Psycholinguistic profiling of a hearing-impaired child

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Abstract

The speech and language processing abilities of a 10 year old with a severe hearing impairment and additional word retrieval difficulties are examined at a single word level using Stackhouse and Wells' psycholinguistic framework. Performance on a variety of output tasks is compared and input processing is investigated in detail. Evidence is found for a breakdown in processing at several levels. The specific point of breakdown for individual contrasts is identified. It is shown to be possible and informative to use a psycholinguistic framework with a child with a hearing impairment to produce a detailed profile which could inform therapy decisions.

Introduction

Psycholinguistic, or cognitive neuropsychological, models of language processing have only recently begun to be widely used with children and are still in a process of development. One of the most recent models is that proposed by Stackhouse and Wells (1997) which, unlike some previous models (e.g. Hewlett, 1990), specifies various levels of input processing, thus allowing a fuller analysis of a child's processing abilities for single words. This is particularly important for a child who has known difficulties with input, including hearing impairment.

Many hearing-impaired children exhibit speech and language levels below that which would be predicted from their hearing loss and 'additional language difficulties' are often hypothesized. This paper presents a case study of just such a child, who had already been diagnosed as both hearing and language impaired using a variety of traditional assessments. These diagnoses, although important, do not reveal her precise difficulties. Assessment using a psycholinguistic model can be used to establish the precise level(s) of breakdown in speech and language processing.

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Stackhouse and Wells' (1997) model is used here to assess and provide a detailed profile of the child's processing at a single-word level. A particular emphasis is placed on input processing to establish the present role of her hearing impairment in her overall profile.

Since a child's phonological processing system is still developing and hearing impairment affects the perception of some phonemes more than others, there may be different levels of breakdown for individual phonemic contrasts. This study therefore aims to establish the level of breakdown for each individual contrast in addition to overall areas of difficulty. Thus therapy can be precisely targeted. This information could also be used to evaluate the effectiveness of therapy as it has the potential to reveal changes in the child's phonological processing system that are not readily revealed by standard tests of phonology. These often measure changes in output phonology only. Improved output may be the end result of many changes within the speech processing system, for example, improved discrimination, updated lexical representations and motor programmes. These changes all represent progress and are only measured by standard tests if the changes have filtered right through to speech output. If the process is only partially complete, such progress could go unnoticed.

Case report

Case history

At the time of testing for this study, TG was 10;4 years old. At 1;6 years she was found to have a moderate to severe hearing impairment. This later proved to be a bilateral sensorineural hearing loss (see Table 1) and she was fitted with bilateral hearing aids. From the time of diagnosis she was supported by a teacher of the deaf who referred her for speech and language therapy at age 4;0. At initial assessment she showed minimal comprehension of single words and used jargon and gesture to communicate. It has been unclear throughout whether her hearing

Table 1 Results of hearing tests

	Threshold (dB SPL)		
Frequency (kHz)	Unaided right	Unaided left	Aided soundfield
0.25	60	70	
0.5	65	75	30
1	85	80	40
2	90	80	35
4	90	80	40

impairment or an additional language impairment has been the main cause of her speech and language difficulties. This has been reflected by her educational placements. She has attended units for both hearing-impaired and language-impaired children and at the time of testing was in a hearing-impaired unit where she integrated into a mainstream class for approximately one-third of the time.

Background

When tested at 9;9 years of age on the clinical evaluation of language fundamentals (CELF-R) (Semel *et al.,* 1994), TG presented with low average comprehension (standard score: 87; normal average range 85–115) with significantly more difficulties of expressive language (standard score 59). Many of her errors were typical of hearing-impaired children: omission of the auxiliary in the present progressive tense, past tense *-ed* and plural *-s* (see Bench and Bamford, 1979). Others, such as difficulty repeating sentences, naming pictures accurately and formulating sentences from given key words, could also be due to her hearing impairment or may be due to an underlying language disorder.

TG has severe word finding difficulties and obtained an age equivalent of 5;4 years (chronological age 9;9 years) on the Renfrew word-finding vocabulary scales (Renfrew, 1980). She has particular difficulties with multisyllable words. She struggles to name the whole word, backtracks and attempts production of the word several times with variable realizations. She also makes some segmental errors consisting of substitutions (which could be due to word finding difficulties, phonological difficulties or her hearing impairment) and phonetic errors which are most likely to be due to her hearing impairment. There is no evidence of any specific difficulties with output. She has no structural abnormalities and there is no evidence of articulatory groping or under/over-shoot such as may be seen with dyspraxic-type difficulties.

Three stages of investigation were carried out. The first stage was a naming test; the second compared this and other single word output tasks while the third stage looked specifically at input difficulties.

Stage 1 – naming

Method

Initially the pictures from the *South Tyneside assessment of phonology* (Arnstrong and Ainley, 1988) were used as stimuli for naming a variety of one- and two-syllable words. Further picture stimuli were then collected to investigate in greater depth those sounds or clusters of sounds where she made more errors. These included particularly initial and final /s/, final consonants and consonant clusters. As longer words seemed to be of particular difficulty, she was also tested on the naming of extra pictures with two, three and four syllables. Testing was carried out in a quiet room and recorded on audiotape. A simultaneous phonetic transcription was also taken.

