WHY DON’T DEAF READERS GARDEN-PATH?

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Abstract

Self-paced reading was used in three experiments to examine online sentence processing in sixteen deaf adults. Experiment 1 examined processing of simple declarative sentences. Experiment 2 examined processing of temporarily ambiguous sentences with filler-gap dependences, and experiment 3 explored sentences with a temporary ambiguity between direct object and subject analysis of an NP. The results from each experiment show that the deaf participants did not process the experimental items in the same way as the hearing participants. In experiment 1 we found no syntactic ‘wrap up’ effect (slowing of reaction times at the end of a sentence) for the deaf; in experiment 2, we found no tendency for the deaf to erroneously anticipate the position of a wh-word; and in experiment 3, we found that deaf readers do not follow a strategy of attempting to incorporate the most recently input material into the parse of an existing phrase. We suggest that lack of access to prosodic information in the language input during acquisition (because of auditory deprivation) results in atypical development of parsing strategies.

1. Introduction

It has long been documented that the reading ability of deaf individuals falls well below that of their hearing counterparts (Conrad 1979, 1977; King & Quigley 1985; Watters & Dowering 1990). More recent research indicates that the situation has not improved significantly over the years (Paul 2003, 1998; Traxler 2000). Although the past three decades have seen the development of a vigorous field of research in sentence processing in the hearing population, to our knowledge, much of this literature has not yet impacted on the study of language processing in the hearing impaired. Our aim in this paper is to begin to make a connection between sentence processing research in hearing adults and reading by the deaf.

1.1 Syntactic knowledge

For hearing children, syntactic structures are learned through daily interaction with parents and others, and not through any formal teaching. However, this is not the case for the deaf child. Most deaf children start school and begin learning to read without the syntactic knowledge that their hearing peers possess. Miller (2000) suggests that pre-lingual deafness may prevent readers from spontaneously internalising the syntactic rules of spoken language.

Successful reading involves accessing and using written information to construct meaning (Paul 2003). Although many deaf readers can access words and their semantic interpretation, this does not necessarily lead to comprehension of the overall meaning of the text (Lillo-Martin, Hanson & Smith, 1991; Kelly 1995; Miller 2000). In order to construct meaning from complex syntactic structures one needs to be able to assign thematic roles (such as agent or patient) to constituents and to link moved constituents (such as question words) to their
original position. Quigley, Power & Steinkamp (1977) and Hatcher & Robbins (1978) found that while deaf subjects could comprehend an idea expressed in a simple sentence, they could not understand the same idea when expressed in a sentence with a more complex syntactic structure. This indicates that lack of syntactic knowledge—or inability to apply such knowledge while reading—does affect comprehension. Even though deaf readers may have sufficient ‘world knowledge’ to enable them to understand an idea, lack of syntactic knowledge/processing ability hinders comprehension in a complex structure. Miller (2005) suggests that deaf individuals may not process text syntactically but rather try to derive meaning ‘by applying their prior knowledge and experience in interpreting its content words’. Others claim that some deaf readers may simply rely on a limited set of syntactic rules (Hatcher & Robins 1978; Quigley 1982).

Quigley, Power, & Steinkamp (1977) tested a group of deaf students aged ten to nineteen using structures such as question formation, negation, conjunction, relative clauses, pronominalization and complementation. These syntactic structures were presented singly in sentences. Quigley et al.’s results revealed that the average eight-year-old hearing subjects performed better than the average eighteen-year-old deaf participants. The main differences occurred in constructions that involved holding information in short-term memory while waiting for semantic or syntactic resolution. It has been shown that many deaf readers who have difficulty comprehending complex syntactic structures such as subordination and conjunction tend to impose a subject–verb–object pattern on English sentences (Quigley 1982; Berent 1988). Miller (2000) suggests that for such individuals, subordinate clause markers function as co-ordinating conjunctions.

Lillo-Martin, Hanson and Smith (1992) studied reading English relative clauses by deaf persons who had learned sign language from birth. They found comprehension was significantly worse for relative clauses that modified the subject of the sentence than relative clauses that modified the object.

1.2 Automaticity

Kelly (2003) found that in less skilled deaf readers: (a) lexical access is not fast enough to allow word meanings to be combined with words read earlier before they have decayed from working memory; (b) poor performance in syntactic analysis affected their subjects’ abilities to fully utilise vocabulary knowledge; and (c) sentences with complex syntactic structures were more difficult for less skilled readers to understand. These findings, together with the fact that average deaf readers read significantly more slowly than skilled deaf readers, led Kelly to claim that even among deaf college students, low automaticity is a significant obstacle to reading comprehension.

