The Influence of Phonemic Awareness Development on Acoustic Cue Weighting Strategies in Children's Speech Perception

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In speech perception, children give particular patterns of weight to different acoustic cues (their cue weighting). These patterns appear to change with increased linguistic experience. Previous speech perception research has found a positive correlation between more analytical cue weighting strategies and the ability to consciously think about and manipulate segment-sized units (phonemic awareness). That research did not, however, aim to address whether the relation is in any way causal or, if so, then in which direction possible causality might move. Causality in this relation could move in 1 of 2 ways: Either phonemic awareness development could impact on cue weighting strategies or changes in cue weighting could allow for the later development of phonemic awareness. The aim of this study was to follow the development of these 2 processes longitudinally to determine which of the above 2 possibilities was more likely. Five-year-old children were tested 3 times in 7 months on their cue weighting strategies for a /so/–/ʃo/ contrast, in which the 2 cues manipulated were the frequency of fricative spectrum and the frequency of vowel-onset formant transitions. The children were also tested at the same time on their phoneme segmentation and phoneme blending skills. Results showed that phonemic awareness skills tended to improve before cue weighting changed and that early phonemic awareness ability predicted later cue weighting strategies. These results suggest that the development of metaphonemic awareness may play some role in changes in cue weighting.

KEY WORDS: speech perception, development, cue weighting, phonemic awareness

The purpose of this study was to examine the relation between weighting of acoustic cues in speech perception and the development of metaphonemic awareness. It is well established that speech contrasts are signaled, or cued, by means of multiple different characteristics of the acoustic signal. For instance, a /da/–/ta/ contrast can be signaled by both the duration of voice onset time and the onset frequency of the following vowel formants (Liberman, Delattre, & Cooper, 1952, 1958; Liberman, Delattre, Cooper, & Gerstman, 1954; Repp, Liberman, Eccardt, & Pesetsky, 1978). A number of studies have found that different cues to a speech contrast are not always equivalent in the relative role that they play in signaling that contrast. That is, in determining

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what speech sound they have heard, listeners do not always give equal importance, or weight, to all of the cues available to them (Dorman, Studdert-Kennedy, & Raphael, 1977; Ohde & Haley, 1997; Walley & Carrell, 1983; Wardrip-Fruin, 1982, 1985; Whalen, 1991).

There is also some evidence that patterns of cue weighting are not fixed developmentally. Studies have shown that for certain contrasts adults and children weight acoustic cues differently. Nittrouer and colleagues (Nittrouer, 1992; Nittrouer, 1996a; Nittrouer & Miller, 1997; Nittrouer & Studdert- Kennedy, 1987), for example, have consistently found that in identifying /s/-vowel versus /ʃ/-vowel contrasts children seem to give more weight to vowel-onset formant transitions compared to adults, and relatively less weight than adults to the spectral characteristics of the fricative noise. Other studies have found further differences between children and adults in their relative weighting of acoustic cues (Greenlee, 1980; Krause, 1982; Lacerda, 1992; Morrongiello, Robson, Best, & Clifton, 1984; Ohde & Haley, 1997; Parnell & Amerman, 1978; Watson, 1997; Wardrip-Fruin & Peach, 1984).

Nittrouer and colleagues (Nittrouer, Manning, & Meyer, 1993; Nittrouer & Miller, 1997) have proposed a theory to explain this apparent developmental change in cue weighting strategy. The hypothesis, called the Developmental Weighting Shift (DWS), asserts that "the weights assigned to various acoustic speech parameters change as the child gains experience with a native language, and that this developmental weighting shift is related to developmental increases in sensitivity to phonetic structure" (Nittrouer, 1996b, pp. 1060–1061).

This hypothesis is rooted in theories that propose that the level of detail required to represent lexical items changes with lexical growth (see, e.g., Jusczyk & Derrah, 1987; Studdert-Kennedy, 1987). Within this type of framework, a small lexicon requires only a global or gross-grained level of detail to adequately accommodate and differentiate between all items stored within it. A child's small lexicon can therefore be represented in terms of syllables or monosyllabic words. As the lexicon grows, a more fine-grained level of detail is required to differentiate between all the items. A larger lexicon (such as an older child or adult would have) must therefore be represented in terms of much smaller units, such as segments or possibly features. Studies of children's speech production provide support for this view. Patterns in early child utterances seem to indicate that for children "the word is an entity, stored and accessed as a block" (Menn, 1971, p. 247, see also Ferguson & Farwell, 1975; Menn, 1983; Nittrouer, Studdert-Kennedy, & McGowan, 1989; Studdert-Kennedy, 1987). Children also appear to be more coarticulatory in their production than adults, suggesting that they organize their speech over larger frames (Nittrouer, 1993, 1995; Nittrouer et al., 1989; Nittrouer, Studdert-Kennedy, & Neely, 1996). Over time, however, children's production patterns, "reveal a gradual qualitative shift from a predominance of processes affecting the structure of whole words (consonant harmony, reduplication, final consonant deletion) to those affecting specific segments or classes of segments (stopping of fricatives, gliding of liquids)" (Vihman, 1996, p. 216).

Relating this framework to her perceptual findings, Nittrouer (1996a) suggested that "perceptual strategies for speech may depend largely on the linguistic decision to be made" (p. 295). That is, listeners' perceptual cue weighting strategies are governed by the level of linguistic information they are trying to recover. If they are trying to recover global or gross-grained levels of detail—as it is proposed that young children do—then they should give more weight to acoustic cues primarily associated with more global characteristics of speech. If they are trying to recover more detailed phonetic structure—as it is proposed that adults do—then they should give more perceptual weight to acoustic cues primarily associated with fine-grained characteristics of speech (Nittrouer, 1996a).

Nittrouer and colleagues have gone on to propose that the physical correlates of global or gross-grained characteristics are vowel-onset formant transitions. Nittrouer, Miller, Crowther, and Manhart (2000) noted that these cues are "perceptually salient and delimit signal portions corresponding to syllables" (p. 268), since characteristics of transitions within a CV syllable depend on the place and manner of articulation of both the consonant and the vowel. Physical correlates of fine-grained characteristics, on the other hand, are suggested to be "all the language-specific properties that acoustic/phonetic research has found over the years to correspond to perceived phonetic units" (Nittrouer et al., 2000, p. 268). Therefore, young children make relatively more use of transitional information than adults because they perceive/process speech more globally, while adults make relatively less use of transitional information because they perceive/process speech more analytically.

The "linguistic experience" referred to by Nittrouer and colleagues (Nittrouer et al., 1993; Nittrouer & Miller, 1997) in their definitions of the DWS is taken to mean the lexical growth that occurs as a result of increased exposure to a native language. But, the DWS theory does not rule out the possibility that "increased sensitivity to phonetic structure" and cue weighting changes could additionally be related to other linguistic experiences. In fact, Nittrouer (1996b) investigated the possibility of a relation between cue weighting strategies and phonemic awareness skills.

Phonemic awareness (which is closely tied to alphabetic literacy; see, e.g., Morais, 1991) is the ability to think about and manipulate phonemic segments. For example, the ability to say that *please* is made up of the sounds [p], [l], [i], and [z] in that order is a metaphonemic skill. Someone who has not yet developed this skill will have the ability to think about larger units, such as syllables and onset-rimes, but will not be able to access single segments. That is, he or she will be able to say that *please* has one syllable and rhymes with (shares the rime [iz] with) *sneeze*, but will say that the first sound in *please* is [pl] (the onset) rather than [p] (the first segment). The development of phonemic awareness, therefore, can be seen as a process of becoming able *consciously* to recover fairly detailed segmental information about speech. In this sense it appears to parallel the changes proposed to take place in perception from more global to more analytical levels of attention.

