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Processing Coordination Ambiguity

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Abstract

We examined temporarily ambiguous coordination structures such as *put the butter in the bowl and the pan on the towel.* Minimal Attachment predicts that the ambiguous noun phrase *the pan* will be interpreted as a noun-phrase coordination structure because it is syntactically simpler than clausal coordination. Constraint-based theories assume that interpretations are the result of a constraint-satisfaction process, which predicts that frequency or context can bias the parser to initially pursue a more complex interpretation. The results showed an initial preference for noun-phrase coordination, despite the fact that sentential coordination is more frequent in imperative structures. These data suggest that the parser uses a syntactic simplicity heuristic for building initial structural analyses.

Keywords

coordination ambiguity, eye movements, language comprehension, syntactic ambiguity resolution, Visual World Paradigm

Processing coordination ambiguity

One of the primary theoretical questions in psycholinguistics concerns the time course in which the sentence processor integrates different sources of information during online comprehension. Currently, there are two broad categories of processing models. Restricted processing models assume that the parser will build initial analyses based on a limited or restricted amount of information. Unrestricted processing models, in contrast, assume that all relevant sources of information can be consulted immediately, and that parsing proceeds by constructing all possible interpretations in parallel. The Garden Path model is one of the most prominent restricted models, and it assumes that the processor builds initial analyses using a simplicity heuristic based on syntactic information, called Minimal Attachment (Frazier, 1987a). The Constraint-based model is the main unrestricted model, and it assumes that parsing is the result of a constraint-satisfaction

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process. The basic idea is that the sentence processor can exploit probabilistic constraints, such as contextual information or frequency of occurrence to initially prefer a more complex analysis of a temporary ambiguity (MacDonald, Pearlmutter, & Seidenberg, 1994; see also Spivey & Tanenhaus, 1998; Trueswell & Tanenhaus, 1994).

Investigations of syntactic processing using the Visual World Paradigm (VWP) have made extensive use of ambiguities such as *put the apple on the towel in the box* (see Ferreira & Tanenhaus, 2007, for an overview). In this sentence, the ambiguous prepositional phrase *on the towel* can be interpreted as either a location or a modifier. However, the presence of *in the box*, given the appropriate visual context, forces the latter interpretation (Spivey, Tanenhaus, Eberhard, & Sedivy, 2002). The current study investigates a different ambiguity, which arises when two phrases are conjoined, such as *put the butter in the bowl and the pan on the towel*.[1] The noun phrase *the pan* is ambiguous because it can be either a location for the butter or an object to be moved. Up to now, coordination ambiguity has been investigated in just a few reading studies (Frazier, 1987b; Hoeks, Hendriks, Vonk, Brown, & Hagoort, 2006; Hoeks, Vonk, & Schriefers, 2002; Staub, 2007; Staub & Clifton, 2006). In this study, we report an experiment in which spoken versions of such sentences were presented to participants in an active version of the VWP. This paradigm allows participants' actions and eye movements during the task to be recorded, and eye movements to certain objects are thought to reveal participants' interpretations.

Coordination is a procedure that links two sentence elements called conjuncts, and it is very common. Sturt and Lombardo (2005) estimated that over half of all sentences include a conjoined phrase of some sort. Conjoined structures may be globally or temporarily ambiguous because it is grammatically permissible to conjoin any type of constituent as long as the conjuncts are from the same syntactic category (Ross, 1967; cf., Frazier, Munn, & Clifton, 2000). The most extensively studied coordination ambiguity is shown in examples (1) and (2). Notice that the ambiguity depends on whether the noun phrase following the conjunction is part of a complex object like in example (1), or the subject of a conjoined sentence as in example (2).

(1) *Mary bumped into* [$_{NP1}$ *the busboy*] *and* [$_{NP2}$ *the waiter*] *last Saturday night*.
(2) [$_{S1}$ *Mary bumped into the busboy*] *and* [$_{S2}$ *the waiter told her to be careful*].

One early study that focused on the processing of ambiguous coordination structures was conducted by Frazier (1987b). She found slower reading times in Dutch when an ambiguous coordination structure was disambiguated to sentence coordination. This result was argued to show that the parser uses Minimal Attachment to create the initial parse because noun-phrase coordination is syntactically simpler than sentence coordination. Minimal Attachment, therefore, predicts longer processing times for sentence coordination because of the extra steps required to revise the structure to the more complex alternative (see also Ferreira & Clifton, 1986; Frazier & Rayner, 1982).

Previous studies have demonstrated that noun-phrase coordination occurs more often than sentential coordination (Desmet & Gibson, 2003; Gibson & Schutze, 1999). But because the current study tested imperative sentences using the VWP, we felt it was important to examine the frequency with which noun-phrase and sentence coordination occur in main-clause imperative structures. We therefore conducted a corpus search for imperative sentences, which were identified as sentences without overt subjects, and we focused on those that also contained the connective *and*. The Switchboard corpus (Godfrey, Holliman, & McDaniel, 1992) contained only fifteen sentences matching these criteria, too few to make any substantive conclusions.

We then conducted a search of six hours of cooking instruction videos (Ray, 2003), under the assumption that imperatives would be more common in a situation in which one person gives instructions to another on how to perform a specific task. We found 113 sentences matching our criteria, 72% were conjoined sentences, 22% were conjoined noun phrases, 5% were conjoined adjective phrases, and 1% were conjoined prepositional phrases. The results therefore revealed a 3:1 preference for sentential coordination over noun-phrase coordination, which sets up the contrasting prediction: Minimal Attachment predicts a preference for noun-phrase coordination, whereas a frequency-based explanation predicts a preference for sentential coordination (MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994). If we still observe the preference predicted by Minimal Attachment, then we will have evidence that simplicity is preferred even in the face of a frequency bias which should favor sentential coordination.

