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The Use of Verb Information in Parsing: Different Statistical Analyses Lead to Contradictory Conclusions

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Abstract The research investigated how comprehenders use verb information during syntactic parsing. Two reading experiments investigated the relationship between verb-specific variables and reading time. These experiments were close replications of prior work; however, two statistical techniques were used, rather than one. These were item-by-item correlations and participant-by-participant regression. In Experiment 1, reading time was measured using a self-paced moving window. In Experiment 2, eye movements were recorded during reading. The results of both experiments showed that the results of two types of statistical analyses support contradictory conclusions. The analyses involving participant-by-participant regression analyses provided no evidence for the early use of verb information in parsing and support syntax-first approaches to parsing. In contrast, the results of item-by-item correlation were consistent with the prior research, supporting the view that verb information can guide initial parsing decisions. Implications for theories of parsing are discussed.

Keywords Sentence processing · Syntactic parsing · Verb information · Syntactic ambiguity · Correlation · Regression

Over the last two decades, numerous studies have investigated how readers and listeners use information about verbs during language processing (See for review Clifton and Duffy 2001). However, there is, as yet, no consensus regarding how readers and listeners use verb information during the resolution of syntactic ambiguity. Syntax-first theories of sentence processing presume that initial decisions rely first on syntactic (or grammatical) information and are influenced by other sources of information, such as verb information, only later during processing (Ferreira and Henderson 1990; Frazier and Rayner 1982; Kennison 2001; Rayner

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et al. 1983). In contrast, interactive or constraint-based theories of sentence processing claim that any and all available information, including verb information, can be used to guide processing of following words or phrases (Garnsey et al. 1997; MacDonald et al. 1994a, b; Trueswell et al. 1993). The data reported by Trueswell et al. (1993) are among the strongest for this view. The researchers reported item-by-item correlations between verb-specific variables and reading time. The purpose of the present research was to revisit these results, determining whether these results could be replicated using both item-by-item correlations and a regression technique recommended by Lorch and Myers (1990) for repeated measures designs.

Lorch and Myers (1990) pointed out that data obtained in repeated measures designs involving nonorthogonal factors are frequently analyzed inappropriately. The most common data analysis procedure involves averaging processing time across participants to obtain item-by-item means and then correlating the item-by-item means with predictor variables, such as item-specific characteristics (e.g., frequency of usage, familiarity, etc.). Lorch and Myers (1990) recommended a different procedure, which involves computing regression equations for each participant, then regressing the multiple observations for processing time for the given participant using the item-specific variables as predictors. Each resulting regression coefficient is subsequently tested to determine whether it is reliably different from zero. The latter procedure, although more time and labor intensive, is less susceptible to a Type I error than the former procedure.

The purpose of the present paper is to provide a case example of how the two procedures recommended by Lorch and Myers (1990) can yield conflicting results and lead researchers to different conclusions. The present work revisits a study published by Trueswell et al. (1993) in which the participants processed sentences similar to those in 1. The design was a 2×2

(1) Ambiguous Conditions

(a) The student forgot the solution was provided in the book. NP-Biased
(c) The student hoped the solution was provided in the book. S-Biased

(2) Unambiguous Controls

(b) The student forgot that the solution was provided in the book. NP-Biased
(d) The student hoped that the solution was provided in the book. S-Biased

repeated measures design with ambiguity and verb type as factors. Twenty sets of sentences were tested, involving 10 different NP-biased verbs and 10 different S-biased verbs. Each verb was associated with three verb-specific variables (i.e., frequency of usage with NP complements, frequency of usage with S complements, and frequency of usage with an overt complementizer *that* in S complements).

Trueswell et al. (1993) reported a self-paced reading experiment and an eye tracking experiment. The expected results, in accordance with interactive or constraint-based views, were that readers in NP-biased verb conditions would interpret the ambiguous NP initially as an NP complement, and when the following disambiguating clausal verb was encountered, readers would reanalyze the NP as the subject of an S complement; thus, reading time on ambiguous sentences was expected to be longer than on unambiguous control conditions beginning at the point in time that the reader process the clausal verb. In S-biased verb conditions, readers were expected to interpret the ambiguous NP initially as the subject of an S complement; thus, no differences in reading time was expected for ambiguous versus unambiguous control

conditions. In contrast, if readers did not use verb information initially during the resolution of the syntactic ambiguity, as predicted by the syntax-first approach, then reading time on ambiguous sentences would be expected to be longer than on unambiguous control conditions for both verb type conditions.

