Interactions between the acquisition of phonetics and phonology

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1 Introduction

On the basis of an extensive review of the instrumental analysis of disordered child speech, Gary Weismer (1984:30) wrote: "broad phonetic transcription may miss important aspects of a phonology. This is especially so when we are dealing with an unfamiliar language, or a familiar language that is more or less distorted by errors of sound production." Weismer's focus was the misarticulating child but we should not forget that from the perspective of adult ears, the speech of *all* infants is another example of the "unfamiliar" — indeed, immature speech is by definition "more or less distorted" with respect to the adult model. Child speech reflects immaturities in the vocal tract, the mental lexicon, the perceptual system, the phonetic implementation of phonological representations, speech motor planning and control, and the phonology itself.[1] These factors all conspire, in conjunction with adult listeners whose language-specific perceptual expectations are attuned to the speech of other adults, to create a mismatch between the child speaker and the adult listener.[2]

For the adult who is a linguist, applying adult norms and categories to child speech data gives an indication of how *successful* the child is in producing *appropriate* output. The linguist's impressionistic judgements are not, however, a true record of the child's speech output (let alone an infallible source of data from which to draw conclusions about the child's internal phonological system). It is well known that making transcriptions without benefit of repeated listening from a recording, or in a broad and cursory style, is problematic methodologically. For example, Amorosa, von Benda, Wagner and Keck's (1985) study found that: "live transcriptions of children's unintelligible speech revealed low agreement on phonetic detail even between experienced transcribers. In addition, especially on complex items, agreement often did not reflect the child's production but rather the transcribers' 'normalisation' of what they had heard" (ibid:281). It is obvious furthermore that impressionistic transcription, even of the most careful and skilled kind, is simply not able to reveal the subtle minutiae of speech irrespective of its intelligibility, nor can it provide truly quantitative phonetic data.[3] The theoretical significance of this "low-level" information, which is missing from the transcription record, has not, however, been universally apprehended, despite the evidence presented over the years by, amongst others: Kornfeld & Goehl (1974), Ohala (1974), Smith (1979), Macken & Barton (1980), Maxwell & Weismer (1982), Hardcastle & Morgan (1982), Weismer (1984), Nittrouer, Studdert-Kennedy & McGowan (1989), Gibbon (1990), Stoel-Gammon, Buder & Kehoe (1995), Snow (1997), Gibbon (1997), Edwards, Gibbon & Fourakis (1997), Scobbie, Gibbon, Hardcastle & Fletcher (1997; to appear) and Smith & Kenney (1998). See also the work of other authors in *this* volume and references therein. Despite all this work, the pre-eminence of transcription continues, and instrumental analysis is often completely absent, presumably because it is seen as irrelevant, trivial and time-consuming by those interested in gaining insight into the cognitive and linguistic aspects of phonological development. The last point is valid, but the first two criticisms are not.

2 Contrasts and cues

Fundamental to the argument to be presented here is the idea that the phonological system may be acquired independently of the means of its expression. The literature review in §3 provides examples of actual cases where this can be demonstrated. The results of children acquiring phonological representations which they cannot articulate in the correct, adult-like way are varied, but in some cases the child will appear to have an immature phonology. This leads to the conclusion that the various reductions, deletions, simplifications and modifications of adult targets that are evident in all child language may be due to

(a) incorrect or incomplete phonological representations being stored in the lexicon or arising from an incorrect or incomplete ruleset,
(b) a grammar of phonetic realisation which uses inappropriate articulatory routines, leading the listener to miscategorise the child's output, or
(c) a grammar of phonetic realisation which uses appropriate articulatory routines, but in such an inappropriate way that the listener is still miscued, and miscategorises the child's output.

