was determined, the researcher counted back 30 ms from that time, and (c) the centroid. In the spectrograms, VO was measured in milliseconds as the time where the first full period of voicing began. Once VO was measured the researcher counted back 30 ms prior to the time noted for VO. This measure was referred to as 30 ms prior to VO. Centroid measures were calculated by averaging the VO time with the vowel offset time.

The variations in mean F2 values between the two types of vowels [I] and [u] and the consonants were examined to provide a measure of interaction (or coarticulation) between the consonant and vowel. Thus, coarticulatory interaction was defined as the effect (based on F2 values) that a vowel ([I] versus [u]) had on the consonant immediately preceding it.

CHAPTER IV

RESULTS

For the measure of F2 30ms prior to VO, the ANOVA revealed significant main effects for Age (2,12) $F=59.21$, $p<.01$, and Word (4,48) $F=22.42$, $p<.01$. The main effect for Test (1,12) $F=1.02$, $p>.05$ failed to reach significance. Importantly, the analysis revealed two interactions. There was a significant interaction for Test x Age, (2,12) $F=6.40$, $p<.01$ indicating that the groups changed differentially over test. The analysis also yielded significant interaction for Age x Word (8,48) $F=8.83$, $p<.01$, indicating that the groups performed differently across words (refer to Figure 4.1 for an illustration of these two findings). The means and standard deviations of the age groups across word and test are in Table 4.1. Duncan's multiple range tests revealed there were significant differences between the three-year-olds, eight-year-olds, and adults on all levels of word across test, except for the production of [sub]. The production of [sub] at pretest was similar for the adults and eight-year-olds, respectively. The Test x Word (4,48) $F=1.28$, $p>.29$ and the Test x Age x Word (8,48) $F=0.93$, $p>.50$ interactions failed to reach significance.

For the measure of VO, the ANOVA yielded significant main effects for Age (2,12) $F=59.21$, $p<.01$, and Word (4,48) $F=22.42$, $p<.01$. The main effect for Test (1,12) $F=1.01$, $p>.05$ failed to reach significance. Like the 30 ms prior to VO measure, the analysis revealed two interactions. There was a significant interaction for Test x Age,

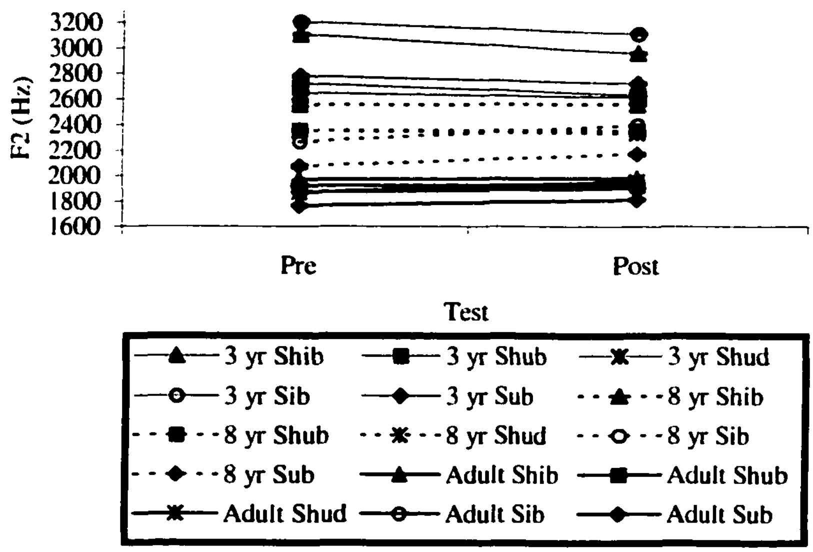

Figure 4.1 30 ms Prior VO: Test x Age Interaction Across Word

(2,12) F=6.40, p<.03 indicating that the groups changed differentially over test and a significant interaction for Age x Word (8,48) F=8.83, p<.01, indicating that the groups performed differentially across words (refer to Figure 4.2 for an illustration of these two findings). The means and standard deviations of the age groups across word and test are in Table 4.2. Moreover, Duncan's multiple range tests revealed there were significant differences between the three-year-olds, eight-year-olds, and adults on all levels of word across test, except for the production of [sub]. The production of [sub] at pretest was similar for the adults and eight-year-olds, respectively. The Test x Word (4,48) F=1.28, p>.29 and the Test x Age x Word (8,48) F=.93, p>.05 interactions failed to reach significance.

For the centroid measure, the ANOVA yielded significant main effects for Age (2,12) F=48.43, p<.01, and Word (4,48) F=27.00, p<.01. The main effect for Test (1,12)

Table 4.1 Means and standard deviations of F2 values (in Hz) measured at 30 ms prior to VO for each word for adults, 8-year old, and 3-year old children across pre-test and post-test. (Standard deviation values are shown in parentheses next to mean values.)

