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Deaf Readers' Response to Syntactic Complexity: Evidence from Self-Paced Reading

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Abstract

This study was designed to determine the feasibility of using self-paced reading methods to study deaf readers and to assess how deaf readers respond to two syntactic manipulations. Three groups of participants read the test sentences: deaf readers, hearing monolingual English readers, and hearing bilingual readers whose second language was English. In Experiment 1, participants read sentences containing subject relative or object relative clauses. The test sentences contained semantic information that influences on-line processing outcomes (Traxler et al., 2002; 2005). All of the participant groups had greater difficulty processing sentences containing object relative clauses. This difficulty was reduced when helpful semantic cues were present. In Experiment 2, participants read active voice and passive voice sentences. The sentences were processed similarly by all three groups. Comprehension accuracy was higher in hearing readers than in deaf readers. Within deaf readers, native signers read the sentences faster and comprehended them to a higher degree than did non-native signers. These results indicate that self-paced reading is a useful method for studying sentence interpretation among deaf readers.

Keywords

deaf readers; syntax; parsing; sentence processing; American Sign Language; ASL; passive voice; active voice; bilingual readers; self-paced reading

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Boi, B1i, B2i, and B3i, represent baseline reading time (inanimate, subject relative condition), the effect of changing from subject to object relative in the inanimate condition, the effect of changing from inanimate to animate in the subject-relative condition, and the effect of changing to the animate, object relative condition, respectively. eij represents random error in the level-1 outcomes. go0, g10, g20, g30 represent the mean value of the corresponding level-1 parameters in the native signers. The other "g" parameters affect deviations in the level-1 parameters associated with membership in the early and late signer groups. The "u" parameters reflect random error in the level-2 outcomes.

Each participant had up to 28 responses. A second set of models was run in which RTs were considered as nested within items rather than participants. For the by-items models, transpose person and item.

Learning to read proceeds in different ways for deaf and hearing readers. The most obvious difference, associating sounds with letters, is just the tip of the iceberg. Deaf readers typically do not have proficiency in the language represented by print prior to learning to read. Signed languages, such as American Sign Language (ASL), are not simply visual analogs of spoken languages, but fully independent languages that arise naturally in Deaf communities (Klima & Bellugi, 1976; Stokoe, 1980; Padden & Humprhies, 1988). Thus, the visual-auditory mappings argued to be a key route to breaking the orthographic code for hearing readers may be of little help to deaf readers (Coltheart, Rastle, & Langdon, 2001; Gough, Hoover, & Peterson, 1996; Harm & Seidenberg, 2004; Perfetti & Sandak, 2000).[i] To develop literacy skill, deaf readers must master the vocabulary and grammatical principles of a novel language, one that is distinct from their primary means of communication. They must simultaneously master the orthographic code that maps visual symbols onto meaning. This contrasts with hearing readers, who have already developed a great deal of knowledge of the language, and whose primary task is to discover how the system of visual symbols maps onto this well-developed knowledge base. To capitalize on visual skills among deaf students, teachers have attempted to use visual analogs of spoken English (*Manually Coded English, or MCE*) to promote reading skill (Goldin-Meadow & Mayberry, 2001). However, little or no evidence indicates that such training methods actually promote acquisition of literacy skill in deaf readers (Luckner, Sebald, Cooney, Young & Muir, 2005; Schick & Moeller, 1992).

Deaf readers vary greatly in reading proficiency (for reviews see Kelly, 2003; Musselman, 2000; Goldin-Meadow & Mayberry, 2001; Mayberry, 2010; Schirmer & McGough, 2005), possibly because different deaf readers apply different strategies to map orthographic forms to meaning, because of differences in instruction methods, differences in first-language experience, or other factors. Although some deaf readers attain high degrees of skill, the average deaf student gains only one third of a grade equivalent each school year, and deaf students on average have a fourth-grade reading level at high school graduation; research indicates that this has been the case since the early twentieth century (Gallaudet Research Institute, 2002; Holt, 1993; Wolk & Allen, 1984). Despite 100 years of research and intervention, no approaches to reading instruction with deaf readers have been developed that result in consistently high reading levels.

To fully comprehend English sentences, readers (including deaf readers) must undertake morpho-syntactic processing. Those morpho-syntactic processes reveal aspects of lexical meaning, such as tense and aspect for verb interpretation, as well as revealing how words in sentences relate to one another. Morpho-syntactic cues will often be supplemented by other kinds of cues (e.g., visual and semantic context, animacy, etc.), but some sentences can be successfully interpreted only after detailed syntactic computations have been undertaken (Ferreira, 2003; Altmann & Steedman, 1988; Tanenhaus et al., 1995; Nicol & Swinney, 1989; Zurif & Swinney, 1995). For example, syntactic cues must be analyzed to establish appropriate thematic relationships in *reversible* passives, such as (1a), whose meaning contrasts with the active-voice (1b)

(1a) *The girl was chased by the boy*.

(1b) *The girl chased the boy*.

Adult native speakers of English respond robustly to these morpho-syntactic cues during on-line interpretation (MacDonald et al., 1994; Gilboy et al., 1994; Traxler et al., 1998; see

[i]Hansen and Fowler (1987) found evidence that proficient college-aged deaf readers were capable of performing accurately on phonological judgment tasks, indicating some knowledge of auditory phonology. However, it is unknown whether knowledge of auditory phonology promotes reading skill among the deaf, or develops as a by-product of increases in literacy skill (Goldin-Meadow & Mayberry, 2001; Mayberry, 2011).

Pickering & van Gompel, 2006; Traxler, 2011, 2012, for reviews). Syntactic parsing theories differ with respect to the details of syntactic analysis, but nearly all of them subscribe to two general tenets: 1) Recovering sentence meaning involves syntactic computations; 2) Comprehenders eventually construct or recover a single description of the syntax of a sentence.

Only a handful of studies have attempted to determine whether difficulties in reading comprehension among deaf readers result from disruptions in syntactic processing (Kelly, 1996, 2003; Lillo-Martin, Hansen & Smith, 1992; Miller, 2000, 2010; Robbins & Hatcher, 1981). These studies have produced conflicting results. Both Kelly (2003) and Lillo-Martin et al. (1992) found that deaf ASL-English bilinguals show similar patterns of comprehending English relative clause sentences as hearing native English speakers, whether they were skilled or poor readers. They suggest that reading comprehension difficulties are related to low levels of processing automaticity (Kelly, 2003) or a phonological processing deficit (Lillo-Martin et al.). By contrast, Miller (2010) compared performance on phonological and orthographic awareness and sentence interpretation tasks by Israeli deaf and hearing readers, and concluded that reading deficits among Israeli deaf students are a product of syntactic processing and not phonological decoding. In his study, deaf participants were compared to controls on a phonological awareness task and a sentence comprehension task involving sentences of differing complexity and plausibility. The results suggested that, by college age, reading comprehension outcomes did not correlate with scores on the phonological awareness task. Adult deaf readers were less accurate than hearing readers on the sentence comprehension task, especially for sentences expressing implausible outcomes. Although syntactic complexity varied across the set of sentences, the relationship between syntactic complexity and comprehension outcomes was not reported. Further, no processing time data were reported.