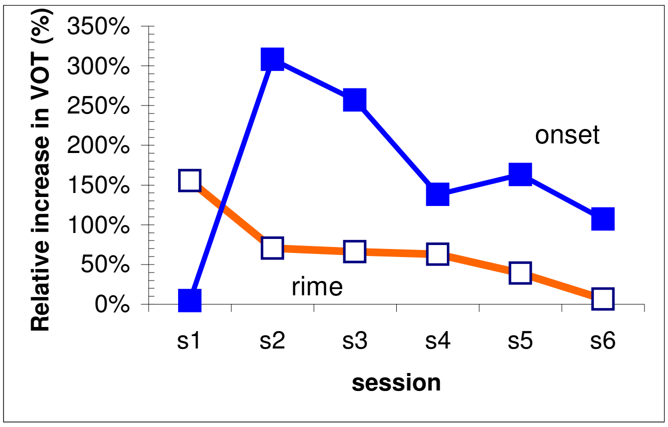
Each language has its own set of phonological contrasts (as well as other, non-contrastive, but nevertheless informative aspects of the system). For contrasts to be perceived and produced, certain articulatory and perceptual skills must be mastered. These information-conveying aspects of phonetic behaviour are called "cues" — cues to a phonological contrast, or cues to other linguistically encoded categories such as as word-boundaries, social class or prosodic prominence. There is a complex web of relationships between cues and categories. Each contrast of English phonology is conveyed by a set of English phonetic cues. The child needs to learn *which* aspects of the phonetics function as cues and *how* to use each cue. Since this knowledge is acquired by the child, we can observe (a) the appearance and (b) the subsequent development of a cue, and (c) the changes in the relative importance of the cue *with respect to a particular linguistic category* as the child matures.

Even putting aside the function of cues in conveying non-contrastive information, each cue may furnish information about more than one phonemic contrast. For example, VOT can be called a "primary" cue to stop voicing and a "secondary" cue to other contrasts such as the place of articulation of the stop and the height of the following vowel. This terminology of rank reflects our understanding of the relative importance of cues in adult speech, but, as with phonetics and phonology themselves, this aspect of the phonetics/phonology interface is highly unlikely to be applicable directly to child speech. Indeed, fascinating developmental changes in the interaction of phonetics and phonology are to be found in children from the two-word stage right up to the teenage years. For example, see Zlatin & Koenigsknecht (1975), Simon & Fourcin (1978), Krause (1982a), Nittrouer & Studdert-Kennedy (1987), Lehman (1988), Nittrouer (1992), Ohde (1994) and Watson (1997) for work in perception. There is a more extensive literature of production studies. For examples see: Naeser (1970), DiSimoni (1974ab), Macken & Barton (1980), Krause (1982b), Catts & Jensen (1983), Ohde (1985), Lehman (1988), Tyler (1988), Nittrouer et al (1989), Tyler, Figurski & Langsdale (1993), Stoel-Gammon et al (1995), Scobbie et al (1995, 1997), Nittrouer, Studdert-Kennedy & Neely (1996), Snow (1997), Smith & Kenney (1998).

In addition, we must not forget that the set of cues to a contrast depends on the prosodic context. For the /voice/ opposition in *post-vocalic* stops, cues include the duration of the preceding vowel, and rate of voicing offset and the amount of voicing in the closure phase. *Prevocalically*, VOT, pitch, spectral tilt and the presence of F1 transitions are important. To signal the contrast /t/ - /d/, the child has to learn which sets of cues apply in which environment.

The developmental interaction of phonetics and phonology can be illustrated by longitudinal VOT data from DB, a child with a phonological disorder, discussed in Scobbie et al (1995, to appear) (and see also Baker, 1998). In this case, we can see the acquisition of two functions for a single acoustic phonetic measure. Figure 1 illustrates the relative increase in VOT in /t/ over /d/ ("onset") and the relative increase in the VOT of /t/ when it is followed by /ir/ over /ae/ ("rime"). Figure 1 shows a relative decrease in the vowel height cue from an excessively large 156% (/tir/=52.5ms, /tae/=20.5ms) in session 1 (4;1) to much lower levels by session 6 (5;10), levels appropriate for this rather minor cue in English (Docherty 1992). On the other hand, VOT is one of the primary cues to the /voice/ feature, but DB does not cue the voicelessness of onset /t/ using VOT in session 1 at all.[4] In session 2, there is a large differential (/t/=115ms, /d/=28ms), which gradually lessens over the next 18 months or so. This is partly due to the VOT of /t/ dropping to 90ms, which is developmentally appropriate, but partly to the VOT of /d/ getting longer at 43ms, which is not. So we can see that the same acoustic measure, VOT,[5] may exhibit more than one pattern of behaviour, and that the path towards adult-like speech is a complex one.

Figure 1. Relative increase in VOT in /t/ over /d/ ("onset", solid marks) and in /ir/ over /ae/ ("rime", hollow marks). Subject DB.