Participants received instructions of three types, as shown in (3)–(5). An example display for these instructions is shown in Figure 1. The ambiguous sentence coordination (4) is the critical instruction. If participants experience a garden-path (i.e. initially parse the sentence as noun-phrase coordination), then the ambiguous sentence condition should show a similar pattern of fixations as the noun-phrase coordination instruction until the disambiguating prepositional phrase. However, after the disambiguating phrase, the pattern of fixations in the ambiguous sentence condition should change to more closely resemble unambiguous sentence condition.[2]

(3) *Put the frogs in the box and the bowl*. (noun-phrase coordination)
(4) *Put the frogs in the box and the bowl on the towel*. (ambiguous sentence coordination)
(5) *Put the frogs in the box and put the bowl on the towel*. (unambiguous sentence coordination)

In previous VWP studies, when participants heard an instruction such as *put the apple on the towel in the box*, there was a tendency to fixate an empty towel shortly after hearing the ambiguous prepositional phrase when the display contained one apple (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). These early saccades were interpreted as revealing participants' initial interpretation, that is, as a measure of garden-pathing. In the current study, we make similar predictions based on two sets of findings. The first is that listeners will make predictable fixations to objects in a display as they hear words corresponding to objects in view (Cooper, 1974). The second is that there is robust coupling between ocular gaze, and planned or ongoing hand movements related to pointing or grabbing (Land, Mennie, & Rusted, 1999; Neggers & Bekkering, 1999, 2000; Pelz, Hayhoe, & Loeber, 2001).

The predicted scan paths for instructions (3) and (5) are shown in Figures 1 and 2. In these figures, we predict two types of fixations. Numbered fixations that are represented with an eyeball show eye movements made in response to hearing a word, and fixations related to carrying out the instructions are represented with a hand. The approximate time course for fixations made during and immediately after the instruction is represented at the bottom of each figure. In Figure 1 (i.e., noun-phrase coordination), we expect participants to fixate the objects as they hear words corresponding to those objects, and afterwards to return to the first named object in order to carry out the instruction. The results from the behavioral experiment showed that on the majority of trials (76%), participants divided the frogs between both goal locations. On the

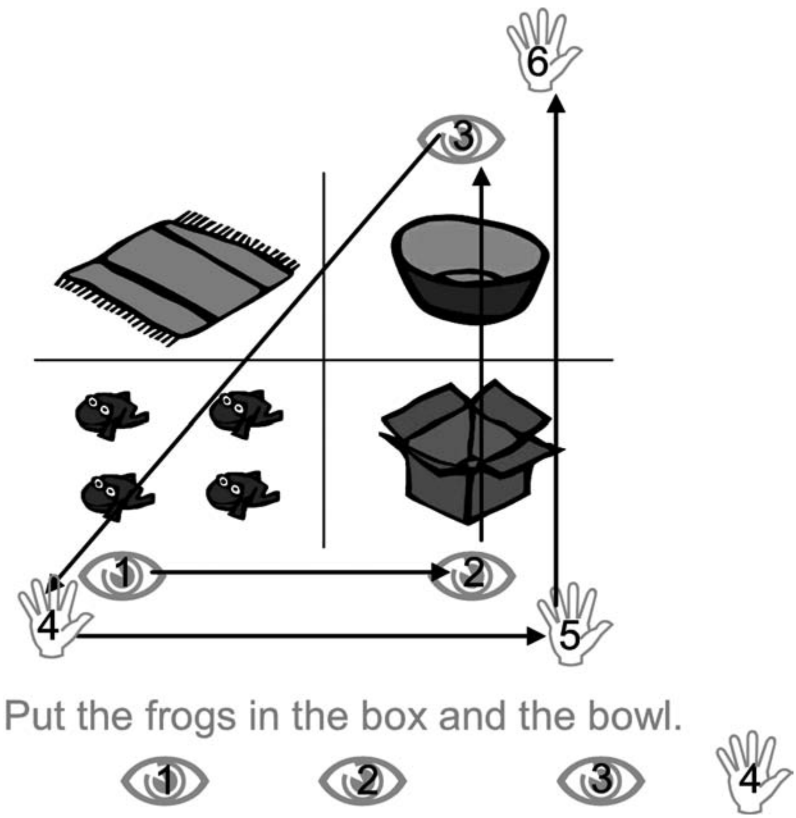

Figure 1. Predicted scan path for noun-phrase coordination

remaining trials, participants placed all of the target objects in the first goal, and then placed the first goal inside the second goal. In Figure 2 (i.e., unambiguous sentence coordination), we expect the second verb *put* will immediately signal that *the bowl* is an object that has to be moved. The unambiguous instruction should therefore draw participants' attention to *the bowl* and subsequently to *the towel*.

If the ambiguous sentence condition (4) is initially interpreted as noun-phrase coordination, then we expect more shifts of attention or a higher probability of fixating *the frogs* during or shortly after the ambiguous noun phrase (i.e., *the bowl*), if participants are indeed preparing to move the frogs. Critically, if participants are garden-pathed with ambiguous sentence instruction, then the probability of fixating the frogs should be high and similar to the rate observed with the noun-phrase coordination condition. In the unambiguous sentence condition, the rate of fixating the frogs should be substantially lower. However, once the disambiguating prepositional phrase is heard in the ambiguous condition, then attention and fixations should be drawn to *the bowl* and/or *the towel* at a similar rate as in the unambiguous sentence condition.