Nittrouer's (1996b) study found that in groups of 8-year-old children with various different social and linguistic histories (low- or mid-socioeconomic backgrounds; with and without significant histories of otitis media), those with poor phonemic awareness skills tended to have more global cue weighting strategies. In contrast, those with good phonemic awareness skills displayed more analytical cue weighting strategies.

This result would suggest that cue weighting changes do not just parallel the development of phonemic awareness, but are related to it. What Nittrouer's (1996b) study was unable to make clear, however, is the exact nature of this relation. As Nittrouer (1996b) pointed out, the cross-sectional design of the study meant that it could say "little about the direction of causality between the development of these processes" (p. 1067). It is possible, therefore, that the development of phonemic awareness should be considered to be one of the linguistic experiences that influence changes in cue weighting. Equally, it could be the case that analytical cue weighting strategies develop as a result of other, nonmetalinguistic, experiences. In this case, the relation observed could be due to the fact that certain developmental changes in speech perception may simply allow for phonemic awareness to develop (see McBride-Chang, 1995a, 1996; McBride-Chang, Chang, & Wagner, 1997).

There are, however, some data from Nittrouer's (1996b) study that could indicate which direction the relation between cue weighting and phonemic awareness might move, if it is indeed causal. For the most part, the results of the study were markedly bimodal: Children with good phonemic awareness skills had very analytical cue weighting strategies, and children with poor phonemic awareness skills had very global cue weighting strategies. However, Nittrouer (1996b) highlighted 2 children who fell outside of these groupings. These 2 participants displayed good phonemic awareness scores but demonstrated global cue weighting. Additionally, there were no participants who showed poor phonemic awareness, but analytical cue weighting. One explanation for this pattern of results is that these 2 children represent an intermediate stage of development between the two larger groups of responses. If this is the case, then it is possible that "discovering syllable-internal structure [i.e., the development of phonemic awareness] may actually create pressure to develop the most effective processing strategies for providing access to that structure" (Nittrouer, 1996b, pp. 1067–1068). Unfortunately, this evidence is too minimal to allow any firm conclusions to be drawn regarding possible causality or the direction of such causality.

The first aim of the current study, therefore, was to determine whether the behavior of the 2 children who showed good phonemic awareness, but global cue weighting, could be replicated. The study then aimed to explore whether children who display this pattern of results could indeed be at an intermediate stage of development between poor phonemic awareness/global cue weighting and good phonemic awareness/analytical cue weighting. To do this, we examined phonemic awareness and acoustic cue weighting within the framework of a longitudinal study. Both the relative speed at which the two processes develop and any predictive relation(s) between the processes should provide evidence to constrain claims regarding the nature and direction of the relation.

The impetus for this investigation was to understand more fully the relation between cue weighting and phonemic awareness. We were interested in the issue of causality in this relation and, in particular, in the direction of any possible causality. It is important to note, however, that we did not aim in this study to establish whether the relation between cue weighting and phonemic awareness is in any way causal. The study will instead simply serve to enlighten arguments regarding possible causal directions.

Method

Participants

Eighteen children participated in this study: 8 female and 10 male. All 18 children were tested at Times 1 and 2 of the study; only 15 were available to be tested at Time 3. All of the children were in their first year of full-time primary education at schools in Edinburgh (Scotland), and all had undergone approximately 6–7 months of reading/reading-readiness training before the study began. In Scotland, children begin formal education when they are aged 4;6 (years;months) to 5;6. At the beginning of the study, therefore, the children ranged in age from 5;2 to 6;0, with an average age of 5;8; at the end of the study the average age was 6;3. This age range was chosen because it covers a period during which one would expect to see the most marked changes in terms of both phonemic awareness (given the extensive reading training that is carried out in the first year of school in Scotland; see guidelines from the Scottish Office Education Department, 1991) and cue weighting (as evidenced by Nittrouer's previous studies of 3–7-year-olds). All of the children were native speakers of Scottish Standard English (SSE; see, e.g., Stuart-Smith, 1999),[1] which is rhotic and has a 12 vowel system. Parental questionnaires determined that none of the children had a history of chronic otitis media (defined as more than three ear infections in the first 3 years of life and/or the implantation of myringotomy tubes; see Nittrouer, 1996b) and that none of the children or their siblings had ever been referred for speech and/or language therapy. All children were required to have passed a pure-tone audiometric screening, in both ears, for the frequencies 250 Hz and 500 Hz (presented at 25 dB HL) and 1000 Hz, 2000 Hz, and 4000 Hz (presented at 20 dB HL). These tests were carried out as part of entry-level hearing screening within the Edinburgh school system. In addition, to ensure that the hearing sensitivity of the children did not change across sessions, no child was tested if he or she was suffering from, or had suffered from at any point in the week preceding the test session, any upper respiratory disease.

To establish cue weighting norms for literate adults for the contrast used in this study, 8 adult listeners (4 female and 4 male) were assessed on their cue weighting strategies. The adults ranged in age from 21 years to 52 years, with an average age of 27 years. All of the adult listeners were native speakers of English, and all had lived in the Edinburgh area for at least 1 year at the time of testing (average number of years = 12). None of the adults reported having hearing deficits or histories of chronic otitis media, and none had ever received therapy for expressive language disorders. Again, none of the adult participants were tested if they were suffering from, or had suffered from at any point in the week preceding the test session, any upper respiratory disease.

Test Stimuli

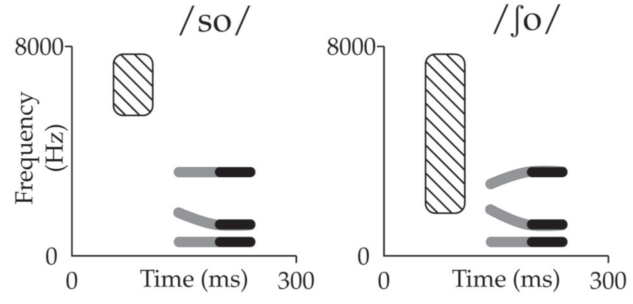
Cue Weighting

The stimuli used for the current cue weighting tests were synthetic /so/–/ʃo/ (*sew–show*) stimuli that varied in terms of the frequency of the fricative spectrum, and the frequency of the formants at vowel onset, both of which are fairly strong cues to the identity of the fricative (see Figure 1). The vowel context (the Scottish monophthongal close-mid-rounded back vowel /o/) is comparable, in terms of the extent of the vowel-onset transitions, to the North American English /u/ used by Nittrouer in her studies (Nittrouer, 1992; Nittrouer & Miller, 1997). This context was used because /u/ as a back vowel does not exist in SSE (Stuart-Smith, 1999).

