In J. Moore and K. Stenning (eds.), Proceedings of the Twenty-third Annual Conference of the Cognitive Science Society (pp. 964-969). Mahwah, NJ, USA: Lawrence Erlbaum Associates, Inc.

On choosing the parse with the scene:

The role of visual context and verb bias in ambiguity resolution

Jesse Snedeker (jessned@psych.upenn.edu)
Kirsten Thorpe (thorpe@psych.upenn.edu)
John Trueswell (trueswel@ psych.upenn.edu)
The Department of Psychology and the Institute for Research in Cognitive Science
Philadelphia, PA 19104 USA

Abstract

Two striking contrasts currently exist in the sentence processing literature. First, whereas adult reading studies indicate an important role for verb biases in the initial consideration of syntactic alternatives (Britt, 1994), studies of adult listeners in world-situated eye-gaze studies suggest an almost exclusive role for referential cues in determining initial syntactic choices (Tanenhaus et al., 1995). Second, in contrast to adults, children in similar listening studies fail to take into account this referential information and instead appear to rely exclusively on verb biases or perhaps syntactically-based parsing principles (Trueswell et al., 1999). The current paper seeks to understand better these surprising contrasts by fully crossing verb bias and referential manipulations within a single experimental design, while using the eye-gaze listening technique. The full pattern is examined in adults (Exp. 1) and children (Exp. 2). Results indicate that adults combine both verb bias and referential information to determine syntactic choice, but children rely exclusively on verb bias. We discuss the implications for current theories of sentence processing as well as prior interpretations of world-situated listening studies.

Introduction

A central interest in the study of human language comprehension has been to understand the role that context plays in resolving linguistic ambiguities. In particular, can readers and listeners take into account extra-sentential information (i.e., information about the current situation or discourse) when making initial decisions about how to structure an incoming utterance? Or, do constraints on the organization of the comprehension system force it to exclude these non-linguistic factors during the early stages of processing?

These questions have played themselves out in the sentence processing literature in a series of studies examining how the referential context of a sentence affects the way readers initially interpret syntactically ambiguous phrases. To illustrate these findings, consider sentence fragment 1. The prepositional phrase (PP) beginning with *with* is temporarily ambiguous because it could be linked to the verb *hit* (verb phrase (VP)-attachment), indicating an Instrument (e.g., *with the stick*); or it could be linked to the definite noun phrase *the thief* (noun phrase (NP)-attachment) indicating a Modifier (e.g., *with the wart*).

1. The store owner hit the thief with the…

Crain and Steedman (1985) hypothesized that ambiguities involving this structure, and others, are initially resolved by taking into account the referential presuppositions of the syntactic analyses, with readers pursuing the analysis that has the fewest presuppositions. In short, if one assumes that a definite NP like *the thief* requires a unique referent, a restrictive modifier analysis of *with the wart* would presuppose the presence of two or more thieves, one of which has a wart. An Instrument analysis makes no such presupposition. Hence, it is predicted that in a context containing two possible referents (two-referent contexts) readers should pursue a modifier (NP-attachment) analysis, but in a one-referent context, or even a null context, readers should erroneously pursue an Instrument (VP-attachment) analysis.

Indeed several studies have found that readers in a two-referent context pursue a modifier analysis for ambiguous phrases of this sort (e.g., Altmann & Steedman, 1988; van Berkum, Brown & Hagoort, 1999, among many). However, several studies have failed to find such affects (e.g., Ferreira & Clifton, 1986; Rayner, Garrod & Perfetti, 1992).

An account of these conflicting findings comes from constraint-satisfaction theories of parsing that propose a role for verb biases in parsing preferences (e.g., MacDonald et al., 1994; Trueswell & Tanenhaus, 1994). These theories predict that referential effects should be weakened or eliminated when lexically specific constraints are strong. Thus, differences in the materials that were used in these prior studies may account for the conflicting findings.