The results of both experiments showed that reading time on disambiguating clausal verb was reliably longer for ambiguous sentences than for unambiguous control conditions for NP-biased verb conditions, but not for S-biased verb conditions. However, for S-biased verb conditions, reading time on the ambiguous NP was reliably longer for ambiguous sentences than for unambiguous control sentences; this pattern was not observed for NP-biased verb conditions. They claimed that this increase in reading time was related to the difficulty readers had in constructing an S complement when the complementizer *that* was absent. Their evidence for this claim was significant correlations between the frequency with which specific S-biased verbs generally occur with an overt complementizer *that* when used with S complements (i.e., *that*-preference) and the difference in reading time for ambiguous versus unambiguous sentences on the regions containing the ambiguous NP and the disambiguating clausal verb. Nevertheless, the correlations between the reading time difference between ambiguous versus unambiguous complements and the frequency with which specific NP-biased and S-biased verbs generally occur with NP and S complements were not significant.

Kennison (2001) reported an eye tracking experiment in which participants read sentences similar in structure to those in 1. The results showed that reading time was reliably longer for ambiguous versus unambiguous conditions for both NP-biased and S-biased verb conditions. The magnitude of the difference did not vary significantly for NP-biased and S-biased verbs. Furthermore, when both item-by-item correlations and participant-by-participant regression equations were conducted, no evidence was found that readers used verb-specific information during the initial processing of the ambiguous NP region or the following disambiguating clausal verb region. On one hand, these results suggested that verb information played no initial role in the resolution of syntactic ambiguity. However, it must be acknowledged that it is possible that the failure to observe strong effects of verb information could have been due to the very different set of constraints involved in the materials being tested. In Kennison (2001), ambiguous NPs were highly plausible as NP complements for both NP- and S-biased verbs; in Trueswell et al. (1993), ambiguous NPs were less plausible as NP complements only for S- than NP-biased verbs. Due to the nature of the constraint-based approach, it is possible that the extent to which competing constraints may affect processing may depend on which constraints are applied and the individual strengths of the competing constraints.

In the present paper, additional experiments are reported, which investigated the role of verb-specific information in syntactic ambiguity resolution. The experiments were modeled closely on the experiments reported by Trueswell et al. (1993). Half of the materials used were the same as those used by Trueswell et al. (1993); half were similar items constructed for the study. The larger sample of verbs provided a statistically more powerful test of how information about specific verbs is used during ambiguity resolution; this was particularly useful for the participant-by-participant regression technique recommended by Lorch and Myers (1990). The length of the ambiguous NP was also varied, as a number of prior investigations have shown that longer ambiguous regions are associated with larger reading time differences between ambiguous versus unambiguous sentences (Ferreira and Henderson 1991; Frazier and Rayner 1982; Kennedy and Murray 1984). It was reasoned that readers may have a more difficult time revising an initial analysis when they have maintained that analysis for a longer period of time. If readers use verb information to construct initial analyses of ambiguous NPs, one would expect that the effect of NP length would influence the processing of

those sentences containing NP-biased verbs more so than those containing S-biased verbs, as reanalysis is predicted to occur in the former, rather than in the latter case. Experiment 1 was modeled on Trueswell et al. (1993) Experiment 1; reading time was measured using a self-paced moving window. Experiment 2 was modeled on Trueswell et al. (1993) Experiment 3; eye movements were recorded during reading.

Experiment 1

The purpose of Experiment 1 was to attempt to replicate Trueswell et al. (1993) Experiment 1. Reading time was measured on sentences that contained ambiguous and unambiguous tensed sentence complements preceded by either a NP-biased verb, such as *forgot,* or a S-biased verb, such as *hope.* Reading time was measured using a self-paced moving window. Ambiguous NPs were either short or long. Short NPs were composed of a determiner and a noun. Long NPs were composed of a determiner, noun, and following modifying phrase or clause, respectively. Table 1 displays sample sentences.

Method

Participants

Forty-eight undergraduates at the University of Massachusetts, who were both native speakers of American English and naive to the purposes of the experiments, participated for course credit.

Materials

Forty experimental sentences were used. Half were the same as those used by Trueswell et al. (1993). The new items were constructed to be highly similar to the hold items. Of the 20 items from Trueswell et al. (1993), one item had been excluded from Trueswell et al.'s data analysis because of an incorrectly selected S-biased verb. In the present experiment, the sentence frame for this item was used with a different S-biased verb (See item #13 in the Appendix). Twenty additional verbs were selected either from the norms provided in

Table 1 Sample sentences from experiment 1

NP-Biased Verb
Unambiguous
The waiter | confirmed | that | the reservation | (of the room) | was made | by a woman.|
Ambiguous
The waiter | confirmed | the reservation | (of the room) | was made | by a woman.|
S-Biased Verb
Unambiguous
The waiter | insisted | that | the reservation | (of the room) | was made | by a woman.|
Ambiguous
The waiter | insisted | the reservation | (of the room) | was made | by a woman.|

Note: The words and phrases enclosed in parentheses occurred in a subset of conditions
The '|' symbols indicate analysis regions

Table 2 Summary of verb characteristics from experiments 1 and 2

Verb Type	Materials Used in Trueswell et al. (1993)		
	NP complement %	S complement %	%*that*-preference
NP-biased	77.90	7.00	0.004
S-biased	3.89	69.78	58.440
New Materials			
NP-biased	73.91	6.45	52.730
S-biased	22.00	55.18	66.090
Overall			
NP-biased	75.91	6.73	26.370
S-biased	12.95	62.48	62.270

Trueswell et al. (1993) or from Kennison (1999). Table 2 displays the usage frequencies for the verbs used. A complete list of experimental sentences is provided in the Appendix.