The creation of the stimuli followed the trading relations design used by Nittrouer in most of her studies of /s/–/ʃ/ contrasts (e.g., Nittrouer, 1992, 1996b; see also Fitch, Halwes, Erickson, & Liberman, 1980). For this type of design, one of the two cues to the contrast is made to vary along a continuum, while the other cue to the contrast takes one of only two forms. For the current study (as for most of Nittrouer's studies), the cue that varied along the continuum was the frequency of the fricative spectrum, which varied from a frequency appropriate for /s/ to a frequency appropriate for /ʃ/. The second cue was the frequency of the vowel-onset formant transitions, and the two forms were (a) onset transitions appropriate for a vowel following /s/ and (b) onset transitions appropriate for a vowel following /ʃ/. By concatenating each of the two vowels onto each point on the fricative continuum, two /s/-vowel to /ʃ/-vowel continua are created. These two resulting continua have identical fricative noises but different vowel-onset transitions, as illustrated in Figure 2. The premise of this methodology is that if a listener's perception is strongly influenced by the vowel-onset transitional information, then his or her category boundaries between /s/ and /ʃ/ should differ depending on the transitions (see boundaries marked in Figure 2). If, on the other hand, a listener's perception is not predominantly influenced by the vowel-onset transitions, then his or her category boundaries should be the same, regardless of the transitions.

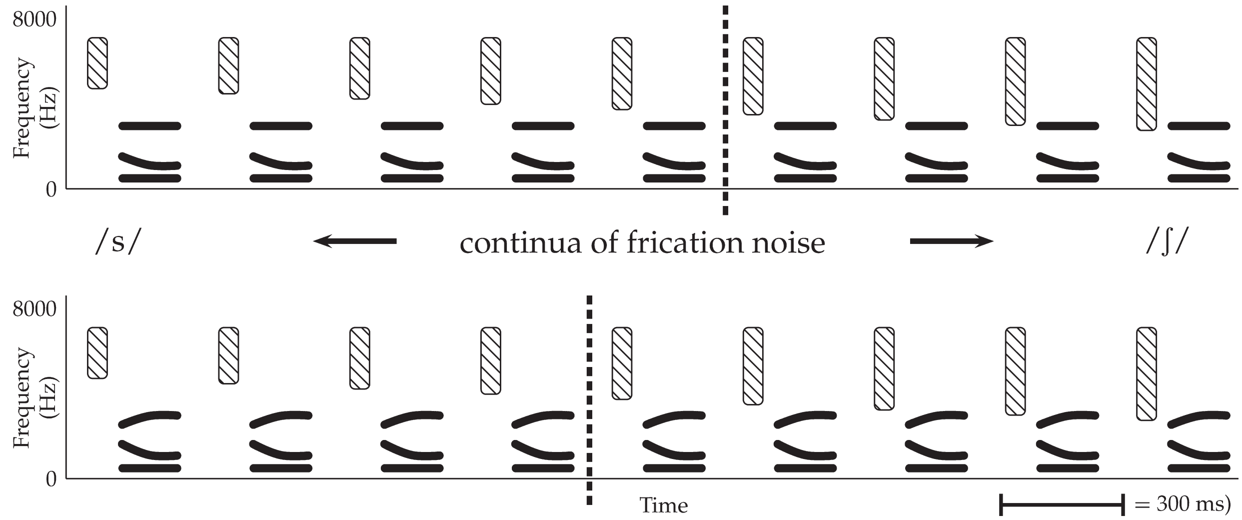
The stimuli used in this study were created using copy synthesis (e.g., Hazan & Rosen, 1991). In this method, highly detailed acoustic analyses are made of

Figure 1. Stylized spectrograms of /so/ and /ʃo/ syllables. Frequencies of the fricative spectra are highlighted with diagonal lines; vowel-onset formant transitions are highlighted in gray.



[1] Six of the 18 spoke a second language in addition to English, to differing degrees of bilingualism, as reported by parents. However, English was the primary language for all 6, and no significant differences in performance were found between these bilingual children and the monolingual children for any of the tests carried out in the study.

Figure 2. Stylized spectrograms of /so/–/ʃo/ continua. The top continuum has /s/-transition vowels, and the bottom continuum has /ʃ/-transition vowels. The dashed lines represent hypothetical category boundaries for a listener whose perception is influenced by the transitions.



natural speech and the resulting values are used to synthesize the stimuli. A native SSE speaker (an adult male) recorded 10 repetitions each of the two target words (/so/ and /ʃo/) in random order. The natural tokens were recorded onto digital audiotape (Sony, Model DTC-60ES) via microphone (Sony, Model ECM-77B) and amplifier (Alice Soundtech Plc, Model Mic-Amp-Pak 2) and were transferred to computer for analysis. The speech was down-sampled to 16 kHz at this point. All acoustic analyses were carried out using ESPS/Waves+ software (Entropic Research Lab Inc., n.d.). The analyses consisted of durational measurements, spectral analysis of the fricative noise, spectral analysis of the vowel formants (eight measurements each were taken from F1, F2, and F3: four from the formant transitions and four from the vowel target), and spectral analysis of F0 (three measurements were made: onset of voicing, midpoint, offset of voicing).

The synthetic test stimuli were created using SenSyn (Sensimetrics Corp., Somerville, MA), a cascade/parallel formant synthesizer (based on Klatt, 1980). Nine different fricative noises were synthesized. Each noise consisted of a single pole of aperiodic noise, varying along a continuum in 200-Hz steps from 2.2 kHz (most /ʃ/-like) to 3.8 kHz (most /s/-like). These endpoint values are consistent with those described in Nittrouer (1992). The amplitude of frication for all stimuli was based on recommendations from Klatt (1980) and was gradient at onset and offset. Measurements from 10 of the 20 natural tokens (five each of /ʃo/ and /so/) were chosen to model 10 synthetic vowels. This follows a strategy adopted by Nittrouer (1992), who used five different natural productions of each transition-plus-vowel to ensure that listeners' responses would not be influenced by idiosyncrasies in any one vowel utterance. Each set of five natural tokens was chosen based on the similarity of vowel formant frequencies and length of transitions. In addition, all 10 tokens were selected based on similarity of vowel target frequencies. For the five /s/-transition vowels, the average vowel-onset formant frequencies were 387 Hz for F1, 1220 Hz for F2, and 2319 Hz for F3, and the average offset frequencies were 387 Hz for F1, 827 Hz for F2, and 2442 Hz for F3. For the five /ʃ/-transition vowels, the average onset frequencies were 387 Hz for F1, 1359 Hz for F2, and 1982 Hz for F3, and the average offset frequencies were 387 Hz for F1, 846 Hz for F2, and 2388 Hz for F3.

Each of the 10 synthetic vowels was combined with each of the 9 fricative noises, resulting in 90 different stimuli. The overall duration of each stimulus was 480 ms, with 230 ms of fricative noise (see Nittrouer, 1992) and 250 ms of vowel. The main change in formant frequencies associated with the transitions occupied the first 75 ms of each vowel, with any residual frequency change generally completed by 125 ms into the vowel. The amplitude of voicing for all stimuli was based on recommendations from Klatt (1980) and was constant from the beginning of the vowel for 185 ms, with a gradient offset over the last 65 ms. F0 for each token began at 160 Hz at 230 ms (the onset of voicing), rose to 180 Hz at 355 ms, and then fell to 100 Hz at 480 ms.

Phonemic Awareness

Phonemic awareness was tested by means of two tasks. The first task was phoneme segmentation, in which the participant is required to divide a specified word into a sequence of separate phonemes (e.g., *please* is [p], [l], [i], [z]). The second task was phoneme blending, in which the participant is required to resynthesize a number of separate phonemes into a single word (e.g., [p], [l], [i], [z] is *please*).