In the present study we investigated how deaf readers respond to syntactic structure cues as they read English sentences. Prior studies have often conflated changes in sentence structure with changes in lexical content, thus making it difficult to disentangle the independent contributions of the multiple sources of meaning in sentence understanding (e.g., Miller, 2010). In the present study we manipulated structural complexity without changing lexical content. This is particularly important in investigating sentence processing in a population that is heterogeneous in language experience and that may exhibit processing differences in multiple domains (phonological, lexical & syntactic). Our study is unique in measuring the time course of comprehension in order to gain insights to parsing. This study was designed to begin to answer two very basic questions: 1. Does syntactic complexity affect deaf readers the way it affects hearing readers? 2. Do deaf readers respond to helpful semantic cues that supplement syntactic structure cues? Answering these two questions can help us begin to develop an account of the on-line parsing processes that deaf readers undertake while reading sentences in English.

The Influence of Syntactic Complexity and Semantic Cues in Hearing Readers

Psycholinguistic research on parsing processes in hearing readers has relied heavily on *chronometric* (reaction time) methods. One such line of research focuses on the comparison between sentences that are more complex syntactically versus those that are less complex (in light of representational assumptions that are supported by linguistic analysis; MacWhinney & Pleh, 1988; Mak et al., 2002; Wanner & Maratsos, 1978; King & Just, 1991; Traxler et al., 2002; Gordon et al., 2001). Several studies in this line have focused on the contrast of sentences with *subject relative clauses* (e.g., 2a) and *object relative clauses* (e.g., 2b):

(2a) The lawyer that phoned the banker filed a lawsuit. (subject relative)

(2b) The lawyer that the banker phoned filed a lawsuit. (object relative)

In (2a) the subject of the sentence (*lawyer*) also serves as the subject of the relative clause *that (trace) phoned the banker*, as in *the lawyer phoned the banker*.[ii] In (2b) the subject of the sentence serves as the direct object of the verb inside the relative clause *that the banker phoned (trace)* as in *the banker phoned the lawyer*.

Generally, sentences with object relative clauses take longer to read than sentences with subject relative clauses, with difficulty manifesting during reading of the relative clause and continuing during reading of the main verb.[iii] Processing accounts variously attribute this difficulty to the dual grammatical function of the subject noun in object relatives (Keenan & Comrie, 1977, *parallel function* hypothesis), changes in the reader's perspective at various points in the sentence (MacWhinney & Pleh, 1988), the potential for confusion between the different role-players in the sentence (Gordon et al., 2001), the number of discourse referents that intervene between a head and the trace or other factors that increase working memory load (Gibson, 1998; Wanner & Maratsos, 1978; but see Traxler et al., 2005; Traxler et al., 2012), or a general tendency to treat subjects of sentences as subjects of embedded clauses (Traxler et al., 2002).[iv]

The difficulty of object relative clauses can be reduced when helpful semantic cues are available to the reader (Mak et al., 2002; Traxler et al., 2002; 2005). In particular, object relatives are processed almost as quickly as subject relatives when the subject of the sentence is inanimate and the noun within the relative clause is animate, as in (3a):

(3a) The pistol that the cowboy dropped remained in the saloon.

When the subject of the sentence is animate and the noun within the relative clause is inanimate, as in (3b), the sentence is much more difficult to process:

(3b) The cowboy that the pistol injured remained in the saloon.

In subject relatives, such as (3c) and (3d), the positions of animate and inanimate nouns have little or no effect on processing difficulty:

(3c) The pistol that injured the cowboy remained in the saloon. (3d) The cowboy that dropped the pistol remained in the saloon.

Reducing semantic confusability of the critical nouns does not, by itself, eliminate processing difficulty that attaches to object relative clauses. If it did, (3a) and (3b) would be equally difficult to process. For the same reason, integration across intervening discourse elements does not provide a complete explanation for the object-relative penalty.

Given the multiple factors involved in object and subject relative clause interpretation it remains an open question whether deaf readers will respond to sentences with subject or object relative clauses the same way hearing readers do. One goal of the current study was to determine whether deaf readers experience the object relative penalty and, if so, whether the penalty decreases when helpful semantic cues are present.

[ii] *Trace* is a hypothetical mental element that serves as a place holder when a constituent is in an unusual position in the verbatim form of the sentence (Chomsky, 1981). See Pickering & Barry (1991) and Traxler & Pickering (1996) for an alternative syntactic analysis under which constituents are directly linked to lexical heads, rather than being associated with traces which are linked to lexical heads.

[iii] The universality of the object-relative penalty is a current topic in sentence processing research. Chinese and Basque are two languages that may pattern differently than English and other Western European languages (Chen et al., 2008; Carreiras et al., 2010), although this is not yet firmly established.

[iv] Extended overviews of relative-clause processing accounts, including those appealing to effects of discourse elements that intervene between dependent elements, can be found in Mak et al. (2002), Traxler et al. (2002, 2005), Gordon et al. (2001). A full discussion of these accounts and their empirical basis is beyond the scope of this paper.

Experiments investigating syntactic complexity have also assessed comprehenders' responses to passive-voice and active-voice sentences like (1a) and (1b), (Ferreira, 2003; Christianson et al., 2006):

(1a) *The girl was chased by the boy*.

(1b) *The girl chased the boy*.

Some linguistic analyses treat passive voice sentences as essentially equivalent to adjectives (e.g., *The girl* was tall; Townsend & Bever, 2001). Other analyses treat it as an example of extraction and movement (Chomsky, 1981, 1995; see also Jackendoff, 2002). If so, passive-voice sentences like (1a) entail more complex representations and potentially more complicated processes than active-voice sentences like (1b). For example, Jackendoff (p. 47) describes a generative account under which passive voice involves an extracted element (*girl* in (1a)), a *trace* located at a gap-site (between *chased* and *boy*) in (1a). The passive voice is comprehended via a derivational process, involving the application of *transformations*. These transformations build a mental representation in which the surface element *girl* ends up in its *canonical* location, immediately adjacent to and following *chased*. On this account, (1b) does not entail such covert transformations, and should impose a lower processing load.

