



Effect of Phonemic Perception Training on the Speech Production and Phonological Awareness Skills of Children With Expressive Phonological Delay

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Children with expressive phonological delays often possess poor underlying perceptual knowledge of the sound system and show delayed development of segmental organization of that system. The purpose of this study was to investigate the benefits of a perceptual approach to the treatment of expressive phonological delay. Thirty-four preschoolers with moderate or severe expressive phonological delays received 16 treatment sessions in addition to their regular speech-language therapy. The experimental group received

training in phonemic perception, letter recognition, letter-sound association, and onset-rime matching. The control group listened to computerized books. The experimental group showed greater improvements in phonemic perception and articulatory accuracy but not in phonological awareness in comparison with the control group.

Key Words: phonological disorders, phonological awareness, phonological treatment, speech perception

Beckman and Edwards (2000) characterized phonological development as a gradual accumulation of knowledge in the perceptual and articulatory domains. Phonological contrasts emerge from the child's experience with increasingly detailed perceptual and motor representations of words and from the process of mapping between these two domains during phonological encoding and decoding. Edwards, Fourakis, Beckman, and Fox (1999) showed that children with expressive phonological delay have concomitant deficits in both of these domains. It appears that phonetic skills and phonological knowledge are inextricably linked in development and simultaneously implicated in phonological disorders. This perspective provides a justification for situating our treatment practices at the intersection of skills that are traditionally dichotomized as phonetic versus phonological.

Many recent articles have focused attention on phonetic factors in the motor domain. For example, electropalatography studies have shown that children with phonological disorders often produce lingual consonants with

“undifferentiated lingual gestures” (Gibbon, 1999) and electropalatography is showing promise as a treatment tool (e.g., Dent, Gibbon, & Hardcastle, 1995). Other researchers have shown that stimulability is a reliable predictor of phoneme acquisition in spontaneous speech (Miccio, Elbert, & Forrest, 1999). Furthermore, the use of phonetic placement to ensure stimulability for target phonemes improves the success of phonological interventions (Powell, Elbert, Miccio, Strike-Roussos, & Brasseur, 1998; Rvachew, Rafaat, & Martin, 1999). The remainder of this article will be focused on the perceptual domain, beginning with a brief review of speech perception development and a discussion of the relationship between speech perception and speech production deficits.

Phonemic Perception and Phonological Development

A large part of speech perception development occurs during the first year of life, prior to the emergence of the

infant's first words. The infant learns to attend selectively to native-language speech–sound contrasts and the locations of category boundaries between phonemes are adjusted to reflect the standard of the ambient language (Eilers, Gavin, & Wilson, 1979; Werker, 1995). When the toddler begins to encode phonological representations of words in the lexicon, these phonological representations are lacking in phonetic detail (Werker, Fennell, Corcoran, & Stager, 2002). The child's ability to encode the fine phonetic detail of speech improves gradually, most likely as a consequence of repeated exposure to words and the challenge of organizing a lexicon that is growing rapidly in size. Edwards, Fox, and Rogers (2002) asked 3–7-year-old children and adults to identify words that contrasted word-final stop consonants. The words were gated to remove some information about the final consonant, reducing the redundancy in the acoustic cues to word-final consonant identity. They found that preschoolers required more acoustic information than adults and older children in order to recognize words accurately. In both the Edwards et al. (2002) and Werker et al. (2002) studies, the children's performance correlated with vocabulary size rather than chronological age. There appears to be a reciprocal relationship between perceptual encoding and vocabulary growth such that the ability to encode fine phonetic detail permits the expansion of the child's vocabulary and, in turn, the size and structure of the lexicon impacts on the way in which speech is perceived (Edwards, Beckman, & Munson, 2004; Munson, Edwards, & Beckman, in press).

A gradual increase in the amount of phonetic detail that is encoded in phonological representations occurs alongside developmental changes in the structure of these representations. Specifically, children's representations become increasingly segmental in nature. Jusczyk (1992) has shown that infants perceive speech in terms of syllables rather than individual segments. Nittrouer and Studdert-Kennedy (1987) demonstrated that 3-, 4-, and 5-year-old children are more sensitive than adults to formant transitions when identifying fricative-vowel syllables. In contrast, adults attend more to the acoustic cues that are associated with the individual segments rather than to the syllable as a whole (i.e., the spectral characteristics of the steady-state fricative and vocalic portions of the syllable). Phonological representations are gradually restructured to reflect a segmental ordering of individual phonemes during a protracted period that can last into late childhood. Phonological awareness tasks also tap the child's knowledge of the segmental structure of speech. Studies using a variety of phonological awareness tasks have demonstrated that children are able to segment words into increasingly smaller units as they get older, starting with word and syllable segmentation during the preschool period, progressing through onset-rime segmentation at kindergarten age, and ending with the segmentation of individual phonemes in grade school (Byrne, 1998). In a review of studies on word recognition and phonological awareness, Metsala and Walley (1998) concluded that lexical restructuring is a gradual, word-specific process that requires cumulative experience with specific words. Furthermore, the process is driven by the child's rapidly expanding

vocabulary and the resulting need to differentiate words with many similar-sounding neighbors.