Hearing children pass through developmental stages, initially focusing on decoding print into sound and recognising word shapes (usually between 6-8 years of age). This is usually fairly automatic by age nine, enabling the child to move on from word level processing to processing at sentence level, then text level and eventually to fluent reading. When decoding is automatic as in fluent reading, attention can focus on comprehension. According to Snyder & Downey (1991), if a child cannot reach this level of automaticity then he/she may be unable to advance to the stage of reading for meaning. Given that the average deaf school leaver has a reading age comparable to that of a nine year old hearing reader it is possible that many do not reach the level of automaticity required in order to progress to fluent reading (Traxler 2000).
1.3 Modality independent comprehension skills

Recent research has focussed on whether cognitive factors over and above language comprehension in general might play a more vital role in the comprehension process than previously thought (Marschark, Sapere & Convertino 2009). Their findings are based on the fact that ‘the weaknesses exhibited by deaf students in many of the subskills involved in reading are paralleled by similar weaknesses in understanding sign language’ (Marschark et al. 2009:359). Marschark et al. found that while deaf readers had difficulty monitoring their own comprehension of written material, deaf signers also appeared to have poor comprehension monitoring skills during communication in sign language or lip reading. They suggest that rather than continue to focus attention on the areas mentioned above, it might be advantageous to investigate the interaction of cognitive processing, language comprehension and learning, regardless of which mode of communication is used (print or sign language).

2. Goals of the present study

The key subskills of reading described in the previous section have all been examined in an effort to find an explanation for the difference in reading ability between deaf and hearing readers. The technique used in our study was self-paced reading (see below for a description of the technique), which has widely been used in studies of reading in hearing adults. Kelly (1995), Wauters, Telling, van Bon & Mak (2007), Van Hoogmoed, Verhoeven, Schreeder & Knoors (2011) and others have used this technique with deaf subjects; the focus of these studies has been the overall comprehension of written passages and the ease of processing different classes of content word vocabulary and morphology. In a recent self-paced reading study closer to the intent of this study, Traxler, Corina & Morford (2010) found that deaf signers reading English had patterns of relative clause and passive sentence comprehension similar to those for hearing adults, particularly for subjects who were native signers.¹

Our study examined whether syntactic reading patterns and the parsing strategies used by hearing adults are also used by deaf individuals. There were some clear predictions from the studies reviewed in the previous section, although it was not always the case that previous findings could be applied to the present testing situation. Thus the documented difficulty deaf readers have with structures that require holding an element in storage (Quigley et al. 1977) led to the prediction that deaf readers would be more prone to errors in interpreting wh-questions, and the shorter digit spans of deaf individuals (King & Quigley 1985) led to the prediction that subjects would have more difficulty with sentences that require revision of the syntactic analysis.

Our first experiment examined the online processing of simple declarative sentences which could be read quite easily by most hearing children. In the hearing population, function words such as a and the are read more quickly than content words, creating a rise and fall pattern in declarative sentences (Aaronson & Scarborough 1976). This experiment thus addressed the issues of automaticity in lexical retrieval and the construction of basic syntactic structures.

Experiments 2 and 3 examined whether deaf readers employ the same strategies for syntactic analysis that hearing readers do. Experiment 2 looked at the processing of questions. In questions, the reader needs to link the sentence initial question phrase to its original position in order to arrive at the correct interpretation. For the hearing population, the processor has been shown to actively seek out a site for the wh-phrase during online processing, sometimes erroneously anticipating a position for the wh-word where one does not exist (Crain & Fodor, 1977).

¹ We have only the abstract of Traxler et al.’s (2010) study.
1985; Frazier & Clifton 1989, Stowe, Tanenhaus & Carlson 1991, 1986). This active search for a position for the question word plausibly follows from pressure to reduce load on working memory (holding the question word in memory until it has been integrated into the incoming sentence). The aim of this experiment was to determine whether or not deaf individuals process questions in the same way as the hearing population and whether pressure on working memory for the deaf would exacerbate patterns that are found in the hearing population.

In experiment 3 we attempted to replicate with deaf readers the findings of Frazier & Rayner (1982). Hearing readers prefer to interpret the phrase his horse in a sentence such as Before the King rides his horse is always groomed as object of the first verb (rides) – an incorrect analysis, since the phrase is in fact subject of the main verb is. This is attributed to a processing principle that dictates that incoming material is associated with the most recently processed phrase.

3. Method

3.1 Procedure

Before the experiment began, written instructions were given on the computer screen used for the presentation of the words. These instructions were also given to the deaf participants in sign language. At the beginning of each sentence the instruction ‘PRESS TO BEGIN NEW SENTENCE’ appeared on the screen. Each word appeared in the centre of the screen and the participant pressed a button on a response box to remove the current word and bring a new word into view. On the screen that appeared after the last word in a sentence, a ‘$’ sign was shown to indicate the end of the sentence (a full stop in the centre of the screen was considered to be too small for comfortable viewing). Participants familiarised themselves with the procedure with practice items before beginning the experiments. The materials for the three experiments were intermingled in blocks of one token of each sentence type. Forty filler sentences were also included.