Another example, this time from normally developing speech, is Stoel-Gammon et al (1995). They show how vowel duration is used to convey contrastive information about (a) the opposition between long /i/ and short /I/ (in conjunction with spectral cues) and (b) non-contrastive prosodic information, since vowels have greater duration phrase-finally. They show that American English and Swedish children of 2;6 differ markedly in their acquisition of the functions of this cue, because of the differences in the target grammars. There is enormous scope for further work of this kind which tracks the phonetic bases for a successful, perceptible contrast. To know that /i/ and /I/ are "different" in transcription is, as Stoel-Gammon et al (1995) reveal, to know only a little about the acquisition and maturation of the contrast.

The final aspect of the relationship between cues and contrasts which I wish to consider is that, by impressionistic transcription alone, *it may be impossible to know that a contrast has in fact been acquired*. If the set of cues used to convey a contrast is insufficient for the adult listener, or if the differential settings for the cues are not perceivably distinct, then the child's phonological contrast will not be recorded unless specific attention is paid to the cues which *are* conveying it. To rely solely on impressionistic transcription limits our understanding of acquisition — it records the acquisition of particular cue-contrast combinations, and reveals the stages of acquisition which are perceptible to the listener. For example, Macken & Barton (1980) discovered that normally developing children might sound as if they had homophonous /t/ & /d/, /p/ & /b/, /k/ & /g/, but in fact there could be a period of several months when children expressed these oppositions as a covert contrast (their "category II"). Against all appearances, the children's phonological systems *did* express the contrast in surface structure.

3 Literature review of investigations into covert contrast

The rest of this paper looks in more detail at the phenomenon of covert contrast, a phenomenon which provides the clearest impetus for the armchair phonologist to make use of laboratory-based instrumental techniques. Without such techniques, a wide range of contrasts would have been erroneously labelled "homophonous". Useful reviews are given as introductions to most of the papers mentioned here. In particular, note Tyler & Saxman (1991), Tyler et al (1993), Edwards et al (1997). Farmer (1997) is a very broad review of instrumental analysis in clinical cases, and Weismer (1984) is a detailed review of instrumental work. Weismer in particular provides copious quantitative information and explanation.

In this review I have listed all the investigations into covert contrast of which I am aware in normally developing and phonologically disordered children: that is, subjects apparently without severe motoric limitations on speech. See §4 for further discussion. Covert contrasts have been discovered in structure, manner, voice and place, showing that in principle no parameter of phonological contrast is immune to covert expression. The cases are presented grouped by the apparent effect they have on the phonological system. Nothing particular hangs on the choice of section headings: the *range* of phonological contrasts which have been studied is the important point. For each reference I give an indication of

1. the phonetic cue encoding the contrast, other cues investigated, and, if not obvious from the cue, the method of analysis.
2. the subject group studied: "nd" for normally developing children and "pd" for children with phonological disorder. The difference between nd and pd children might be very important, especially if the pd children had been receiving therapy prior to the contrast being detected (Tyler & Saxman, 1991). The subjects' approximate age is also provided if appropriate.

the frequency of occurrence of covert contrast. We need to consider not only the number of cases discovered, but also the number of investigations which have been made. Together, these give a "hit rate". Sometimes the evidence for covert contrast is equivocal or the number of relevant subjects who have homophonony for the relevant parameter is not clear, and the numbers are therefore somewhat approximate. Further, it should be noted that interim or negative results are not likely to be published, and since I am only considering publications, the hit rates may be unrealistically high (cf. footnote 23). On the other hand, it is sometimes the case that additional analysis of a negative results reveals that covert contrast *is* present (Scobbie et al, to appear). Finally, note that the hit rate may raised by the preponderance of studies of older children with phonological disorder.

3.1 Obstruent voicing neutralisation (word-initial)

This is one of the areas in which the greatest number of investigations have been made, with convert contrast uncovered quite often, in both nd and pd children. Here and below, the duration of VOT and other events is measured from waveforms and/or spectrograms.