	Adults		**8-year-olds**		**3-year-olds**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
Shib	1971 (270)	1982 (283)	2555 (134)	2561 (140)	3105 (107)	2960 (136)
Shub	1920 (231)	1928 (228)	2357 (167)	2356 (121)	2724 (59)	2634 (100)
Shud	1866 (196)	1958 (205)	2356 (94)	2336 (177)	2646 (121)	2614 (216)
Sib	1873 (154)	1906 (211)	2266 (210)	2403 (69)	3207 (83)	3112 (127)
Sub	1763 (195)	1812 (183)	2072 (352)	2172 (104)	2781 (61)	2721 (124)

$F=1.10$, $p>.05$ failed to reach significance. Like the previous two F2 measures, the analysis yielded two significant interactions. The analysis for Test x Age, (2,12) $F=4.63$, $p<.03$ (Figure 7.4) and Age x Word (8,48) $F=4.26$, $p<.01$ were both significant (refer to Figure 3.4 for an illustration of these two findings). The means and standard deviations of the age groups across word and test are in Table 4.3. Duncan's multiple range tests revealed there were significant differences between the three-year-olds, eight-year-olds, and adults on all levels of word across test, except for similarities among the eight-year-olds and adults on the pre-test productions of [shub] and [sub] and the post-test productions of [shub], [sub], and [shud]. The Test x Word (4,48) $F=1.72$, $p>.16$ and the Test x Age x Word (4,48) $F=1.82$, $p>.14$ interactions failed to reach significance.

Post hoc analyses were conducted to determine the test effect within age groups. For each of the F2 measurement locations, a Word x Test ANOVA was performed. The comparisons from these ANOVAs are presented in Table 4.4. In all cases, three-year-olds and adults differed from pre- to post-test, indicating a learning effect for coarticulation. Subsequently, in all instances the eight-year-olds did not differ from pre-

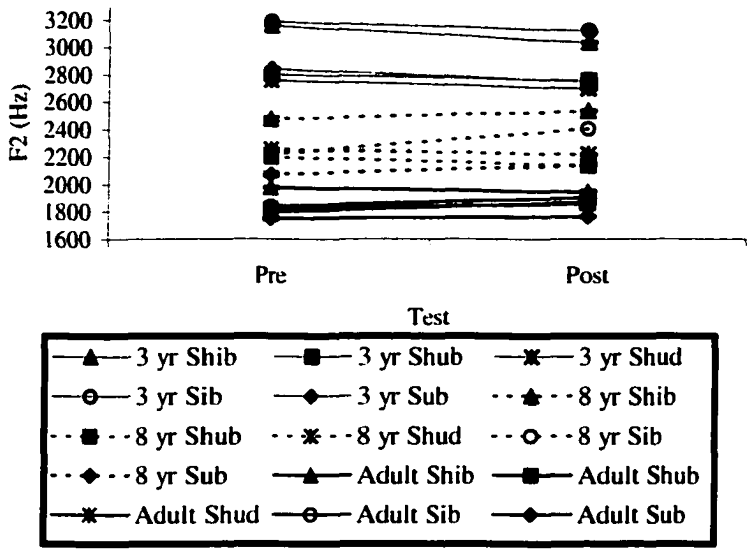

Figure 4.2 VO: Test x Age Interaction Across Word

to post-test. Furthermore, it was observed that the eight-year-olds data was highly variable, potentially leading to the lack of significant findings.

Table 4.2 Means and standard deviations of F2 values (in Hz) measured at VO for each word for adults, 8-year old, and 3-year old children across pre-test and post-test. (Standard deviation values are shown in parentheses next to mean values.)

	Adults		8-year-olds		3-year-olds	
	Pre	Post	Pre	Post	Pre	Post
Shib	1971 (270)	1982 (127)	2555 (134)	2561 (140)	3105 (107)	2960(136)
Shub	1920 (104)	1928 (102)	2357 (167)	2356 (121)	2724 (59)	2634 (100)
Shud	1866 (196)	1958 (205)	2356 (94)	2336 (177)	2646 (121)	2614 (216)
Sib	1873 (154)	1906 (211)	2266 (210)	2403 (69)	3207 (83)	3112 (127)
Sub	1763 (195)	1812 (183)	2072 (352)	2172 (104)	2781 (61)	2721 (124)