A secondary comprehension task was used to ensure that participants were reading for meaning: subjects were required to answer a yes/no question about the previous sentence. The questions were randomised throughout the test battery with a ratio of one question to every three sentences. The question appeared on the screen immediately after the sentence and the subject answered by pressing one of two buttons, Y for yes or N for no. This task was chosen as opposed to sentence repetition, which is also commonly used in self-paced reading tests, because we felt it to be more appropriate for (place less burden on) our deaf participants. The average number of correct responses was 90% for the deaf and 94% for the hearing.

3.2 Participants

Sixteen deaf and sixteen hearing adults from the Belfast, Northern Ireland region took part in the study. Only deaf individuals who were either born deaf or prelingually deafened and who had hearing parents were included. No subjects had cochlear implants. They were all educated in an oral system, learned English as their first language and could be termed high achievers within the deaf population. Both deaf and hearing participants had an education level of the UK General Certificate of Secondary Education or above; most of the deaf
participants had ‘A’ levels (university entrance examinations) or degrees. Reading assessment tests were not carried out, but we reasoned that in order to pass written examinations in various subjects at GCSE level the participants’ reading ability must be adequate.

4. Experiment 1

4.1 Previous research

Aaronson & Scarborough (1976) and others have shown that in self-paced reading tests hearing readers produce a rise and fall pattern with shorter reaction times at functions words (determiners, auxiliaries, prepositions) than at content words (nouns, verbs). This may be attributed to the difference in time taken to access the different categories and/or to time taken to integrate material at the end of a phrase (in languages such as English, where function words typically are phrase initial).

4.2 Goals

The goal of Experiment 1 was to see if reading times for deaf readers differentiated between function words and content words, using simple sentence types. We considered it useful to include materials that could easily be read by most hearing children, since the literature indicates that the reading age of the average deaf eighteen year old is eight to nine years (Traxler 2000).

4.3 Materials

The experimental items were of four types:

(1) The clown entertained his audience (Det, N, V, Det, N)
(2) A teenager would choose this holiday (Det, N, Aux, V, Det, N).
(3) An old man walked up our street (Det, Adj, N, V, Prep, Det, N).

(Det = Determiner, N = Noun, Aux = Auxiliary, Adj = Adjective, Prep = Preposition, Adv = Adverb). There were five tokens of each of the four sentence types.²

4.4 Results

Figures 1–4 below show the mean reading time for each group at each position in sentence types (1–4). In this and the two experiments reported below outliers were identified as scores higher than 2.5 times the standard deviation from the mean score and were replaced with the subject’s mean score for that position in that condition.

² A complete set of the experimental materials used in all three experiments is available on request.
As can be seen from each figure, the deaf are reading much more slowly than the hearing participants and there is more variation in their reading times.

An inspection of Figures 1–4 shows that the only position at which the reading times for the hearing change appreciably is at the end of sentence (EOS) position. Elevated reading times at EOS in studies with hearing participants are thought to reflect some aspect of sentence final processing and have been referred to as an end of sentence ‘wrap-up effect’ (Mitchell & Green 1978; Just & Carpenter 1980; Rayner, Sereno, Morris, Schmauder & Clifton 1989; Millis & Just 1994). An EOS effect for the deaf subjects is seen only for sentence type 1.

Figures 1–4 also show that reading times for the deaf are shorter at function words and longer at content words, as we expected based on the previous literature on hearing subjects. Paired sample t tests comparing the transitions from one position to the next were carried out to examine the effects of position. Reading times for the hearing group did not vary much from one position to another throughout the sentence. Of the 25 transitions from one word to the next for the four sentence types, only three were significant or near significant, and each of these three were for the transition between the last word and the EOS marker (Sentence type 1: N2 to EOS, t(15) = -5.09, p < .001, by subject, t(4) = -2.61, p = .059, by item. Sentence type 2, N2 to EOS, t(15) = -3.66, p = .002, by subject, t(4) = -5.51, p = .010, by item; Sentence type 3: N2 to EOS, t(15) = -2.50, p = .025, by subject, t(4) = -6.00, p = .004, by item).
For the deaf group, of the 25 transitions 12 were significant by subject, of which only one was the transition between the last word and the EOS marker (Sentence type 1: transition D1 to N1, t(15) = -3.72, p = .002, all probabilities here and below, two tail; V to D2, t (15) = 2.58, p = .021; N2 to EOS, t(15) = -2.31, p = .036. Sentence type 2: N1 to Aux, t(15) =2.48, p = .025. Sentence type 3: A to N1, t(15) = -2.56, p = .008; V1 to P, t(15) =2.75, p = .015; D2 to N2, t(15) = -2.56, p = .022). Sentence type 4: D1 to N1, t(15) = -3.17, p = .006; N1 to P1, t(15) = 3.36, p = .004; P1 to D2, t (15) = 2.51, p = .024; D2 to N2, t(15) = -2.72, p = .016). By item, nine of the 25 transitions were significant, of which again only one was for the last word to EOS marker, again for sentence type 1 (Sentence type 1: V1 to D2, t(4) = 3.40, p = .027; N2 to EOS, t(4) = -4.24, p = .013. Sentence type 2: Aux to V1, t(4) = -3.58, p = .006; V1 to D2, t(4) = 3.93, p = .017; Sentence type 3, Adj to N1, t(4) = -3.11, p = .036; D2 to N2, t(4) = -2.78, p = .050. Sentence type 4: N1 to P1, t(4) = 3.17, p = .034; P1 to D2, t(4) = 6.06, p = .004; D2 to N2, t(4) = -3.94, p = .017).