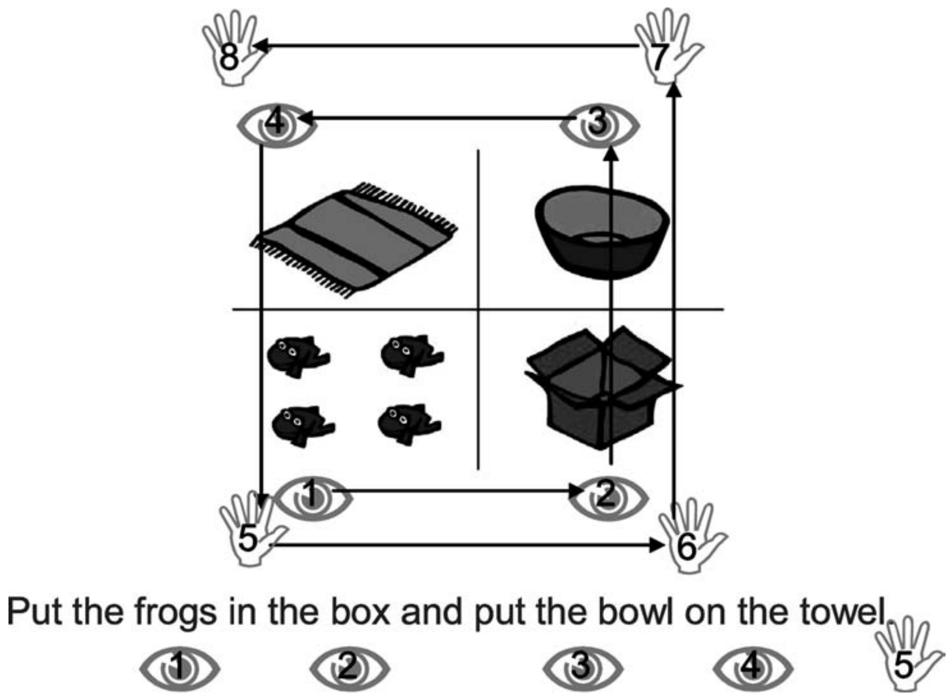

Figure 2. Predicted scan path for unambiguous sentence coordination

Method

Participants

Twenty-one participants from the undergraduate subject pool at Michigan State University participated for course credit. Participants were native speakers of English and had normal or corrected-to-normal vision. Three participants were excluded from the analysis because they adopted an unusual response strategy during the task. Three additional participants were run so that seven subjects completed each list.

Materials

We created a total of 33 visual displays: Three were for practice, 15 were experimental items, and 15 were fillers. For all of the critical displays, objects had an equal probability of appearing in any of the four quadrants, and no constraints were placed on the direction of movement. Experimental trials always consisted of four "target" objects, two locations that should be described as "in", and one location that should be described as "on" (see Table 1 for a list of all possible objects). Filler trials contained a variable number of target and location objects.

Two versions of each experimental utterance were recorded by a female native speaker of English, who was naïve to the design of the experiment and who uttered the sentences in a natural

Table 1. Objects used in VWP experiment

Target objects	"in" destinations	"on" destinations
bat	basket	felt
brush	bowl	glove
candle	box	napkin
car	flower pot	sock
dinosaur	mug	sponge
frog	pan	towel
jeep		
lizard		
plane		
pencil		
golf ball		
soldier		
marker		
battery		
whistle		

manner (see examples 5 & 6). The utterances were then digitized using Computerized Speech Laboratory (Kay Elemetrics), and converted to .wav format. The ambiguous instruction (4) was created by digitally excising the second verb (*put*) and the pause following *put* from the unambiguous instruction (5). This ensured that on average the pause from the offset of *and* to the onset of the next word was roughly equal in both sentence coordination instructions (unambiguous 65 ms vs. ambiguous 83 ms). The noun-phrase coordination instruction was created from a separate utterance like example (6), and *put the towel in* was digitally removed. We constructed the noun-phrase coordination instruction in this way for two reasons. The first was so that all of the instructions had the prosodic features of sentence coordination up to the connective *and*. The second reason was so that the final noun phrase had normal declination and lengthening. The average pause from the offset of *and* to the onset of *the* in this condition was 61 ms. Acoustic measurements of the experimental stimuli are presented in Table 2.

(6) Put the frogs in the box and put the towel in the bowl.

For the acoustic analysis, we examined four separate regions (see Figures 3–5). The first corresponded to the initial portion of the utterance (e.g., *Put the frogs in the box*). The second corresponded to the connective *and*. The third region was only a comparison between the two sentence coordination instructions, and was from the onset of the third determiner to the offset of the utterance (e.g., *the bowl in the towel*). The fourth region was the final noun phrase (e.g., *the towel* or *the bowl*).

The results from a series of t-tests showed that there were no significant acoustic differences, all p's > .50, between the two sentence coordination instructions. In contrast, the comparison between the ambiguous sentence condition and the noun-phrase coordination condition showed several differences (see bold numbers in Table 2). The noun-phrase coordination had higher pitch than the ambiguous sentence condition during the initial portion of the utterance, $t(28) = 6.79$, $p < .01$. During the connective *and*, the noun-phrase coordination instruction had longer duration, $t(28) = 2.22$, $p < .05$, higher pitch, $t(28) = 2.66$, $p < .05$, and greater intensity,

Table 2. Mean duration (ms), pitch (Hz), and intensity (db) for the three conditions of the experiment. Standard deviations are in parentheses

	Duration	F0	Intensity
Put the frogs in the box			
Unambiguous S	1492 (151)	211 (12)	65 (2)
Ambiguous S	1502 (140)	**209 (11)**	66 (2)
NP coordination	1443 (177)	**249 (20)**	67 (2)
and			
Unambiguous S	102 (20)	155 (32)	59 (4)
Ambiguous S	**102 (21)**	**151 (34)**	**59 (4)**
NP coordination	**125 (34)**	**174 (6)**	**63 (3)**
the bowl in the towel			
Unambiguous S	1275 (126)	166 (8)	61 (3)
Ambiguous S	1283 (144)	165 (10)	62 (3)
the towel/the bowl			
Unambiguous S	635 (118)	158 (13)	58 (2)
Ambiguous S	639 (112)	158 (14)	59 (3)
NP coordination	603 (95)	162 (11)	60 (2)

Note. Numbers in bold show significant differences between the adjacent pairs of means.

$t(28) = 3.95$, $p < .01$. There were no differences between any of the conditions during the final noun phrase.