Results

Overall TG produced 83 out of 125 target words correctly, an average of 66% (see Appendix 1 for error responses – transcriptions throughout are phonetic unless indicated with slashed brackets). If the extra probes, which focused particularly on the sounds she had difficulty producing, are discounted, she scored 65 out of 94 correct, or 69%. However, this percentage was not consistent across word length as can be seen in Figure 1. When naming multisyllabic words, she often produced searching-type behaviours, e.g., 'television' → [tɛlɪf ... tɛlɪf ... tɛlɪfə ... teləfɪnə ... teləɪn]. On one- and two-syllable words the errors were mostly segmental, some errors were merely phonetic distortions of the target sound and some were substitutions of other (correctly articulated) phonemes.

To establish whether the scores for any two word lengths were statistically different from each other, a binomial test was used. The results

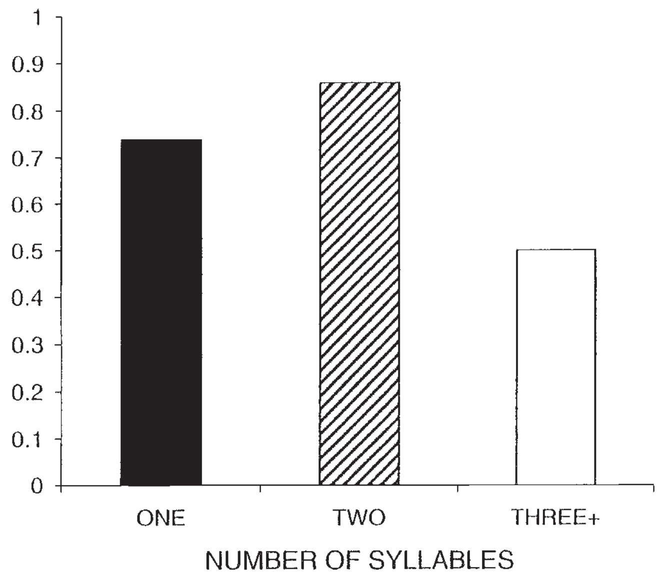

Figure 1 Proportion of words correctly produced in naming test for data excluding extra probes

of this test showed that the score for words with three or more syllables is different from one- and two-syllable words (at a significance level of $p < 0.05$) but that the scores for one- and two-syllable words are not statistically different ($p > 0.1$).

Discussion

TG produced two types of errors on this task. The first were segmental. These may be due to difficulties at a variety of levels: discrimination, faulty phonological representations, 'frozen' motor programmes which have not been updated to match her phonological representations or output difficulties. The second were less consistent and appeared to be caused by word retrieval difficulties and were particularly common on multisyllable words. These were characterized by searching and backtracking behaviours.

Stage 2 – comparison of tasks

The above naming test is not sufficient to establish precisely the source of difficulty underlying TG's errors. Therefore it was decided to test her on a variety of other output tasks and compare her performance on these and on the naming task. The tasks were repetition of words and non-words, both with and without lip cues, and reading. Comparison of these allows inferences to be made about phonological processing strengths and weaknesses as each task uses different processing routes. The following descriptions of the processing involved in the naming and repetition tasks is based on the current hypotheses of Stackhouse, Wells and colleagues (see Constable *et al*., 1997; Stackhouse and Wells, 1997). The description of reading is based on adult models of processing (see Ellis, 1993).

During a picture-naming task, a semantic representation is triggered by the picture, and this in turn triggers the corresponding motor programme. The motor programme is the blueprint for the articulatory gestures necessary for production of the word (Constable *et al.,* 1997). Output follows from here in the same manner on all tasks.

Real word repetition in contrast does not rely purely on accessing the motor programme from the semantic representation. Auditory input is recognized as matching an internal phonological representation (which is used for recognition of a particular string of phonemes as a lexical item) and this triggers the corresponding semantic representation and motor programme. In this case, therefore, there are two routes to the motor programme. Non-word repetition investigates speech processing without involving stored lexical representations. Auditory input is analysed and then a new temporary motor programme for output is constructed.

Reading can proceed via two routes. The first is the whole-word visual route where the semantic representation is accessed from a visual representation of the written word and hence a stored motor programme is accessed as for naming. The second uses phoneme-to-grapheme conversion to construct a motor programme. These two routes may be used either individually or in parallel. If both are used in parallel then the motor programme accessed via the semantic system could be checked for accuracy by comparison with the information available from the graphemes. TG's results on a reading task and an analysis of any errors may give further information about her word retrieval difficulties and also indicate whether reading can be used as an aid in therapy if this proves to be a strength.