4.5 Discussion of Experiment 1

The data from deaf participants showed effects of position across the sentences types except at the end of sentence marker, whereas the hearing only produce an effect of position at EOS. Kelly (1995) did report an EOS wrap-up effect with deaf subjects. However, Kelly’s analysis was carried out on the last word of the sentence and the word preceding it, whereas we measured EOS wrap-up between the last word in the sentence and the end of sentence marker. It may be that the difference Kelly found between the penultimate and final words in the sentence reflected the difference between function and content words, similar to that found for the deaf subjects in this experiment (Kelly’s materials were not published and so we cannot directly verify this).

The overall reading patterns produced by the deaf are what we expected from previous research on hearing persons: reading times rose from determiners to nouns, and fell from verbs to determiners and other function words. For the hearing subjects, the absence of any effect of position except EOS wrap up can be attributed to the subordinate task we chose. Yes–no questions as a subordinate task have been found to lead to faster reaction times and smoother profiles across the sentence than sentence repetition as a subordinate task (Aaronson & Scarborough 1976).

5. Experiment 2

5.1 Previous research

A substantial literature in sentence processing by the hearing, using self-paced reading and other techniques, has shown that (1) overall, reading times are longer for wh-questions than for declaratives or yes–no questions, and (2) readers may incorrectly predict a position in the incoming sentence in which to place a wh-question word (Crain & Fodor 1985; Stowe 1986; Frazier & Clifton 1989; Stowe et al. 1991). With respect to (1), reaction times are expected to be longer in the subordinate clause in (5a) than in (5b):

(5) a. The chef wondered what he would cook the lamb with that night.
   b. The chef wondered if he would cook the lamb with roast potatoes that night.

(5a) contains an embedded question, in which the processor must link the wh-word what to
the position after the preposition with. (5b) contains an if clause (an embedded yes–no question), in which no such linkage is required. (5a) also contains another potential position for the wh-word, as object of the verb cook. This location for the wh-word is shown to be incorrect when the phrase the lamb is encountered. Studies beginning with Crain & Fodor (1985) have shown that hearing subjects incorrectly anticipate a position for the wh-word after the verb. This is reflected in longer reading times to access the word after the determiner that follows the verb in wh-question sentences such as (5a) than in yes–no sentences such as (5b). It is reasoned that the processor initially places the wh-word as object of the verb, only to discover its mistake when it accesses the following determiner, leading to a delay in requesting the noun that follows the determiner. This is termed a ‘filled-gap’ effect – the place (gap) posited for the wh-word turns out to be filled by another noun phrase. This is one type of error known in the literature as a ‘garden path’ effect, the processor temporarily positing an incorrect analysis of the input.

5.2 Hypotheses

We expected the hearing subjects to show longer reading times in sentence such as (5a), and to show the ‘filled gap’ effect in encountering the object of the embedded verb. Following Quigley, Power & Steinkamp (op cit.), we expected holding a wh-word in memory would produce a greater effect for deaf readers than for hearing readers, and that either this greater load would enhance the effect of misplacement of the wh-word, and/or that it would cause a breakdown in parsing procedures normally used by hearing adults.

5.3 Materials

There were ten sentences frames of the type in (5a/b). The two versions of each sentence (wh/if) were counterbalanced across experimental lists, each participant seeing only one form of each sentence, for a total of five tokens of each condition per subject. The order of the sentences was arranged so that no two tokens of the same condition were presented adjacently.

5.4 Results

Figures 5 and 6 below show the mean reading time per word for each group at each position in the critical region (the verb and subsequent positions) of the sentence for each condition (wh (cond. 1) vs. If (cond. 2)) and syntactic position (V = verb, D = determiner, N = noun, P = preposition). As can be seen the pattern for the deaf is quite different from the pattern produced by the hearing subjects. Although for both groups reading times are generally longer for the wh condition than for the if condition, only the hearing group displays the expected pattern of an increase in reaction times at the determiner and noun. The deaf group, by contrast, show a pattern of higher reaction times at content words (the noun and verb) than at function words, reminiscent of their performance in experiment 1.
Four (position) x 2 (condition) repeated measures ANOVAs were carried out on the mean reading time for position in the critical region of the sentence. Analyses were carried out for both subjects (F₁) and items (F₂). Separate ANOVAs were conducted for the hearing and deaf groups.