The child's gradually increasing perceptual knowledge about phonemes can be linked to improvements in the accuracy and stability of articulation as the child adjusts his or her speech productions to match the acoustic–phonetic characteristics of native language speech-sound categories (e.g., Macken & Barton, 1980; Zlatin & Koenigsnecht, 1976). Nittrouer, Studdert-Kennedy, and McGowan (1989) found that 3–7-year-old children produced /s/ and /ʃ/ sounds that were less clearly differentiated in their acoustic characteristics than did adults. Furthermore, the children produced these fricatives with a greater degree of fricative-vowel coarticulation than did the adults. This result was consistent with their previous finding that children perceive fricatives in a less segmental manner than do adults (Nittrouer & Studdert-Kennedy, 1987). Even among adults, variations in perceptual performance are associated with variations in articulatory precision. For example, Perkell et al. (2003) found that some adults perceived vowel contrasts with a sharply defined boundary between vowel categories while others perceived vowels in a less categorical manner. Measures of tongue height and advancement during the production of these vowels revealed that the degree of vowel contrast during articulation was correlated with vowel discrimination performance. Newman (2003) reported a close relationship between the acoustic characteristics of adult listeners' perceptual prototypes for certain consonant contrasts and the acoustic details of these adults' productions of these phonemes.

Speech Perception and Expressive Phonological Delay

Early investigations of the speech perception skills of children with phonological disorders yielded somewhat conflicting results. Some studies found that these children demonstrated poorer speech discrimination abilities than their normally developing peers (Cohen & Diehl, 1963; Sherman & Geith, 1967), whereas others did not find a relationship between speech discrimination performance and the severity of the child's articulation deficit (Aungst & Frick, 1964; Waldman, Singh, & Hayden, 1978). Even when children with articulation errors were found to perform more poorly on speech discrimination tasks than children without misarticulations, the difference was so small that the functional significance of these findings was questioned (McReynolds, Kohn, & Williams, 1975).

Most of the earlier studies used a speech discrimination task and presented children with adult-produced, prototypical exemplars of the test contrasts. Subsequent research has used more sophisticated methods, partly as a result of technical innovations such as synthetic speech and partly as a consequence of a change in perspective regarding the nature of speech delay. Locke (1980) criticized the use of the speech discrimination task because this procedure does not provide information about the child's underlying phonological representations. A word identification task is more appropriate because it provides insight into the

child's system of underlying phonological contrasts, as well as into the specificity of the child's acoustic-phonetic definition for a given phoneme category.

Subsequent studies using synthetic speech continua and a word identification task revealed that children with speech delay are very likely to have difficulty with the categorical perception of liquid and fricative phoneme contrasts (Broen, Strange, Doyle, & Heller, 1983; Hoffman, Daniloff, Bengoa, & Schuckers, 1985; Rvachew & Jamieson, 1989). It has also been shown that children with phonological delay have difficulty with the categorization of suboptimal natural speech stimuli, such as words recorded from children (Chaney, 1988; Hoffman, Stager, & Daniloff, 1983) or speech that has been digitized and electronically altered to remove cue redundancy (Edwards et al., 2002; Monnin & Huntington, 1974).

Rvachew and Jamieson (1995) reviewed this literature and concluded that these children's perceptual and productive errors reflect a mismatch between the child's phonological knowledge and the adult's system of underlying phonological contrasts. For example, some children lack an underlying phonemic category for phonemes that occur in the native language. Some children appear to be unaware of /ʃ/ as a phoneme, and therefore stimuli containing [ʃ] are assimilated to the /s/ phoneme category during perception and production tasks involving these fricatives (Rvachew & Jamieson, 1989). Other children demonstrate knowledge of a given phoneme contrast but define it in terms of nonstandard acoustic cues. For example, Hoffman et al. (1983) found that /r/-misarticulating children produced target /r/ with a second formant frequency that was midway between the value appropriate for /w/ and the value appropriate for /r/. These same children were apt to categorize words produced with this aberrant second formant frequency as exemplars of the /r/ category, whereas normally developing children and adults perceived these words to be exemplars of the /w/ category. This example is of particular interest to the current discussion because it shows that a child's pattern of articulation errors can be based on knowledge deficits at the level of the phonetic details rather than at the level of abstract phonemic contrast.

The studies cited above show that some children with expressive phonological delay have incorrectly or imprecisely specified underlying representations for phoneme categories. There is also good evidence that these children show delayed development of segmental organization of those representations. Several studies have shown that children with phonological delay have difficulty with phonological awareness tasks, including tapping out the number of syllables or phonemes in a word (Webster & Plante, 1992), matching words that share an onset or a rime (Bird, Bishop, & Freeman, 1995; Rvachew, Ohberg, Grawburg, & Heyding, 2003), and deleting syllables or phonemes from words (Larrivee & Catts, 1999). Recently, we described the phonological awareness skills of over sixty 4-year-old children who were being treated for phonological delay and found that the severity of the child's articulation deficit itself explained no variance in phonological awareness performance. For this group of children, the best predictors of phonological awareness

skills were receptive vocabulary size and phonemic perception abilities (Rvachew, 2003).

Treatment of Phonological Delay

Intervention studies have further illuminated the relationship between speech perception and speech production by showing that the relationship is causal in nature. Jamieson and Rvachew (1992) conducted a single-subject intervention study with 5 children who had expressive phonological delay. The children were taught to identify synthetically produced words that contrasted fricative phonemes such as *seat* versus *sheet* and *sick* versus *thick*. Three children who misarticulated the target phoneme and who learned the word identification task demonstrated improved articulation of the target phoneme, even though no explicit sound production training was provided. A child who demonstrated good speech perception ability prior to training and another who failed to learn the word identification task did not show a treatment-related change in articulation performance.

This study was followed by a study in which 27 preschoolers who were unstimulable for /ʃ/ were taught to identify naturally produced words (Rvachew, 1994). The children were randomly assigned to one of three different conditions. Children in the experimental group learned to categorize correct and incorrect versions of the word *shoe* that were recorded from multiple adult and child talkers. Other children learned to identify well-produced versions of the words *shoe* and *moo*, recorded from a single adult talker. Control group children learned to identify the words *Pete* and *meat*, words unrelated to their articulation errors. All children received traditional articulation therapy targeting the /ʃ/ phoneme in the word-initial position. Posttreatment performance for the word identification task and for articulation of the /ʃ/ phoneme was significantly greater for the experimental group.