Indeed, studies that have manipulated both referential context and verb bias have found that effects of referential factors disappear when a verb strongly prefers a single analysis (e.g., Britt, 1994; Spivey-Knowlton & Sedivy, 1995). Using materials like "*Susan put/dropped the book on the civil war onto the table"* Britt (1994) found that 2-book vs. 1-book contexts failed to guide parsing preferences when the verb required a PP argument. That is, for verbs like *put*, readers initially pursued VP-attachment regardless of context but for verbs like *dropped*, context guided parsing. These reading studies suggest that context only has an influence in the absence of strong lexical constraints, leading some researchers to contend that verb information plays the privileged role of proposing syntactic structures, which are only compared against context at a later stage (Boland & Cutler, 1996; Britt, 1994).

Recent work on syntactic ambiguity resolution in spoken language comprehension however has raised questions about the relative contributions of context and verb information. Tanenhaus, Spivey and colleagues (Tanenhaus et al., 1995;

Spivey et al., 2001) have found that under the right conditions situation-specific contextual information can completely override strong verb biases that support a competing syntactic alternative. In their studies, participants were given spoken instructions to move objects about on a table while their eye movements were recorded. Target instructions, like 2 below, contained a temporary PP-attachment ambiguity, in which the verb's argument preferences strongly supported an initial VP-attachment analysis of *on the napkin*.

2. Put the apple on the napkin into the box.

Even though the verb *put* requires a destination role, usually a PP, the two-referent context was sufficient to allow listeners to override the strong bias for VP-attachment. In particular, scenes containing two apples, one of which was on a napkin, eliminated early and late looks to an incorrect destination object (e.g., an empty napkin). Similar scenes with one apple resulted in large numbers of early and late looks to the incorrect destination. The authors concluded that when referential cues to attachment are salient, co-present with the linguistic utterance, and hence easy to maintain in memory, they can prevail over even the strongest of verb biases. However, they also noted that such strong effects of context are unexpected under most views of constraint-satisfaction, given the overwhelming structural bias of *put*.

Trueswell, Sekerina, Hill & Logrip (1999) replicated the findings of Tanenhaus et al. (1995) using essentially the same auditory eye-gaze task. In addition, they tested children, ages 4 and 5 , with the same materials. The children pursued the VP-attachment analysis, ignoring referential constraints even for the purpose of reanalysis. In particular, both two-referent and one-referent scenes showed early and late eye movements to the incorrect destination. Moreover, children's actions frequently involved the incorrect destination (e.g., moving an object to the empty napkin). By age eight, children acted like adults in this task, using referential context to guide parsing commitments. The authors concluded that the child parsing system relies heavily on verb-argument preferences to assign structure, and that processing demands prevented any use of the referential facts.[1] This developmental shift is surprising and a bit mysterious. How and why would lexicalist children become referentially-driven adults?

The current paper explores the striking and somewhat puzzling contrasts that we have outlined above. First, we wish to better understand the differences between adult reading and auditory studies, which paradoxically suggest that verb-specific preferences play little or no role in world-situated syntactic ambiguity resolution. Second, we wish to better understand the developmental change that occurs in sentence processing, to discover whether the parsing strategies of children and adults are as incommensurable as they appear.

[1] The children's parsing pattern might instead be attributable to the use of a syntactically-based parsing strategy (e.g., Minimal Attachment, Frazier & Fodor, 1978). This will be addressed in Experiment 2.

To achieve these goals, we follow the lead of the prior reading studies that have, in a single experiment, fully crossed verb bias preferences with manipulations of referential context, except we now perform these manipulations in the world-situated eye-gaze task of Tanenhaus and colleagues. Such manipulations should reveal the relative contributions of these factors under all possible combinations. Second, we collected similar observations in five year olds, to observe the full pattern of information combination in this age group.

Experiment 1

In this experiment adults heard instruction containing a PP-attachment ambiguity (e.g., "Feel the frog with the feather") in both two-referent and one-referent contexts. For some subjects the target sentence contained a verb that typically uses an instrument phrase. Others heard instructions containing verbs that rarely use instruments. A third group was given instructions with equi-biased verbs.

The target instructions were globally ambiguous sentences rather than the temporarily ambiguous sentences typically used in comprehension studies. This was done for two reasons. First, we wanted to use the simplest sentences possible (i.e., ones without a second preposition) to avoid confusing children with uncommon sentence types (Exp. 2). Second, we were concerned that the previous listening studies (Tanenhaus et al., 1995; Trueswell et al., 1999) may have failed to find evidence that a VP-analysis was being considered in two-referent contexts because the disambiguating preposition occurred so soon after the introduction of the ambiguous phrase (see MacDonald, 1994, for the effects for post-ambiguity cues on parallel processing).