The ANOVA for the hearing group revealed a significant effect of condition for subjects (F₁ (1,15) = 16.10, p = .001), but not for items. There was no effect of position for subjects, but there was an effect for items (F₂ (3,24) = 5.12, p = .019). There was a significant position x condition interaction for both subjects and items (F₁ (3,45) = 3.10, p = .047, F₂ (3,24) = 4.73,
Pair sample t tests\(^3\) for condition (wh vs. if) x position showed no significant difference in reading times between conditions at the verb. However, consistent with the literature on the filled-gap effect there was a significant difference immediately after the verb. Elevated reading times for the wh-condition were recorded at the three positions following the verb, i.e. at the determiner (t(15) \(=2.72, p = .016\)), noun (t (15) = 2.90, \(p = .011\)) and preposition (t(15)= 3.64, \(p = .002\)).

The results of the ANOVA for the deaf participants showed an effect of condition for subjects (F\(_1\) (1,15) = 5.00, \(p = .041\)), but not for items. The deaf group also produced an effect of position for subjects (F\(_1\) (3,45) = 4.02, \(p = .024\)), but not for items. There was no position x condition interaction for subjects or for items. Planned comparison t tests showed that there was a near significant difference in reading time between the wh items and the if items at the verb (t(15) = 2.05, \(p = .058\)) and a significant difference at the noun (t(15) = 2.24, \(p = .041\)), with elevated reaction times for the wh items. T-tests to examine the effect of position (transitions from one position to the next) obtained in the main ANOVA revealed a significant difference between the noun and preposition in the wh items, (t(15) = 4.25, \(p = .001\)) but not in the if items.

5.5 Discussion of Experiment 2

Our results for the hearing subjects are exactly as we predicted based on the previous literature, there are elevated reaction times to wh items, and there is a garden path effect in for these items. In contrast, no clear garden path effect was found for the deaf readers. Although there was a difference for the deaf readers at the noun between the wh and if conditions, this may be explained, not as a filled-gap effect, but as the pattern of elevated reaction times at content as opposed to function words, a pattern that is more exaggerated due to the overall slower reading times for the wh condition. In support of this interpretation, there was no significant difference at the verb for the hearing subjects (\(p = .609\)) but a near-significant difference for the deaf subjects (see above, \(p = .058\)).

6. Experiment 3

6.1 Previous research

Studies such as Frazier & Rayner (1982) have found evidence that hearing readers process according to the principle of Late Closure. Late Closure dictates that at a position that requires a choice between two alternative structures, the processor opts to attach incoming material to the phrase that has just been input, rather than to initiate a new phrase/sentence. This can lead to a garden path, when the correct analysis is to posit a new phrase/sentence, i.e. the correct analysis is Early Closure. The propensity for such error may be modulated by the length of time (number of words) that intervenes before it becomes apparent that the Late Closure analysis is incorrect, and a new phrase/sentence should have been posited. For example, in Frazier & Rainer’s study, subjects were to better able to recover from a garden path of assuming that the noun phrase that follows the first verb is object of that verb in (6b) than in (6a), since the noun phrase is shorter and the misanalysis is likely to be less entrenched.

\(^3\) In this experiment and Experiment 3 (below) t-tests were conducted only in the case of significant effects in the main ANOVA.
(6) a. Before the King rides his beautiful white horse is always groomed.
   b. Before the King rides his horse is always groomed.

6.2 Hypotheses

For hearing individuals, we predicted processing difficulty in early closure sentences when
the second verb is accessed (is in (6)), indicating that the preceding noun phrase is in fact not
the object of the first verb. We predicted that for hearing individuals, as in the Frazier &
Rayner study, the long versions of the early closure sentences would cause more processing
difficulty than the short versions.

Deaf individuals have consistently been found to have shorter digit spans than hearing
individuals (King & Quigley 1985). In view of this finding, we hypothesised that deaf
subjects would experience greater processing difficulty than the hearing when trying to
recover from an initial parsing decision which was incorrect.

6.3 Materials

The materials for this experiment were the same as those used by Frazier & Rayner (1982),
with some lexical changes to accommodate Northern Irish English usage (for example, the
word ‘roommate’ was replaced by ‘flatmate’). In half the materials there was an initial
subordinate clause followed by a main clause (as in 7); in the remaining half of the materials,
there were three conjoined clauses (as in 8). Each sentence had four versions: Late closure
long (LCL), early closure long (ECL), late closure short (LCS) and early closure short (ECS).