Reference	Cue/analysis	S	Hit rate
Macken & Barton (1980)	VOT	nd >1;6	3 of 3 + 1 overt
Maxwell & Weismer (1982)	VOT, voicing during closure, perceptual test [6]	pd 3;11	1 of 1
Gierut & Dinnsen (1986)	VOT, closure duration	pd 4;4	1 of 2
Forrest & Rockman (1988)	Perceptual test, F1, F0, burst spectra and amplitude [7]	pd ≈ 4	2 of 3
Tyler, Edwards & Saxman (1990) [8]	VOT	pd ≈ 5	2 (D1, D4) of 4
Tyler, Figurski & Langsdale (1993)	VOT	pd 4;7	1 of 4
Scobbie et al (to appear) [9]	Breathy voice quality (H1-H2) [10]	pd 4;1	1 of 1
Catts & Jensen (1983)	VOT	pd	0? of 2 [11]

3.2 Obstruent voicing neutralisation (word-final)

Reference	Cue/analysis	S	Hit rate
Weismer, Dinnsen & Elbert (1981) & Weismer (1984)[12]	DVD [13]	pd 4-7	4 of 5
Smit & Bernthal (1983)	Vowel duration	pd ≈ 5	5 (or 6) of 6

3.3 Weak syllable deletion

Reference	Cue/analysis	S	Hit rate
Carter & Gerken (to appear)	Duration of whole word	nd 2;4	9 of 10

3.4 Consonant harmony

I know of no cases in which a supposed consonant harmony has been shown to involve only an apparent change in place of articulation.

3.5 Velar fronting

Reference	Cue/analysis	S	Hit rate
Forrest, Weismer, Hodge, Dinnsen & Elbert (1990)	Spectral moments analysis of burst spectra	pd 3;6 – 6;6	1 of 4
Tyler, Edwards & Saxman (1990) [14]	VOT	pd ≈ 4	1 (D2) of 2
Tyler, Figurski & Langsdale (1993)	VOT	pd 4;7	0 (or 2?) of 3
Young & Gilbert (1988)	VOT	pd 3;9	0 of 13 [15]

3.6 Alveolar backing

Reference	Cue/analysis	S	Hit rate
Gibbon (1990)	EPG analysis of place of articulation [16]	pd 4;10	1 of 1
Gibbon, Dent & Hardcastle (1993)	Place of articulation EPG	pd 9	1 of 1
Tyler, Edwards & Saxman (1990) [17]	VOT	pd ≈ 4	1 (D1) of 2

3.7 Glide and liquid homophony

Reference	Cue/analysis	S	Hit rate
Kornfeld & Goehl (1974)	Formant analysis	?[18]	
Hoffman, Steger & Daniloff (1983)	Formant analysis (F2) [19]	pd	8 of 12
Chaney (1988)	Formant analysis [20]	nd/pd	3? of 4/ 2? of 4
McLeod & Isaac (1995)	Duration and intensity [21]	pd 5;0	1 of 1

3.8 Stopping

Reference	Cue/analysis	S	Hit rate
Tyler (1995)	VOT	pd 5	1 of 3

3.9 /s/ dentalising

Reference	Cue/analysis	S	Hit rate
Baum & McNutt (1990)	duration, amplitude & centroid	nd 5-8	8 of 10?

3.10 Cluster reduction and coda deletion (word-final)

Reference	Cue/analysis	S	Hit rate
Weismer, Dinnsen & Elbert (1981) & Weismer (1984) [22]	DVD	pd 4-7	4 of 5
Weismer (1984)	F2 at end of vowel	pd	2 of 4
Tyler & McComber (1998)	Pitch to indicate plural	pd >3;1	2 of 4
Camarata & Gandour (1985)	Pitch, duration & intensity for plural suffix	pd 3;8	1 of 1
Camarata & Erwin (1988)	Pitch & duration to indicate plurality	pd 3;7	1 of 1

3.11 Cluster reduction and onset deletion (word-initial)

Reference	Cue/analysis	S	Hit rate
Catts & Kamhi (1984) [23]	VOT	nd 2;3	1 of 6
Tyler (1995)	VOT	nd ≈ 5	1 of 3
Scobbie et al (1996, to appear)	Breathy voice quality (H1-H2)	pd 4;1	1 of 1 [24]
Weismer (1984)	Obstruent Interval	pd 7;2	1 of 1
Smit & Bernthal (1983)	VOT	pd ≈ 5	1? (s21) of 6