Because the sentences used in this study are never definitively disambiguated, we should expect continuity between the listeners' online attachment preferences and their ultimate interpretations. If listeners rely entirely on the visual context, then in two referent contexts they should interpret the ambiguous phrase as a modifier, regardless of verb bias. This preference should be reflected in both their eye movements and their actions. In contrast, if listeners simultaneously consider both lexical and contextual information then we would expect to find: 1) an effect of verb bias in both the one- and two-referent contexts and 2) an effect of referential context in some or all of the verb classes.

Methods

Participants Thirty-six students at the University of Pennsylvania volunteered for the experiment (twelve in each of the verb bias conditions). They received extra course credit or were paid for their participation. Twelve of the participants were males and all were native speakers of English.

Procedure The adult subjects were told that they were going to listen to and follow prerecorded instructions and that their responses would serve as a point of comparison for a study of how children follow directions. The subject sat in front of an inclined podium. At the center of the podium was a hole for a camera that focused on the subject's face. In each quadrant of the podium was a shelf where one of the props

could be placed. At the beginning of each trial one experimenter laid out the props and introduced each one using indefinite noun phrases (e.g., *This bag contains a dog, a fan.…*).

A second experimenter then played three prerecorded sound files from a laptop computer connected to external speakers. The first sound file was the same on every trial and simply told the subject to look at a fixation point at the center of the display. The second and third sound files were single sentence commands involving the props. The subject heard the first command, performed that action, and then heard the second command. Subjects signaled that an action was completed by saying "done". A second camera, placed behind the subject, recorded their actions and the locations of the props.

Stimuli On the critical trials, the first command contained an ambiguous Prepositional Phrase attachment, as in (3 a-c) below. The scene that accompanied these sentences contained the following objects: 1) a Target Instrument, a full scale object that could be used to carry out the action (e.g., for 3b a large feather); 2) a Target Animal, a stuffed animal carrying a small replica of the Target Instrument (e.g., a frog holding a little feather); 3) a Distractor Instrument; a second full scale object (e.g., a candle); and 4) A Distractor Animal, a stuffed animal carrying a replica of the Distractor Instrument. For Two Referent Trials the Distractor Animal and Target Animal were of the same kind (e.g., both frogs) for the One Referent Trials the Distractor Animal was of a different kind (e.g., a leopard carrying a candle).

3a. Choose the cow with the stick. (Modifier Bias)
3b. Feel the frog with the feather (Equi Bias)
3c. Tickle the pig with the fan. (Instrument Bias)

Examples of the three different types of verbs were used in this study are given in (3a-c). The verbs were identified in an earlier sentence completion study (see Snedeker, Dardick & Trueswell, 1999). In that experiment, adult subjects were asked to complete sentence fragments that ended with the ambiguously attached preposition (e.g., "Touch the teddy bear with…"). The verbs in the Modifier Bias condition were ones for which modifier completions (e.g., "the big brown eyes") were at least three times as frequent as Instrument completions (e.g., "your toes"). For the Instrument Bias verbs the opposite rule applied. Equi Bias verbs were those that fell somewhere in between.

The Target Instruments for each sentence were also chosen on the basis of a prior norming study (Snedeker et al., 1999). Subjects were shown several objects for each verb and asked to rate them as instruments for performing that action on a seven-point scale. We selected objects with mean ratings between 2 and 5 and balanced the ratings across the three Verb Bias conditions (M = 3.60, 3.65, and 3.64 for Modifier, Equi, and Instrument Biased respectively, $p > .9$).

Two presentation lists were constructed for each Verb Bias condition, so that each of the 8 target trials appeared in only one of the conditions on a given list but appeared in both conditions across lists (resulting in four target trials in each condition per subject). Thus Verb Bias was manipulated between subjects. This was done to minimize the number of trials per participant to ensure that children could complete the same study. Referential Context was manipulated within subjects but blocked. The first half of one list contained all One Referent Contexts while the first half of the other list contained just Two Referent Contexts. The critical trials were interspersed with twenty-four filler trials. The prop sets for the filler trials were similar to those used in the target trials: the attributes of the animals were matched to the large objects and animals of the same kind were used in half of the filler prop sets. Each list was presented in two orders (forward and reverse).