All of the words selected for the phonemic awareness tests were real words that had appeared five or more times in the CHILDES database (MacWhinney, 1995). A number of factors have been shown to affect performance on phonemic awareness tests, namely: the type of phonemes to be manipulated (i.e., stop, fricative, nasal, vowel); placement of these different types of phoneme within words (i.e., word-initial, word-medial, word-final); total number of phonemes in a word; number of consonants in a consonant cluster; placement of consonant clusters; and possible phoneme–morpheme confounds for /t/, /d/, /s/, and /z/ in word-final position (McBride-Chang, 1995b). Therefore, to the extent possible within the constraints of the database, the test items were chosen to be balanced within tests for the type and placement of phonemes. No words with word-final /t/, /d/, /s/, or /z/ were used if these sounds possibly could be mistaken for past tense or plural morphemes (e.g., a child unfamiliar with the word *cord* could construe this as the past tense of the nonsense word [kɔr]). The total number of phonemes in each test word was manipulated deliberately (i.e., was increased throughout each test) to maintain a reasonably high level of difficulty throughout the longitudinal testing period. Both tests had 50 test items each: 20 three-phoneme words, 20 four-phoneme words (CCVC and CVCC), and 10 five-phoneme words (CCVCC and CCCVC). The four-phoneme words were balanced for the position of the clusters. The five-phoneme words were predominantly CCVCC, with only 3 words in the blending test and 4 in the segmentation test of the configuration CCCVC.

The stimuli for both tests (including practice and pretest stimuli) were recorded for presentation to the participants by a phonetically trained, native SSE speaker (an adult male). The speaker was instructed to produce all words clearly and to produce all individual voiceless phonemes without a following schwa (e.g., [s], [t], [p] rather than [sə], [tə], [pə]).

Procedures

Test materials were presented at a listening level that each participant indicated was comfortable. The stimuli were presented via headphones (frequency response approximately 20 Hz to 20 kHz) from a portable MiniDisk player (Sony, Model MZ-R3). For the child participants, the signal was split to two headphones, and the presentation of the stimuli was monitored by the experimenter throughout to ensure that the chosen listening level was indeed both audible and comfortable. Each participant was tested individually in a quiet room. In the case of the children, this room was the library in their respective schools (three schools participated; statistical analyses subsequent to testing showed no difference in performance due to school/room). To maintain a fairly consistent listening environment for all participants, the adults were also tested in a similarly quiet but not soundproof room.

Child participants were tested three times over the course of 7 months, with testing taking place at Months 1, 4, and 7. This was frequent enough to give a picture of the fairly rapid development of the two processes in question, without causing retest effects. The testing for the child participants was spread out over two 20–30-min sessions on consecutive days, with both cue weighting and phonemic awareness being tested on each day. Testing for the adult participants took place in one 30–45-min session, with a short break halfway through testing. The adults were tested only on their acoustic cue weighting strategies.

Cue Weighting

Cue weighting testing always preceded phonemic awareness testing. This was done so that the children were not encouraged by the phonemic awareness tests to adopt any unnaturally analytical processing strategy that might influence their performance in the perceptual tests. The children were introduced to the target words *sew* and *show* by means of a short story (recorded by the same SSE speaker who had made all previous recordings) and an accompanying picture book. A synthesized version of the story was also presented to familiarize the children with computer-generated speech. Pictures from the story corresponding to the two target words were used to elicit the children's responses: They indicated which of the words they had heard by placing a counter on the appropriate picture and saying which word they had heard. Before testing, the children were given a brief practice session with corrective feedback to ensure they understood the task. The stimuli used in this practice were natural tokens of the two words, presented (unrecorded) by the experimenter. The adult participants did not listen to either version of the story or to the unrecorded natural tokens of the two target words. Instead, they were told that they would hear repetitions of the two words *sew* and *show* in random order, and were instructed to indicate which one they had heard by placing a tick in a box on a form provided.

A pretest was administered to both child and adult participants. This test consisted of the endpoints of the fricative continua with the appropriate vowel-formant transitions for each fricative. These were the 3.8-kHz noise plus vowels with an /s/ transition (the most *sew*-like stimuli) and the 2.2-kHz noise plus vowels with an /ʃ/ transition (the most *show*-like stimuli). There were 10 stimuli in the pretest (5 vowels in each transition condition), which were presented in random order. All listeners were required to identify 9 of the 10 pretest stimuli correctly for their results to be included in analysis. For the main test, five different randomizations of the 90 stimuli were generated, and each randomization was split into nine blocks of 10 stimuli for presentation. All participants heard the entire set of 90 stimuli twice (in two different random orders), resulting in 180 responses per participant and 10 responses per transition type for each point on the fricative continuum. All listeners were required to respond correctly to at least 8 of the 10 continuum endpoints (i.e., the stimuli presented in the pretest) for their results to be included in analysis. These criteria, and those described for the pretest, were used to eliminate any listener who was unable to perform the task.

Consistent with the procedure adopted by Walley and Carrell (1983), the interstimulus interval was not fixed for presentation of the perceptual stimuli to the children. Instead, the experimenter (who monitored the stimuli via headphones) paused the presentation briefly after every stimulus to allow the children sufficient time to respond. A bell indicated the end of each block of 10 stimuli, at which point the children were allowed to choose a small prize (a sticker). The interstimulus interval for presentation to the adults was fixed at 3 s, and the interblock interval was set at 5 s.

Phonemic Awareness

The phoneme blending task was always presented before the phoneme segmentation task. This sequence was adopted because the practice session for the phoneme segmentation task made reference to stimuli from the phoneme blending task, as described below. Before testing, the children were introduced to a puppet that "says every word all broken up into little bits." For the phoneme blending test, the children listened to a word as the puppet would say it (i.e., segmented into phonemic units) and were asked to guess what word the puppet had said (i.e., blend the segments into a single word). A correct response was simply the correct identification of the segmented word, with all the phonemes present and in the correct order. For the phoneme segmentation test, the children were asked to say a word "all broken up into little bits" (i.e., segmented into phonemes) as the puppet had said it in the previously presented phoneme blending task. A correct response was one in which all phonemes were segmented from each other and were presented accurately and in the correct order. If the child segmented the word into units larger than the target units (e.g., onset-rime, rather than phoneme) then they were encouraged to "try to break the word up into even smaller bits." Only phoneme sounds were accepted as answers. If responses were given as letter names, then the child was encouraged to respond again, using sounds only. There was some flexibility in terms of what was considered an accurate response: Diphthongs were allowed to be segmented as either one phoneme or two (e.g., *mouse* = [m], [aʉ], [s] or [m], [a], [ʉ], [s]), dialectal variation was allowed (e.g., *train* = [t], [r], [e], [n] or [ʧ], [r], [e], [n], and both phonetic and phonological approaches were accepted where appropriate (e.g., *space* = [s], [p], [e], [s] or [s], [b], [e], [s]). A clear silence between segments was required for the sequence to be considered to have been segmented.

Both phonemic awareness tasks were introduced and explained by one experimenter. The same experimenter also presented the tasks and transcribed all of the children's responses. In each case, the experimenter asked the child to listen to the recorded stimuli and to perform the required manipulation (e.g., the experimenter would say, "Can you break this word up into little bits?", followed by the recorded voice saying, "pig"). Before testing, the children were introduced to the concept of the relevant metalinguistic manipulation for each task. This practice period began with manipulation of syllable-sized units (e.g., *cowboy* = [kaʉ], [bɔi]) and moved to gradually smaller units (i.e., onset-rime units followed by phonemes). The children received feedback on their performance throughout this practice.