Procedure

Each participant in the reading experiment was tested individually in a well-lit, private cubicle. Sentences were presented on a cathode ray tube interfaced with a microcomputer. All experimental sentences were presented on a single line, using a non-cumulative display procedure (Kennedy and Murray 1984). When the participant pulled the trigger, a series of dashes was presented on the computer screen, which corresponded to where the characters of the sentence would appear. When the participant pulled the trigger again, the first phrase of the sentence replaced the corresponding dashes. When the participant pulled the trigger again, the first phrase was replaced by dashes and the second phrase appeared, and so on. Experimental sentences were presented in multiple presentation regions: (1) the subject of the sentence; (2) the NP or S biased verb; (3) the complementizer; (4) the determiner-noun; (5) the modifier; (6) two words, including the disambiguating verb; (7) the remainder of the sentence. Ambiguous conditions and conditions without modifiers were presented in the resulting fewer number of regions. A practice set of 10 sentences was presented, followed by the set of 140 sentences (40 experimental sentences and 100 fillers). Forty of the filler sentences were foils, containing verbs that permitted NP and sentence complements and continuing temporarily ambiguous NPs as NP complements. Participants received simple true/false comprehension questions after 58% of the sentences. The purpose of including comprehension questions was to encourage participants to read sentences for meaning; thus, participants were tested on their comprehension more than half of the time. After an incorrect response, the word ERROR appeared on the computer screen. Each participant received a different randomized order of sentences. Each participant viewed each experimental sentence only once (in only one version). Eight counterbalancing lists were used so that each item was viewed equally often in each condition across participants. Each session lasted between 30 and 50 min.

Experimental Design

A repeated measures design was used. Each of the three within-subjects factors had two levels: (a) Ambiguity (ambiguous vs. unambiguous); (b) Verb Type (NP- biased vs. S-biased); and (c) NP Length (short vs. long).

Table 3 Mean self-paced reading time by presentation region from experiment 1

Verb type	Sentence type	Presentation region					
		R2	R3	R4	R5	R6	R7
Short ambiguous NPs							
NP bias	Ambiguous	574	–	626	–	683	777
	Unambiguous	585	490	603	–	584	783
	Difference	−11	–	+23	–	+99	−6
S bias	Ambiguous	615	–	633	–	600	744
	Unambiguous	610	490	569	–	553	735
	Difference	+5	–	+64	–	+47	+9
Long ambiguous NPs							
NP bias	Ambiguous	588	–	639	760	678	775
	Unambiguous	584	477	568	769	589	784
	Difference	+4	–	+71	−9	+89	−9
S bias	Ambiguous	624	–	674	800	598	728
	Unambiguous	604	501	584	757	582	710
	Difference	+20	–	+90	+43	+16	+18

Results

The data were initially trimmed to remove outliers. Observations longer than 2 s or shorter than 100 ms were removed, resulting in a loss of less than 1% of the data. Reading time was analyzed for the seven presentation regions: (1) the subject of the sentence; (2) the NP or S biased verb; (3) the complementizer; (4) the determiner-noun; (5) the modifier; (6) two words, including the disambiguating verb; (7) the remainder of the sentence. For regions containing multiple words, reading time per word was summed. Table 3 displays mean reading time in milliseconds by presentation region. Data were analyzed in three ways. Mean reading time was analyzed in analyses of variances (ANOVAs) treating participants (F_1) and sentences (F_2) as random effects, following Clark (1973).[1] Item-by-item correlations between verb-specific variables and the reading time difference between ambiguous and unambiguous conditions were conducted for each region. Lastly, participant-by-participant regression equations were computed using each of the verb-specific variables to predict the reading time difference between ambiguous an unambiguous conditions for each region. These three sets analyses are discussed in turn.

Analyses of Mean Reading Time

Results for reading time were similar to those observed Trueswell et al. (1993). At the disambiguating clausal verb region (Region 6), when sentences contained an NP-biased verb, readers took significantly longer in ambiguous conditions than unambiguous condition, $F_1(1, 47) = 31.26, MSe = 6{,}788, p < .001, F_2(1{,}38) = 16.72, MSe = 10{,}479, p <$

[1] One item was removed from the data analysis due to the omission of the word 'the' following the complementizer in two of the four unambiguous tensed sentence complement conditions.