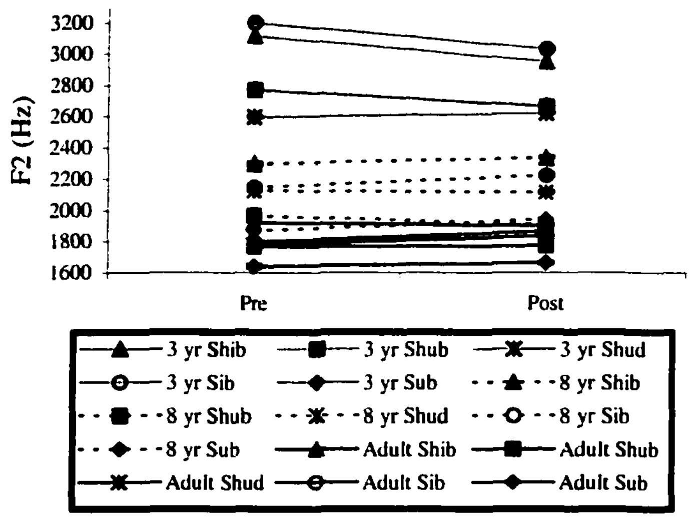

Figure 4.3 Centroid: Test x Age Interaction Across Word

Table 4.3 Means and standard deviations of centroid values (in Hz) for each word for adults, 8-year old, and 3-year old children across pre-test and post-test. (Standard deviation values are shown in parentheses next to mean values.)

	Adults		8-year-olds		3-year-olds	
	Pre	Post	Pre	Post	Pre	Post
Shib	1923 (333)	1902 (368)	2297 (97)	2335 (158)	3120 (60)	2954 (104)
Shub	1771 (326)	1775 (392)	1966 (144)	1905 (112)	2770 (42)	2662 (117)
Shud	1780 (249)	1836 (256)	2131 (173)	2119 (153)	2600 (87)	2624 (255)
Sib	1798 (254)	1868 (225)	2150 (242)	2227 (128)	3205 (85)	3035 (94)
Sub	1640 (308)	1664 (316)	1871 (252)	1943 (199)	2774 (80)	2670 (128)

Table 4.4 Word x Test analysis of variance results at 30 ms prior to VO, VO and centroid.

	30 ms prior to VO	VO	Centroid
3-year-olds	(1,20) F=12.51, p<.002	(1,20) F=12.51, p<.002	(1,20) F=12.75, p<.002
8-year-olds	(1,20) F=1.90, p>.18	(1,20) F=1.90, p>.18	(1,20) F=0.35, p>.56
Adults	(1,20) F=5.95, p<.02	(1,20) F=5.95, p<.02	(1,20) F=6.19, p<.02

CHAPTER V

DISCUSSION

The purpose of the current study was to investigate the developmental trends of coarticulation. As such, this research addressed the question of whether coarticulation is "hard-wired" (i.e., an ability humans have at birth) or the result of learning. This question was investigated by comparing the coarticulation abilities of three year-olds, eight year-olds and, and adults. There were two levels of comparisons. First, the ability of three year-olds, eight year-olds and, and adults to coarticulate with nonsense words were compared. Then, all groups underwent a training protocol with these words and then were retested for coarticulation ability. Several salient hypotheses could be tested using this paradigm. If children as young as three years old showed similar patterns in their speech productions as adults, this would suggest that coarticulation is hard-wired in humans. In contrast, if a young child's productions were not consistent with that of adult productions, but did show patterns that suggested they were approaching more adult-like speech patterns through practice, this would imply there is a learning component involved in coarticulation. Several findings, consistent across all measures, support the hypothesis that there is a learning component to coarticulation. Although the main effect for Test failed to reach significance, probably due to the large differences between the age groups at the initiation of the study, the Test x Age interaction (investigated at each

word) at 30 ms prior to VO, VO, and centroid showed there were differences among the age groups speech productions from pre-test to post-test. Prior to practice, the children's speech pattern did not approximate that of adults. That is, on 30 ms prior to VO and VO pre-test measures, the eight-year-olds and adults productions differed, except on the word [sub]. The three-year-olds productions were different from both the eight-year-olds and adults. The pre-test centroid measure revealed similarities in the production of two words, [shub] and [sub] between the eight-year-olds and adults, while the other four words were different. Again, the three-year-olds productions differed from those of the eight-year-olds and adults. Following practice, however, the child productions were approximating those of the adults.

Follow-up analyses showed that practice significantly influenced the adults and the three-year-olds ability to coarticulate, although not significantly changing the eight-year-old productions. Despite the statistically insignificant practice effect, eight-year olds did exhibited speech patterns that appeared to be approximating that of the adults. At each of the dependent measures, the Test x Age at each word graphs nicely illustrate this.

One possibility for the insignificant practice effects in the eight-year-olds was probably due to the large amount of variability within the age group compared with the other ages. It could be, for example, that an eight-year-old is experiencing a unique period of rapid cognitive development and/or potentially has just undergone structural changes, such as changes in the shape and size of the speech apparatus related to growth, for which cognitively they must readjust. Thus, relative to a three-year-old who has not

lived long enough for this to occur or an adult whose cognitive mechanisms and speech apparatus are largely developed, an eight-year-old is dynamically changing.