Method

Testing in this stage was carried out only on those words where the correct phonological form was not produced in the picture naming condition. In the repetition tasks the target word or non-word was produced with careful and slow articulation but without altering the stress pattern. In order to allow direct comparison of real words and non-words they need to be of comparable articulatory difficulty. Hence the non-words were created by changing the vowels in the corresponding real words, replacing them with vowels of the same length and state (i.e. diphthongs were replaced by diphthongs and monophthongs by monophthongs, for example: 'snake' and /snəʊk/; 'vest' and /vɪst/; 'selotape' and /sɒlɪtəʊp/; see also Appendix 1). The stress pattern of the original word was maintained in the non-word. In the non-word repetition tasks, TG was asked to 'say exactly what I say' as recommended by Wells (1995). She was not told that the stimulus was a 'new word' as this may encourage her to search for a word in her lexicon and hence produce a similar sounding real word. For the reading task she was shown the written word in isolation and asked to read it aloud.

The conditions of no lip-reading were achieved by asking TG to hold a piece of paper so that she could not see the tester's lips, but the tester could see hers and therefore would be able to note silent articulatory movements. This was done in preference to covering the tester's lips as this may distort the speech signal.

Testing was split into five conditions covering the different combinations of real words versus non-words, reading versus repetition and lip-reading versus no lip-reading:

1) real word repetition with the aid of lip-reading;

2) real word repetition without the aid of lip-reading;
3) reading the real word aloud;
4) non-word repetition with the aid of lip-reading;
5) non-word repetition without the aid of lip-reading.

Each word was used only once in each session. Where TG gave more than one response, the best response was used in all quantitative analyses (although other responses were also recorded). The responses on these tasks and the corresponding responses in the naming task were then analysed according to Bryan and Howard's (1992) strict method for calculating the total percentage of consonantal features correct per stimulus item. Each consonant realization is compared with its target according to the three features of voicing, manner and place. A score out of three is then given according to the number of features correct. The proportion of consonantal features correct for the whole word is then calculated by dividing the total number of consonantal features correct in the word by the maximum possible score (see Bryan and Howard, 1992 for more details). To analyse TG's realizations some additional criteria were added to account for her phonetic errors (see Appendix 2). A score based on proportion of features correct provides more information than a simple correct/incorrect score as it gives a numerical value indicating the degree to which a response differs from the target, and also allows much more sensitive comparisons across tasks. Errors which did not fit this method (e.g. vowel errors) were omitted from any analyses.

Results

TG's responses in the six conditions are listed in Appendix 1. The mean proportions of features correct obtained for each of the six conditions are shown in Figure 2. The means ranged from 0.66 to 0.89. It should be noted that many of the one- and two-syllable words were specifically chosen to include phonemes TG finds difficult, whereas the multisyllable words were only chosen by length and would contain many easier phonemes – hence the higher scores for the multisyllable words. To address this bias, word length was controlled in the analyses; thus words of a similar length were compared across conditions. The proportions of consonants correct in each condition were compared using the sign test taking all the data as a whole and also for each individual word length.

To summarize the salient results, taking first real words, real word repetition with lip cues was better than naming ($p < 0.05$); real word repetition without lip cues was also better than naming for all word lengths but this only reached significance for multisyllable words ($p < 0.02$).

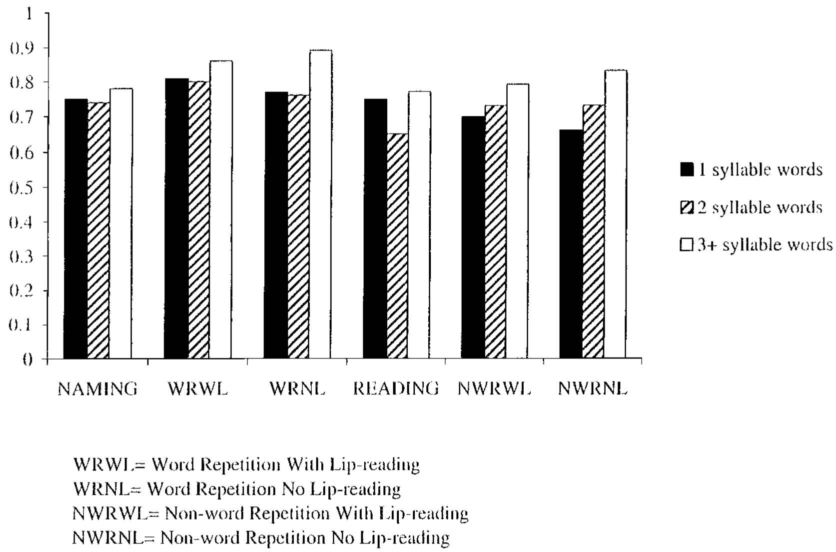

Figure 2 Mean proportion of features correct in six conditions

Taking non-words, naming was significantly better than non-word repetition ($p < 0.05$) for one-syllable words only; real word repetition was better than non-word repetition whether lip cues were allowed or not ($p < 0.1$). Interestingly, for both real word and non-word repetition, lip cues did not produce any significant effect.

Finally, there was no significant difference between reading and naming.