Coding Trained coders watched the videotape of the subject's actions and judged whether they made an Instrument response (performed the target action using the Target Instrument or the miniature instrument). A different coder viewed the videotape of the subject's face and recorded the onset of the target sentence and the onset and location of each fixation that occurred from the beginning of the instruction up until the subject began the action.

Results

Eye Movements For each trial we determined whether the subject looked at the Target Instrument during the time between the onset of the direct-object noun and the beginning of the action.[2] Figure 1 shows the proportion of trials with Instrument Fixations in each of the six conditions.

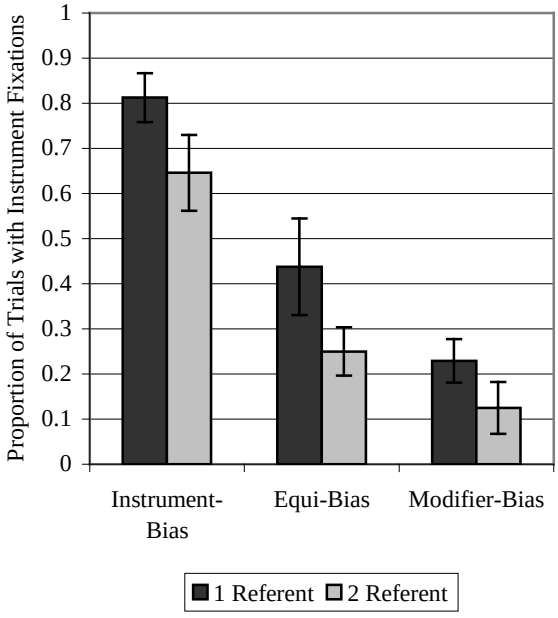


Figure 1: Proportion of Instrument Fixations for Adults (Experiment 1)

[2] This is essentially the same measure used by Tanenhaus et al., 1995. More fine-grained analyses of the pattern of fixations over time, indicate an early use of verb information even in Two Referent contexts.

Subjects' fixations during the ambiguous instructions were strongly affected by the type of verb in the sentence ($F1(2,24) = 27.71$, $p < .001$; $F2(2,18) = 35.01$, $p < .001$). Subjects who heard Instrument Biased verbs looked at the Target Instrument on 73% of the trials, indicating that they were considering the VP-attachment. Those who were given Modifier Biased verbs looked at the Target Instrument on only 18% of the trials.

Referential Context also had a strong and reliable effect on performance ($F1(1,24) = 10.52$, $p < .005$; $F2(1,18) = 11.90$, $p < .005$). When the ambiguous sentence occurred in a Two Referent Context only 34% of the trials included an Instrument Fixation, while in One Referent Contexts 49% of the trials did so. There was no significant interaction between Verb Type and Referential Context ($F1(2,24) > 1$, $p > .5$; $F2(2,18) > 1$, $p > .5$).

Actions The analysis of the Actions closely paralleled the analysis of the Instrument Fixations. Subjects tended to look at the Target Instrument when they were going to use it to perform the action but seldom fixated on it otherwise. The proportion of Instrument responses in each of the six conditions is presented in Figure 2.

Again there was a large and reliable effect of Verb Type ($F1(2,24) = 36.54$, $p < .001$; $F2(2,18) = 69.99$, $p < .001$). When the subjects heard an Instrument Biased verb, they produced Instrument actions 77% of the time. When they heard a Modifier Biased verb, they produced Instrument actions only 7% of the time.