Comprehension of passive-voice sentences is more susceptible to impairment by brain damage (Grodzinsky, 1986, Zurif et al., 1993). Further, interpretations based on fully specified syntactic structure representations are more likely to be over-ruled by lexical-semantic features in passives than in actives (Ferreira, 2003). As a result, readers are more likely to assign an incorrect interpretation to *The mouse was eaten by the cheese* than *The cheese ate the mouse.*

We do not have much information about how deaf readers interpret passive-voice sentences (Quigley, 1982). Power & Quigley (1973) showed deaf middle school and high school students index cards with a written English sentence. Participants were asked to demonstrate the meaning of the sentences, such as "The car was pushed by the tractor," using toys representing the subject and object. Even the oldest age group, 17–18 year olds, completed only 3 or 4 of 6 trials correctly. In agent-deleted passives, such as "The car was pushed," participants completed only a third of the trials correctly on average. Performance on a production task was poorer than on the comprehension task. In this case, participants were shown a picture, and then asked to fill in a blank from a set of provided words. 17–18 year olds completed only 2 or 3 of 6 trials correctly. Quigley and colleagues, who systematically investigated a range of syntactic structures, concluded that deaf school aged children are not sensitive to many syntactic cues, and rely instead on a general assumption that English sentences follow SVO word order (Quigley, 1982; Quigley et al., 1976). This poses a particular problem for passives since the order of the subject and object are reversed. Power & Quigley report that students who were most successful in their study appeared to rely on the presence of the word "by" to identify the structure as a passive (p. 9). This word was more consistently included in the production task than the appropriate auxiliary and past tense form of the main verb, and comprehension performance was *below chance* on agent-deleted passives, suggesting that the students did not detect the passive when the word "by" was not present as a cue. Note that these investigators did not assess language proficiency in ASL or English, nor did they report the hearing status of the deaf students' parents. Thus, there is no way to know what proportion of the students was exposed to a first language in early childhood.

The present study comprised two experiments assessing deaf readers' responses to two sentence types. The first experiment tested responses to sentences containing subject and object relative clauses. The second experiment tested responses to active-voice and passive-voice sentences. If deaf readers make early syntactic commitments similar to hearing readers, then object relatives should take longer to read than subject relatives. If deaf readers are sensitive to semantic cues to sentence structure, the object-relative penalty will be reduced when the subject of the sentence is inanimate and the noun within the relative clause is animate. If deaf readers interpret passives via a transformation-like process of affiliating the subject of the sentence with a gap located after the main verb, then they should take longer to read passives than active-voice sentences.

Experiment 1

Experiment 1 assessed deaf readers' responses to sentences like (3a)-(3d):.

Object Relative, Inanimate Subject

_(3a) The pistol that the cowboy dropped remained in the saloon.

Object Relative, Animate Subject

_(3b) The cowboy that the pistol injured remained in the saloon.

Subject Relative, Inanimate Subject

_(3c) The pistol that injured the cowboy remained in the saloon.

Subject Relative, Animate Subject

_(3d) The cowboy that dropped the pistol remained in the saloon.

If deaf participants respond like hearing, native English readers do, then sentences containing object relative clauses (3a, b) should be read slower than sentences containing subject relatives (3c, d). Further, if deaf readers are sensitive to semantic cues, then the object relative disadvantage should be reduced when the sentence has an inanimate subject (e.g., 3a).

Method

Participants—There were three groups of participants: deaf readers (*Deaf*), monolingual hearing English speakers (*English*), and hearing bilingual readers, whose first language was not English (*Bilingual*). There were 68 participants in the Deaf group, 31 in the English group, and 34 in the Bilingual group. The deaf participants were recruited from the Sacramento, San Francisco, and Los Angeles regions through community contacts and community service centers for the deaf. The current experiments were conducted as part of a larger project investigating language processing as a function of age of exposure to ASL. 22 Deaf readers were classified as native signers if they began to learn ASL from birth. These readers' median age was 34 years old (range: 22–45). 24 *Early* signers learned ASL before puberty, but not from birth (median: 35, range 21–65). 22 *Late* signers learned ASL after puberty (median age: 47, range 27–69). The hearing monolingual and bilingual readers were recruited from the UC Davis Psychology Department participant pool. The bilingual participants all had English as their second language, and had a wide variety of first languages. Their self-reported English proficiency averaged 3.0 on a scale of 1 (poor) to 7 (native proficiency), with a range of 1–6. They averaged 66% correct on the Nelson-Denny vocabulary test (range 24 to 100% correct). The monolingual English group provides us with a baseline. The Bilingual group resembles the Deaf group in that they are reading the experimental sentences in their second language. Hence, the Bilingual group provides an indication whether differences in performance between the Deaf and English groups are due to language status (first versus second language) or hearing status.

Stimuli—The stimuli consisted of 28 quadruplets of sentences similar to (3a)-(3d). These stimuli were the same as those used in previous experiments with hearing readers (Traxler et al., 2002, 2005).

Each participant also read 24 sentences from Experiment 2, as well as 50 filler sentences with a variety of simple sentence structures (active-voice sentences, active intransitives, etc.). One version from each quadruplet was assigned to one of four lists of items using a Latin square design. Each participant saw only one version of each item; and every participant read equal numbers of items from each of the four sub-types. Each participant read a total of 102 sentences, 28 sentences from the current experiment, 24 from Experiment 2, and 50 filler items.

Apparatus and Procedure—Participants read each test sentence one word at a time. Participants were instructed to read at a normal, comfortable pace in a manner that would enable them to answer comprehension questions.[v] Sentences were presented with a self-paced moving window procedure using a PC running custom software. Each trial began with a series of dashes on the computer screen in place of the letters in the words. Any punctuation marks appeared in their exact position throughout the trial. The first press of the space bar replaced the first set of dashes with the first word in the sentence. With subsequent space-bar presses, the next set of dashes were replaced by the next word, and the preceding word was replaced by dashes. A yes-or-no question followed 45 of the sentences and participants did not receive feedback on their answers. The computer recorded the time from when a word was first displayed until the next press of the space bar.

Analyses—We analyzed reading times for the *relative clause region* (the three words between the word “that” and the main verb of the sentence) and the *main verb* region (the main verb of the sentence) using *hierarchical linear modeling* (*HLM;* Raudenbush & Bryk, 2002; Blozis & Traxler, 2007; Traxler et al., 2005). Separate models were run for each scoring region. At the first level of the model, reading times were considered a function of *clause type* (subject vs. object relative), *animacy* (the subject of the sentence was inanimate or animate), and the interaction of clause type and animacy. Group (Deaf vs. English vs. Bilingual) was entered into the second level of the model. At this level, parameter slopes and error terms were allowed to vary freely between individuals.[vi] Level-1 and level-2 parameters were estimated simultaneously.