Each participant was run through three practice trials, 15 experimental trials, and 15 filler trials. Three lists were constructed, so that for each experimental visual display, all three experimental instructions were created. Each visual display appeared only once per list and lists were counterbalanced so that one-third of experimental trials were paired with each instruction type. Participants were randomly assigned to one of the three lists, with seven participants completing each list.

Apparatus

Eye movements were recorded using an ISCAN model ETL-500 head mounted eye tracker (ISCAN, Inc.). Subjects were able to view 103 degrees of visual angle horizontally and 64 degrees vertically. The eye tracker consists of two cameras, both attached to a visor. The left eye was sampled at 60 Hz. Both video streams were recorded using a Sony Digital 8. The merged video was digitized at 30 Hz using a Sony Mini-DV recorder. The pre-recorded audio files were played to participants using Superlab Pro (Cedrus Corp.), and hand coding of the data was performed from the onset of the word *put* to the time at which the participant finished moving the objects.

Design and procedure

The design consisted of a single variable, instruction type, with three levels: noun-phrase coordination, ambiguous sentence coordination, and unambiguous sentence coordination. Prior to the experiment, participants were shown all of the objects that would be used and told the names of each (see Table 1). The eye tracker was fitted onto the participant and calibrated, after which three practice trials were completed in order to familiarize the participant with the procedure.