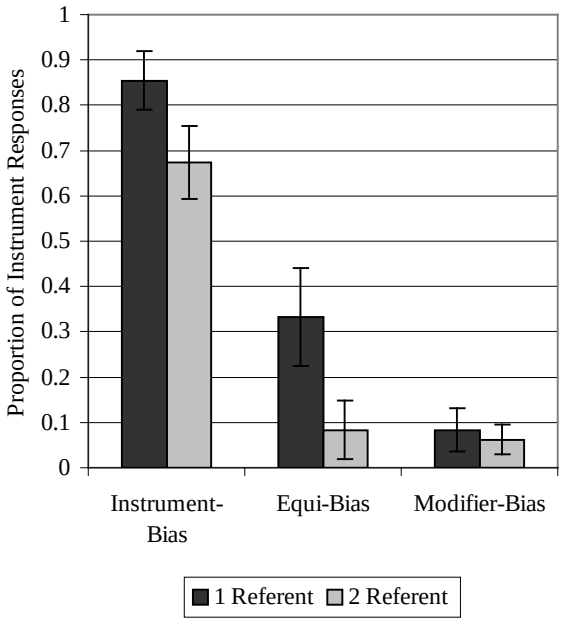


Figure 2: Proportion of Instrument Actions for Adults (Experiment 1).

Referential Context also had a strong effect on performance ($F1(1,24) = 10.81$, $p < .005$; $F2(1,18) = 15.99$, $p < .001$). In One Referent Contexts 42% of the responses involved the Target Instrument, in Two Referent Contexts only 27% did. Although the interaction between Verb Type and Referential Context was not reliable ($F1(2,24) = 2.20$, $p < .2$; $F2(2,18) = 3.28$, $p = .06$), the effect of context appeared to be isolated to the Equi Biased Verbs ($F1(1,8) = 5.33$, $p < .05$; $F2(1,6) = 11.39$, $p < .05$) and Instrument Biased Verbs ($F1(1,8) = 5.59$, $p < .05$; $F2(1,6) = 4.74$, $p = .07$). There was no significant effect of Referential Context for the Modifier Biased Verbs ($F1(1,8) < 1$, $p > .5$; $F2(1,6) = 1.00$, $p > .3$).

Experiment 2

A very similar experiment was conducted with five-year old children. Recall that Trueswell et al (1999) found an overwhelming VP-attachment bias in children of this age. As mentioned above this finding could be the result of the strong attachment bias of *put* or it could be evidence that children use a general structural parsing principle (e.g., minimal attachment). This experiment gives us the opportunity to distinguish between these explanations. A lexically based theory would predict that attachment preferences would be guided by verb information. A minimal attachment explanation would predict that children would show a VP-attachment preference independent of verb type. In addition, manipulating verb type allows us to see whether children's failure to use referential context is limited to strongly biased verbs (ala, Britt, 1994). We reasoned that children might prove to be sensitive to context for the Equi Biased verbs.

Methods

Participants Thirty-six children between 4;6 and 5;10 participated in the study ($M = 5;1$). Parents were contacted from Philadelphia area preschools and a commercial mailing list. Four additional children participated but were not included in the analyses because they refused to cooperate (1) were bilingual (1), or had been identified as developmentally delayed (2). Half of the children were male. Sex and age were balanced across the Verb Bias conditions and Lists.

Procedure and Stimuli The procedure was identical to Experiment 1 with the following exceptions. First, the children were told the names of each object twice. Second, the children were not asked to tell us when they had finished performing each action. Instead the experimenter who introduced the toys waited until the child finished moving the toys or looked at her and then praised the child for her response regardless of his or her action. Third, the number of filler trials was reduced from 24 to 10.

Results

Eye Movements Figure 3 shows the proportion of trials with Instrument Fixations in each of the six conditions. An Instrument Fixation was defined as any fixation to the Target Instrument that occurred between the onset of the direct object noun and the initiation of the action.

Like the adults, the children's fixations were strongly affected by the type of verb in the sentence ($F1(2,24) = 43.49$, $p < .001$; $F2(2,18) = 18.60$, $p < .001$). Subjects who heard Instrument Biased verbs looked to the Target Instrument on

82% of the trials, while those who heard the Modifier Biased verbs looked at the Target Instrument on only 21% of the trials. In contrast, Referential Context had no significant effect on the children's Instrument Fixations ($F1(1,24) < 1$, $p > .5$; $F2(1,18) = 1.41$, $p > .25$). There was no significant interaction between Verb Type and Referential Context ($F1(2,24) > 1$, $p > .5$; $F2(2,18) > 1$, $p > .5$). The children's fixations suggest that in all three Verb Bias Conditions, Referential Context played no role in determining the attachment of the ambiguous phrase.[3]