Results and Discussion

Comprehension Question Results

Comprehension questions were asked after a subset of the sentences in the experiment, with most questions being presented after filler sentences. Due to sparse data, it was not possible to compare comprehension outcomes across the different conditions. A multilevel model testing for between-group accuracy differences (Deaf vs. English vs. Bilingual) showed that

[v]These instructions were used in previous eye-tracking studies involving subject- and object-relatives (Traxler et al., 2002, 2005, 2012).

[vi]For completeness, the following describes how the multi-level models were configured:

$$\text{Level 1: RT for person } i, \text{ for item } j = \text{Boi} + B1i\ (\text{clause type})j + B2i\ (\text{animacy})j + B3i\ (\text{clause type } x \text{ animacy})j + \text{eij}$$

$$\begin{aligned} \text{Level 2:} \quad & \text{Boi} = \text{go0} + \text{go1}\ (\text{English}) + \text{go2}\ (\text{Bilingual}) + \text{uo} \\ & B1i = g10 + g11\ (\text{English}) + g12\ (\text{Bilingual}) + u1 \\ & B2i = g20 + g21\ (\text{English}) + g22\ (\text{Bilingual}) + u2 \\ & B3i = g30 + g31\ (\text{English}) + g32\ (\text{Bilingual}) + u3 \end{aligned}$$

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the English group had the highest accuracy, at 89% [significantly higher than the Deaf group, 72.3%, t (130) = 6.52, p < .001, Se = .021]. The Bilingual group (84%) also had higher accuracy than the Deaf group [t (130) = 3.24, p < .01, Se = .024]. A multilevel model testing for between-group effects that divided the deaf readers into three sub-groups (native, early, and late signers) showed that the native signer group had greater accuracy than the early [81% (range: 51–97%) vs. 68% (range: 47–90%), t (128) = 2.66, p < .01, Se = .037] and late signer groups [68% (range: 46–96%, t (128) = 2.52, p = .01, Se = .040], lower accuracy than the English group [t (128) = 2.71, p < .01, Se = .026], but did not differ from the Bilingual group [t (128) < 1, NS, Se = 0.028].

Reading Time Results

Table 1 shows mean self-paced reading time and standard errors for the relative clause and main verb scoring regions by condition for Experiment 1.

Relative Clause (RC) Region—Multilevel models for the relative clause region suggested that baseline reading time (in the inanimate, subject relative condition) was greater in the Deaf group than in the English group [significant by participants, with t1 (130) = 2.30, p < .05, Se = 90.5; but not by items, t2 (25) = 0.55, NS, Se = 90.2]. The analyses also produced an animacy by sentence type interaction, indicating that sentences with animate subjects and object relative clauses were harder to process than the other three sentence types [t1 (130) = 1.83, p = .06, Se = 27.8; t2 (25) = 2.13, p < .05, Se = 50.3]. Follow-up analyses conducted separately for the Deaf, English, and Bilingual groups showed a significant interaction of animacy and clause type in the Deaf group [t1 (67) = 2.43, p < .05, Se = 49.1; t2 (27) = 2.36, p < .05, Se = 82.2] but not the Bilingual group [t1 (33) = 1.06, NS; t2 (33) < 1] or the English group [all t < 1, NS].

Main Verb (MV) Region—Models of data from the main verb region also produced an interaction of animacy and sentence type [t1 (130) = 5.26, p < .001, Se = 17.4; t2 (25) = 2.44, p < .05, Se = 42.5]. Follow-up analyses conducted separately for the Deaf, English, and Bilingual groups showed a significant interaction of animacy and clause type in all three groups [Deaf: t1 (67) = 2.66, p = .01; t2 (27) = 3.83, p < .001; English: t1 (30) = 2.90, p < .01, Se = 29.2; t2 (27) = 2.87, p < .01, Se = 25.7; Bilingual: t1 (33) = 3.11, p < .01, Se = 31.8; t2 (27) = 1.95, p = .06, Se = 65.1].

Individual Differences Analysis for deaf readers—A further set of multi-level models were conducted to assess group differences between native, early, and late signers. To assess these differences, group (native vs. early vs. late signer) was added as a categorical variable at the second level of a two-level model. The same text variables from the preceding analyses were entered at Level 1. Cross-level interactions indicate that Level 1 parameters differ significantly across the three groups.

These multi-level models indicated that baseline reading time (reading time in subject relatives with inanimate subjects) differed across the three groups in both the relative clause and main verb regions. Native signers read the relative clauses at a faster rate than early signers [1306 ms vs. 1622 ms; t (65) = 2.06, p < .05], and late signers [1306 ms vs. 1748 ms; t(65) = 2.24, p < .05]. Similar results occurred in the main verb region [native vs. early: 424 vs. 513 ms; t (65) = 1.75, p = .09. native vs. late: 424 vs. 593 ms; t(65) = 3.50, p < .001]. Group (native vs. early vs. late) did not interact with clause type (object vs. subject relative). Similarly, group did not moderate the size of the clause type by animacy interaction. Thus, the results do not indicate that the three groups responded differently to the clause type and animacy manipulations.

The comprehension data indicate that the Deaf group comprehended the sentences to a lesser degree than the English or Bilingual group. Comprehension in the native signer group, however, was comparable to the Bilingual group, and higher than the other two groups of deaf participants. A cross-language transfer hypothesis, according to which English sentences are comprehended by mapping them to ASL equivalents could account for the difference between the deaf reader sub-groups. Such an account would appeal to differences in the quality of ASL representations. One possibility is that native signers have more robust and more finely differentiated conceptual representations. Another possibility is that English-to-ASL mapping processes are more robust and reliable in native signers. Alternatively, it is possible that these comprehension differences reflect different degrees of mastery of English syntax. However, such an account would predict differences in sensitivity to English morpho-syntactic cues across the native, early, and late signers. If such differences were present, they did not lead to different patterns of reading time results in the three groups.

For the reading time results, multilevel models in which participant group (Deaf vs. English vs. Bilingual) was included as a predictor did not produce cross-level interactions (exception: one model indicated an overall reading speed difference between the Deaf and English groups). Thus, there is no strong evidence that patterns of processing time differed between the three groups. All groups showed the commonly-found interaction of animacy and sentence type. All three experienced more difficulty processing object relatives with animate subjects, compared to the other three sentence types.

The absence of the animacy-by-clause type interaction in the relative clause region for the hearing readers is a departure from previous findings (e.g., Traxler et al., 2002, 2005). Given the robust nature of this interaction in English readers and cross-linguistically, one plausible possibility is a Type II error.