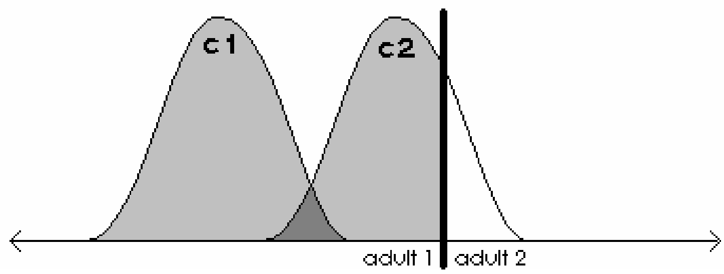
4 Where to look for other examples

Apart from papers which I have inadvertently overlooked, there are a number with suggestive results which may indicate covert contrast, but where not quite enough information is given to be conclusive one way or the other. For example, McLeod, van Doorn & Reed (1998) carried out acoustic comparison of reduced /sk/ and /st/ against /k/ and /t/ in a study of 16 nd English-speaking children. In 12 token pairs, children differentiated the reduced cluster (VOT=26ms) from the aspirated singleton (VOT=80ms). It is not clear whether this was an easily perceptible difference or whether /st/ was transcribed as [t^h] despite the difference in aspiration. Nor, unfortunately, were reduced /st/ and /sk/ analysed against /d/ and /g/, with which they were presumably homophonous, both being short-lag stops.

A second source is any case of articulation disorder which is classified as having a significant general motoric aspect. I have excluded them from consideration here, but it may be that further insights can be drawn by broadening the scope of investigation. For example, Hardcastle & Morgan (1982) is an EPG and acoustic study, which includes two children diagnosed as dyspraxic with mild dysarthria. One (Stephen, 13) may have initial stop voicing contrasts using VOT. The other (June, 14) has a covert contrast /sn/ as [s] vs. /s/: "fricative cluster reduction was not simply a process of 'omission' of the stop leaving a single fricative element. The articulatory patterns for the fricative during the attempted cluster production were clearly quite different from those during production of fricatives as single elements." (ibid: 64).

Another likely source of cases are studies which have inadvertently hidden the effects of gradual development under the heading of "variability". When measurements from instrumental data are categorised using adult norms, then *covert contrasts within a category will not be detected, by definition.* After all, the reason these contrasts are covert in the first place is that the child's phonetic output for both members of the opposition lies within a single adult category (Figure 2). It may be, however, that data at one extreme of a child's distribution of tokens might result in a rump of correct categorisations. Thus the child might appear to get only a *percentage* of articulations correct. As the child's productions of category 2 (c2) gradually push into the adult category 2 area, the percentage of productions which appear to be "correct" will rise. Such variability does not indicate that the child's output fluctuates between categories. At every stage, the child has a fixed target with a distribution of tokens around the target.

Figure 2. Two covertly contrastive distributions of tokens (c1 & c2) falling mostly within a single adult category (adult 1). A tail of c2 cases (unshaded) falls into the other adult category. This child's output of category 2 sounds variable: it's sometimes categorised as adult 1 and sometimes as adult 2.



Catts and Kamhi (1984), for example, is a longitudinal study of cluster reduction in which instrumental measures of VOT are categorised as short-lag, long-lag or prevoiced. If reduced clusters are typically short lag, they are identified with /d/, and if they are typically long lag, then with /t/. Catts and Kamhi report that all six children have predominately short lag productions when the clusters are reduced to stops, although prevoiced stops and long-lag VOT productions occur too. On this basis, they conclude that /st/, for example, is reduced phonologically to /d/, because /d/ is typically produced in adult speech with a short lag VOT.

The distribution of VOT primarily into the adult short-lag region is a useful finding. Unfortunately, the simple categorisation of VOT into three groups means that detecting covert contrast within one of the groups (such as the short-lag region) is impossible. It *is* possible, however, for undetected patterns of covert contrast to cause variability in such a category-based analysis. In this case, the youngest subject (AS) started the study at 1;9 with poor phonetic control of VOT. In sessions 1 to 3, 33.3% of voiceless singleton stops were categorised as short lag. Following the phonetic mastery of long lag VOT for /p t k/ in session 4, her output for the clusters altered too. /st/ changed: it was typically reduced to a fricative, and while /sp/ and /sk/ remained as stops,[25] it seems that these stop productions became variable (Table 1) *in terms of the categories used.*