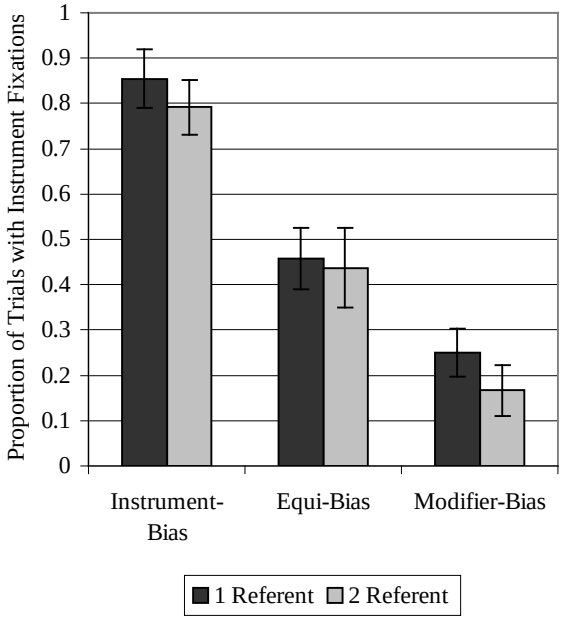
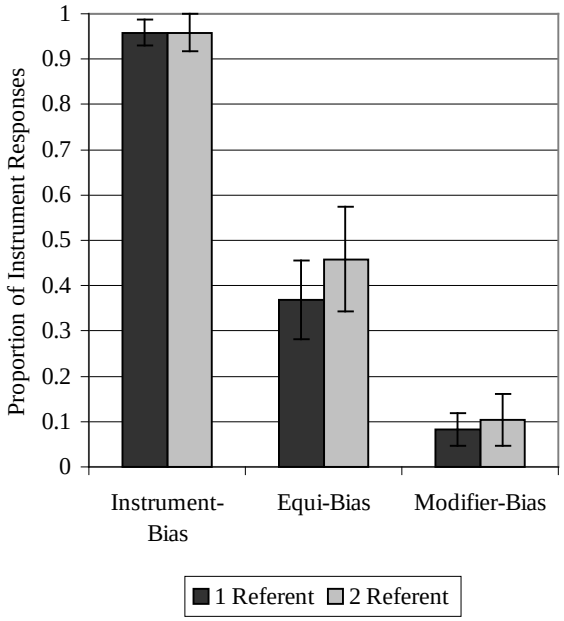


Figure 3: Proportion of Instrument Fixations for Five-Year Olds (Experiment 2)

Actions The proportion of Instrument responses in each condition is presented in Figure 4. Here again the offline actions and the online eye movements provide convergent evidence of the children's interpretation of the *with*-phrase.

Verb Bias had a striking effect on the children's actions ($F1(2,24) = 58.21$, $p < .001$; $F2(2,18) = 309.47$, $p < .001$). When the Subjects heard an Instrument Biased verb, they produced Instrument Actions 96% of the time. When they heard a Modifier Biased verb, they produced Instrument actions only 9% of the time. In contrast Referential Context appeared to have no effect on the children's actions ($F1(1,24) = 1.15$, $p > .2$; $F2(1,18) = 1.46$, $p > .2$). In One Referent Contexts instruments were used on 47% of the trials, in Two Referent Contexts they were used on 51% of the trials. There was no significant interaction between Referential Context and Verb Bias ($F1(2,24) < 1$, $p > .5$; $F2(2,18) < 1$, $p > .4$).

A direct comparison of the data from the two experiments revealed a main effect of Age Group ($F1(1,66) = 9.57$, $p < .005$; $F2(1,21) = 17.32$, $p < .001$) and an Age Group by Referential Context interaction ($F1(1,66) = 7.66$, $p < .01$; $F2(1,21) = 9.79$, $p < .005$). Five-year-old children produce



more Instrument responses than adults but this difference is limited to the Two Referent Condition.