.001; the difference for sentences containing an S-biased verb approached significance, $F_1(1,47) = 6.07, MSe = 3{,}975, p < .02, F_2(1, 38) = 3.23, MSe = 6{,}955, p < .09$. At this region, the interaction between verb type and ambiguity was significant, $F_1(1,47) = 9.90, MSe = 9{,}415, p < .003, F_2(1,38) = 7.13, MSe = 10{,}128, p < .02$. The main effect of ambiguity was significant, $F_1(1,47) = 31.33, MSe = 12{,}110, p < .001, F_2(1,38) = 13.06, MSe = 24{,}740, p < .001$ as was the main effect verb type, $F_1(1,47) = 16.45, MSe = 14{,}087, p < .001, F_2(1, 38) = 17.63, MSe = 11{,}363, p < .001$. Reading time on the region following the disambiguating clausal verb (Region 7) was significantly longer for NP- than for S-biased verb conditions, resulting in a significant main effect of verb type, $F_1(1,47) = 10.52, MSe = 23{,}634, p < .003, F_2(1,38) = 10.86, MSe = 17{,}711, p < .003$. The interaction between verb type and ambiguity was not significant, $Fs < 1$.

Reading time on the regions containing the ambiguous NP (Region 4) was significantly longer ambiguous than unambiguous sentences, $F_1(1,47) = 38.22, MSe = 9{,}686, p < .001, F_2(1, 38) = 13.55, MSe = 23{,}659, p < .001$. However, the interaction involving verb type and ambiguity was not significant, $Fs < 1$; both NP- and S-biased verb conditions showed the pattern of increased reading time on the ambiguous versus unambiguous NP. There were no significant effects or interactions observed on the region containing the modifier in long NP conditions (Region 5), $Fs < 1$.

Reading time on the regions preceding the ambiguous noun appeared to be most strongly influenced by the printed frequency of the verbs (as assessed by (Francis and Kuèera 1982). Reading time on the matrix verb (Region 2) was longer when the verb was S-biased than NP-biased, $F_1(1,47) = 11.39, MSe = 9{,}913, p < .002, F_2(1,38) = 5.10, MSe = 20{,}939, p < .03$. S-biased verbs were on average lower in printed frequency than NP-biased verbs (82 vs. 140, respectively). Reading time on the complementizer *that* (Region 3) was longer when the preceding verb had been an S-biased verb; the main effect of verb type was significant by participants only, $F_1(1,47) = 7.51, MSe = 8{,}830, p < .009, F_2(1, 40) = 2.99, MSe = 16{,}244, p < .10$. The imbalance in printed word frequency was present in the original Trueswell et al. (1993) materials as well (S-biased: 78 vs NP-biased 179).

Item-by-Item Correlations

These analyses were conducted in the same manner as Trueswell et al. (1993). The mean reading time was averaged across participants to obtain item-by-item means. To test for the effect of verb-specific *that*-preference, two predictor variables were used: *that*-preference and transformed *that*-preference (log(p/1−p)), which is desirable as the percentage range for *that*-preference is bounded. The results observed using this method were similar to those observed by Trueswell et al. (1993). As the *that*-preference and transformed *that*-preference of S-biased verbs increased, reading time differences difference between ambiguous and unambiguous sentence complements on the disambiguating verb region (Region 6) also increased, $r = .28, p < .04$ and $r = .26, p < .06$, respectively. Significant correlations were also observed between printed frequency for S-biased verbs and the reading time difference between ambiguous and unambiguous sentences at the disambiguating verb region, $r = -.34, p < .02$, indicating that the effect of ambiguity increased as the printed frequency of S-biased verbs decreased. The correlation between *that*-preference for S-biased verbs and the printed frequency of those verbs was also significant, $r = -.44, p < .003$; *that*-preference was lower for higher frequency verbs.

Participant-by-Participant Regression Analyses

For each participant, regression equations were compute. The difference in reading time for ambiguous and unambiguous sentence complements was used for the regression; *that*-preference and transformed *that*-preference (log(p/1−p)) as predictor variables. The regression coefficients were then tested to determine if they were different from zero. The results that were observed at the disambiguating verb region (Region 6) indicated that there was no significant relationship between *that*-preference or transformed *that*-preference and reading time differences for ambiguous and unambiguous tensed sentence complements, $F_1(1, 47) < 1.854$, $p > .18$ and $F\text{s} < 1$, respectively. No significant results were observed at the regions containing the ambiguous noun or modifier, $F\text{s} < 1$. Also no significant results were observed in the analyses in which verb-specific frequency of usage with NP and S complements was used to predict the reading time difference between ambiguous and unambiguous conditions, $F\text{s} < 1$.