(7) LCL:  Before the King rides his beautiful white horse it’s always groomed.
         ECL:  Before the King rides his beautiful white horse is always
groomed.
         LCS:  Before the King rides his horse it’s always groomed.
         ECS:  Before the King rides his horse is always groomed.

(8) LCL:  Anne was watching the people on the street she laughed and nobody knew
         why.
         ECL:  Anne was watching the people on the street were laughing and nobody knew
         why.
         LCS:  Anne was watching you she laughed and nobody knew why.
         ECS:  Anne was watching you were laughing and nobody knew why.

The materials consisted of sixteen sentences, half of which were of type (7) and half of type
(8). Each subject saw only one version (Late Closure/Early Closure) of each sentence, for a
total of four tokens of each condition (LCL, ECL, LCS, ECS). The sentences were ordered
so that no two tokens of the same construction were ever presented consecutively.

6.4 Results

We averaged the reading time per word in each of three regions: prior to the syntactically
ambiguous phrase (*his (beautiful white) horse* in 7), in the ambiguous phrase, and in the
disambiguating phrase. Response times are reported separately for the adverbial materials
(sentences of type 7) and the conjoined clause materials (sentences of type 8), since there was
a large difference between the sentence types.\textsuperscript{4} Figures 7–10 below show mean reading times per region for each of the three regions, for each sentence type, for both the hearing and deaf subjects. One generalization that can be seen from an inspection of all four graphs is that for both the hearing and the deaf subjects, adverbial sentences are read slower than conjoined sentences.

Fig. 7 shows reading times for the late closure long items. On the adverbial items, reading times for the deaf subjects tend to decrease as they proceed through the sentence. Reading times for the hearing do not vary much in the three regions of these items. On the conjoined items, reading times for the deaf decrease as reading proceeds but less so than for the adverbial sentences. Reading times for the hearing subjects increase as they proceed through the sentence.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure7}
\caption{Mean reading times. Late closure long by sentence type.}
\end{figure}

\textsuperscript{4} There were only two tokens each of the adverbial/conjoined structures per condition; the distinction between the structures was strong, nonetheless.
Figure 8 shows the scores by region for the early closure long items x type. It is clear that the hearing subjects were garden-pathed in both the adverbial and conjoined items. However, the effect of the garden-path is greater for the adverbial items. The deaf were not garden-pathed in either the adverbial or conjoined items.

Figure 9 shows the scores by region for the late closure short items x type. The pattern is similar across the three regions for both subject groups.

Figure 10 shows the scores by region for the early closure short items x type. It is clear that the hearing subjects were garden-pathed on both the adverbial and conjoined items.
ANOVAs were carried out for each group, with the factors 2 (sentence type) x 2 (closure) x 2 (length) x 3 (region). The ANOVA on the data from the hearing group revealed a significant effect of sentence type ($F_1 (1,15) = 17.02, p = .001, F_2 (1,7) = 30.57, p = .001$), an effect of closure for subjects, ($F_1 (1,15) = 6.36, p = .023$), but not for items, and a significant effect of region for both the subject and item analyses ($F_1 (2,30) = 13.60, p = .002, F_2 (2,14) = 40.64, p = .001$). The closure x region interaction was significant ($F_1 (2,30) = 13.90, p = .001, F_2 (2,14) = 19.91, p = .001$), as was the type x closure x region interaction ($F_1 (2,30) = 4.36, p = .045, F_2 (2,14) = 5.09, p = .047$). The length x region interaction was significant for subjects ($F_1 (2,30) = 5.48, p = .012$), but not for items.

Paired sample t tests revealed a significant difference between region 2 and region 3 of the late closure short conjoined sentences ($t(15) = -2.76, p = .014$) but not for the adverbial sentences. This indicates that the hearing subjects experienced greater processing difficulty in the disambiguating region of the late closure conjoined items than in the adverbial items.

The ANOVA for the deaf subjects revealed a significant effect of sentence type for subjects and items ($F_1 (1,15) = 21.21, p = .001, F_2 (1,7) = 11.91, p = .011$). There was a near significant effect of region for subjects and a significant effect for items ($F_1 (2,30) = 3.61, p = .051, F_2 (2,14) = 8.69, p = .004$). There was no effect of closure for either subjects or items. No other scores reached significance.

Paired sample t tests showed that the transition from region 1 to region 2 in the early closure short versions of both the adverbial ($t(15) = 2.76, p = .015$) and conjoined ($t(15) = 2.69, p = .017$) items was significant, but no significant difference was found between region 2 (the ambiguous region) and region 3 (the disambiguating region) in the early closure versions of the conjoined items (or between region 1 and region 3). There was a significant difference between region 2 and region 3 in the early closure short versions of the adverbial items ($t(15) = -2.59, p = .020$).
6.5 Discussion of Experiment 3

Our results for hearing subjects are different from those of Frazier and Rayner to the extent that in their study (a) no main effect of sentence type (adverbial vs. conjoined) and (b) greater garden path effects for the long early closure sentences were found. With respect to (b), Ferreira & Henderson (1991) argue that the resilience of a late closure misanalysis may depend not on the number of words intervening before the correct analysis is signalled, but on the structure of the intervening material. However, we used exactly the same materials as Frazier and Rayner, but still did not replicate their length effect. Possibly an explanation for both (a) and (b) lies in the difference in methodology between Frazier & Rainer’s study, which used eye-tracking, and this one, which used self-paced reading.