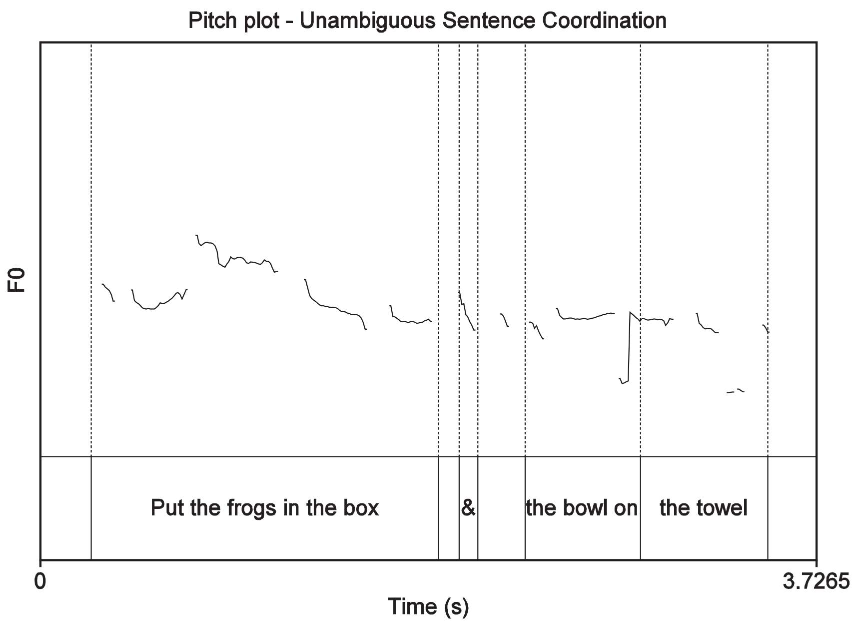

Figure 3. Example pitch plot for the unambiguous sentence condition

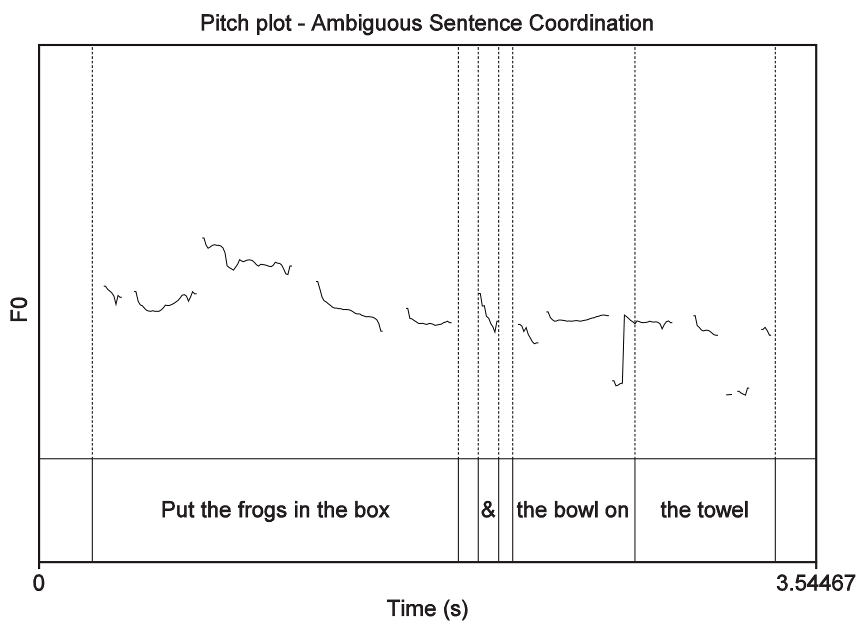

Figure 4. Example pitch plot for the ambiguous sentence condition

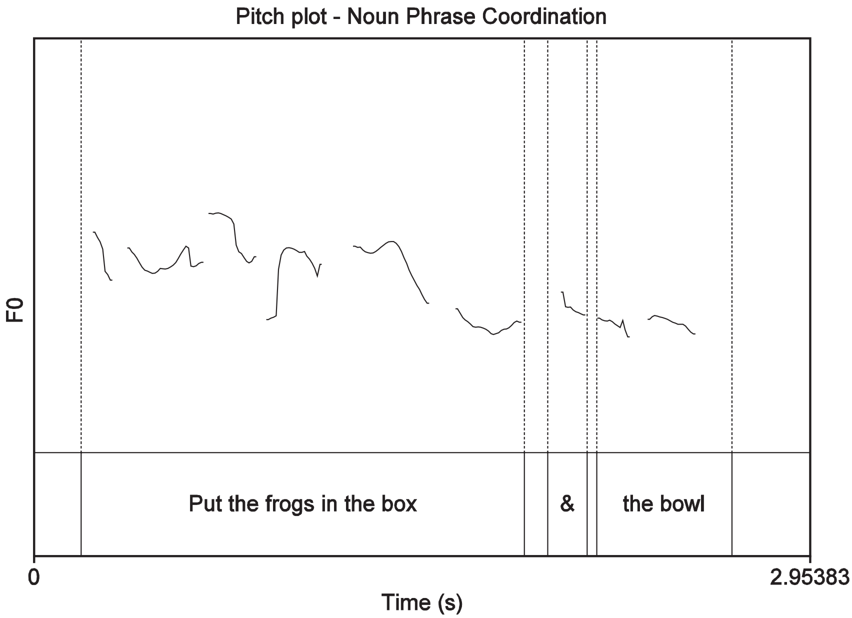

Figure 5. Example pitch plot for the noun-phrase coordination condition

Participants were allowed to view each display as it was being set up, so they had several seconds in which to view all objects and locations before the instructions began. Three instructions occurred on each trial, as in the relevant previous studies (Engelhardt, Bailey, & Ferreira, 2006; Spivey et al., 2002; Tanenhaus et al., 1995). The critical instruction was always first and the subsequent two were fillers. Participants performed the task while standing up and objects were located on a table at a comfortable height in front of them. Participants were tested individually, and the entire session lasted approximately 30 minutes.

Results

We analyzed time segments corresponding to words, beginning with the ambiguous noun (e.g., *bowl*). For all of the following results, we focus on the differences in the looks to the frogs because this is the region of the display where the garden-path effect was predicted to occur, and was based on subjects' anticipation to move the frogs. Time windows for the analysis were identified by aligning utterances on a word-by-word and trial-by-trial basis (Altmann & Kamide, 2004).

The time windows corresponding to words were shifted forward by 150 ms to account for the time necessary to plan a saccade (Altmann & Kamide, 2004). For each trial, we determined whether there was a fixation to the frogs during one of the time windows. Our dependent variable was therefore binomial, and so we utilized a mixed logit model for the analysis (Jaeger, 2008). Mixed effects modeling has been advocated as a superior data analysis technique because it allows for multiple random factors, and handles missing data better than standard ANOVAs (Baayen, Davidson, & Bates, 2008). In this analysis, we included both subjects and items as random factors, as well as the length of the time window as a covariate. We included the latter variable because the final noun in the noun-phrase coordination instruction was slightly longer than in the other two conditions. Therefore, it was important to control for differences in the length of this time window.

To analyze each time window, we first created a model to serve as the baseline. This model contains an intercept and the three random factors. This model was then compared to a second model that included a bivariate within subject's factor comparing the ambiguous sentence coordination condition to either the noun-phrase coordination condition or the unambiguous sentence coordination condition. If the inclusion of the within subject's factor significantly improves fit over the baseline model, then we can conclude that the "instruction type" factor captures a significant amount of variation in the data. We assessed model improvement via log-likelihood ratio tests using the R statistical package (Bates, Maechler, & Dai, 2008). This test compares models using a χ^2 test which determines whether an additional predictor significantly improves model fit. In cases where a predictor significantly improved fit, the Wald statistic was used to show that coefficients differed significantly from zero (Agresti, 2002).

We began by comparing the noun-phrase coordination condition to the ambiguous sentence condition. During the ambiguous noun (e.g., *bowl*), we observed no improvement over the baseline with the inclusion of instruction type, $\chi^2(1) = 0.77$, $p > .35$. The resulting model had a log-likelihood of −118.0. The coefficients are provided in Table 3, and the data for proportion of trials with a fixation to the frogs are provided in Figure 6. For the comparison between the two sentence coordination instructions, also shown in Table 3, we observed a significantly improved fit over the baseline by the inclusion of instruction type in the model, $\chi^2(1) = 6.40$, $p < .01$. The resulting model had a log-likelihood of −129.0. These results show that during the ambiguous noun there was essentially no difference between the noun-phrase and ambiguous sentence conditions, but there was a significant difference between the two sentence coordination instructions. This pattern of results suggests that the ambiguous noun phrase was initially parsed as noun-phrase coordination, which is consistent with the predictions of Minimal Attachment.

Table 3. Coefficients, standard errors, and *p*-values for the critical time window

Predictor	Mixed logit analysis	
	Coefficient	Std. error
NP vs. S		
Intercept	0.859	0.322
Instruction	0.347	0.383
S vs. S		
Intercept	−0.0437	0.3016
Instruction	0.8953***	0.3115

Note. *$p < .05$, **$p < .01$, ***$p < .001$.

We then examined the three words in the disambiguating prepositional phrase. Here we only compared the two sentence coordination conditions. The results, however, showed that there were no significant differences during any of these three words. As can be seen in Figure 6, the same trend from the ambiguous noun carries over to the preposition (i.e., ambiguous higher than unambiguous), but the pattern reverses during the determiner. Finally, the two instructions are almost identical during the final noun. We return to this issue, and present several possible reasons for the lack of differences between the instructions at the disambiguating region, in the General Discussion.