Figure 4: Proportion of Instrument Actions for Five-Year Olds (Experiment 2)

In the One Referent Context, there was no effect of Age Group nor an Age Group by Verb Bias interaction (all Fs < 1, all p's > .3), indicating that the children and adults were equally responsive to the combinatorial properties of the verbs. In the Two Referent Contexts, there was both an effect of Age Group ($F1(1,66) = 16.54$, $p < .001$; $F2(1,21) = 26.93$, $p < .001$) and a marginal Age Group by Verb Bias interaction ($F1(2,66) = 3.00$, $p = .06$; $F2(2,21) = 4.90$, $p < .05$). Children gave more Instrument Responses, especially in the Instrument Biased and Equi Biased Conditions.

General Discussion

Two important findings emerge from this work. First, we observe that lexical biases do play an important role in adult parsing preferences in a world-situated task. Even when there is a rich and potentially constraining context that is co-present with the utterance, verb bias and referential cues combine to determine adult listeners' parsing preferences. Second, children show a complete inability to use referential information to inform parsing decisions, and instead reveal detailed sensitivity to verb biases. The implications of the adult and child data are considered separately below.

The data from our adult study indicate a greater continuity between the reading and listening than previous studies would suggest. Like Britt (1994), we observe contributions of both factors in on-line parsing commitments. This pattern is consistent either with a constraint-satisfaction approach that weighs both sources of evidence (e.g., Trueswell & Tanenhaus, 1994) or a 'propose-and-select' model which gives

[3]More detailed analyses of the time course of the eye movements support these claims. Verb Bias has an early effect on fixations but Referential Context does not.

a privileged status to lexical items in computing syntactic alternatives (e.g., Boland & Cutler, 1996).

Why then did the previous *put* studies show no consideration of the VP-attachment analysis? We speculate that two additional sources of information present in those studies may have further reduced consideration of VP-attachment. First, the appearance of a second prepositional phrase (*into the box*) right at the very moment that eye movements should show consideration of VP-attachment may have served as a post-ambiguity cue that squelched consideration of this parse. Second, prosodic cues may have provided evidence during the first PP that a second potential argument was forthcoming. Prosody was held constant across conditions in these studies, but the neutral prosody that the experimenters aimed for may have revealed that the utterance would continue. Indeed, our own studies of prosody, which used a similar task and measure, suggest that differences of this kind can influence parsing as rapidly as lexical information (Snedeker et al, 2001). These additional cues may not have been enough to completely eliminate the VP-attachment analysis in the one referent condition but may have been adequate to eliminate it in the two referent condition where context also supports a modifier analysis.

Implications from the child data are clear. First, children are not 'miniature minimal attachers'. The lack of a general VP-attachment bias, and a clear sensitivity to verb information speaks to this issue. Second, children seem instead to have formed parsing strategies that derive from their syntactic/semantic knowledge of individual verbs, lending further support to constraint-based lexicalist models of parsing.

An issue that remains less understood is why children fail to use referential specificity to guide their parsing commitments (i.e., the Referential Principle). This failure occurs even verbs that have no strong attachment preferences, which might override the effects of context. We strongly suspect that the failure to employ the referential principle is not due to a general lack of knowledge about specificity or the proper use of modification—our own studies show a clear talent in children's utterances for specifying a referent via locative modification (e.g., Hurewitz et al., 2001).

A controversial position, which our current data cannot rule out, is that children show a degree of bottom-up priority for lexically-based cues to syntax, perhaps because of the architectural configuration of the system. If children have memory limitations that prevent them from considering improbable syntactic alternatives, and probability is determined solely by distributional facts gleaned from utterances, then such a pattern might emerge. Only after the processing system gains the ability to maintain parallel parses over numerous words may the contextual facts further drive processing decisions. Indeed, this may also explain the inability of children in the Trueswell et al. study to revise initial commitments. It remains to be seen however, whether other contextual factors (e.g., related to conversational goals of a discourse) might better guide parsing preferences in children.

Acknowledgments

We thank Amy Nichols, Jessica Lilleston, John Paul Moorehead, Stefanie Poulos, Kate Ruane, Sandy Yim, and Lauren Cornew for their assistance with testing, coding and subject recruitment. We also gratefully acknowledge Tracy Dardick who carried out the norming studies. This work was supported by NIH Grant 1-R01-HD3750707-01 and a NSF Center Grant to the University of Pennsylvania Institute for Research in Cognitive Science.

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