The three sub-groups of deaf readers responded to the syntactic and semantic manipulations very much like hearing readers do. Previous studies have established that English object relatives are relatively difficult to process. Previous studies have also shown that semantic cues can reduce the object-relative penalty (in English and other western European languages). Specifically, having an inanimate sentence-subject and an animate relative-clause subject greatly reduces processing load. This pattern occurred to about the same degree in all three groups of deaf readers, indicated by the significant clause type by animacy interaction in the multi-level models in combination with the absence of by-group interactions (native vs. early vs. late signers). Overall, the results indicate that deaf readers undertake similar parsing processes to hearing readers to interpret subject and object relative clauses. Deaf readers respond differently to different relative clause types, mediated by the specific semantic properties of the nouns in the sentence. This result contradicts prior accounts suggesting that deaf readers are insensitive to English syntax or that they ignore word order as a cue to syntactic structure.

Experiment 2

Experiment 2 assessed deaf and hearing readers' response to active voice and passive voice sentences. We measured participants' reading times on the main verb and the following noun phrase. These are two areas where influences of syntactic complexity would be expected to emerge. In the test sentences used here, the main verb codes for two argument slots, but the thematic roles assigned to the pre-verbal and post-verbal arguments differ. In the active voice, the pre-verbal argument also serves as a thematic agent, while in the passive voice, that same constituent would serve as thematic patient. The unusual ordering of thematic roles could induce greater load during processing of the main verb. Similarly, the post-verbal argument in the passive voice sentences would constitute a thematic agent occupying a position more normally occupied by a patient, theme, or experiencer. Assigning the post-verbal argument an agent thematic role could require additional syntactic computations (relative to those undertaken for the active voice sentences; see, e.g., Jackendoff, 2002). However, this assumes that prior syntactic cues (the presence of an auxiliary verb, the preposition *by*) have not sufficiently prepared the participants to cope with unusual ordering of thematic roles by the time they encounter the post-verbal noun-phrase. If participants predicted a passive after encountering the auxiliary verb *was*, then we might observe little or no processing difficulty in the passive-voice sentences.

Method

Participants—The participants were the same individuals who participated in Experiment 1.

Stimuli—The test sentences included 24 pairs of active and passive-voice sentences, such as (4a) and (4b):

(4a) The farmer tricked the cowboy into selling the horse. (Active voice)

(4b) The farmer was tricked by the cowboy into selling the horse. (Passive voice)

Plausibility Norming—Because the lexical content of the scoring regions was kept the same between the active and passive voice conditions, the meanings of the two sentences differed. Although we intended the test sentences to be fully reversible, it is possible that the active voice sentences were significantly more plausible than the passive voice sentences. To see whether this was the case, we had 16 participants rate the plausibility of the active-voice sentences (e.g., 4a) and active-voice paraphrases of the meanings of the passive-voice sentences (e.g., *The cowboy tricked the farmer*). One version of each item (either the original active-voice sentence or the paraphrase of the passive counterpart) was assigned to one of two lists of items. The critical items were randomly interspersed with three other types of items, *implausible*, *impossible*, and *plausible* sentences. The *implausible* sentences were active-voice sentences like *The burglar arrested the policeman*, which expressed an unlikely event. The *impossible sentences* were active-voice sentences like *The student believes the stairwell* which express impossible events. The *plausible* sentences were included to fill out the lists to a total of 44 items and to provide a further comparison to assess the plausibility of the experimental items. The *plausible* sentences were active voice sentences that expressed common activities (*The mother fed the baby; The doctor treated the patient*, etc.). Participants were instructed to read the sentences and indicate, on a 1 (plausible) to 7 (impossible) scale, how likely the events expressed by the sentences were. The rating data were submitted to a one-way, repeated measures ANOVA (condition: active voice experimental items vs. passive voice paraphrases vs. implausible vs. impossible vs. plausible). This analysis revealed an overall effect of condition [$F(1, 15) = 39.1$, $p < .0001$, MSe = 0.22]. Sentences like (4a) received a mean rating of 2.1 out of 7. Active-voice paraphrases of sentences like (4b) received a mean rating of 2.3. These two conditions did not differ ($t < 1$, N.S.). These two conditions (4a and b) both differed from the implausible (mean rating = 5.7) and impossible conditions (mean rating = 6.6; all $t > 15$; all $p < .0001$). The two experimental conditions (e.g., 4a, 4b) were rated less plausible than the *plausible* norming sentences (mean rating = 1.3; all $t > 6.4$, all $p < .0001$). Thus, while the meanings of the experimental sentences (4a, 4b) were not at ceiling in plausibility, they did not differ from each other.

Apparatus and Procedure—The apparatus and procedure were identical to Experiment 1.

Analyses—We analyzed data from three scoring regions. The *main verb* region consisted of the main verb of the sentence (e.g., *tricked*). The *determiner* consisted of the determiner following the main verb. The *noun* region consisted of the head of the post-verbal noun phrase (e.g., *cowboy*). The data were analyzed using multilevel models. The first level of the model included the sentence type variable (active vs. passive). Group (Deaf, English, Bilingual) was entered at the second level of the model. Participant and item-based analyses were conducted separately.

Results and Discussion

Table 2 presents mean reading time by scoring region and sentence type (active vs. passive voice).

Reading Time Results

Verb—Multilevel models with sentence type (active vs. passive) at level 1 and group (Deaf vs. English vs. Bilingual) at the second indicated a main effect of sentence type in the Deaf group [passive faster than active, t1 (130) = 3.02, $p < .01$, Se = 19.3; t2 (23) = 2.87, $p < .01$, Se = 11.8]. The hearing bilingual group had longer reading times in the passive than in the active condition [significant by participants t1 (130) = 2.14, $p < .05$, Se = 14.6; but not by items, t2 (23) < 1, NS]. In the English group, reading times at the verb were numerically shorter in the passive than the active condition. As a result, the magnitude of the sentence type effect in the English group did not differ from the sentence type effect in the Deaf group [both t < 1, NS]. However, the numerical advantage in the English group for passive voice at the verb was not statistically significant [both t < 1, NS].

Determiner—At the determiner, reading times for the passive were shorter than for the active voice sentences for the Deaf group [t1 (130) = 8.37, $p < .01$, Se = 5.48; t2 (23) = 3.92, $p < .01$, Se = 10.7]. The hearing bilingual group also had shorter reading times in the passive voice sentences [t1 (130) = 2.77, $p < .01$, Se = 13.0; t2 (23) = 5.04, $p < .01$, Se = 14.5]. Data from the English group did not produce an effect of sentence type (active vs. passive; both t < 1, NS).

Noun—Data from the noun region produced null results for the sentence-type effect in all three groups of participants [all t < 1.4, NS]. Reading times in the active voice sentences were slower in the Bilingual group than in the Deaf group [t1 (130) = 2.22, $p < .05$, Se = 38.8; t2 (23) = 7.29, $p < .01$, Se = 14.1].