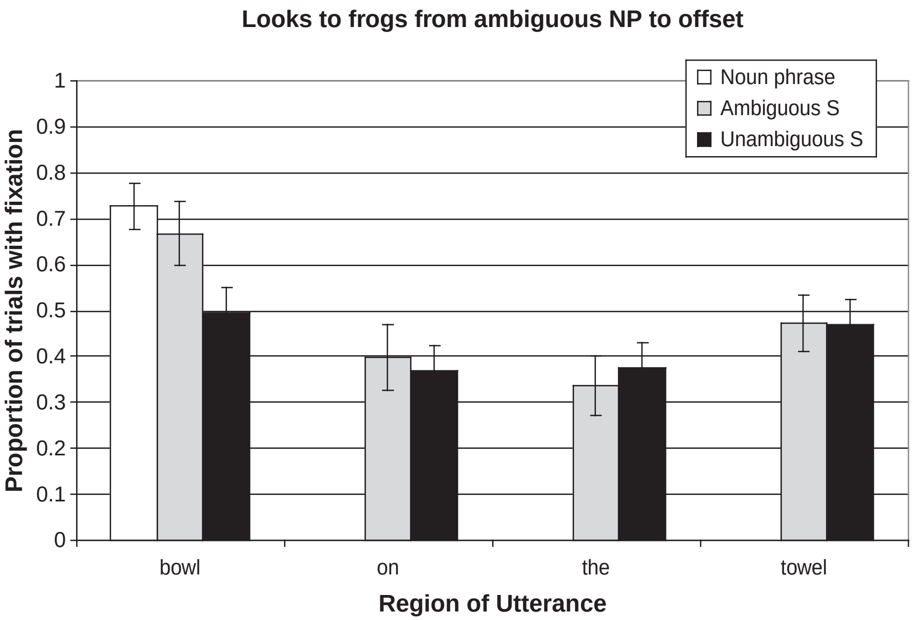

Figure 6. Proportion of trials with fixation to the frogs during the ambiguous NP and the disambiguating prepositional phrase

Three other data points are worth mentioning here. The first is that there were no differences in looks to the frogs between any of the three instructions prior to the word *and*. The second is that there were more looks to the bowl (.54 vs. .34) during the critical time region with the unambiguous sentence instruction compared to the ambiguous sentence instruction, $\chi^2(1) = 6.78$, $p < .01$. Therefore, during the ambiguous noun there were more looks to the frogs in the ambiguous sentence condition, and more looks to the bowl in the unambiguous sentence condition, which is consistent with predictions (see Figure 7, panel A). The final point is that there was no difference between the two sentence coordination instructions in looks to towel as the word referring to that object was heard (see Figure 7, panel B). Again there is a high degree of similarity between the two sentence coordination instructions in the post-disambiguation region.

Discussion

This experiment revealed a preference for noun-phrase coordination. This result is noteworthy because there was one factor, and possibly two, that should have worked against the noun-phrase coordination interpretation. The first is frequency. Our corpus analysis focusing on imperative structures revealed that sentence coordinations were nearly three times more common than noun-phrase coordinations, so experience should bias toward the sentence coordination interpretation. The second potential bias against noun-phrase coordination is prosody: because of the way the materials were created, the ambiguous sentence instruction had the prosodic features of sentence coordination, and this information, to the extent that it exists, was available to inform parsing decisions even before the connective *and* was heard. Nevertheless, we observed a high degree of similarity between the noun-phrase coordination instruction and the ambiguous sentence instruction, suggesting that both were processed similarly up to the point of disambiguation.

There were two rather unexpected results. The first was a relatively high probability of fixating the frogs with the unambiguous sentence instruction. We do not view this result as evidence that participants were garden-pathed half of the time with the unambiguous instruction, as there is no linguistic basis for a garden-path interpretation. Instead, we assume that saccades and fixations are linked to both visual as well as linguistic processing, and the visual complexity of the frogs might have made them objects of interest to the visual system, thus triggering saccades to them. In reality, the scan paths shown in Figures 1 and 2 occur on less than one-third of trials, suggesting that saccades are caused by factors other than word recognition, motor planning, and syntactic processing. The second unexpected finding was that the garden-path effect was observed only through the ambiguous noun phrase. Frazier (1987b), in contrast, showed longer reading times for the disambiguating verb in the second clause of a Dutch sentence like *Peter kissed Mary and her sister laughed* (translated); however, in her study, the second verb was also the last word of the sentence, which contaminates disambiguation with sentence final wrap-up effects. Hoeks et al. (2002) also reported different reading times for the second verb in their reading study. However, we found no differences between the ambiguous and unambiguous sentence instructions during the disambiguating prepositional phrase.

We think there are three possible explanations that can account for the early recovery from the garden path in our experiment. First, coordination is a weak ambiguity compared with other types of garden paths (Bailey & Ferreira, 2003; Fodor & Inoue, 1998; cf., Staub & Clifton, 2006), and therefore the processing system may recover more easily (i.e., earlier) from the misanalysis. Second, it is possible that the prosody of our stimuli signaled sentence coordination, allowing revision to occur simultaneously with the disambiguating lexical information. Finally, the frequency bias in favor of sentence coordinations with imperative structures might have also weakened the garden path; however, we think this possibility is unlikely given the clear pattern of results at the ambiguous noun.

Recall that the frequency bias in favor of sentence coordination with imperative structures set up the contrasting theoretical prediction tested in this study. Minimal Attachment predicts that noun-phrase coordination should be preferred because it is syntactically simpler than sentence coordination. The Constraint-based Model, in contrast, assumes that comprehension preferences follow from experience with language. More specifically, the assumption is that the processor is sensitive to statistical regularities, which emerge probabilistically from one's past exposure to language. However, when we combine our corpus data with the results from the VWP experiment, we can only conclude that this assumption is not supported by the data (see Pickering, Traxler, &