Rvachew et al. (1999) reported that the success of children receiving a group therapy program based on the cycles approach (Hodsen & Paden, 1983) could be predicted by pretreatment stimulability and phonemic perception performance for their target phonemes. In a follow-up study, the addition of individual treatment sessions to ensure stimulability and categorical perception of target phonemes prior to group therapy substantially improved the effectiveness of this intervention.

The purpose of the study described herein was to further investigate the benefits of a perceptual approach to the treatment of phonological delay. Thirty-four participants were randomly assigned to the experimental condition or the control condition. All children received their regular speech-therapy program as provided by a speech-language pathologist and an additional computer-based intervention that was administered by a research assistant. The computer-based intervention that was provided to the experimental group taught the children to identify correct and incorrect versions of commonly misarticulated words. Children in the control group were exposed to computer-based books. There were two significant differences between the current study and previous studies that

examined the effectiveness of a perceptual approach to phonology intervention, one relating to the speech production training component of the treatment and the other relating to the outcome measures.

Previous studies used very strict controls over all aspects of the treatment program for both experimental and control group children. However, these laboratory procedures do not replicate typical clinical practice, in which clinicians may change treatment targets and/or treatment approaches as the intervention progresses in response to the needs of the child. The purpose of the current study was to determine if the addition of a perceptual component to the child's treatment program would be valuable under less controlled, more typical clinical conditions.

Furthermore, previous publications have reported short-term outcomes relating solely to the production of target phonemes as produced in nonspontaneous speaking contexts such as picture naming and sentence imitation. In the current study, the outcome measures were expanded in three ways: first, the posttreatment assessment occurred 6 months after the pretreatment assessment and 4–8 weeks after the completion of the child's fall treatment block; second, articulation outcomes were assessed in conversation across a variety of consonant phonemes, including phonemes that were not specifically targeted in therapy; and finally, a measure of phonological awareness was included in our battery of outcome measures. The addition of phonological awareness tasks to the perception training and outcome measurement procedures was made in response to the studies cited above that showed a relationship between phonological delay, phonemic perception, and phonological awareness skills.

Method

Participants

This study was conducted at the Alberta Children's Hospital, which is located in an urban center in midwestern Canada. The participants in this study were 34 children who were scheduled to receive speech therapy from this hospital during the fall of their prekindergarten year. The children were randomly assigned to the experimental group or the control group, each comprising 5 girls and 12 boys.

Socioeconomic status was rated for each child's family by combining the parents' occupation and level of education to yield a Blishen score (Blishen, Carroll, & Moore, 1987). The resulting Blishen scores ranged from 30 (high school not completed) to 76 (professional credentials), with a mean of 53 (some postsecondary education). The children ranged in age from 41 to 59 months on the day of the pretreatment assessment. All of the children had moderate or severe delays in expressive phonological skills, with Goldman-Fristoe Test of Articulation–Second Edition (GFTA-2; Goldman & Fristoe, 2000) percentiles ranging from less than 1 to 6 and percentage of consonants correct in conversation ranging from 30% to 73%. Standard scores on the Peabody Picture Vocabulary Test–Third Edition (PPVT-III; Dunn & Dunn, 1997) ranged from 80 to 135. All children demonstrated average or above average receptive vocabulary skills, except 1 child in the control group who achieved a standard score of 80 on this test. Developmental sentence scores (DSSs) ranged from 1.75 to 7.81, with these scores identifying 67% of these children as having significantly delayed expressive syntax skills. The mean scores and associated standard deviations are shown in Table 1 for each of these variables as a function of group. There were no significant differences between groups for any of these participant characteristics. All of the children passed a hearing screening test. The referring speech-language pathologist reported that their oral-peripheral examination indicated normal oral-motor structure and function.

Procedure

Each child received (a) a pretreatment assessment in the fall of their prekindergarten year; (b) speech therapy directed at the remediation of their sound production errors, with the duration, frequency, and number of treatment sessions determined by the child's treating speech-language pathologist; (c) sixteen 15-min treatment sessions using either the experimental or the control procedures and administered by a student research assistant and the child's parent; and (d) a posttreatment assessment administered 6 months after the pretreatment assessment. The child's group assignment was not divulged to the

Table 1. Means (and standard deviations) of pretreatment participant characteristics and test scores by group.

Participant characteristic	Experimental group		Control group		<i>t</i>	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
SES	55.88	13.59	50.88	13.72	0.86	.40
Age (months)	52.88	3.30	50.29	5.03	1.48	.15
GFTA-2 (percentile)	2.35	2.09	1.94	1.95	0.69	.53
PCC (all consonants)	62.17	8.19	60.19	12.65	0.54	.59
PPVT-III	106.71	12.08	101.24	15.16	1.27	.21
DSS	4.86	1.28	5.04	1.69	–0.35	.73

Note. SES = socioeconomic status (Blishen score); GFTA-2 = Goldman-Fristoe Test of Articulation–Second Edition, percentile rank; PCC = percentage of consonants correct; PPVT-III = Peabody Picture Vocabulary Test–Third Edition, standard score; DSS = developmental sentence score. All between-group comparisons were assessed by two-tailed *t* tests (*df* = 32).

sensorimotor approach targeted specific syllable shapes and incorporated nonspeech oral-motor exercises into her treatment sessions, and the remaining clinicians targeted one or two phonemes until they were mastered and then selected new treatment targets. All clinicians used phonetic placement procedures when necessary. Some clinicians incorporated minimal pairs procedures on a sporadic basis. Auditory bombardment was used in the context of the cycles approach, but those clinicians using a traditional approach did not use ear training or other auditory approaches to the remediation of their clients' speech-sound errors. These clinicians provided session notes to the research team, so that we could determine the number of treatment sessions and the minutes of speech therapy provided, as well as the duration of the treatment program in months. On average, children in the experimental group received 624 min of speech therapy in 12.47 treatment sessions provided over a 4.73-month period. On average, children in the control group received 603 min of speech therapy in 12.38 treatment sessions provided over a 4.75-month period. There were no significant differences between groups with respect to the amount of speech therapy received.