Discussion

The results call into question Trueswell et al. (1993) conclusion that readers use verb-specific information during the initial analysis of syntactic ambiguities. Reading time results that were observed at the disambiguating clausal verb region indicated that although there was a larger difference between ambiguous and unambiguous conditions for NP-biased verbs, the difference for S-biased verbs approached significance. Reading time results that were observed at the ambiguous noun region indicated that readers took longer to process ambiguous nouns than nouns in unambiguous conditions both for sentences containing NP- and S-biased verbs. The only evidence that verb-specific *that*-preference information influenced processing in conditions containing S-biased verbs was obtained in the item-by-item correlational analyses. In the analyses using participant-by-participant regressions, no evidence was found that readers used verb-specific *that*-preference information during processing. There was no evidence that NP length influenced the difficulty involved in syntactic reanalysis. The purpose of Experiment 2 was to determine whether similar results could be observed when reading time was measured using eye tracking, which is a methodology that permits reading to occur under more normal conditions (i.e., without manual key presses).

Experiment 2

In Experiment 2, eye tracking was used to measure reading time on the same sentences used in Experiment 1. As the collection of eye movement data occurs throughout a trial, a reader's initial processing of a region and any rereading that occurs can be analyzed separately. With this methodology, it is possible to observe when during comprehension verb information begins to influence processing.

Method

Participants

Twenty-four undergraduate and graduate students at the University of Massachusetts, who had normal or corrected vision, were native speakers of American English, and were naive to the purpose of the experiment, participated for course credit or for $5.00.

Materials

The experimental materials were those used in Experiment 1.

Apparatus and Procedure

Eye movements were recorded by a Stanford Research Institute Dual Purkinje Eye tracker, which has a resolution of less than 10 min of arc. Viewing was binocular with eye position recorded from the right eye. The eye tracker was interfaced with an 80486 microcomputer, which controlled the presentation of the sentences. Up to 80 character spaces per line were used. The characters were in lower-case, except where uppercase characters were called for (at the beginning of sentences and proper names). Participants were seated 62 cm from the monitor and 4 characters equaled one degree of visual angle. The luminance from the monitor was adjusted to a comfortable brightness level for the participant and then held constant throughout the study, and the room was dark. For each participant, a bite-bar was constructed to minimize head movements during the experiment. The eye tracking system was then calibrated. This procedure required the participant to fixate nine markers sequentially (three markers on the top, middle, and bottoms areas of the computer screen). The voltage was recorded and interpolated for the intervening columns and rows. Before each trial, the calibration was checked and repeated, if necessary. The participant read 10 practice sentences followed by 140 experimental sentences (40 experimental sentences and 100 fillers). Forty of the filler sentences were foils, containing verbs that permitted NP and sentence complements and continuing temporarily ambiguous NPs as NP complements. All experimental sentences were presented on a single line. Comprehension questions appeared in the lower half of the computer screen. After incorrect responses, the word ERROR appeared on the computer screen. Fifty percent of sentences had comprehension questions. Each participant received a different randomized order of sentences. Each participant viewed each experimental sentence only once (in only one version). Eight counterbalancing lists were used so that each item was viewed equally often in each condition across participants. Each session lasted between 30 and 50 min.

Experimental Design

The same design was the same as that used in Experiment 1.

Results

Following the recommendations of Rayner et al. (1989), fixations shorter than 80 ms in duration and only one character away from the prior or next fixation were merged with that fixation. Fixations shorter than 40 ms and less than three characters away from the prior or next fixation were deleted. Remaining individual fixations longer than 1,000 ms or shorter than 50 ms were deleted. Two measures of reading time were analyzed: first pass reading time and total reading time. First pass reading time provides information about initial processing on a region and is defined as the sum of all fixations in a region from the time of first entering the region to the time of first leaving the region. Total reading time provides information about global processing on a region and is defined as the sum of all fixations in a region, summing first pass reading time with any fixations resulting from rereading on a region. Analysis regions were the same as the presentation regions used in Experiment 1. Tables 4 and 5 display mean first pass reading time and mean total reading time in milliseconds for Regions 2–7. As in Experiment 1, participants (F_1) and sentences (F_2) were treated as random effects.