Individual Differences Analysis for deaf readers—The multi-level models indicated that native signers read the noun faster than early or late signers [native vs. early, 413 vs. 494 ms; t (65) = 1.97, $p = .05$; native vs. late; 413 vs. 502 ms, t (65) = 2.04, $p < .05$]. There was a non-significant trend in the same direction at the verb [native vs. early, 433 vs. 501 ms, t (65) = 1.68, $p < .10$; native vs. late, 433 vs. 498 ms, t (65) = 1.68, $p < .10$].

Figure 1 represents reading time differences between the active and passive voice conditions for the three groups of deaf readers at the main verb. Positive values indicate that the participant read the passive condition faster than the active condition. All three groups of readers had shorter reading times in the passive than active voice conditions (ranging from 34 ms in the native group to 11 ms in the late signer group). Although the biggest numerical effect was in the native signer group, the model failed to detect differences in the magnitude of the sentence-type effect between the three groups.

Some results in the Deaf and Bilingual groups could reflect “spillover” effects. For the Deaf group, the verb and determiner regions were read faster when they followed function words. For the Bilingual group, only the determiner followed that pattern.

For all of the readers (Deaf, Bilingual, and English), the multilevel models did not produce cross-level interactions in any of the scoring regions. These results indicate qualitatively similar responses across the three groups of participants to the sentence type manipulation. The fact that none of the groups produced slower reading times in the passive voice sentences was surprising. Further experiments will be required to determine whether this pattern is reliable.

General Discussion

Experiment 1 tested deaf bilingual, hearing bilingual, and native English readers’ response to sentences containing object and subject-relative clauses. In some of the stimuli, animacy of the critical nouns offered potentially useful cues to sentence structure and interpretation. Deaf readers exhibited both a general object-relative penalty and a reduction in that penalty when animacy cues pointed towards the correct interpretation while reading the relative clause and the main verb. Both groups of hearing readers showed similar effects of sentence type and animacy, but those effects emerged most strongly at the main verb. These results resemble results for hearing readers from previous studies (Traxler et al., 2002; Traxler et al., 2005). The absence of clear results in the relative clause for the hearing readers may reflect a more “risky” reading strategy on their part or ordinary type II error.

Experiment 2 tested deaf bilingual, hearing bilingual, and native English readers’ response to sentences containing active-voice and passive-voice sentences. Tests for simple effects indicated that Deaf readers, but not hearing readers, processed the main verb faster in passive voice than active voice sentences. However, because the multilevel models did not produce cross-level interactions based on group membership (deaf vs. hearing bilingual vs. native English), there is no strong evidence supporting qualitative differences in processing between the three groups. Deaf and hearing bilingual readers exhibited evidence of lexically based spillover effects at the determiner, as reading times were shorter in the passive than the active condition (i.e., determiner reading times were shorter after the word *by* than after a semantically weighty main verb). Relatively short reading times in the Deaf group at the main verb could be similarly interpreted as reflecting a spillover effect.

These results provide an initial glimpse into real-time sentence interpretation in deaf readers. These are the first studies that we know of using self-paced reading methods to assess sentence processing in deaf readers while controlling first language experience (cf. Kelly, 1995, 2003). Comprehension in all three groups of signers was lower than native English speaking college-aged readers. However, comprehension was indistinguishable in deaf and hearing bilinguals who had acquired a first language from birth, and acquired English as a second language. Further, while comprehension performance was lower in deaf readers as a group than the other two groups, their performance was well above chance. These results demonstrate that deaf readers comprehend English sentences while undertaking the self-paced reading task. Hence, it appears that this technique is a feasible chronometric method for testing hypotheses relating to deaf readers’ on-line interpretive processing. Future studies should probe readers’ comprehension more systematically, as our experience suggests that adding additional comprehension questions will not unduly tax deaf readers’ endurance. Moreover, these results underscore the importance of considering deaf readers’ first language experience in evaluating reading ability in the second language. Prior studies have generally disregarded first language proficiency when evaluating reading outcomes.

Future studies should also explore the extent to which knowledge of ASL grammar is activated and used by deaf readers during the interpretation of English sentences. Previous studies of hearing bilingual readers have shown cross-language transfer from first-language grammars during second-language tasks (e.g., Hartsuiker et al., 2004). Further, evidence indicates that deaf signers activate ASL signs when making semantic decisions about pairs of English print words (Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011). English sentence processing may be affected by transfer from ASL grammar, especially for highly proficient native signers.

Finding such cross-language transfer effects is not guaranteed, however. What makes the situation with signers unique is that morpho-syntactic features in ASL are signaled by visuo-spatial cues. While some of the underlying syntactic relationships between words in ASL and words in English could be captured in a similar fashion (by phrase-structure or dependency diagrams), there are aspects of ASL grammar (e.g., spatial verb agreement) that do not have analogs in English. A detailed program of research will be required to determine the extent to which deaf readers activate and use ASL syntactic representations while interpreting sentences in English. Our working hypothesis is that ASL syntactic representations are activated. Continuing to keep in mind that deaf readers are operating in a second-language context, Experiment 1 provides the first demonstration that we are aware of that the object-relative penalty can be reduced by animacy cues in bilinguals operating in their second language (but see Jackson & Roberts, 2010). We know very little about relative clause structures and processing in ASL, except that these are among the most difficult structures to process for native signers of ASL (Boudreault & Mayberry, 2006). However, no evidence to date indicates whether or not animacy influences relative clause interpretation strategies in ASL. Thus, it is not yet clear whether deaf second language learners of English transfer L1 strategies for the processing of relative clauses to second language contexts, or whether they discover the utility of this cue solely from exposure to the second language. This state of affairs points towards the strong need for syntactic parsing studies of ASL itself. It also points towards the need for studies of English reading experience as a potential influence on the parsing of ASL.

The clause type by animacy interaction from Experiment 1 has been obtained in monolingual English (Traxler et al., 2002, 2005), Dutch (Mak et al., 2002), Spanish (Betancourt et al., 2009), and French (Baudiffier et al., 2011) speakers, all western European languages that have similar typological roots. ASL is typologically distinct from all of these languages. Thus, the interaction of clause type and animacy may reflect something fundamental about constituent embedding and canonical ordering of thematic roles. This conclusion is based on consistent patterns in the way hearing readers respond across these several languages. Both subject and object relative clauses involve an embedding within a larger structure, which could lead to increased processing load relative to non-embedded expressions, because the contents and interpretation of a main clause must be held in abeyance while the contents and interpretation of an embedded clause are worked out. The relative ease of processing object relative clauses when the sentence has an inanimate subject and the relative clause has an animate subject indicates either that embedding in and of itself is not problematic or that the animacy cues somehow allow a comprehender to by-pass potentially costly syntactic computations.