Discussion

Naming versus real word repetition. The results show TG's repetition of words is better than naming. This indicates a difficulty on the naming task which is being bypassed in repetition. The most obvious explanation for this is that there is a deficit in the link between the semantic representation and the motor programme as this is the only route available for naming. Difficulty accessing the motor programme could lead to the searching-type behaviours described above, as she rejects her own inaccurate realizations, which do not match her phonological representations, and repeatedly attempts to produce a form which is closer to these. Repetition would be superior as the motor programme can be accessed directly from the phonological representation.

TG's repetition of real words, although better than naming, also shows many errors. However, these errors are only of the segmental type and do not display the searching-type behaviours indicative of word retrieval difficulties which were also present in the naming task. Segmental errors could be due to the following:

1) An accurate phonological representation, but inaccurate stored motor programme. Often young children can recognize as incorrect their own realizations when produced by an adult, can produce all the sounds required in the positions required and copy related non-words, but persist in producing incorrect realizations in repetition and naming, particularly with more automatic tasks (see Hewlett *et al.,* 1998). This occurs when the motor programme has not been updated in the light of new phonological knowledge (see also Bryan and Howard, 1992).
2) An inaccurate phonological representation and thus also an inaccurate motor programme.
3) Specific articulatory output difficulties beyond the motor programme. As mentioned, TG showed no obvious signs of specific difficulties in this area.

To test which of the first two possible levels of breakdown apply to TG, the accuracy of her phonological representations needs to be further investigated (see stage 3).

Non-word repetition versus real word repetition and naming. When we compare real word with non-word repetition we see that there is a significant real word advantage. This is as expected as semantic and stored phonological information can assist in real word repetition, thus reducing the load on short-term memory. We would expect a similar result for naming but this is only true for one-syllable words. No significant difference was obtained for longer words because of her difficulties naming these.

Lip-reading. The results showed there was no significant advantage of lip-reading in the repetition of either real words or non-words. In the real word repetition task it is less surprising that lip-reading had no effect if TG is primarily using the lexical route. In this case she only needs sufficient information to distinguish the correct phonological representation from other similar sounding representations and then her output could follow directly from this, taking little account of the precise information available from the tester's production. In non-word repetition, the only source of information as to the correct production of the stimulus is the input given by the tester and it was expected that extra visual information would aid TG in her performance on this task. This unexpected result was not due to order of presentation as repetition without lip cues was tested prior to repetition with lip cues. If there were a practice effect one would expect superior performance on the second task. The finding of no significant difference is therefore strong evidence that TG made no use of lip cues in the repetition tasks.

Reading. A significantly higher score for reading over naming would indicate that additional information concerning the pronunciation of the target is being gained from the graphemes. This is not the case for TG; she showed no significant difference in performance between reading and naming. This indicates that either: (a) she is failing to use the grapheme-to-phoneme route and is merely accessing semantic representations directly via a whole word visual lexicon and is using the same output route as for the naming task, or (b) the grapheme-to-phoneme route is being used and is improving her pronunciation of some words but this effect is being cancelled out by her failure to recognize some of the other words, resulting either in failure to produce any output in response to these or production of a pure 'guess', and thus a drastic reduction in her score.

There were some words that she clearly failed to recognize, but she did not appear to be using graphemic information to inform her attempts at guessing the word, some of her guesses bearing little resemblance to the target (*certificate* → 'selotape'). On other occasions she showed no attempt to 'sound out' the word (*radiator* → 'like the heater'). In this case she has accessed the semantic representation as she clearly knows the meaning of the word but has failed to access the corresponding motor programme. If she made even limited use of the graphemic information present, this together with the semantic information already accessed could be sufficient to trigger the motor programme. She does not do this, despite some knowledge of grapheme-to-phoneme rules evidenced by her ability to provide the sounds for individual graphemes.

Further indications of failure to use the graphemic information is given by her production of a couple of semantic errors such as may be found in the adult syndrome of deep dyslexia (*crocodile* → 'alligator' and, on a different task, *South America* → 'North Africa'). Such errors suggest that the stimulus is accessing a vague semantic representation, which can trigger more than one motor programme. Parallel use of the grapheme-to-phoneme route would inhibit output of these alternative motor programmes.

If TG is not using the non-lexical grapheme-to-phoneme conversion route, then her output route when reading would be identical to that used when naming, and we would expect identical errors. For one example, this is certainly the case: *crocodile* → [kɒtəndəʊn] on both the reading and naming tasks, the same faulty motor programme being accessed from the semantic representation in both cases.

In terms of developmental models of reading (Frith, 1985), TG's lack of use of the grapheme-to-phoneme route would suggest that she has not yet progressed to the *alphabetic* phase of reading and is still in the *logographic* phase using a visual whole word recognition strategy of reading.

Conclusions

1) There is as yet no conclusive evidence that any routes of processing assessed are intact.
2) There is evidence of possible deficits in the link between the semantic representations and the motor programme which particularly affect multisyllable words in naming tasks.
3) More evidence is needed to identify whether phonological representations and motor programmes are accurate.
4) TG does not make use of lip-cues to improve her performance in repetition tasks.
5) TG does not use graphemic information when reading real words although she is able to provide the sound represented by particular graphemes in isolation.