Like other studies investigating the notion of a developmental trend of coarticulaton, the present data demonstrated differences in coarticulatory ability between age groups. First, it substantiates the notion of developmental coarticulatory effects across age that had been previously demonstrated by Siren and Wilcox (1995), Nittrouer et al. (1989), and with two-year- to three-year olds, by Goodell and Studdert-Kennedy (1991). Second, and most unique, the current study elucidated the role of practice on speech productions. Specifically, this investigation examined the effects of a distributed practice schedule on speech production, and thus, it investigated a potential learning component involved in speech production. By comparing the speech productions of three-year-olds and eight-year-olds with adults, prior to and following distributed practice, it could be determined if practice and learning play a role in aspects of speech production. As noted, the mean F2 values changed from pre-test to post-test for the three year-olds and adults.

Although maturation effects such, as changes in vocal tract morphology are a potential reason for changes in children's speech productions, this study used a brief (one week) practice session to demonstrate that the changes were cognitive in nature rather than maturational. It is highly unlikely that a child would experience significant changes due to maturation in such a short period of time.

The sum of all the effects in the present study suggest that aspects of coarticulation are influenced by practice and as demonstrated by changes in the three-year-old childrens utterances, may approach mature phonetic structure through practice. Thus, learning is a

salient feature in the development of coarticulation. Although this finding does not completely exclude the fact that there may be other aspects of coarticulation that are hard-wired, this investigation does provide support for the claim that coarticulatory effects between [I] and [u] are influenced by practice.

APPENDIX I

INFORMED CONSENT FORM

INFORMED CONSENT FORM

University of Nevada, Las Vegas, Department of Kinesiology
Motor Behavior Laboratory

1. The principal investigator for this study is Kimberly M. Wieberg, who is a graduate student at UNLV in the Department of Kinesiology.
2. You are invited to participate in a study of speech motor development and human brain function.
3. The purpose of this study is to explore the relationship between age and speech motor development. The effect of practice on speech productions will be used to assess this relationship. Participants in the experimental condition will be given an audiocassette tape of nonsense words to study at home, three times a week, for one week. Participants will then return to the lab. Their productions of the items on the list will then be recorded using a microphone.
4. There are no known risks or discomforts associated with this research. This information is based on a review of past experience with the same or similar tasks. Individual participants will not experience any benefits from this study. Even though no individual benefits occur, participation will help to increase the sum of scientific knowledge on speech motor development.
5. Child participants will be given peel off stickers for participating in this study.
6. Any personal information that is obtained in the course of this study will remain confidential. The results of this study may be published in scientific journals, ,but only statistical data will be published and no individual participant will be identified.
7. If you have any questions or concerns about this research or if you wish information about the rights of research subjects, you may contact the Office of Sponsored Programs, UNLV, at 702-895-1357, or Dr. Mark Guadagnoli, Department of Kinesiology, at 702-895-1241.
8. Participation in this study is entirely voluntary, and you or your child may withdraw from participation at any time. Your decision whether or not to participate or to withdraw will not prejudice your future relations with the University of Nevada, Las Vegas.

Your signature below indicates that you have read the above information and that you are consenting to participate in this research study.

____________________	____________________
Printed Name	**Date and Time**
____________________	____________________
Signature	**Participant Number**

APPENDIX II

HEALTH STATUS QUESTIONNAIRES

CHILD HEALTH STATUS QUESTIONNAIRE

Child's Name:____________________________

Phone Number:___________________________

Child's Age:_________

Child's present grade level (if applicable):________
Does your child read? If so, at what level:________

Has your child been diagnosed with any of the following medical conditions (if yes, please explain in the blank space provided on the bottom of this form):

Any learning disability?_________________

Any speech and/or language disorders?____________________

Any psychological disorder or illness?_____________________

Any head injury that resulted in loss of consciousness for more than 5 minutes?_________

Any head injury or disorder that impairs your child's hearing?_____________

Any vision problem _________ Does your child wear eyeglasses or contact lenses?_____

Do you own an audiocassette (tape) player?____________

ADULT HEALTH STATUS QUESTIONNAIRE

Name:____________________________

Phone Number:____________________________

Age:__________

Highest level of formal education you have completed:

High School_______ Associate's degree________ Bachelor's degree_________

Master's degree_____ Doctorate degree________ Other_______

Have you been diagnosed with any of the following medical conditions (if yes, please explain in the blank space provided on the bottom of this form):

Any learning disability?_________________

Any speech and/or language disorders?____________________

Any psychological disorder or illness?_____________________

Any head injury that resulted in loss of consciousness for more than 5 minutes?__________

Any head injury or disorder that impairs your child's hearing?_____________

Any vision problem __________ Do you wear eyeglasses or contact lenses?_____

Do you own an audiocassette (tape) player?____________

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