Experimental treatment program. Each child in the experimental group received sixteen 15-min experimental treatment sessions on a weekly basis. Whenever possible these sessions were scheduled to occur directly after the child's regular speech-therapy session. During these sessions, the child played a computer game with the assistance of the parent and/or a student research assistant. In any case, the research assistant was always present in the room to ensure that the parent followed the instructions for the assigned lesson and to provide assistance when necessary. The research assistants provided a written report about each session, including impressions about the child's and parent's interest in the intervention procedures. The authors reviewed these notes weekly and observed sessions periodically to ensure compliance with the program. The computer game was based on the SAILS platform and the basic procedure was the same as described above for the testing of phonemic perception, except that the child was provided with corrective feedback and given another chance to respond to an item if the child at first selected the wrong response alternative. For example, if the child pointed to the picture of the rake when the word *wake* was presented, he or she was told "No, that word did not sound

like rrrake. Listen again." The stimulus item was then re-presented. The first eight lessons focused on one of the following sounds, in order as written, in the word-initial position: /t, p, m, k, l, r, f, s/. The last eight lessons targeted these consonants in the same order, but in the word-final position. Each lesson comprised the same four tasks—phonemic perception, letter recognition, letter-sound association, and onset (or rime) matching. The words targeted by these lessons were as follows: *toe, pea, man, coat, lamb, rope, feet, soap, mitt, top, ham, book, nail, door, knife, and bus*. Table 2 shows the instructions given to the child, using the /s/-initial lesson as an example. The sequence of tasks was repeated three times in each session, providing a minimum of 30 trials for each task.

Control treatment program. Each child in the control group received sixteen 15-min control treatment sessions on a weekly basis. Whenever possible, these sessions were scheduled to occur directly after the child's regular speech-therapy session. The research assistants provided a written report about each session, including impressions about the child's and parent's interest in the intervention procedures. The authors reviewed these notes weekly and observed sessions periodically to ensure compliance with the program. Each lesson was based on commercially available computer-presented stories. The computerized books that were selected for these lessons were three books from the Living Books series, *Just Grandma and Me* (Broderbund Software, Ltd., 1997), *Arthur's Birthday* (Broderbund Software, Ltd., 1994a), *Arthur's Teacher Trouble* (Broderbund Software, Ltd., 1994b), and one from Disney Interactive, *Winnie the Pooh and the Honey Tree* (Disney Interactive, 1995). One quarter of each book was completed during each lesson. Each page of the book, including pictures, text, and an oral reading of the text, was presented by the computer. When auditory presentation of the text was complete, the parent asked the child some questions about the illustration and story following the script developed specifically for the pages covered in the lesson. The parent provided correct responses, if necessary, and then encouraged their child to click different items in the illustrations while commenting on the entertaining visual and auditory consequences. The questions became increasingly complex and abstract during each lesson, with each lesson targeting the following levels, as defined by Blank, Rose, and Berlin (1978): (a) matching perception (e.g., "Click the mailbox."), (b) selective analysis of

Table 2. Instructions and stimuli used for each of the four tasks that composed the experimental treatment session for the /s/ phoneme in the word-initial position.

Task	Instructions	Target stimuli	Foil stimuli
Phonemic perception	Point to the picture of "soap" when you hear the word "soap."	Soap	[top], [tsop], [θop], etc.
Letter recognition	Point to the "s" when you are asked to "Show me the 's'."	Show me the "s".	Show me the "m," "f," "z," etc.
Sound symbol association	Point to the "s" when you hear the snake sound "sss."	"sss"	"mmm," "fff," etc.
Onset identification	Point to the "s" when you hear a word that starts with "sss."	Sun, sick, sad, etc.	Fun, lick, mad, etc.

Table 3. Means (and standard deviations) of posttreatment test scores for measures of phonemic perception, articulation, and phonological awareness skills.

Outcome measure	Experimental group		Control group		<i>F</i>	<i>p</i>	η^2
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>			
Phonemic perception ^a	74.96	8.10	70.13	8.38	9.24	.003	.230
Articulation (single words) ^b	28.06	9.90	37.06	11.76	7.07	.005	.186
Articulation (conversation) ^c	52.79	18.76	37.38	18.30	8.51	.004	.215
Phonological awareness ^d	16.47	11.05	13.76	10.63	0.08	.387	.003

Note. The statistical significance of between-group differences in posttreatment test scores was assessed using analysis of covariance, with the participants' pretreatment test scores entered as the covariate in each case. One-tailed probability values are reported. A large effect size corresponds to a partial $\eta^2 > .138$.

^aSAILS (Speech Assessment and Interactive Learning System, Version 1.2) percentage correct. ^bNumber of errors on the GFTA-2. ^cPCC-difficult. ^dNumber correct on the test of phonological awareness.

perception (e.g., “Where are Grandma and Little Critter going?”), (c) reordering perception (e.g., “What do you think is in Grandma’s basket?”), and (d) reasoning about perception (e.g., “What would happen if Little Critter ran out on the road?”). The lessons did not include any active teaching of phonemic perception, phonological awareness, phonics, or reading.

Posttreatment assessment. The posttreatment assessment was conducted 6 months after the pretreatment assessment. During this assessment, the GFTA-2, the Bird et al. (1995) test of phonological awareness, and the SAILS test of phonemic perception were administered as described for the pretreatment assessment. Another spontaneous speech sample was recorded and then transcribed to yield the PCC.