Stage 3 – input processing

This stage aims to answer the questions raised by stages 1 and 2:

- Are TG's phonological representations accurate?
- Are her motor programmes accurate?
- Does she have further input difficulties?

The first test looks at the accuracy of TG's internal phonological representations. Where these are faulty the possible reasons for this are investigated; does she fail to detect differences between sounds (due to her hearing impairment) or does she detect the differences but does not give them phonological status (i.e. is treating them as allophones of the same phoneme). The tests start with the phonological representations and then work progressively 'backwards' through the input system, at each point using the results of the previous stage so that the level of breakdown for each word and phonological contrast can be precisely located.

Method

To test the integrity of TG's phonological representations, her own incorrect responses on the naming and repetition tasks and combinations of features of these were spoken by the tester, along with the correct form, and TG was asked to indicate whether the tester said the target words correctly. She was shown a picture of the target word and asked 'Is this a ...?' to which she replied 'yes' or 'no' (as recommended by Locke, 1980). Approximately eight forms were given for each word. Where she had produced many varying realizations in the previous tests, more than eight forms were given in order to test her internal representations of all of her own forms. Following the example of Locke (1980) the *yes* and *no* responses were presented in a quasi-random sequence with never more than two consecutive *yes* responses or three consecutive *no* responses.

To discover which inaccurate representations may be due to auditory discrimination difficulties a further test was conducted. Where she produced false positive responses to this test (i.e. where an incorrect realization was identified as correct) a further test was carried out to see whether she could detect the difference between this and the target form. The tester read pairs of words and then asked TG if they were both 'the same'. TG merely answered 'yes' or 'no' (again as recommended by Locke, 1980). The pairs consisted either of two identical readings of the target word in its correct form, or the correct form of the target paired with one of her previous false positive responses. Each word was paired once with itself and once with each of her previous false positive responses. These were then presented in a random order. Where the words were different, the order of presentation of the correct or incorrect word was varied at random. The same rising intonation pattern was used on both words of each pair.

Results

Identification of the correctness of different realizations of target words. Overall TG scored 250 correct answers out of 363 stimuli. Using a binomial test (with $p = q = 0.5$) we can see that the likelihood of TG obtaining this score by random guessing alone is low ($n = 363$, $z = 7.19$, $p < 0.01$). Considering each word separately, only in three cases out of 42 did she correctly identify all realizations of a word as either right or wrong. The average percentage of her responses that were false negatives was only

4.6%, whereas the average percentage of responses that were false positives was 26.5%.

A qualitative analysis of the false positives provides us with more information which may help us identify more precisely the level of breakdown for individual contrasts. The varying realizations of consonants that she accepted in the tester's speech are listed in Table 2.

In four cases (all multisyllable words) it was not possible to fit TG's errors into such a table as the forms accepted did not differ from the target form merely in terms of the realization of individual consonants ('dictionary' → [dɪʃərɛri], 'vegetable' → [venʃəbl], 'crocodile' → [krɒtədaʊn], [kɒkədaʊn] and 'calculator' → [kaʊntjuleɪtə]).

A qualitative analysis of those errors which TG produced in the naming task but correctly rejected on this task is also of interest. These were: (a) additions of consonants, e.g. 'spade' → [speɪnd]; (b) a change of vowel, e.g. 'web' → [wʌb]; (c) replacement of /s/ and /z/ by [d] and /ʊ/ by [f] (these substitutions were also accepted in some words).

Identification of when tester's production of two words are 'the same'. TG scored 64 correct out of 90 on identification of pairs as 'the same' or 'different'. The probability of this being due to random guessing is very small (binomial distribution $p = q = 0.5$, $n = 90$, $z = 4.01$, $p < 0.006$). Of the errors, 10 were false negatives (failed to identify a matching pair as being the same) and 16 false positives (identified a non-matching pair as being the same). Again, a qualitative analysis is of interest as it shows us which of the realizations of phonemes that were accepted in the previous task she cannot distinguish from each other. These are listed in Table 3.

Table 2 Realizations of phonemes in target words accepted as correct

Word initial		Within word		Word final	
Target phoneme	Realizations accepted	Target phoneme	Realizations accepted	Target phoneme	Realizations accepted
θ	θ, ʃ	!	t, k	p	p, ʔ
s	s, st, ts, d, dz	k	k, t	b	b, d
z	z, dz, d	g	g, d	d	d, n, g, dg, ʔ
sm	sm, m	s	s, ts, dz	k	k, t, ts, s, ʔ, ts
sn	sn, n	z	z, d	n	n, m, gh, l
sl	sl, l			ŋ	ŋ, -
sp	sp,			s	s, ts, t
str	str, tʃr,			st	st, sɫ
				ts	ts, st, tc, ʔ
				sps	sps, sts, s
				nd	nd, n
				nɛ	nɛ, n
				nt	nt, n

Table 3 Realizations of phonemes in target words judged as 'the same'