The children were required to perform a pretest relevant to each of the tasks. For both tasks, the manipulation required at this pretest level involved onset-rime awareness only. For example, for the phoneme blending pretest, the children could be asked to blend [k], [aʉ] into *cow*, but not [k], [a], [t] into *cat*. Each child was required to manipulate at least one pretest item correctly to continue to the main test. For the main test, the stimuli were split into two balanced sets for each task. The words in each set were presented in order of increasing number of phonemes, and thus increasing difficulty (McBride-Chang, 1995b). If any child was unable to manipulate five out of six consecutive stimuli correctly, then that test was discontinued. This presentation procedure was arranged to avoid causing any children undue discomfort in the event that their phonemic awareness skills were not well developed at the onset of testing. Presenting the stimuli in order of increasing difficulty and discontinuing testing after a certain number of incorrect answers avoided prolonged testing of any child who was unable to perform the required task. Unlike for the cue weighting tests, failure to pass the pretest criteria or complete both main tests did not result in exclusion from the study.

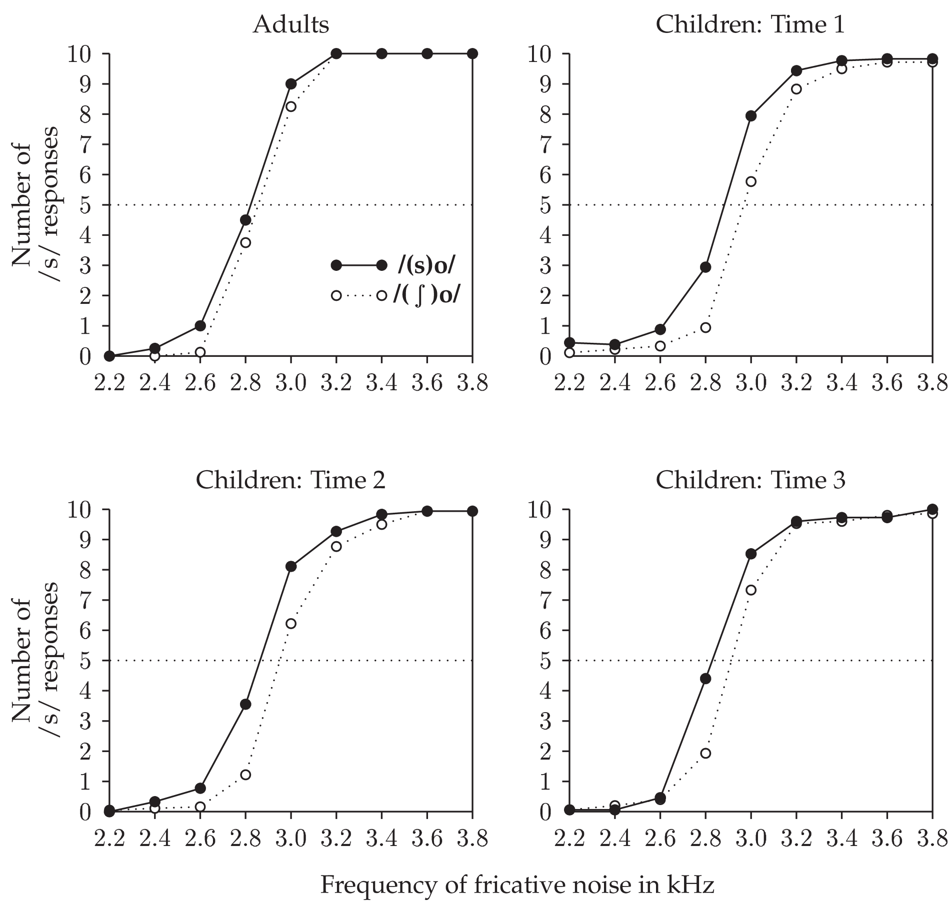
Results

Cue Weighting

The data from the cue weighting tests were normalized using a probit transformation (e.g., Nittrouer & Studdert-Kennedy, 1987). This transform assumes data on an S-shaped curve, from which it extracts rate-of-change information (i.e., in this case, the rate at which a listener's responses changed from mostly /ʃ/ to mostly /s/). Probit analysis yields estimates of values that can be used to describe each set of response curves (Cohen & Cohen, 1983). These values are the *mean*: the point along the fricative continuum at which the /s/ responses reach 50%, and the *slope*: the degree of categoriality of each individual response curve. The degree of *separation* of the response curves can also be calculated by taking the difference between the means for the continuum with /s/ transitions and the continuum with /ʃ/ transitions. This gives a measure of the extent to which the participant's category boundaries were shifted as a result of the presence of the two different sets of formant transitions. Separation of the response curves can therefore be seen as representative of the *transitional effect* (i.e., the extent to which the participant attended to, or weighted, the transitional information). Separation is reported in kilohertz, which corresponds to a frequency difference in the placement of category boundaries along the /s/–/ʃ/ continuum. A separation of 0.05 kHz for a given listener, for example, means that to change from predominantly /ʃ/ responses to predominantly /s/ responses, that listener required the frication noise to be 0.05 kHz higher for /ʃ/-transition stimuli than for /s/-transition stimuli. Slope is reported in terms of change in probit units per unit of frication noise.

The average perceptual response curves for the 8 adults, the 18 children at Times 1 and 2, and the 15 remaining children at Time 3 are shown in Figure 3. The children's response curves at Time 1 were shallower and more widely separated than those of the adults. The average separation of the adults' response curves was 0.06 kHz, while the average separation for the children was 0.13 kHz. The average slope of the response curves

Figure 3. Adults' and children's responses to /ʃo/–/so/ stimuli with /s/ transitions (solid line) and /ʃ/ transitions (dashed line) as a function of frequency of frication noise, ranging from 2.2 kHz (most /ʃ/-like) to 3.8 kHz (most /s/-like).



was 1.578 for the adults and 1.173 for the children (a higher number indicates a steeper slope). Analyses of variance (ANOVAs) with the measures of slope and separation as dependent variables and age (i.e., adult or child) as the independent variable yielded significant differences for both: separation [$F(1, 24) = 6.42, p = .01$], slope [$F(1, 24) = 4.25, p = .05$].

Over the subsequent two sessions, the children's responses became less widely separated. The average separation at Time 2 was 0.11 kHz, and at Time 3 it was 0.07 kHz. ANOVAs, with separation as the dependent variable and time (i.e., Time 1, 2, 3) as the independent variable, yielded a significant change in separation of response curves from Time 1 to Time 3 [$F(2, 48) = 3.24, p = .04$]. There was no significant difference in slope across the three sessions. This decrease in separation of response curves meant that over the course of the three sessions, the children's responses became more similar to those of the adults. The significant difference (noted above) between adults and children at Time 1 for both slope and separation remained significant at Time 2: separation [$F(1, 24) = 3.95, p = .05$]; slope [$F(1, 24) = 5.92, p = .02$], but not at Time 3. The fact that the difference in perceptual responses between adults and children remained significant until Time 2 raises the possibility that the majority of the change in the children's cue weighting strategy took place after Time 2.

ANOVAs, with separation as the dependent variable and day of testing and time as independent variables, yielded a significant difference in perceptual behavior across the three sessions. No significant differences in behavior were obtained across the different days of testing. These combined findings indicate that changes in perceptual behavior were due to differences from session to session, rather than day-to-day variation.

Phonemic Awareness

The mean scores for the phonemic awareness tests across all three sessions are shown in Table 1. There was a progressive increase in phonemic awareness ability across all three sessions, with the largest increase occurring between Time 1 and Time 2 for both tasks. The two measures of phonemic awareness correlated very highly with each other within all sessions.