Like the hearing subjects, deaf readers show longer readings times for adverbial clauses than for conjoined clauses, a finding that runs against the proposal by Miller (2000) that the deaf may treat subordinate clause markers as co-ordinating conjunctions. Despite this similarity, the basic result – a robust late closure effect – is found for hearing subjects, but not for deaf subjects.

7. Summary of the results of Experiments 1–3

Overall, the results of the three experiments we have reported show both similarities and differences in the reading patterns of deaf and hearing subjects. The similarities are:

- A pattern of longer reading times on content words than on function words in reading simple sentences (Experiments 1 for deaf readers and for hearing readers in other studies in the literature). 5
- Longer reading times for *wh*-questions than for yes–no questions (Experiment 2)
- Longer reading times for preposed adverbial clauses than for conjoined clauses (Experiment 3).

The differences are:

- Little evidence of an end of sentence wrap up effect for deaf readers (Experiment 1)
- An absence of a filled-gap effect for deaf readers (Experiment 2)
- An absence of Late Closure garden-pathing for deaf readers (Experiment 3).

8. General discussion

8.1 Syntactic processing by deaf readers

We believe that the best explanation of the data from our experiments is that the deaf participants are not processing syntactically in the same manner as hearing participants. This is not to say that no syntactic analysis is taking place, but rather that, as proposed by Miller (2000), processing may be different in the deaf population. In the case of our experiments, the data indicates that the deaf are not processing in a manner that is guided by the processing principles that lead to the filled gap effect for hearing subjects in Experiment 2 and difficulty with early closure sentences in Experiment 3. The view that processing by the deaf is not syntactic in the same way as it is for hearing individuals is bolstered by the fact that an end of sentence wrap up effect is largely absent for the deaf hearers.

5 As suggested in the discussion of Experiment 1, the lack of a distinction between content and function words for hearing readers in that experiment may reflect the choice of a subordinate task.
If our deaf subjects are not processing syntactically, then we need to explain the similarities between deaf and hearing subjects: the rise at content words and fall at function words pattern produced by deaf readers in this study and hearing readers in other studies, the longer reaction times for *wh* as compared to *if* questions in this study, and the longer reaction times for adverbial as compared to conjoined clauses in this study. Also, how can we account for the fact that comprehension by our deaf subjects on the secondary yes–no question task was at such a high level (90%)?

The first of the similarities in processing indicates that lexical storage and access is similarly organized for deaf and hearing readers. The second similarity requires that we acknowledge that processing a *wh*-question entails for the deaf, as for the hearing, a working memory burden due to storage of the *wh*-word. The third similarity may arise because the adverbial subordinating conjunction/preposition initiates a semantic analysis that requires a more complex mapping between the main and subordinate clause than is required in the case of the mapping between conjoined clauses. As stated above, what our deaf subjects appear to lack are syntactic strategies that in the case of *wh*-sentences act to minimize memory load, and in the case of early closure sentences to resolve a syntactic ambiguity.

So then why are the deaf so competent when it comes to answering the yes–no questions in the subordinate task? Recent literature on hearing individuals has argued that in certain circumstances the sentence processor may rely on a ‘shallow’ analysis – i.e. on an analysis that is not fully specified with respect to syntactic structure and the reference of, for example, pronouns (Townsend & Bever, 2000; Sanford & Sturt 2002; Clahsen & Felser 2006). On examination, the yes/no questions used in the secondary task could have been answered without an understanding of the details of the syntax of the sentence. For example, the question for sentence (9) below, ‘Were the customers happy?’ could be answered by reference to semantic information in the sentence i.e. ‘the angry customers’ and ‘everyone seemed extremely upset’.

(9) The angry customers were cursing the manager all the waiters were running back and forth and everyone seemed extremely upset.

Even if the deaf subjects in this study were not processing syntactically in the same way as hearing readers, they would still have been able to answer the yes/no questions by relying on semantic information. Since the comprehension questions were used to ensure that subjects were reading for meaning and that they attended to the primary task without distraction, the questions used were adequate for the task. We cannot, however, take the results of the question task to reflect that the deaf subjects correctly analyzed details of the syntactic structure in all of the test sentences.