Conclusions

These experiments provide an initial snapshot of deaf readers' on-line parsing and sentence comprehension performance. Deaf readers' comprehension, on the whole, was somewhat lower than hearing readers', although native signers performed as well as the other group of bilingual readers. Within the deaf readers, early and late signers read somewhat more slowly than native signers and comprehended the sentences at a lower degree of accuracy. Deaf readers responded much the same as hearing readers to semantic cues in interpreting subject and object relative clauses. Differences in comprehension performance across native, early, and late deaf signers illustrate the potential value of an individual differences approach to building a theory of reading performance in deaf ASL-English bilinguals.

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Appendix: Experimental Items

Experiment 1: Subject and Object Relatives with Animate and Inanimate Subjects

The musician that witnessed the accident angered the policeman a lot.

The musician that the accident terrified angered the policeman a lot.

The accident that terrified the musician angered the policeman a lot.

The accident that the musician witnessed angered the policeman a lot.

The contestant that misplaced the prize made a big impression on Mary.

The contestant that the prize delighted made a big impression on Mary.

prize that delighted the contestant made a big impression on Mary.

The prize that the contestant misplaced made a big impression on Mary.

The cowboy that carried the pistol was known to be unreliable.

The cowboy that the pistol injured was known to be unreliable.

The pistol that injured the cowboy was known to be unreliable.

The pistol that the cowboy carried was known to be unreliable.

The scientist that studied the climate did not interest the reporter.

The scientist that the climate annoyed did not interest the reporter.

The climate that annoyed the scientist did not interest the reporter.

The climate that the scientist studied did not interest the reporter.

The director that watched the movie received a prize at the film festival.

The director that the movie pleased received a prize at the film festival.

The movie that pleased the director received a prize at the film festival.

The movie that the director watched received a prize at the film festival.

The student that attended the school was visited by the governor.

The student that the school educated was visited by the governor.

The school that educated the student was visited by the governor.

The school that the student attended was visited by the governor.

The teacher that watched the play upset a few of the students.

The teacher that the play angered upset a few of the students.

The play that angered the teacher upset a few of the students.

The play that the teacher watched upset a few of the students.

The woman that reported the accident caused a number of serious injuries.

The woman that the accident bothered caused a number of serious injuries.

The accident that bothered the woman caused a number of serious injuries.

The accident that the woman reported caused a number of serious injuries.

The plumber that dropped the wrench was found near the back door.

The plumber that the wrench bruised was found near the back door.

The wrench that bruised the plumber was found near the back door.

The wrench that the plumber dropped was found near the back door.

The banker that refused the loan created a problem for the mayor.

The banker that the loan worried created a problem for the mayor.

The loan that worried the banker created a problem for the mayor.

The loan that the banker refused created a problem for the mayor.

The lawyer that reviewed the trial was covered by the national media.

The lawyer that the trial confused was covered by the national media.

The trial that confused the lawyer was covered by the national media.

The trial that the lawyer reviewed was covered by the national media.

The psychologist that printed the notes got lost somewhere in the basement.

The psychologist that the notes annoyed got lost somewhere in the basement.

The notes that annoyed the psychologist got lost somewhere in the basement.

The notes that the psychologist printed got lost somewhere in the basement.

The child that loaded the revolver injured the teenage babysitter.

The child that the revolver scared injured the teenage babysitter.

The revolver that scared the child injured the teenage babysitter.

The revolver that the child loaded injured the teenage babysitter.

The golfer that mastered the game was ignored by most sports writers.

The golfer that the game excited was ignored by most sports writers.

The game that excited the golfer was ignored by most sports writers.

The game that the golfer mastered was ignored by most sports writers.

The salesman that examined the product was mentioned in the newsletter.

The salesman that the product excited was mentioned in the newsletter.

The product that excited the salesman was mentioned in the newsletter.

The product that the salesman examined was mentioned in the newsletter.

The fireman that fought the fire caused only a small amount of damage.

The fireman that the fire burned caused only a small amount of damage.

The fire that burned the fireman caused only a small amount of damage.

The fire that the fireman fought caused only a small amount of damage.

The fish that attacked the lure impressed the fisherman quite a lot.

The fish that the lure attracted impressed the fisherman quite a lot.

The lure that attracted the fish impressed the fisherman quite a lot.

The lure that the fish attacked impressed the fisherman quite a lot.

The farmer that purchased the tractor arrived at the store late last night.

The farmer that the tractor impressed arrived at the store late last night.

The tractor that impressed the farmer arrived at the store late last night.

The tractor that the farmer purchased arrived at the store late last night.

The gardener that trimmed the plants helped make the house more attractive.

The gardener that the plants pleased helped make the house more attractive.

The plants that pleased the gardener helped make the house more attractive.

The plants that the gardener trimmed helped make the house more attractive.

The pilot that crashed the plane was grounded by the safety board.

The pilot that the plane worried was grounded by the safety board.

The plane that worried the pilot was grounded by the safety board.

The plane that the pilot crashed was grounded by the safety board.

The elephant that drank the water was located in the heart of Africa.

The elephant that the water cooled was located in the heart of Africa.

The water that cooled the elephant was located in the heart of Africa.

The water that the elephant drank was located in the heart of Africa.

The actor that rehearsed the play was given first prize at the awards dinner.

The actor that the play delighted was given first prize at the awards dinner.

The play that delighted the actor was given first prize at the awards dinner.

The play that the actor rehearsed was given first prize at the awards dinner.

The student that practiced the instrument had been around for a few months.

The student that the instrument frustrated had been around for a few months.

The instrument that frustrated the student had been around for a few months.

The instrument that the student practiced had been around for a few months.

The spy that encoded the message was smuggled out of the country in a crate.

The spy that the message alarmed was smuggled out of the country in a crate.

The message that alarmed the spy was smuggled out of the country in a crate.

The message that the spy encoded was smuggled out of the country in a crate.

Experiment 2: Actives and Passives

The policeman found the lost child at the airport.

The policeman was found by the lost child at the airport.

The farmer tricked the cowboy into selling the horse.

The farmer was tricked by the cowboy into selling the horse.

The basketball player helped the coach to put away the equipment.

The basketball player was helped by the coach to put away the equipment.

The teacher criticized the principal before the school board meeting.

The teacher was criticized by the principal before the school board meeting.

The professor admired the students in the biology class.

The professor was admired by the students in the biology class.

The lion found the zebras near the watering hole.

The lion was found by the zebras near the watering hole.

The baker hired the woman to help out with the wedding.

The baker was hired by the woman to help out with the wedding.

The painter recruited the model after the art show.