ANOVAs, with both phonemic awareness measures used as dependent variables and time as the independent variable, confirmed that there was a significant change in ability for both measures between Time 1 and Time 3: blending [$F(2, 48) = 3.983, p = .025$]; segmentation [$F(2, 48) = 6.865, p = .002$]. The change in phonemic awareness ability was significant between Time 1 and Time 2: blending [$F(1, 34) = 4.077, p = .05$]; segmentation [$F(1, 34) = 5.762, p = .02$], but not between Time 2 and Time 3. This finding suggests that the majority of phonemic awareness development took place before Time 2. In comparison with the results of the cue weighting tests, phonemic awareness ability appears to develop before extensive changes in cue weighting take place.

Table 1. Phonemic awareness test scores and correlations for blending and segmentation skills evaluated at times corresponding to 1, 4, and 7 months in developmental test period.

Time	Blending[a]	Segmentation[a]	*r*
1	28	25	.8942*
2	39	36	.7898*
3	41	42	.8690*

[a] Raw scores shown are based on a maximum score of 50.

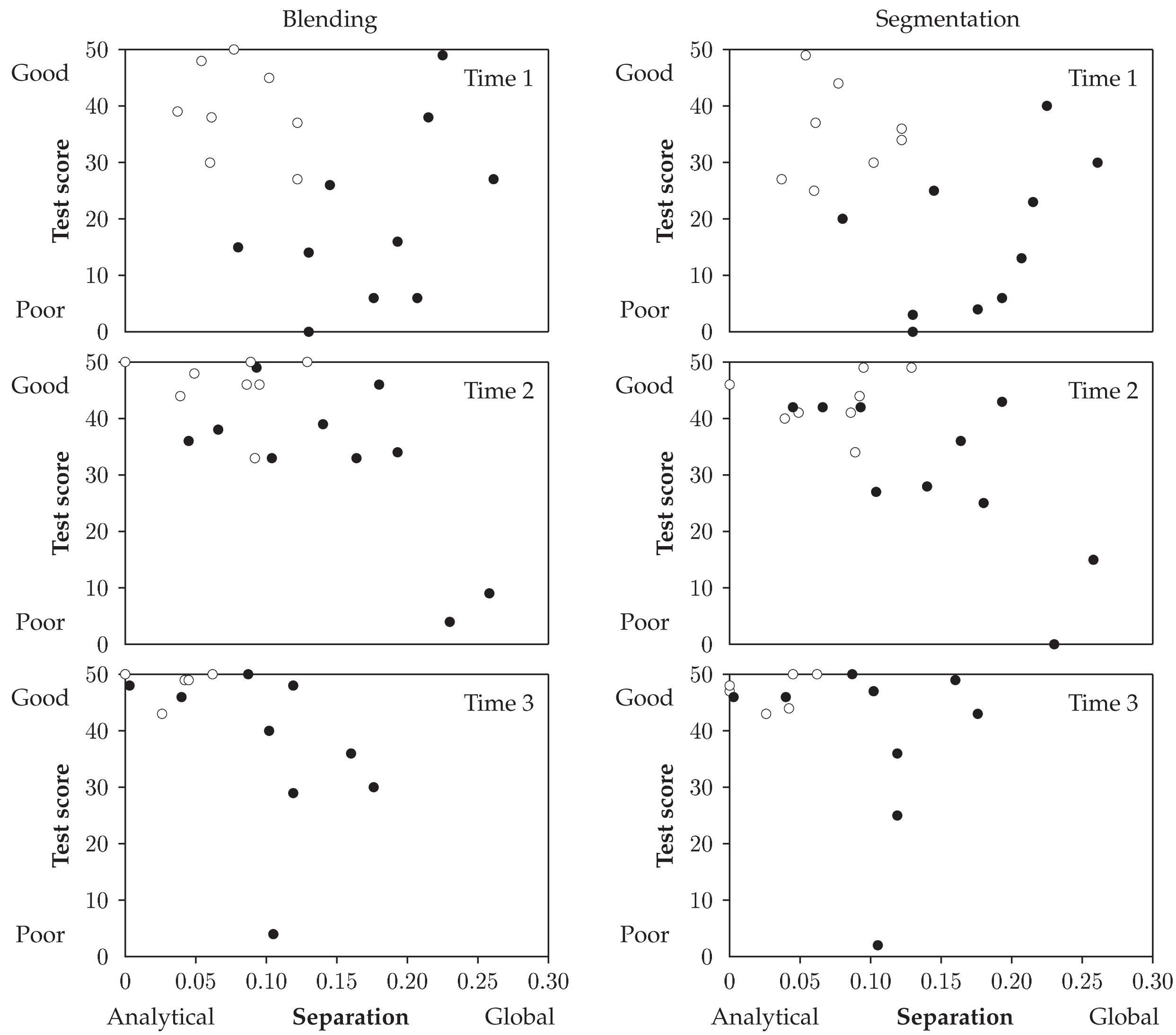
*Correlation values are significant at $p < .001$.

Relation Between Cue Weighting and Phonemic Awareness

The relation between cue weighting and phonemic awareness for the children at Times 1, 2, and 3 is shown in Figure 4. An analytical cue weighting strategy is characterized by a smaller influence of transitional information and, thus, by a smaller separation of response curves. Progress from relatively global to relatively more analytical cue weighting is, therefore, indicated by movement from the right half to the left half of the graphs in Figure 4. For all three sessions, there were children with both good phonemic awareness and analytical cue weighting strategies (top left corner), and for the first two sessions there were children with both poor phonemic awareness and global cue weighting strategies (bottom right corner). There were also a number of children with very good phonemic awareness skills who displayed very global cue weighting strategies (top right corner), but few children who had poor phonemic awareness and very analytical cue weighting strategies (bottom left corner). This response pattern suggests again that phonemic awareness develops before changes in cue weighting take place.

The movement of data points from Time 1 through Time 3 is similar to that seen for any individual session of the study. There was a general tendency for phonemic awareness to improve early on, while analytical cue weighting tended to develop later (i.e., the data points moved upward from Time 1 to Time 2 and leftward from Time 2 to Time 3). This pattern can even be seen in those children who began the study with above average phonemic awareness skills and relatively analytical cue weighting (see the open circles in Figure 4). Although

Figure 4. Relation between cue weighting and phonemic awareness for children evaluated developmentally over a period of 7 months at Times 1 (Month 1), 2 (Month 4) and 3 (Month 7). Phonemic awareness measures are displayed by raw test score as a function of cue weighting displayed by separation of response curves. Blending and segmentation measures of phonemic awareness are shown in the left and right columns, respectively. Open circles represent children who began the study with above average phonemic awareness and fairly analytical cue weighting (the same children are highlighted for both sets of graphs).



their scores at Time 1 fell roughly within the "adult" range for both processes, these children tended to show improved phonemic awareness at Time 2, and more analytical cue weighting at Time 3 than at Time 2. In contrast, none of the children in the study developed strongly analytical cue weighting strategies (i.e., comparable to those of the adults, who showed an average separation of 0.06 kHz) while still having very poor phonemic awareness skills.