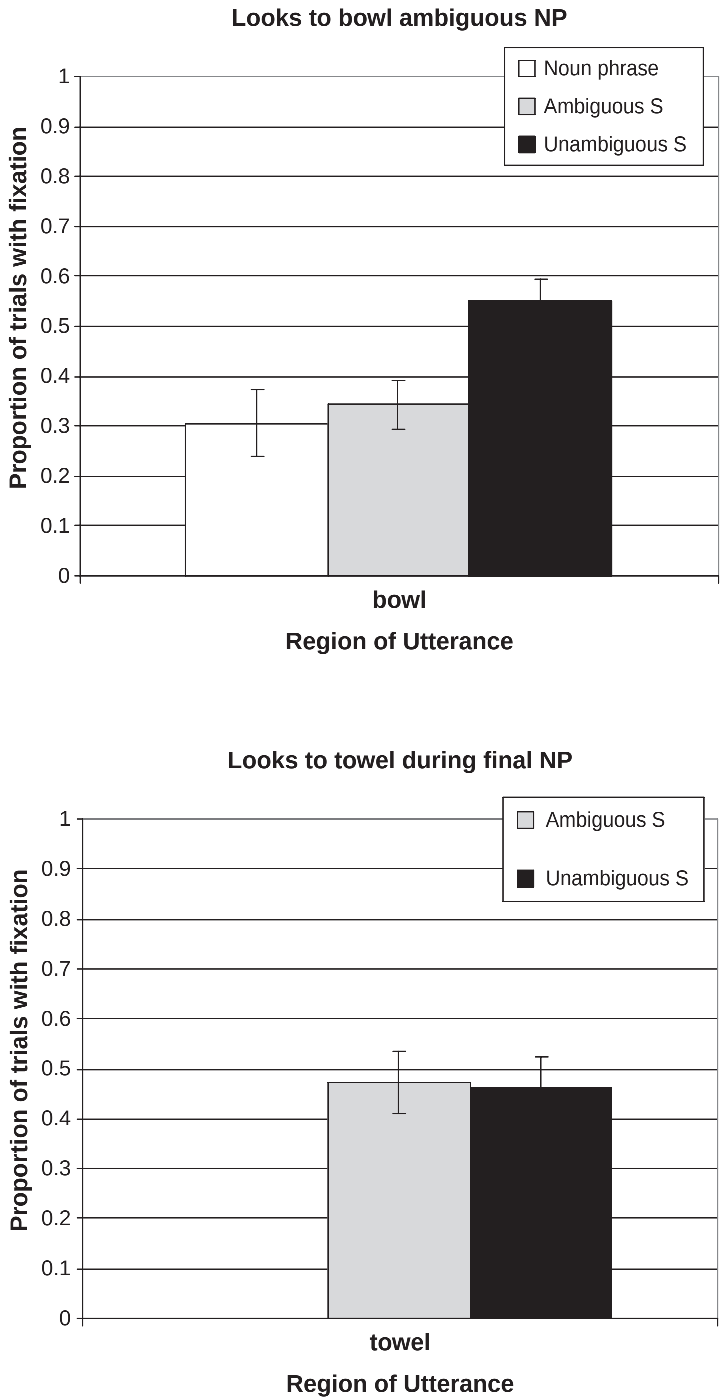

Figure 7. Proportion of trials with fixation—panel A shows looks to the bowl during the ambiguous noun (e.g., bowl), and panel B shows looks to the towel during the final noun (e.g., towel)

Crocker, 2000, for a similar result concerning verb argument structure frequencies). There is one open issue with this conclusion: the two previous corpus searches showed the opposite pattern, that is, noun-phrase coordination was more common than sentence coordination (Desmet & Gibson, 2003; Gibson & Schutze, 1999). It could be the case that noun-phrase coordination is more common when collapsing over all sentence types: declaratives, imperatives, interrogatives, etc. If so, then our results might be accommodated by a processing model that specifically relies on coarse-grained frequency counts (e.g., Mitchell, Cuetos, Corley, & Brysbaert, 1995). Alternatively, it is possible that the domains of discourse which encourage imperative structures are more likely to involve coordination of events rather than objects, as might be expected in instructional contexts. This is an intriguing possibility for future studies of frequency effects on parsing.

The results of the current experiment present a clear picture regarding the processing of ambiguous coordination structures. The VWP experiment showed that an ambiguous coordination structure was initially interpreted as noun-phrase coordination, consistent with the predictions of Minimal Attachment. These results are not consistent with constraint-satisfaction models, which assume that probabilistic constraints based on frequency guide initial parsing decisions (MacDonald & Seidenberg, 2006; Spivey & Tanenhaus, 1998; Trueswell & Tanenhaus, 1994). In this case, the data allow us to rule out unrestricted processing models which rely on fine-grained frequency counts to determine parsing preferences. Instead, the data favor the use of a simplicity heuristic, such as Minimal Attachment, or an architecture which relies on coarse-grained frequency.

Notes

1 This sentence is globally ambiguous because the noun phrase following the conjunction can be either a location (NP coordination) or an object that must be moved (sentence coordination). If it is the former, then *on the towel* must be a modifier denoting which pan the butter must be placed into. However, if the context contains only a single pan, which is not on a towel, then the instruction is only temporarily ambiguous. In this case, the pan is an object that must be moved onto the towel. The experiment reported in this study used such a context as the basis for making this type of instruction temporarily ambiguous.

2 We assume that the frogs are processed as a collective for two reasons. First, all of the objects were highly similar in physical appearance. Second, for all of the critical trials there was a collection of objects in one quadrant of the display. So the objects themselves are homogenous, and their location in the display suggests that they should be treated similarly.

References

AGRESTI, A. (2002). *Categorical data analysis*. Hoboken, NJ: Wiley.

ALTMANN, G. T., & KAMIDE, Y. (2004). Now you see it, now you don’t: Mediating the mapping between language and the visual world. In J. M. Henderson & F. Ferreira (Eds.), *The interface of language, vision, and action* (pp.347–386). New York: Psychology Press.

BAAYEN, R. H., DAVIDSON, D. J., & BATES, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, **59**, 413–425.

BAILEY, K. G. D., & FERREIRA, F. (2003). Disfluencies affect the parsing of garden-path sentences. *Journal of Memory and Language*, **49**, 183–200.

BATES, D., MAECHLER, M., & DAI, B. (2008). Lme4: Linear mixed-effects models using S4 classes [Computer software manual]. Available from http://lme4.r-forge.r-project.org/

COOPER, R. M. (1974). The control of eye fixation by the meaning of spoken language. *Cognitive Psychology*, **6**, 84–107.