Results

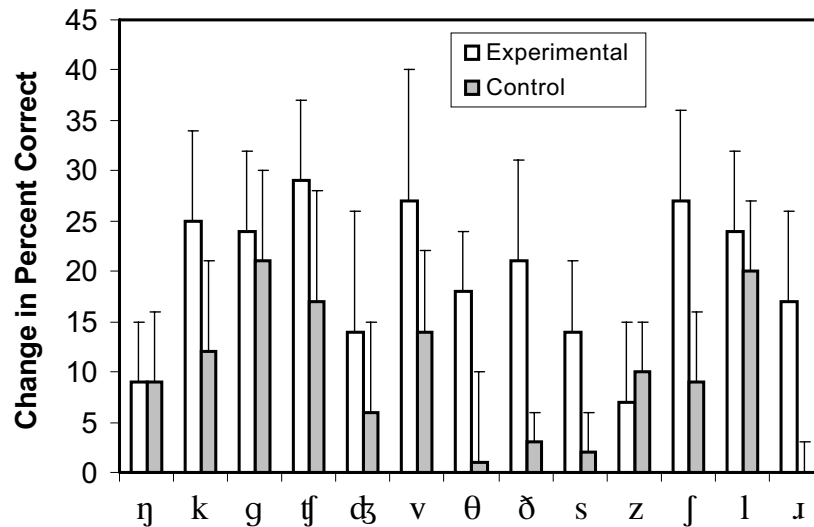
The three outcome measures in this study were as follows: (a) the children’s phonemic perception skills as measured by the SAILS test; (b) their articulation skills as measured by the PCC in conversation for those consonants that were produced with less than 60% accuracy by the majority of the children prior to treatment (i.e., PCC-difficult) and by the number of errors on the GFTA-2; and (c) their performance on the test of phonological awareness skills. The mean posttreatment scores on these assessments are shown in Table 3 along with the associated standard deviations. In each case, between-group differences in posttreatment performance were submitted to analysis of covariance (ANCOVA) with pretreatment performance entered as the covariate and treatment condition being the between-subjects variable (multiple regression analysis was used to ensure homogeneity of regression coefficients before conducting the ANCOVA). The results of these analyses are also shown in Table 3. In addition to these outcome measures, one control variable, namely DSS, was submitted to a repeated measures analysis that indicated no main effect of DSS, $F(1, 32) = 2.41, p = .131$; no main effect of group, $F(1, 32) = 0.02, p = .816$; and no interaction of DSS and group, $F(1, 32) = 0.12, p = .773$. This means that neither group made significant gains in expressive syntax ability, a variable that was not targeted by

either the experimental or the control treatment program or by the children’s regular speech-therapy program. This finding suggests that none of the improvements that are described below can be attributed to generalized maturation of linguistic abilities during the period of the study or to between-group differences in the rate of generalized linguistic development during this time period. The results shown in Table 3 for phonemic perception demonstrate that the children in the experimental group made greater gains in phonemic perception performance than did children in the control group, after controlling for the participants’ pretreatment level of phonemic perception ability.

The results shown in Table 3 for the GFTA-2 (raw score) and for PCC-difficult indicate that the children in the experimental group also made greater gains in articulatory accuracy than did the children in the control group. Figure 1 shows the gains in percentage correct articulation for each of the phonemes that were produced with less than 60% accuracy by the participants during the pretreatment assessment. The remaining consonants were produced with greater than 80% accuracy prior to treatment and therefore provided very little opportunity for change over the course of the treatment. Consequently, these phonemes were not included in our measure of improvements in productive accuracy in conversation. The children in the experimental group showed greater gains in accuracy of articulation for all of these relatively difficult phonemes except /ŋ/ and /z/. Averaged across this set of phonemes, the experimental group showed a 20% increase in PCC-difficult, and the control group showed a 9% increase in PCC-difficult. An ANCOVA revealed that posttreatment PCC-difficult was significantly greater for the experimental group than for the control group when pretreatment PCC-difficult was the covariate.

Figure 2 (upper panel) shows pre- and posttreatment performance on the GFTA-2 as a function of treatment group. Children who received the experimental treatment program made significantly greater gains in articulatory accuracy than did children in the control group, as shown in Table 3. An additional analysis was conducted to determine if improvements in articulation accuracy by each group were mediated by pretreatment phonemic perception

Figure 1. Mean change, by treatment group, in percentage of consonants correct in conversation for consonants that were not mastered by the majority of children prior to treatment (standard error bars shown).



ability. For this analysis, children in each group were classified as demonstrating either good or poor pretreatment phonemic perception, using a criterion of at least 70% correct responses because this level of performance has been shown to be the lower limit of the average performance range for this test among normally developing 4-year-olds (Bagatto, 1999; Rvachew et al., 2003). A factorial analysis of variance (ANOVA) revealed significant differences in posttreatment articulation accuracy as a function of both treatment group, $F(1, 30) = 7.36, p = .010$, and pretreatment phonemic perception ability, $F(1, 30) = 6.76, p = .014$. However, there was no interaction of pretreatment phonemic perception and treatment condition, $F(1, 30) = 0.023, p = .880$. When pretreatment GFTA-2 scores were added as a covariate to this model, it was found that the degree of improvement in articulation accuracy was not significantly related to pretreatment phonemic perception skills, $F(1, 29) = 1.77, p = .190$, and again there was no interaction of pretreatment phonemic perception and treatment condition, $F(1, 29) = 0.06, p = .804$.