We can account for 72% of the variability of the separation measures at Time 3 by a combination of separation at Time 2 and the phoneme blending skills measured at Time 1 and Time 2 [R^2 = .72, $F(3, 11) = 9.497$, p = .002]. Each of these variables made a unique contribution in explaining the variability: Separation at Time 2 accounted for 16.75% (of the 72%) [β^2 = .1675, p = .007]; blending at Time 2 accounted for 34.65% [β^2 = .3465, p = .01]; blending at Time 1 accounted for 48.6% [β^2 = .4860, p = .003]. None of the variability of separation measures at Time 3 can be accounted for by any combination of phoneme segmentation measures. By contrast, none of the variability of either phoneme blending or phoneme segmentation measures at Time 3 was accounted for by measures of separation in previous sessions of the study. For measures of blending at Time 3, 81% of the variability was accounted for by blending at Time 2 [$R^2 = .81, F(1, 13) = 57.815, p < .0001$]. When measures of response curve separation at Time 1 and Time 2 were added, however, neither made a unique contribution to phoneme blending at Time 3. Similarly, 83% of the variability in segmentation measures at Time 3 was accounted for by segmentation measures at Time 2 [$R^2 = .83, F(1, 13) = 63.553, p < .0001$]; however, response curve separation did not make any meaningful contribution to the variability of phoneme segmentation skill.

Interestingly, the relation between the slope of the children's response curves and the phonemic awareness measures shows a different pattern from that seen in the relation between separation and phonemic awareness. As noted above, 83% of the variability in segmentation measures at Time 3 was accounted for by segmentation measures at Time 2. If the slope of the response curves at Time 1 and Time 2 are added, 89% of the variation in segmentation measures at Time 3 can be accounted for [$R^2 = .89, F(3, 11) = 30.48, p < .0001$], with slope making a unique (though very small) contribution to the variability: Segmentation at Time 2 accounted for 80.71% (of the 89%) [$\beta^2 = .8071, p < .0001$]; slope at Time 1 accounted for 9.17% [$\beta^2 = .0917, p = .04$]; slope at Time 2 accounted for 10.12% [$\beta^2 = .1011, p = .03$]. However, none of the variability in phoneme blending measures could be accounted for by any combination of measures of slope.

These analyses of the relation between cue weighting and phonemic awareness support the findings described above for each individual measure separately. Phonemic awareness appears to develop before any extensive cue weighting changes take place, and early phonemic awareness appears to make some contribution to the state of later cue weighting strategies.

Discussion

The first aim of this study was to replicate the behavior of 2 participants from Nittrouer's (1996b) study of cue weighting and phonemic awareness. The 2 children in that study were found to have developed good phonemic awareness skills while still displaying global cue weighting strategies. This unique set of findings lead Nittrouer to suggest that the development of phonemic awareness might be a factor in changes in cue weighting. In the present study we have demonstrated that the behavior of Nittrouer's 2 participants was not anomalous. There were a number of participants who began this study with good phonemic awareness skills and very global cue weighting, while there were almost none with poor phonemic awareness and analytical cue weighting (see Figure 4). In fact, no participants demonstrated poor phonemic awareness and extremely analytical cue weighting.

Our second aim was to determine to what extent this pattern of results is indicative of an intermediate stage of development between poor phonemic awareness/global cue weighting and good phonemic awareness/analytical cue weighting. The present study shows, first, that all of the children developed in terms of both their phonemic awareness ability and their cue weighting strategies over the course of the study. The latter is especially notable because this is the first time that the change from global to analytical cue weighting strategies has been observed longitudinally. More important, however, is the relative time scale at which these two processes developed. Better phonemic awareness skills tended to develop before cue weighting strategies changed. That is, it appears that the relation between phonemic awareness and cue weighting observed in the 2 children from Nittrouer's (1996b) study, and in the first session of the current study, holds throughout development. Statistical analyses backed this up. There was a significant increase in phonemic awareness ability between Time 1 and Time 2, but no significant difference in ability between Time 2 and Time 3. For cue weighting, the children's strategies were significantly different from those of the adults at both Time 1 and Time 2, but by Time 3 the children and the adults were no longer significantly different. A similar pattern can be seen in the relation between the two processes: 72% of the variance seen in the participants' cue weighting strategies at Time 3 could be accounted for by a combination of cue weighting strategies at Time 2 and phoneme blending ability at both Time 1 and Time 2 (with all three measures making a unique contribution to the variability).

Finally, it is noteworthy that although phoneme blending ability was found to predict cue weighting, as measured by separation of response curves due to transitional context, the categoriality (slope) of listeners' responses was found to predict a small, but significant amount of the variation in phoneme segmentation ability. The fact that these two different patterns of influence were found suggests that observable changes in perceptual behavior may reflect the development of multiple different underlying processes. Some changes in speech perception, such as a change in categoriality of responses, might reflect a more general maturation of ability to categorize sounds, which would be necessary for the development of phonemic awareness. Other changes, such as the shifts in acoustic cue weighting described by the DWS, could reflect alterations in perceptual strategy due to pressure from processes external to the development of the perceptual system itself, such as metalinguistic (or other) development. Future perceptual studies should investigate this apparent division.

Conclusions

This study has established a clear correlation between developmental changes in cue weighting and phonemic awareness. Furthermore, we have demonstrated the relative order in which these two processes develop, which should help to constrain any discussions of possible causal directions in the relation. It should be reiterated at this point that the results of this study cannot establish that the relation between changes in cue weighting and the development of phonemic awareness is in any way causal. However, if at some future date the relation is shown to be causal, then this study has shown the most likely direction of that causality. Specifically, most improvements in phonemic awareness ability took place earlier on in the study, while changes in cue weighting strategies tended to take place later on in the study. Additionally, early phonemic awareness ability predicted later cue weighting strategies. Given these results, therefore, it appears more likely that phonemic awareness acquisition has a developmental impact on cue weighting changes than the other way around. This idea receives some additional support from pilot studies of later-reading (but normally developing) children, whose results indicate that delaying phonemic awareness acquisition results in delayed cue weighting changes (Mayo, 2000). Thus, as proposed by Nittrouer (1996b), it appears that the development of phonemic awareness may be part of the linguistic experience that promotes changes in cue weighting.

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References

Cohen, J., & Cohen, P. (1983). *Applied multiple regression/correlation analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Dorman, M. F., Studdert-Kennedy, M., & Raphael, L. J. (1977). Stop-consonant recognition: Release bursts and formant transitions as functionally equivalent, context-dependent cues. *Perception & Psychophysics*, *22*, 109–122.

Entropic Research Lab Inc. (n.d.). Entropic ESPS/Waves+ [Computer software]. Cambridge, UK: Author.

Ferguson, C. A., & Farwell, C. B. (1975). Words and sounds in early language acquisition. *Language*, *51*, 419–439.

Fitch, H. L., Halwes, T., Erickson, D. M., & Liberman, A. L. (1980). Perceptual equivalence of two acoustic cues for stop-consonant manner. *Perception & Psychophysics*, *27*, 343–350.

Greenlee, M. (1980). Learning the phonetic cues to the voiced voiceless distinction: A comparison of child and adult speech perception. *Journal of Child Language*, *7*, 459–468.

Hazan, V., & Rosen, S. (1991). Individual variability in the perception of cues to place contrasts in initial stops. *Perception & Psychophysics*, *49*, 187–200.

Jusczyk, P. W., & Derrah, C. (1987). Representation of speech sounds by young infants. *Developmental Psychology*, *23*, 648–654.

Klatt, D. (1980). Software for a cascade/parallel formant synthesizer. *Journal of the Acoustical Society of America*, *67*, 971–995.

Krause, S. E. (1982). Vowel duration as a perceptual cue to postvocalic consonant voicing in young children and adults. *Journal of the Acoustical Society of America*, *71*, 990–995.