DESMET, T., & GIBSON, E. (2003). Disambiguation preferences and corpus frequencies in noun phrase conjunction. *Journal of Memory and Language*, **49**, 353–374.

ENGELHARDT, P. E., BAILEY, K. G. D., & FERREIRA, F. (2006). Do speakers and listeners observe the Gricean maxim of quantity? *Journal of Memory and Language*, **54**, 554–573.

FERREIRA, F., & CLIFTON, C. (1986). The independence of syntactic processing. *Journal of Memory and Language*, **25**, 348–368.

FERREIRA, F., & TANENHAUS, M. (2007). Introduction to the special issue on language–vision interactions. *Journal of Memory and Language*, **57**, 455–459.

FODOR, J. D., & INOUE, A. (1998). Attach anyway. In J. D. Fodor & F. Ferreira (Eds.), *Reanalysis in sentence processing* (pp.101–141). Dordrecht: Kluwer.

FRAZIER, L. (1987a). Sentence processing: A tutorial review. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp.601–681). Hillsdale, NJ: Erlbaum.

FRAZIER, L. (1987b). Syntactic processing: Evidence from Dutch. *Natural Language and Linguistic Theory*, **5**, 519–559.

FRAZIER, L., MUNN, A., & CLIFTON, C. (2000). Processing coordinate structures. *Journal of Psycholinguistic Research*, **29**, 343–370.

FRAZIER, L., & RAYNER, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology*, **14**, 178–210.

GIBSON, E., & SCHUTZE, C. T. (1999). Disambiguation preferences in noun phrase conjunction do not mirror corpus frequency. *Journal of Memory and Language*, **40**, 263–279.

GODFREY, J. J., HOLLIMAN, E. C., & McDANIEL, J. (1992). SWITCHBOARD: Telephone speech corpus for research and development. *Proceedings of the International Conference of Acoustical Speech Processing*, ICASSP-92, vol. 1, pp.517–520.

HOEKS, J. C. J., HENDRIKS, P., VONK, W., BROWN, C. M., & HAGOORT, P. (2006). Processing the NP- versus S-coordination ambiguity: Thematic information does not completely eliminate processing difficulty. *Quarterly Journal of Experimental Psychology*, **59**, 1581–1599.

HOEKS, J. C. J., VONK, W., & SCHRIEFERS, H. (2002). Processing coordinated structures in context: The effect of topic-structure on ambiguity resolution. *Journal of Memory and Language*, **46**, 99–119.

JAEGER, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language*, **59**, 434–446.

LAND, M., MENNIE, N., & RUSTED, J. (1999). The roles of vision and eye movements in the control of activities of daily living. *Perception*, **28**, 1311–1328.

MacDONALD, M. C., PEARLMUTTER, N. J., & SEIDENBERG, M. S. (1994). Lexical nature of syntactic ambiguity resolution. *Psychological Review*, **101**, 676–703.

MacDONALD, M. C., & SEIDENBERG, M. S. (2006). Constraint satisfaction accounts of lexical and sentence comprehension. In M. J. Traxler & M. A. Gernsbacher (Eds.), *Handbook of Psycholinguistics* (2nd ed.) (pp.581–611). London: Elsevier Inc.

MITCHELL, D. C., CUETOS, F., CORLEY, M. M. B., & BRYSBAERT, M. (1995). Exposure-based models of human parsing: Evidence for the use of coarse-grained (non-lexical) statistical records. *Journal of Psycholinguistic Research*, **24**, 469–487.

NEGGERS, S. F. W., & BEKKERING, H. (1999). Integration of visual and somatosensory target information in goal-directed eye and arm movements. *Experimental Brain Research*, **125**, 97–107.

NEGGERS, S. F. W., & BEKKERING, H. (2000). Ocular gaze is anchored to the target of an ongoing pointing movement. *Journal of Neurophysiology*, **83**, 639–651.

PELZ, J., HAYHOE, M., & LOEBER, R. (2001). The coordination of eye, head, and hand movements in a natural task. *Experimental Brain Research*, **139**, 266–277.

PICKERING, M. J., TRAXLER, M. J., & CROCKER, M. W. (2000). Ambiguity resolution in sentence processing: Evidence against frequency-based accounts. *Journal of Memory and Language*, **43**, 447–475.

RAY, R. (Writer). (2003). Thirty minute meals with Rachel Ray [Television series episode: A little spice is nice, Fast and Light, & Fasta Pasta]. In Television Food Network.

ROSS, J. R. (1967). *Constraints on variables in syntax*. PhD dissertation MIT.

SPIVEY, M. J., & TANENHAUS, M. K. (1998). Syntactic ambiguity resolution in discourse: Modelling the effects of referential context and lexical frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **24**, 1521–1543.

SPIVEY, M. J., TANENHAUS, M. K., EBERHARD, K. M., & SEDIVY, J. C. (2002). Eye movements and spoken language comprehension: Effects of visual context on syntactic ambiguity resolution. *Cognitive Psychology*, **45**, 447–481.

STAUB, A. (2007). The parser doesn't ignore intransitivity, after all. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **33**, 550–569.

STAUB, A., & CLIFTON, C., JR. (2006). Syntactic prediction in language comprehension: Evidence from *either…or*. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **32**, 425–436.

STURT, P., & LOMBARDO, V. (2005). Processing coordinate structures: Incrementality and connectedness. *Cognitive Science*, **29**, 291–305.

TANENHAUS, M. K., SPIVEY-KNOWLTON, M. J., EBERHARD, K. M., & SEDIVY, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science*, **268**, 1632–1634.

TRUESWELL, J. C., & TANENHAUS, M. K. (1994). Toward a lexicalist framework for constraint-based syntactic ambiguity resolution. In C. Clifton, L. Frazier, & K. Rayner (Eds.), *Perspectives in Sentence Processing* (pp.155–179). Hillsdale, NJ: Lawrence Erlbaum Assoc.