Table 4 Mean first pass reading time by analysis region from experiment 2

Verb type	Sentence type	Presentation region					
		R2	R3	R4	R5	R6	R7
Short ambiguous NPs							
NP bias	Ambiguous	339	–	373	–	416	520
	Unambiguous	321	260	402	–	385	525
	Difference	+18	–	−29	–	+31	−5
S bias	Ambiguous	361	–	405	–	393	543
	Unambiguous	348	270	369	–	376	479
	Difference	+13	–	+36	–	+17	+64
Long ambiguous NPs							
NP bias	Ambiguous	365	–	405	564	420	564
	Unambiguous	333	280	390	572	354	517
	Difference	+32	–	+15	−8	+66	+53
S bias	Ambiguous	358	–	407	532	368	508
	Unambiguous	333	243	404	527	350	518
	Difference	+25	–	+3	+5	+18	−10

Table 5 Mean total reading time by analysis region from experiment 2

Verb type	Sentence type	Presentation region					
		R2	R3	R4	R5	R6	R7
Short ambiguous NPs							
NP bias	Ambiguous	430	–	465	–	552	611
	Unambiguous	366	254	481	–	487	557
	Difference	+64	–	−16	–	+64	+54
S bias	Ambiguous	429	–	520	–	501	593
	Unambiguous	403	264	466	–	482	545
	Difference	+26	–	+54	–	+19	+48
Long ambiguous NPs							
NP bias	Ambiguous	458	–	500	718	584	562
	Unambiguous	385	297	473	634	447	539
	Difference	+73	–	+27	+84	+137	+23
S bias	Ambiguous	445	–	512	676	468	548
	Unambiguous	389	316	488	596	422	522
	Difference	+56	–	+24	+80	+46	+26

First Pass Reading Time

First pass reading time on the disambiguating verb was longer for ambiguous than for unambiguous sentences, resulting in a significant main effect of ambiguity, $F_1(1, 23) = 14.71$, $MSe = 3{,}610$, $p < .001$, $F_2(1{,}38) = 4.85$, $MSe = 16{,}510$, $p < .04$. The interaction between type of preceding verb and ambiguity was not significant, $F_1(1{,}23) =$

1.83, $MSe = 6{,}515$, $p < .19$, $F_2 < 1$, indicating that the reading time difference between ambiguous and unambiguous conditions did not vary significantly. The main effect of verb type was significant (by participants), $F_1(1{,}23) = 4.52$, $MSe = 5{,}026$, $p < .05$, $F_2(1{,}38) = 3.57$, $MSe = 15{,}061$, $p < .07$. No other effects or interactions reached significance. In the analyses of first pass reading time on the material following the disambiguating clausal verb (analysis region 7), there were no effects or interactions that reached significance, $Fs < 1$.

First pass reading time on the ambiguous noun (analysis region 4) was influenced by an interaction involving verb type and ambiguity, significant by participants only, $F_1(1{,}23) = 4.91$, $MSe = 4{,}122$, $p < .04$, $F_2(1{,}38) = 2.93$, $MSe = 12{,}243$, $p < .10$. The effect of ambiguity was slightly larger for S-biased verb conditions than for NP-biased verb conditions. No other effects or interactions reached significance, $Fs < 1$. First pass reading time on the modifier was longer for S-biased verb conditions than for NP-biased verb conditions, resulting in a main effect of verb type, significant by participants only, $F_1(1{,}23) = 5.89$, $MSe = 5{,}879$, $p < .03$, $F_2(1{,}38) = 1.64$, $MSe = 24{,}250$, $p < .21$. No other effects or interactions reached significance, $Fs < 1$.

First pass reading time on the matrix verb was longer when it was not followed by a complementizer, resulting in a significant main effect of ambiguity, $F_1(1{,}23) = 9.69$, $MSe = 2{,}349$, $p < .005$, $F_2(1{,}38) = 10.76$, $MSe = 2{,}932$, $p < .001$. This result may have occurred because of word skipping patterns across conditions. When a word is skipped, there can be an increase in reading time on the word fixated immediately before the skipped word (Morrison 1984). When the probability of skipping the complementizer was compared with the probability of skipping the determiner in ambiguous tensed S comp conditions, the difference was highly significant (ambiguous: 75% vs. unambiguous: 49%), $F_1(1{,}23) = 43.88$, $MSe = 718$, $p < .001$, $F_2(1{,}38) = 55.37$, $MSe = 888$, $p < .001$. First pass reading time on the complementizer did not differ significantly across conditions.

Total Reading Time

The reading time difference between ambiguous and unambiguous conditions was larger for NP-biased verb conditions than for S-biased verb conditions; the interaction between verb type and ambiguity was significant by participants only, $F_1(1{,}23) = 6.84$, $MSe = 8{,}077$, $p < .02$, $F_2(1{,}38) = 1.60$, $MSe = 45{,}606$, $p < .21$. The main effect of ambiguity was significant, $F_1(1{,}23) = 27.43$, $MSe = 7{,}807$, $p < .001$, $F_2(1{,}38) = 9.08$, $MSe = 38{,}223$, $p < .005$. The main effect of verb type was significant, $F_1(1{,}23) = 8.00$, $MSe = 14{,}425$, $p < .01$, $F_2(1{,}38) = 6.44$, $MSe = 30{,}534$, $p < .02$. The main effect of NP length was significant by participants, $F_1(1{,}23) = 4.40$, $MSe = 6{,}860$, $p < .05$, $F_2(1{,}38) = 2.95$, $MSe = 19{,}156$, $p < .10$. No other interactions reached significance, $Fs < 1$. On the region following the disambiguating clausal verb, readers took longer to process ambiguous conditions than unambiguous conditions; the main effect of ambiguity was significant by participants, $F_1(1{,}23) = 4.44$, $MSe = 15{,}401$, $p < .05$, $F_2(1{,}38) = 3.20$, $MSe = 29{,}637$, $p < .09$. No other effects or interactions reached significance, $Fs < 1$.