Lacerda, F. (1992). Young infants' discrimination of confusable speech signals. In M. E. H. Schouten (Ed.), *The auditory processing of speech: From sounds to words* (pp. 229–238). The Hague, The Netherlands: Mouton de Gruyter.

Liberman, A. M., Delattre, P. C., & Cooper, F. S. (1952). The role of selected stimulus-variables in the perception of the unvoiced stop consonants. *American Journal of Psychology*, *65*, 497–516.

Liberman, A. M., Delattre, P. C., & Cooper, F. S. (1958). Some cues for the distinction between voiced and voiceless stops in initial position. *Language and Speech*, *1*, 153–166.

Liberman, A. M., Delattre, P. C., Cooper, F. S., & Gerstman, L. J. (1954). The role of consonant-vowel transitions in the perception of the stop and nasal consonants. *Psychological Monographs: General and Applied*, *68*, 1–13.

MacWhinney, B. (1995). *The CHILDES project: Tools for analyzing talk* (2nd ed.). Mahwah, NJ: Erlbaum.

Mayo, C. (2000). *The relationship between phonemic awareness and cue weighting in speech perception: Longitudinal and cross-sectional child studies*. Unpublished doctoral dissertation, Queen Margaret University College, Edinburgh, United Kingdom.

McBride-Chang, C. (1995a). Phonological processing, speech perception, and reading disability: An integrative review. *Educational Psychologist*, *30*, 109–121.

McBride-Chang, C. (1995b). What is phonological awareness? *Journal of Educational Psychology*, *87*, 179–192.

McBride-Chang, C. (1996). Models of speech perception and phonological processing in reading, *Child Development*, *67*, 1836–1856.

McBride-Chang, C., Chang, L., & Wagner, R. (1997). Growth modeling of phonological awareness. *Journal of Educational Psychology*, *89*, 621–630.

Menn, L. (1971). Phonotactic rules in beginning speech. *Lingua*, *26*, 225–251.

Menn, L. (1983). Development of articulatory, phonetic and phonological capabilities. In B. Butterworth (Ed.), *Language production* (Vol. 2, pp. 3–50). London: Academic Press.

Morais, J. (1991). Constraints on the development of phonemic awareness. In S. S. Brady & D. P. Shankweiler (Eds.), *Phonological processes in literacy: A tribute to Isabelle Y. Liberman* (pp. 5–27). Hillsdale, NJ: Erlbaum.

Morrongiello, B. A., Robson, R. C., Best, C. T., & Clifton, R. K. (1984). Trading relations in the perception of speech by five-year-old children. *Journal of Experimental Child Psychology*, *37*, 231–250.

Nittrouer, S. (1992). Age-related differences in perceptual effects of formant transitions within syllables and across syllable boundaries. *Journal of Phonetics*, *20*, 351–382.

Nittrouer, S. (1993). The emergence of mature gestural patterns is not uniform—evidence from an acoustic study. *Journal of Speech and Hearing Research*, *36*, 959–972.

Nittrouer, S. (1995). Children learn separate aspects of speech production at different rates: Evidence from spectral moments. *Journal of the Acoustical Society of America*, *97*, 520–530.

Nittrouer, S. (1996a). Discriminability and perceptual weighting of some acoustic cues to speech perception by 3-year-olds. *Journal of Speech and Hearing Research*, *39*, 278–297.

Nittrouer, S. (1996b). The relation between speech perception and phonemic awareness: Evidence from low-SES children and children with chronic OM. *Journal of Speech and Hearing Research*, *39*, 1059–1070.

Nittrouer, S., Manning, C., & Meyer, G. (1993). The perceptual weighting of acoustic cues changes with linguistic experience. *Journal of the Acoustical Society of America*, *94*, S1865.

Nittrouer, S., & Miller, M. E. (1997). Predicting developmental shifts in perceptual weighting schemes. *Journal of the Acoustical Society of America*, *101*, 2253–2266.

Nittrouer, S., Miller, M. E., Crowther, C. S., & Manhart, M. J. (2000). The effect of segmental order on fricative labeling by children and adults. *Perception & Psychophysics*, *62*, 266–284.

Nittrouer, S., & Studdert-Kennedy, M. (1987). The role of coarticulatory effects in the perception of fricatives by children and adults. *Journal of Speech and Hearing Research*, *30*, 319–329.

Nittrouer, S., Studdert-Kennedy, M., & McGowan, R. (1989). The emergence of phonetic segments: Evidence from the spectral structure of fricative-vowel syllables spoken by children and adults. *Journal of Speech and Hearing Research*, *32*, 120–132.

Nittrouer, S., Studdert-Kennedy, M., & Neely, S. T. (1996). How children learn to organize their speech gestures: Further evidence from fricative-vowel syllables. *Journal of Speech and Hearing Research*, *39*, 379–389.

Ohde, R. N., & Haley, K. L. (1997). Stop-consonant and vowel perception in 3- and 4-year-old children. *Journal of the Acoustical Society of America*, *102*, 3711–3722.

Parnell, M. M., & Amerman, J. D. (1978). Maturational influences on perception of coarticulatory effects. *Journal of Speech and Hearing Research*, *21*, 682–701.

Repp, B. H., Liberman, A. M., Eccardt, T., & Pesetsky, D. (1978). Perceptual integration of acoustic cues for stop, fricative and affricate manner. *Journal of Experimental Psychology: Human Perception and Performance*, *4*, 621–637.

Scottish Office Education Department. (1991). English language 5–14. *Curriculum and assessment in Scotland: National guidelines*. Edinburgh, Scotland: Scottish Executive Education Department.

Sensimetrics Org. (n.d.). SenSyn Laboratory Speech Synthesizer [Computer software]. Cambridge, MA.

Stuart-Smith, J. (1999). Glasgow: Accent and voice quality. In P. Foulkes & G. Doherty (Eds.), *Urban voices: Accent studies in the British Isles* (pp. 201–222). London: Edward Arnold.

Studdert-Kennedy, M. (1987). The phoneme as a perceptuomotor structure. In A. Allport, D. G. MacKay, W. Prinz, & E. Scheerer (Eds), *Language perception and production: Relationships between listening, speaking, reading and writing* (pp. 67–84). London: Academic Press.

Vihman, M. M. (1996). *Phonological development: The origins of language in the child*. Oxford, U.K.: Blackwell.

Walley, A. C., & Carrell, T. D. (1983). Onset spectra and formant transitions in the adult's and child's perception of place of articulation in stop consonants. *Journal of the Acoustical Society of America*, *73*, 1011–1022.

Wardrip-Fruin, C. (1982). On the status of temporal cues to phonetic categories: Preceding vowel duration as a cue to voicing in final stop consonants. *Journal of the Acoustical Society of America*, *71*, 187–195.

Wardrip-Fruin, C. (1985). The effect of signal degradation on the status of cues to voicing in utterance-final stop consonants. *Journal of the Acoustical Society of America*, *77*, 1907–1912.

Wardrip-Fruin, C., & Peach, S. (1984). Developmental aspects of the perception of acoustic cues in determining the voicing feature of final stop consonants. *Language and Speech*, *27*, 367–379.

Watson, J. (1997). *Sibilant-vowel coarticulation in the perception of speech by children with phonological disorder*. Unpublished doctoral dissertation, Queen Margaret College, Edinburgh, United Kingdom.

Whalen, D. H. (1991). Perception of the English /s/–/ʃ/ distinction relies on fricative noises and transitions, not brief spectral slices. *Journal of the Acoustical Society of America*, *90*, 1776–1784.

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