Although both groups improved their phonological awareness skills during the 6-month duration of this study, the gains observed for the experimental and control groups were not significantly different, as shown in Table 3. Figure 2 (lower panel) shows pre- and posttreatment performance on the test of phonological awareness as a function of treatment group. This figure highlights the findings revealed by the statistical analysis shown in Table 3: On average, children in both groups made similar gains in phonological awareness ability during the 6-month period of the study. An additional analysis was conducted in order to determine if improvements in phonological awareness by each group were mediated by pretreatment phonemic perception ability, using the same categorization of participants by pretreatment phonemic perception described above. A factorial ANOVA revealed

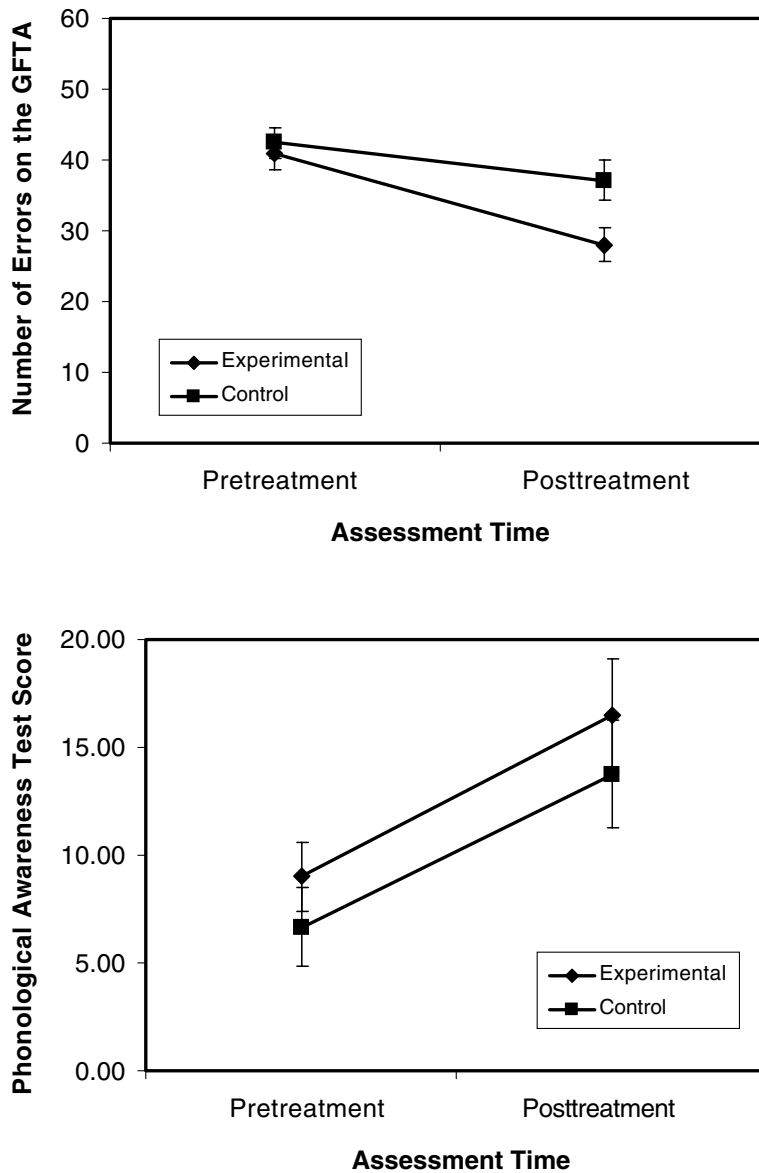
no significant differences in posttreatment phonological awareness as a function of treatment group, $F(1, 30) = 0.47, p = .498$, or pretreatment phonemic perception ability, $F(1, 30) = 2.84, p = .102$, and no interaction of pretreatment phonemic perception and treatment condition, $F(1, 30) = 0.55, p = .466$. When pretreatment PA scores were added as a covariate to this model, it was found that the degree of improvement in phonological awareness was not significantly related to treatment group, $F(1, 29) = 0.06, p = .810$, or pretreatment phonemic perception skills, $F(1, 29) = 1.77, p = .19$, and again there was no interaction of pretreatment phonemic perception and treatment condition, $F(1, 29) = 0.06, p = .804$.

Although improvement in phonological awareness skills was not correlated with pretreatment level of phonemic perception skills, phonemic perception was significantly correlated with absolute levels of phonological awareness at a given point in time. Table 4 shows the correlations between the children's performance on all pretreatment measures and both pretreatment and posttreatment phonological awareness scores. Articulation accuracy was not

Table 4. Correlations between pretreatment SES, age, articulation (GFTA-2 raw scores), expressive syntax (DSS), receptive vocabulary (PPVT-III), phonemic perception (SAILS), and pretreatment and posttreatment phonological awareness (PA) test scores.

Pretreatment variable	Pretreatment PA	Posttreatment PA
SES	$r = .05, p > .05$	$r = .08, p > .05$
Age	$r = .30, p > .05$	$r = .23, p > .05$
GFTA-2 raw score	$r = -.23, p > .05$	$r = -.23, p > .05$
DSS	$r = .33, p > .05$	$r = .15, p > .05$
PPVT-III	$r = .50, p = .002$	$r = .56, p = .001$
SAILS	$r = .45, p = .008$	$r = .37, p = .03$

Figure 2. Number of errors on the Goldman-Fristoe Test of Articulation–Second Edition (upper panel) and number of correct responses on the test of phonological awareness (lower panel) prior to and after treatment (standard error bars shown).



significantly correlated with phonological awareness abilities at either assessment time. Pretreatment phonemic perception and vocabulary skills were significantly correlated with pre- and posttreatment phonological awareness abilities. When considering all possible pre- and posttreatment correlates of posttreatment phonological awareness, the strongest correlate was posttreatment phonemic perception ($r = .59, p = .000$).