Table 1. Categorisation of voicing/aspiration of stop reductions of AS

Age	1;9	1;10	1;11	2;0	2;1	2;3	2;4	2;5
% short lag	81.3	80.0	75.0	46.7	52.9	47.4	50.0	0
% long lag	6.3	4	8.3	26.7	47.1	31.6	41.7	100
% pre-voiced	12.5	16	0	0	0	0	0	0
Sample size	16	25	24	15	17	19	12	2

Catts & Kamhi (1984:560) realise that such variability may mean that "perhaps at this point, AS represented clustered stops *differently* than she represented voiced and voiceless singleton stops" (my emphasis) but do not go so far as to propose that they are represented *correctly*, as is proposed here. Catts and Kamhi saw the significance of this variability, and undertook further, non-categorising, analysis of AS in sessions 6 to 8, and the indications are that AS did indeed have a covert contrast. Pooling the data from sessions 4-8, the mean VOT of cluster reduced stops (39.7ms) was different from singleton voiced stops (21.3ms) $t(103)=4.0$, $p<0.01$ and from singleton voiceless stops (64.4ms) $t(101)=4.2$, $p<0.01$.

Bond and Wilson (1980) is a more ambiguous case. They analyse 5 subjects (1;10-3;0) who have productive voice contrast in initial stops and cluster reduction to stops ("group II"). Only 9 cluster tokens from each child was analysed, so we have to use the results with caution. However, two of the children used long lag VOT (>30ms) in 100% of reduced clusters, one child in 0%, and the other two were "variable": S1 (1;10) used long lag VOT in 4 cases (44%) and S5 (3;0) in 5 cases (56%). Rather than these children having *variable* output, it maybe that they had (a) an appropriate representation of the clusters and (b) invariable but *inappropriate* phonetic targets for the clusters. The "variable" children may have assigned a VOT target to the clusters which was intermediate between /d/ and /t/.

Bond & Wilson (1980) are aware that /t/, /d/ and /st/ might be homophonous and yet be phonologically distinct: "the children in group II, being aware of the phonological contrast between voiced stops, voiceless stops, and clusters, but being unable to control the complex articulatory gestures necessary for the cluster production, substitute aspiration — a phonetic parameter within their control" (p157). The key theoretical issue is the nature of this substitution. It would be a mistake to think that the only way to achieve long-lag aspiration for /st/ is a categorical and phonological rule mediating two levels of phonological representation (/st/ → /t/). Such neutralisation rules erroneously make covert contrast between /t/ and /st/ impossible. It may be rather that these children's phonetics/phonology interface assigns aspiration directly as the interpretation of the /s/ in /st/ rather than assigning a lingual fricative gesture. The evidence (from covert contrast, "variability", immature overt contrasts, and from speech perception) is that in many cases, the child has a stable, adult-like lexical representation but immature linguistic speech motor and perceptual interpretations of the adult-like cognitive categories.

Finally, see Weismer (1984) and Farmer (1997) for a few other possible cases which it has not been possible to consult in the preparation of this paper. It has also not been possible to consult Menyuk (1972) nor Kornfeld (1971), though the discussion in Bond & Wilson (1980) suggests that both may be relevant.

5 Conclusion

It must be recognised that the child has to acquire both the phonological system *and* the phonetic system of their native language, and these subgrammars develop in tandem over several years. It is essential that we scrutinise both areas *and* the interface between them if the acquisition of spoken language is to be understood. Covert contrast is one clear example of this interaction: a phenomenon in which contrasts are made by the speaker but not detected by the listener. Impressionistic transcriptions of speech are fatally flawed as a means of investigating the speaker's phonological system in all such cases.

In this paper I have reviewed the cases of covert contrast of which I am aware, in order to try to estimate how widespread the phenomenon is. It is clear that covert contrast can affect any aspect of phonetic production, causing misperception of contrasts in voicing, manner, place and structure. In that sense, it is ubiquitous. But we cannot tell how many children have covert contrasts. The majority of studies have a reasonably high hit-rate, but most have concentrated on older children, most of whom have been diagnosed with, and may be being treated for, a phonological disorder. Only future research, especially on younger children who appear to be developing normally, will be able to reveal the extent to which this phenomenon of the phonetics/phonology interface is a normal aspect of child language.