Total reading time on the ambiguous noun (analysis region 4) did not differ significantly across condition, $Fs < 1$. Total reading time on the modifier region was longer for ambiguous than for unambiguous sentences, resulting in a significant main effect of ambiguity, $F_1(1{,}23) = 18.07$, $MSe = 8{,}933$, $p < .001$, $F_2(1{,}38) = 14.19$, $MSe = 18{,}807$, $p < .001$. No other effects or interactions reached significance, $Fs < 1$.

Total reading time on the matrix verb was longer when it was not followed by a complementizer, $F_1(1{,}23) = 26.97$, $MSe = 5{,}374$, $p < .001$, $F_2(1{,}38) = 26.56$, $MSe = 9{,}156$, $p < .001$. These effects of ambiguity appear to differ from those observed in first pass reading

time on the matrix verb, which were attributed to the pattern of skipping the following word. The present effects of complementizer can be directed traced to how often readers made regressive eye movements back to the matrix verb region from a subsequent region of the sentence. This rereading occurred on the matrix verb significantly more often in ambiguous sentences than unambiguous sentences (15.4% vs. 8.8%, respectively), $F_1(1,23) = 10.95$, $MSe = 192$, $p < .003$, $F_2(1,38) = 9.40$, $MSe = 302$, $p < .005$. Total reading time on the complementizer region was longer for sentences containing NP- rather than S-biased verbs, resulting in a significant effect of Verb Type, $F_1(1,17) = 8.90$, $MSe = 6{,}028$, $p < .007$, $F_2(1,38) = 10.46$, $MSe = 9{,}811$, $p < .003$.

Item-by-Item Correlational Analysis

As in Experiment 1, correlational analyses were conducted to explore the relationship between reading time differences involving ambiguous and unambiguous sentence complements observed at the disambiguating verb region (Analysis Region 6) and the *that*-preference and transformed *that*-preference (log(p/1−p)) of specific S-biased verbs. Significant relationships were not found in first pass reading time: $r = .13$, $p > .19$ and $r = .22$, $p > .08$, respectively, but were observed in total reading time, the relationship between transformed *that*-preference and reading time difference (ambiguous versus unambiguous) was significant, $r = .29$, $p < .04$. The similar relationship involving *that*-preference (untransformed) in total reading time was not significant, $r = 19$, $p > .13$. Further analyses indicated that there were also significant relationships between *that*-preference of S-biased verbs and reading time differences difference between ambiguous and unambiguous sentence complements on the determiner-noun region (Analysis Region 4): first pass reading time, $r = .28$, $p < .04$, and total reading time, $r = .31$, $p < .03$. The relationship between transformed *that*-preference and the same reading time differences on Analysis Region 4 failed to reach significance in first pass, $r = .13$, $p > .21$, but was significant in total reading time, $r = .34$, $p < .02$.

Participant-by-Participant Regression Analyses

No significant relationships were observed in either first pass or total reading time at any analysis region, Fs < 1.61, ps $> .21$.

Discussion

The results were consistent with the results of Experiment 1. The only evidence that was obtained supporting Trueswell et al. (1993) conclusion that readers use verb-specific information during the initial analysis of syntactic ambiguities was obtained using the item-by-item correlational analysis. In the analyses using participant-by-participant regressions, no evidence was found that readers used verb-specific *that*-preference information during processing. First pass and total reading time results showed that larger differences between ambiguous and unambiguous conditions were observed for NP-biased verb conditions than S-biased verb conditions; however, interactions involving verb type and ambiguity were not significant. There was no evidence that NP length influenced processing involved in syntactic reanalysis.

General Discussion

The research presented in this paper suggests that the conclusions reached by Trueswell et al. (1993) regarding the role of verb information in syntactic ambiguity resolution must be reconsidered. Although the reading time difference between ambiguous and unambiguous conditions was generally larger for NP-biased verb conditions than S-biased verb conditions, there was little evidence that readers use information about a verb's *that*-preference when reading sentences containing ambiguous S complements. There also was no evidence obtained in the correlational or regression analyses that verb-specific frequency of usage information either with NP or S complements influenced reading time.