Discussion

In this study, an intervention that was focused on the identification of correct and incorrect exemplars of

commonly misarticulated words significantly improved the effectiveness of speech therapy directed at the remediation of children's sound production errors. This study replicates the findings of three previous studies but extends the findings of this research in several respects. Previously, the phonemes targeted by the speech perception intervention corresponded to the targets of the child's speech-therapy program. In this case, every child received the same standard program, targeting /t, p, m, k, l, r, f, s/ in the onset and coda position of words. Furthermore, the program proved to be effective when conducted concurrently with speech therapy that was provided in an uncontrolled manner reflecting typical clinical practice. The speech

perception treatment program was modified, relative to previous studies, to include activities targeting letter name knowledge, letter–sound association, and awareness of onset and rime units. Unfortunately, this intervention was not differentially effective, with both experimental and control group children showing the same degree of progress in phonological awareness skills over the course of the treatment program.

Speech Perception Intervention

The success of the speech perception intervention to improve the children’s phonemic perception skills can be attributed to the extent to which the program adheres to known principles of speech perception learning. In particular, this treatment program is based on a word-identification task and the training stimuli were recorded from multiple talkers who collectively produced both good and poor exemplars of the target phoneme category and good and poor exemplars of the contrasting phoneme category. Guenther, Husain, Cohen, and Shinn-Cunningham (1999) demonstrated these principles in a recent study in which adults were taught to perceive nonspeech stimuli in a categorical manner. The hallmarks of categorical perception are identification performance that reflects a sharply defined perceptual boundary between categories, and discrimination performance that reflects reduced discriminability of within-category stimuli and enhanced discriminability of between-category stimuli, even when the acoustic differences between stimuli are held constant. In a series of experiments, Guenther et al. showed that the following training variables are necessary to the induction of categorical perception: (a) the use of a category identification task (with feedback about the accuracy of responding) rather than a discrimination task and (b) the inclusion of multiple stimuli from the categories being learned, including both prototypical and less prototypical exemplars of the categories. These factors have also been shown to be crucial when training second language learners to perceive nonnative phoneme contrasts. Logan, Lively, and Pisoni (1991) demonstrated that Japanese listeners could acquire categorical perception of the American English /t/ versus /l/ contrast when trained on a word-identification task. Their success contrasted with previous efforts to improve Japanese listeners’ perception of this contrast using a discrimination task (e.g., Strange & Dittmann, 1984). Lively, Logan, and Pisoni (1993) demonstrated that the use of stimuli recorded from multiple talkers during training is essential for successful generalization of new perceptual knowledge to untrained words produced by unfamiliar talkers.

It is interesting to consider the extent to which the typical speech-therapy context does not reflect the training principles illuminated by laboratory research and validated by the clinical research described in this report. Typically, the child receiving speech therapy will be presented with somewhat exaggerated prototypical speech models provided by a single adult talker. Although some trial-to-trial variability in the clinician’s models of the target words will inevitably occur, the child does not receive the kind of

variability in exemplar quality that has been shown to be important for the learning of categorical perception. In fact, Guenther et al. (1999) observed a significant reduction in posttreatment categorical perception performance when participants were presented with only the most prototypical exemplar of the category to be learned during training.

Phoneme Production Learning

The notion that phonology emerges from the integration of information across the auditory and articulatory domains has been expressed across many decades in different forms (e.g., Beckman & Edwards, 2000; Kent & Lybolt, 1982; Van Riper, 1963). Efforts to instantiate this idea in the form of a computational model represent a more recent innovation (e.g., Guenther, 1995; Plaut & Kello, 1999). Guenther (1995) stated that “the true job of the speech production mechanism is the creation of an appropriate set of acoustic signals to convey linguistic units from the speaker to listener” (p. 596). Consequently, his DIVA model of speech-motor control includes an acoustic frame in addition to the phonetic, orosensory, and articulatory frames. Learned mappings between these frames produce simulations of speech behavior that replicate many effects described in natural speech, such as coarticulation and speaking rate effects. In the simulation of babbling, the model’s knowledge of language-specific speech–sound categories shapes the acquisition of appropriate orosensory targets and articulatory behaviors. Guenther (1995) described the babbling simulation as corresponding to “a situation wherein an infant learns when a match occurs between acoustic effects of his or her own productions and sound categories established by listening to the productions of others” (p. 599).

We propose that the phonemic perception intervention described here is effective because it provides the children with more accurate acoustic representations for speech–sound categories, which in turn serve as targets for the child’s articulations. The importance of underlying perceptual knowledge of the sound system to accurate articulation is shown in both pretreatment and posttreatment performance on a picture naming task. Before and after treatment, the best articulation performance was observed for those children with the best phonemic perception skills. However, the rate of progress in articulation ability was significantly faster for those children who received the phonemic perception intervention, regardless of the child’s pretreatment level of phonemic perception performance. Furthermore, this improved rate of articulation learning was also observed in conversational speech.

Phonological Awareness

Phonological awareness refers to the knowledge that spoken words can be segmented into smaller abstract units such as syllables or phonemes. It is an important preliteracy skill and one of the best predictors of success in the acquisition of reading (Torgeson, Wagner, & Rashotte, 1994). It has been shown that children with phonological delay have significant difficulty with phonological awareness during

the preschool period (e.g., Bird et al., 1995; Larrivee & Catts, 1999; Rvachew et al., 2003). Swan and Goswami (1997) proposed that poor phonological awareness skills arise from deficiencies in both “(1) the precision of the phonological specification of the underlying representations and (2) the segmental organization of those representations” (p. 19). The measure of phonemic perception used in this study provides information about the preciseness of the children’s phonological representations while the phonological awareness test provides information about the segmental nature of those representations. The results of this study support Swan and Goswami’s proposal in that children with the poorest pretreatment phonemic perception skills also demonstrated the poorest phonological awareness, and this relative decrement in phonological awareness was maintained for this subgroup throughout the 6-month period of the study. Unfortunately, however, the experimental treatment program that was investigated in this study did not result in a greater level of posttreatment phonological awareness for the experimental group in comparison with the control group.