6 Notes

[*] This paper would never have been written without Bill Hardcastle, Fiona Gibbon and Paul Fletcher. It stems directly from their work on the acquisition of speech, specifically from their project on consonant cluster acquisition in phonological disorder into which I fell. Thanks to Bill, Fiona and Paul, and also to Jocelynne Watson, Sharynne McLeod, Nigel Hewlett, Ben Matthews, Alice Turk, Anne McPhail, Lesley Baker, Karen Budewig, Lucy Ellis, Diana Archangeli, Ann Tyler, Daphne Waters and Cassie Mayo. All the above have been very stimulating in discussion and/or helpful in providing references: sadly there is much more to be set down than there is space for here. They are not, of course, responsible for any oversights, omissions or misguided opinions in the text. Financial support for the research and attendance at CLS is gratefully acknowledged: MRC grant #G9117453, ESRC grant #R00023 7135, and the Department of Speech and Language Sciences at QMC. Email: **j.scobbie@sls.qmced.ac.uk**

[1] In addition, there are non-linguistic motor control and general cognitive immaturities.

[2] Due to pressures of space, the discussion is biased towards speech production rather than perception and on children approaching and beyond the two-word stage, rather than infants.

[3] Acoustic and articulatory methods of analysis are not perfect, of course.

[4] Nevertheless, DB conveys the contrast /t/ - /d/ covertly in session 1: see §3.1, §3.11.

[5] It is highly probable that there are different control strategies for each "type" of VOT, with the /t/-/d/ contrast being basically laryngeal, and the /ir/-/ae/ contrast being due to supraglottal vocal tract aerodynamics and/or physiology (Docherty, 1992) typical of high vowels.

[6] Stop duration was also investigated, and was not a cue to the contrast.

[7] No solid contrast in VOT.

[8] See also §3.5.

[9] See also §3.11.

[10] Extensive durational analysis of VOT, stop closure, vowel offset, or rime revealed no contrast, but see McPhail (1998) for suggestive durational results on the delay in onset of modal voicing. Spectral study of F2 transitions revealed no covert contrast (Baker, 1998).

[11] There are 9 subjects in all, some making not contrast, others an exaggerated one.

[12] See also §3.2.

[13] DVD = differential vowel duration as conditioned by the voice of the target coda stop.

[14] See also§3.1 & §3.6.

[15] The subjects were treated as a group. No information about individuals.

[16] Masked alveolar gestures were discovered in one sister. The other, whose alveolars sounded correct, were *also* doubly articulated in a very similar way, but sounded velar due to timing differences.

[17] See also§3.1 & §3.5.

[18] I did not gain access to this paper due to an oversight.

[19] There was no difference in F1, segmental duration or amplitude.

[20] F1, F2 & F3 were studied, plus F2 transition rate. No general result for groups. Informal conclusions about hit rate are given.

[21] F2 and F3 showed no difference.

[22] See also §3.2 — same studies, same subject, both contrasts simultaneous.

[23] See §4.

[24] To date, extensive durational analysis has revealed no covert contrast in initial cluster reduction in any of the eight monolingual pd subjects in the QMC Cluster Acquisition Database, though analysis is still underway. (The hit rate refers to the use of the H1-H2 spectral tilt analysis measure). Scobbie et al (1997) conclude that two other subjects have a phonetic basis to their /s/+ stop cluster reduction to fricatives on the basis of the spirantised and lenited phonetic realisation of the clusters *after* they'd been overtly acquired, but durational analysis didn't furnish proof of covert contrast.

[25] Subject RS (pd) in Scobbie et al (1997) shows reduction of /st/ to a fricative while /sp/ and /sk/ are articulated correctly. In his case it appears that the reduction of /st/ is due to phonetic spirantisation of the homorganic cluster. This conclusion is drawn because spirantisation is strong even after /st/ begins to be transcribed [st]. The homorganic nature of /st/ gives rise to different problems of gestural timing and coordination than heterorganic /s/ + stop clusters. If it proves difficult to master the transition from [s] to [t], /st/ may be articulated by a lingual movement which provides enough constriction to generate alveolar friction but not enough to enable closure, pressure build-up and release. The case of AS in Catts & Kamhi (1984) provides further support for the analysis of RS.

7 References

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