Word initial		Within word		Word final	
Target phoneme	Realizations 'the same'	Target phoneme	Realizations 'the same'	Target phoneme	Realizations 'the same'
s	s, ts, st	t	t, k	p	p, ʔ
sn	sn, sn	g	g, d	k	k, t, ts, s, ʔ
sp	sp, b	s	s, ts, dz	n	n, ŋ
		z	z, d	nt	nt, n

Discussion

Identification of correctness of different realizations of target words. We will consider first those incorrect realizations TG correctly rejected which involved addition of consonants and changes of vowel and occurred only in response to the original naming test (e.g., [zɛsmaʊk] for 'smoke', [wʌb] for 'web' and [spɪnə] for 'spanner'). These realizations do not match her phonological representation for the lexical item. Therefore, when she produced these, the source of difficulty must have arisen at a later stage of processing. As discussed in stage 2, the differing performance between repetition and naming indicates the most likely source of these incorrect realizations is difficulty accessing the motor programme from the semantic representation when naming.

Some segmental errors were accepted in some cases and rejected in others ([d] for /s/ and /z/ and [f] for /θ/). The following realisations were accepted: [dæn] for 'sand', [dɪp] for 'zip' and [fʌm] for 'thumb' while [dʌn] for 'sun' and [fri] for 'three' were not. This variable performance suggests that TG is in the process of updating her phonological representations in the light of a developing awareness of the phonological nature of these distinctions (these are all distinguished in the same/different task, see below). Hence such substitutions will be rejected only for those lexical items where the phonological representations has been updated.

We now turn to those incorrect realizations which TG accepted as correct (false positives). These fell into two groups: the majority, which involved substitutions at a single phoneme level, and the four multisyllable words where more widely varying forms were accepted. We will discuss the latter first. In these cases, the forms accepted have the same number of syllables and the same stress pattern as the target. We hypothesize that TG's phonological representations for these words are 'fuzzy', i.e. she is unsure of their precise form, so realizations which have a similar broad form to the target are also accepted. 'Fuzzy' phonological representations would lead to imprecisely defined motor programmes and therefore output errors.

The majority group of false positives (those involving a substitution at a single phoneme level) could arise for two reasons: (a) TG simply cannot hear the difference between the target sound and the substitution or, (b) she *can* hear the difference but is failing to give it any significance, treating the different realizations as allophonic variations of the same phoneme. The following 'same/different' test was designed to distinguish between these two possibilities.

Identification of when tester's production of two words are 'the same'. It is likely that those differences TG failed to identify in this task are due to her hearing impairment as this task uses processes that are very close to the input periphery in psycholinguistic processing models. With the exception of one case (/p/ → [p,ʔ]) none of the pairs of sounds she fails to distinguish can be distinguished using lip cues. Eight out of 11 errors involve voiceless consonants which may be difficult even for a person with only a mild hearing loss to distinguish and are thus likely to cause TG considerable difficulties. However, only 28% of her single phoneme errors on the preceding identification task are also errors on this task, providing strong evidence that her hearing impairment cannot be the only cause of her difficulties (she scored 75.5% correct on this task which is well above a chance response). This shows that she can hear many distinctions even though she regards the two realizations as being the same in phonological terms.

Conclusions

1) TG has 'fuzzy' phonological representations for some words so a variety of heard realizations are accepted as correct. These lead to imprecise motor programmes and therefore output errors.
2) Some naming errors are due to difficulty accessing the motor programme. This can lead to vowel errors and addition of consonants.
3) The majority of the faulty phonological representations (consisting of segmental errors) are not due directly to her hearing impairment as she can hear the difference between the correct realization and her own faulty realization when produced by an adult.
4) The difficulty in these cases probably lies with a lack of awareness of the phonological significance of some sound contrasts that she can hear.
5) Some errors are due solely to faulty motor programmes as the phonological representations are accurate. The hypothesis is that she is in the process of updating her phonological representations in the light of a new awareness of some phonological distinctions and has not yet updated her motor programme so they correspond.

General discussion

The extensive investigations carried out into TG's speech processing system clearly show that there is no single level of breakdown that is the root cause of all her difficulties. Indeed there are multiple levels of breakdown in which her hearing impairment now plays a relatively minor part. This is in contrast to some studies of children with phonological difficulties which have been published to date which tend to present a relatively clear cut outcome (Bryan and Howard, 1992; Bryan and North, 1994). This study shows that we should not expect all cases to be so clear and in the presence of multiple levels of breakdown a psycholinguistic model can help identify which particular difficulties are originating at which levels. We can then plan therapy to treat the root cause of each.

TG's psycholinguistic profile follows.

Output

There is no evidence of any structural abnormalities, difficulty articulating individual phonemes or in the motor planning of sequences of phonemes. All TG's errors can be accounted for by hypothesized deficits in the earlier stages of processing.

Input

TG's hearing impairment affects her ability to hear differences between some pairs of sounds. These are listed in Table 3.

TG fails to give phonological significance to some contrasts which she can hear (those listed in Table 2 but not appearing in Table 3).