We wish to emphasise that we are not claiming that deaf readers do not process syntactically, but rather that they are not processing in the same way as hearing readers. It may be that the deaf are more heavily influenced by factors that have been shown to play a role in processing by hearing readers. Ferreira, Christianson & Hollingworth (2001) found that hearing subjects who read sentences such as (10) were often satisfied with an incorrect interpretation, thinking that Anna dressed the baby,

(10) While Anna dressed the baby spit up on the bed.

The longer the ambiguous phrase, the less likely readers were to achieve successful re-analysis. Ferreira et al. suggest that the incorrect interpretation based on the initial misparse
lingers and is more likely to do so in sentences with a long ambiguous phrase because the parser has been committed to the incorrect syntactic structure for longer. They also point out that misinterpretation is somewhat selective and does not hold of the interpretation is implausible. If, as Ferreira et al. claim, individuals who are aware of ambiguity and who perform reanalysis do not end up with a perfect interpretation for early closure sentences but accept ‘good enough representations’, then perhaps the deaf generally interpret sentences using a ‘good enough’ strategy, i.e. keep processing until you think you understand the intended meaning. This fits well with the results of Miller (2000), who found the deaf were more reliant on semantic cues in comprehending sentences than the hearing, and that the oral deaf were more so than signing deaf subjects.

8.2 Why do the deaf not develop the same parsing strategies as the hearing?

Although there is now a large body of work documenting research on phonological coding skills in the deaf population (Paul 1998; Perfetti & Sandak 2000; Izzo 2002; Miller 2002; Burkholder & Pisoni 2003, among others), no clear consensus has emerged on the degree to which ability in this area can account for lack of reading success in the deaf. Nonetheless, it has been suggested that a rich oral language is necessary for reading skills to develop successfully (Clay 1985).

Inefficient phonological coding has been argued to be at the core of reading failure in hearing readers (Ehri 1999). Since phonological skills are based on sound, the hearing child is able to internalize phonological knowledge as a matter of course, but this is not the case for the deaf child. It is well documented that the phonological ability of deaf individuals is poor (Conrad 1979; Hanson 1989; Lillo-Martin, Hanson & Smith 1991). Some evidence suggests that deaf readers with a high level of skill do use phonological encoding (Bebko 1998; Perfetti & Sandak 2000; Miller 2002). However, Miller (2002) found that although deaf readers who were raised orally did process phonologically, they did not have the same level of skill as their hearing counterparts. Other studies have shown that although some deaf readers use phonological coding, this is not the case with all deaf readers (Conrad 1973, 1972; Lillo-Martin et al. 1991).

Prosodics in speech and punctuation in written text can prevent garden-pathing in some cases. Bader (1998: 1) claims that ‘for certain kinds of syntactic ambiguities re-analysis is prosodically constrained’. He argues that this explains why some garden path sentences are easier to interpret than others. Consider the following pairs of sentences (11) and (12), in which the reader will be garden-pathed in the (b) versions. Bader suggests that (11b) produces a greater garden path than (12b) because in (11b) the prosodic structure has to be revised as well as the syntactic structure whereas in (12b) the prosodic structure can be left intact (see also Kjelgaard & Speer 1999, for a study of the role of prosody in late/early closure structures, and Frazier, Carlson & Clifton 2006, for a review of the importance of prosody for language comprehension).

(11) a. In order to help the little boy Jill put down the package she was carrying
   b. In order to help the little boy put down the package he was carrying

(12) a. Peter knew the answer immediately
   b. Peter knew the answer would be false.

Given that the deaf participants in this study did not exhibit garden-path effects, we consider it possible that lack of prosody during language acquisition may have resulted in atypical
development. Prosodic features such as stress, pitch and length are an integral part of speech and the hearing child benefits from such prosodic information as a matter of course. The relation between use of prosody and the development of particular reading patterns in the deaf can only be an indirect one. Prosodic information can resolve Early/Late Closure ambiguities, but not examples such as (12) or the garden path of wrongly anticipating a position for a question word (experiment 2). In the course of development the deaf reader may come to focus on lexical information as a safe option for how to figure out the meaning of a sentence, leading to strategies that can result in typical garden paths being side-stepped.6

9. Conclusion

The absence of increased reading times associated with syntactic processing (the end of sentence wrap up effect, filled gap effect and the late closure effect) in the data from the deaf readers in each of our three experiments indicates that they were not processing the materials in the same way as the hearing participants. We suggest that lack of access to prosodic information in the input during language acquisition may result in deaf children developing atypical processing strategies. We propose that the longer reading times produced by both the deaf and hearing participants in sentences with embedded wh-questions in experiment 2 and in the adverbial sentences in experiment 3 can be attributed to lexical processing and/or an increased burden on memory.

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References


6 As a reviewer notes, sign language ‘probably conveys some kind of prosody’, and it would be valuable to compare persons educated in the oral system and who learnt sign language as a second language (as in this study), to subjects who were native signers.


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