The painter was recruited by the model after the art show.

The accountant visited the banker before the audit.

The accountant was visited by the banker before the audit.

The mechanic phoned the customer after the car was repaired.

The mechanic was phoned by the customer after the car was repaired.

The old lady ran over the drunk last Saturday night.

The old lady was run over by the drunk last Saturday night.

The interpreter confused the diplomat during the treaty negotiations.

The interpreter was confused by the diplomat during the treaty negotiations.

The scientist frightened the assistant during the thunderstorm.

The scientist was frightened by the assistant during the thunderstorm.

The tourist photographed the tour guide in front of the museum.

The tourist was photographed by the tour guide in front of the museum.

The comedian liked the agent with the shiny black shoes.

The comedian was liked by the agent with the shiny black shoes.

The judge smiled at the defense attorney before the trial started.

The judge was smiled at by the defense attorney before the trial started.

The cheerleader asked the football player for his phone number.

The cheerleader was asked by the football player for her phone number.

Two ducks approached the old woman who had a bag of bread crumbs.

Two ducks were approached by the old woman who had a bag of bread crumbs.

The pilot saluted the ground crew before the plane took off.

The pilot was saluted by the ground crew before the plane took off.

The salesman amused the customers at the used car dealership.

The salesman was amused by the customers at the used car dealership.

The mayor approached the councilman about the new library.

The mayor was approached by the councilman about the new library.

The coal miner pushed the bartender and the people at the bar laughed.

The coal miner was pushed by the bartender and the people at the bar laughed.

The neighbors upset the college students living next door.

The neighbors were upset by the college students living next door.

The child upset the nurse at the clinic this morning.

The child was upset by the nurse at the clinic this morning.

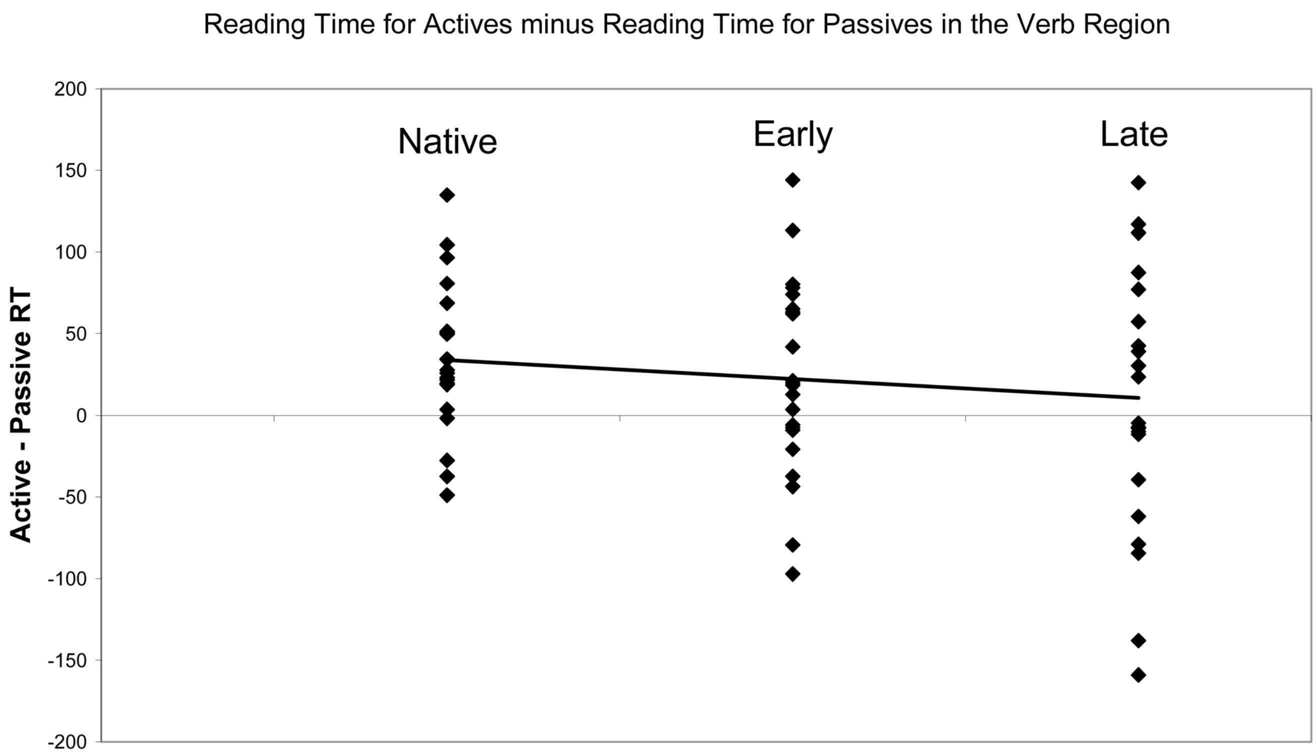

Figure 1.
Reading time in the Active Voice Condition minus Reading Time in the Passive Voice Condition at the Main Verb, Experiment 2.

Table 1

Mean self-paced reading time and standard errors (in parentheses) for the relative clause scoring region by condition and group for Experiment 1.

Relative Clause Region			
	Deaf	**Native English**	**Bilingual**
Subject Relative			
Inanimate	1624 (42.6)	1330 (90.5)	1520 (90.0)
Animate	1560 (82.5)	1332 (43.0)	1540 (38.7)
Object Relative			
Inanimate	1552 (49.1)	1367 (40.0)	1484 (47.5)
Animate	1672 (35.7)	1319 (70.3)	1579 (67.8)
Main Verb Region			
	Deaf	Native English	Bilingual
Subject Relative			
Inanimate	521 (16.1)	485 (28.7)	522 (30.0)
Animate	511 (30.4)	436 (24.1)	505 (21.7)
Object Relative			
Inanimate	505 (44.2)	502 (21.3)	515 (22.3)
Animate	622 (35.9)	570 (40.0)	618 (41.6)

Table 2

Mean self-paced reading time and standard errors (in parentheses) for the main verb, determiner, and noun scoring regions by group (deaf vs. native English vs. bilingual) and sentence type (active vs. passive voice) for Experiment 2.

Group	Main Verb	Determiner	Noun
Deaf			
Active Voice	488 (12.7)	418 (9.73)	497 (15.4)
Passive Voice	467 (6.43)	372 (5.48)	482 (11.5)
Native English			
Active Voice	479 (30.3)	423 (25.5)	528 (38.8)
Passive Voice	469 (19.5)	424 (16.8)	504 (29.5)
Bilingual			
Active Voice	533 (30.6)	434 (20.4)	582 (38.8)
Passive Voice	559 (14.4)	356 (13.0)	599 (34.8)