Lexical representations

Some of TG's phonological representations are imprecise. She accepts as correct several realizations (and substitutions) of some phonemes when spoken by the tester in the target words (listed in Table 2). She also appears to have 'fuzzy' representations for some (multisyllable) words (those errors on the identification of correctness task that could not be explained in terms of single phonemes, e.g. 'calculator' and 'crocodile').

In some cases, TG has an accurate phonological representation but an inaccurate motor programme (those realizations which were rejected on the judgement of correctness task but still produced by her in the repetition task).

On the naming task we have hypothesized that TG has difficulty accessing a motor programme from its semantic representation.

Conclusions

Discussions of the use of psycholinguistic frameworks found by the author to date have always used subjects with normal hearing acuity. This study has shown that it is possible to use such a framework with a hearing-impaired child and to gain insights into the difficulties of such a child which could inform therapy. If the same stimulus words are used throughout testing then the precise level of breakdown for each word and thus each phonological contrast can be identified. This procedure will also give information about variation in levels of breakdown for different phonological contrasts. A naming task can provide a base for tests with matched items designed to tap the integrity of representations and input processing skills. For hearing-impaired children, words and contrasts that are not affected by lower level input processing skills may respond more quickly to therapy as children can use the auditory discrimination skills they do have to update phonological representations. Thus the identification and treatment of these is invaluable in maximizing intelligibility prior to working on those contrasts which the child cannot distinguish and will therefore require more intervention. This should result in more efficient and effective therapy that is specified exactly to suit the child's needs. The next stage of research needs to focus on the results of such therapy with hearing-impaired children.

The child studied here had already been identified as having language difficulties over and above that which would be expected from her degree of hearing impairment. It would be interesting to see whether a psycholinguistic approach would provide any additional insights into the speech and language processing of hearing-impaired children who have not been identified as having any difficulties over and above their hearing impairment.

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Appendix 1: list of stimuli and responses in six conditions

WRWL = word repetition with lip-reading; NWRWL = non-word repetition no lip-reading; WRNL = word repetition no lip-reading; NWRNL = non-word repetition no lip-reading.