It is possible that the experimental program was beneficial to the children but that the control intervention was equally effective in improving the children’s phonological awareness skills. In this study and in a descriptive study involving twice as many children (Rvachew, 2003), receptive vocabulary skills were highly correlated with phonological awareness skills, a finding that is fully consistent with the perspective outlined by Metsala and Walley (1998). The control program likely taught the parents to use book reading activities as an opportunity to expand their children’s vocabulary and verbal reasoning skills. However, the mean performance of both groups of participants during the posttreatment assessment of phonological awareness skills is similar to that observed for a group of same-age children with phonological delay who received neither treatment and is 6 to 8 points below that obtained by 4-year-olds with normally developing speech and language skills (see Rvachew et al., 2003).

Any effort to understand the failure of the experimental intervention to have an impact on phonological awareness skills necessarily involves a deep understanding of the nature of phonemic perception and phonological awareness skills and the relationship between these skills. A full discussion of these issues is beyond the scope of this article, but a brief description of the component processes may suffice. As noted above, it has been proposed that imprecise phonological representations of words are associated with deficits in phonological awareness and that our measure of phonemic perception assesses the precision of the children’s phonological representations (McBride-Chang, 1995; Swan & Goswami, 1997). According to some recent theoretical perspectives, underlying representations for individual words are derived from the set of specific exemplars of that word stored in long-term memory (Pierrehumbert, 2002). The quality and precision of any given underlying representation will depend on the child’s access to a large set of stored exemplars (i.e., sufficient input), the ability of the child’s auditory and linguistic systems to encode the acoustic/phonetic

information contained in that input, and the child’s tendency to attend to and encode the most relevant aspects of that input. We believe that the phonemic perception intervention provided the children with appropriate exemplars of certain words and forced them to attend to certain aspects of the acoustic/phonetic input that were previously unencoded by the child, subsequently influencing the encoding of all words containing the targeted phonemes.

Improvements in the precision with which specific words are encoded in long-term memory and in the phonological specificity of the underlying representations for these words do not by themselves lead the child to explicit phonological awareness abilities. A further step is required: The child must reorganize the set of underlying representations contained in the lexicon to reflect similarities and differences among words on the basis of subsyllabic units such as onsets, rimes, and individual phonemes. The extent to which these are separate processes was recently demonstrated by Mayo, Scobbie, Hewlett, and Waters (2003), who reported that improvements in the “categoriality” of children’s perceptual performance preceded phonological awareness while a shift in perceptual focus to segmental rather than syllabic aspects of speech input followed developmental improvements in phonological awareness performance. It may be that it was not a reasonable expectation to remediate both phonemic perception and phonological awareness simultaneously, or that a longer follow-up period is required for the children to demonstrate a reorganization and segmentation of their underlying representations.

An alternative explanation is offered by analogy to the similarly curious situation of the relationship between phonological awareness and reading. Longitudinal and correlation studies imply a clear causal relationship between these variables, but phonological awareness treatment programs conducted with children who have identified reading deficits are not often effective in the remediation of reading deficits per se unless reading is targeted directly and intensively (see Castles & Coltheart, 2004, for a review of this literature). An explanation for this finding was recently put forward by Harm, McCandliss, and Seidenberg (2003) and assessed using a connectionist model. They demonstrated that interventions targeting phonological representations are most effective when they are introduced before or at the early stages of learning to read. When reading instruction is provided prior to the acquisition of segmentally organized underlying phonological representations, an inefficiently organized system of orthographic representations becomes entrenched, and reorganization of the child’s orthographic representations requires explicit teaching. It may well be that our phonemic perception intervention was offered too late in the developmental process to effect change in the segmental organization of representations across the lexicon without more explicit and intensive teaching of the relationships between words that share onsets or rimes.

Other researchers have conducted nonexperimental studies that suggest that deficits in phonological awareness among children with speech delay can be remediated with

explicit and intensive intervention (Gillon, 2000, 2002; Hesketh, Adams, & Nightingale, 2000; Hesketh, Adams, Nightingale, & Hall, 2000). For example, Gillon (2000) investigated the effectiveness of a phonological awareness intervention that was provided in twenty 1-hr sessions over a 4.5-month period. The posttreatment phonological awareness performance of the experimental group was significantly greater than that observed for two nonexperimental comparison groups that received traditional speech therapy or a minimal intervention in the form of consultations with teachers and parents. Furthermore, the phonological awareness performance of the treatment group was similar to that of a comparison group that had normally developing speech and language skills, and the effectiveness of the experimental treatment was maintained over an 11-month follow-up period (Gillon, 2002).

Conclusion

This study compared the effectiveness of two computer-based interventions, one targeting phonemic perception and another targeting vocabulary knowledge, provided as an addition to regular speech therapy. The results replicate three previous studies showing that a phonemic perception intervention significantly improves the effectiveness of speech therapy that is directed at the remediation of children's articulation errors. The pre- and posttreatment assessment results show that there is a relationship between phonemic perception and articulation accuracy and between phonemic perception and phonological awareness. However, the phonemic perception intervention did not improve the children's phonological awareness skills over and above the level of improvement seen in the control group that received an intervention focused on vocabulary and verbal reasoning skills. This finding is consistent with Gillon's (2000, 2002) conclusion that remediation of expressive phonological delay does not automatically lead to the attainment of age-appropriate phonological awareness skills. We are currently conducting another study to determine if the phonemic perception intervention will enhance the outcomes of a more intensive phonological awareness treatment program.

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