The results are most reconcilable with the syntax-first approach to syntactic parsing that presumes that following the construction of the initial analysis, verb information can become available and be used to trigger reanalysis. Because the occurrence of lexically-based reanalysis would be difficult to predict for different items and for different participants, results similar to those observed in the present research would be expected (i.e., no reliable relationships between verb-specific variables and reading time). It could occur for some of the participants for some S-biased items, but not all. It could occur early in the processing of the ambiguous noun or relatively late, just as the disambiguating clausal verb is encountered.

The results appear inconsistent with interactive or constraint-based approaches. If readers indeed use verb information initially to determine the analysis of syntactically ambiguous phrases, then one would expect there to have been a strong relation between verb-specific variables and reading time in experiments reported in the present paper. One caveat is that future research may be able to reveal an explanation for the failure this relationship. Because it is possible that the extent to which competing constraints affect processing may depend on which constraints are applied and the individual strengths of the competing constraints, it is possible that some explanation can be developed.

In sum, the present results showed that the evidence for the early use of verb information in syntactic ambiguity resolution is less convincing than previously claimed. The pattern of processing observed is most consistent with the syntax-first approach to sentence parsing. The research demonstrates why researchers using repeating measures designs involving non-orthogonal variables should avoid using item-by-item correlation to explore the effects of item-specific variables on processing time and look to more appropriate techniques, such as using participant-by-participant regression.

Appendix

The following list includes the sentences used in Experiments 1 and 2. Items 1–20 were created and used by Trueswell et al. (1993). Items 21–40 were created for use in the present research. The verbs are listed with the S-biased and NP-biased verbs separated by a slash, respectively. The material in parentheses was added to items 1–20 for long NP conditions.

(1) The waiter insisted/confirmed that the reservation (of the room) was made by a woman.
(2) The scientist insisted/confirmed that the hypothesis (about HIV) had been studied at NIH.
(3) The chef claimed/remembered that the recipe (from the book) would be expensive to make.
(4) Mr. Smith claimed/remembered that the directions (to the park) were not exactly accurate.

(5) The athlete pretended/revealed that the injury (of his leg) had been very serious.
(6) The attorney hinted/advised that the client (who was guilty) was planning to jump bail.
(7) The professor pretended/revealed that the wounds (on his face) were caused by a student.
(8) The accountant hinted/advised that the executive (from Texas) was cheating on his taxes.
(9) The author boasted/wrote that the novel (about the depression) was likely to be a hit.
(10) The boy wished/accepted that the verdict (that involved his mom) would be decided soon.
(11) The salesman boasted/wrote that the memo (about the raises) was sent by the CEO.
(12) The man wished/accepted that the award (given by the lodge) would go to his brother.
(13) The gardener admitted/maintained that the lawn (behind the school) had not been mowed.
(14) The student hoped/forgot that the solution (to the problem) was provided in the book.
(15) The mechanic admitted/maintained that the motor (from the Mustang) could be repaired.
(16) The woman hoped/forgot that the address (to the store) could be found in the directory.
(17) The apprentice realized/learned that the skill (for the task) could be quite useful.
(18) The teacher implied/recalled that the answer (for the problem) would be complicated.
(19) The spy realized/learned that the dialect (from that region) could be acquired easily.
(20) The poet implied/recalled that the reason (for leaving) had been very unusual.
(21) The speaker concluded/imagined that the voyage (to the Arctic) had been enjoyable.
(22) The secretary indicated/explained that the letter about the incident was sent on Monday.
(23) The woman concluded/imagined that the argument (about the car) had been pointless.
(24) The coach indicated/explained that the scholarship (that was for runners) would cover tuition.
(25) The investigators presumed/observed that the reasons (given by William) had been valid.
(26) The manager suggested/resented that the renovations (of the entrance) would take all year.
(27) The military presumed/observed that the information (about the crime) had been researched.
(28) The director suggested/foresaw that the change (of the costumes) would improve the film.
(29) The doctors assumed/denied that the diagnosis (of the disease) would upset the family.
(30) The journalist insinuated/concealed that the report (about the agency) had been stolen.
(31) The mechanic assumed/denied that the damage (of the new engine) could be repaired.
(32) The instructor insinuated/concealed that the grade (on the final exam) had been very high.
(33) The chemist hypothesized/established that the theory (about light) could be disproved easily.
(34) The agents speculated/verified that the quake (in the region) had occurred in the desert.
(35) Airline experts hypothesized/established that the causes (of the crash) were not human error.
(36) The sheriff speculated/verified that the accusation (about the actor) was not at all true.
(37) The audience suspected/considered that the guest (from Montana) was not being truthful.
(38) The book keeper deduced/debated that the message (about the money) was only a clerical error.
(39) The children suspected/considered that the babysitter (from the agency) had been drinking.
(40) The counselors deduced/debated that the problem (of the teenager) was not very serious.

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