WORD	NAMING	WRWL	WRNL	READING	NON-WORD	NWRWL	NWRNL
1 syllable							
sun	dʌn	sʌn	sʌn	s̪ʌn	/sæn/	dæŋk	dæŋ
smoke	zɛsməʊk	s̪məʊk	sməʊk	s̪məʊk	/smaɪk/	m̥aɪk	m̥aɪk̚
red	ʋɛd̬	ʋɛg̚	ɹɛdg̰	ɹɛd̬	/ræd/	ɹæn	ɹæŋ
three	fɹi	fɹi	tɹi	fəɹi	/θɹɑ/	kɹɑ	fɹɑ
sock	s̪ɒkʔ̰	sːə̆lɒk	sɒʔ	s̪ɒʔ	/sek/	dɛk	s̪ɛʔ
moon	mu	mun	mun	mun	/mɑːn/	mɑŋ	mɑn
snake	n̥eɪk	s̪neɪk	n̥eɪk	n̥eɪk	/snəʊk/	n̥əʊk	n̥əʊk
thumb	fʌm	θʌm	sʌn	b̪ʌm	/θim/	ðim	fɪm
web	wʌb	wɛb̚	wɛd̚	wɛd̪	/wɪb/	wɪb	wɪɟ
vest	vɛsː	vɛt^{h}	vɛs	vɛsə̆	/vɪst/	vɪɟ̥t	vɪʔb
zip	dɪp	djɪp	dɪp	dɪp	/zɛp/	dɛp	d̪jɛp
spade	speɪn	speɪnd	speɪn	speɪn	/spəʊd/	s̪pəʊn:	spəʊ:
crisps	kɹɪsə	kɹɪsp	kɹɪsts	kɹɪs	/kræsps/	kɹæʔ	kɹæʔ
sand	dæn	stæn	dæn	dæn:	/sɒnd/	dɒŋ	dɒŋ
case	keɪs	keɪs	keɪt	keɪsə	/kaɪs/	qaɪʔ	kaɪʔ
cake	keɪt	keɪt	keɪtʂ	keɪs	/kaɪk/	kaɪt^{h}	kaɪtʔ̰
spots	spɒst	spɒʔ	fɒt	s̪pɒʔ	/spets/	bɛtʂ	spɛtʂ
sponge	s̪pʌn	bʌndʒə	bʌntʃ	s̪pʌn	/spɪnʒ/	s̪pɪndʒ	bɪŋn
2 syllables							
spanner	spɪnə	s̪pænə	saʊnwə	no response	/spɛnə/	s̪pɛnə	spɛnə
sailor	seɪlə	s̪eɪlə	tseɪlə	seɪlə	/sɒɪlə/	t̪ɒɪləʔ	sɒɪlə
sitting	sɪtsɪn	s̪itiː	s̪ɪt̪s̪iː	sɪsiː	/sʌtɪŋ/	stʌtiʔːŋ	tʌtiʔ
seaside	stitsaɪ	s̪isaɪ	sis̪aɪ	sisaɪ	/sɑsəʊd/	stɑdzəʊ	sɑbwəʊ
sleeping	ɬipɪn	slipɪn	slipɪŋ	s̪lipɪn	/slupɪŋ/	s̪ɬupi	tɬupɪ
spider	baɪdə	s̪paɪdʒ	s̪paɪdʒ	baɪdə	/spəʊdə/	bəʊdə	bəʊdə
present	pɹɛdən	pɹɛdɪn	pɹɛdən	pɹɛdən	/præzənt/	pɹædən	pɹɛdənt̚
engine	ɛndʒu	ɛndʒɪn	ɛndʒu	ɛndʒɪə̆	/ændʒɪn/	ændʒi	ændʒɪt
3 syllables							
motorbike	məʊkəbaɪʔ	məʊkəbaɪʔ	məʊtəbaɪʔ	məʊtəbaɪk̚	/mɪtəbəʊk/	mɪkɪbəʊʔ	mɪkt̰ɪbəʊk̚
cardigan	kɑdədən	kɑdədən	kɑdɪdən	kɑdɪdən	/kuːdɪgən/	kudɪgɪn	kudɪdən
cinema	dɪnəmɑ	dzɪnəmɑ	tsɪnəmɑ	tsɪnəmɑ	/senəmuː/	s̪enəmu	dɛnɪmu
elephant	ɛləfən	ɛləfənːt	ɛlɪfən	ɛlɪvənː	/ɒlɪfɪnt/	ɒlɪfən	ɒlɪfɪz
dinosaur	daɪnədzɔə	daɪnədzɔ	daɪnəsɔ	daɪnəzɔ	/daɪnəsɜː/	daɪnədʒ	daɪnədzʒ
selotape	dɛləteɪp	sɛləreɪp	sɛləreɪp̚	seɪsɔː	/sɒlɪtəʊp/	d̥ɒlɪtsəʊ	fɒlɪtəʊ
vegetable	vɛndʒəteɪbl	vɛnʃəbəl	vɛnʃəbəl	vɛnʃəteɪbl̩	/vɪdʒtəbəl/	vɪdʒʃəbl̩	vinʃəbl̩
dictionary	dɪkʃəɹɛɹi	dɪkʃənɹi	dɪkʃənɹi	dɪkʃəɹɛɹi	/dækʃənɹuː/	dækʃəɹu	dæʔʃənəɹu
lemonade	lɛmɒneɪ	lɛmɒneɪ	lɛmɒneɪn	lɛmɒneɪn	/lʌmənəʊd/	lɛmənəʊn	lɛmənəʊ
fingerprint	fɪŋgəpɹɪn	fɪŋgəpɹɪn	fɪŋgəpɹɪn	fɪŋgəpɪnt	/fʌŋgəprænt/	fɪŋgɪp^{h}æn	fʌŋgəpɹæn
marmalade	mɑməleɪ	mɑməleɪ	mɑməleɪ	no response	/miməlәʊd/	miməlәʊn	nimənəʊ
strawberry	ʃvɔbɛɹɪ	dɔbɹɪ	stɹɔbɹɪ	stɹɔbɛɹɪ	/struːbriː/	kxubi	tʃɹubɹɪ
crocodile	kɒtəndəʊn	kɹɒtəndaɪl	kɹɒtədaʊn	kɒtəndaʊn	/krɪkedəʊl/	kɹɪtədəʊː	kɹɪtədəʊn
4 syllables							
television	tɛləvɪn	tɛləvɪʒn	tɛləvɪdʒn	tɛlɪvɪʒən	/tʌləvæʒən/	tɛləvæʒən	tɛləvæʒən
calculator	kælkjuleɪkə	cælcəleɪtə	kaʊntəleɪtə	kaʊtəleɪtə	/kʌlkɪləʊtə/	kaʊtɪləʊtə	kʌltələʊtə
radiator	ɹeɪdɪəʊeɪtə	ɹeɪdɪeɪtə	ɹeɪdjueɪtə	ɹeɪdɪəʊeɪʔ	/raɪdɪəʊtə/	ʋaɪdɪəʊtə	ɹaɪdɪəʊtə

Appendix 2: additions to scoring method to account for phonetic errors

1) Half a point was deducted for phonetic distortions which did not result in the loss of a phonological distinction.
2) Clusters where the features from both phonemes were combined together were scored together as one combined target. For example, for the cluster /sm/, the six features required in total are: voiceless, alveolar, fricative, voiced, bilabial and nasal. Where TG realized this with the voiceless bilabial nasal [m] she was given credit for the three out of the six target features that she produced. By Bryan and Howard's method, she would only have scored 2/6 because the sound produced was closer to /m/ so this would be taken as the target sound. Only two features of this sound are present and she would score nothing by comparison with the /s/ which would count as an omission.
3) Clusters involving /s/ – voiceless plosive: if she realized /sp/ as [b] she was credited with 3/6 features because the voice onset time for /p/ in the context of an /s/ cluster is closer to /b/ in isolation than /p/ and she was not therefore penalized for retaining this phonetic feature.