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Structural priming among prepositional phrases: Evidence from eye movements

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This experiment was designed to determine whether prepositional phrases are treated as a single undifferentiated type, or whether the parser may recognize different subtypes. In the experiment, participants read temporarily ambiguous prime and target sentences that had either *agent* or *instrument* prepositional phrases in the syntactically disambiguating position. Agent and instrument primes both led to significant priming effects for agent targets. Agent primes led to a nonsignificant priming effect for instrument targets, and this priming effect was smaller than the effect that instrument primes had on instrument targets. This pattern can be explained if verb argument structure information is used in structural decisions, and if agent but not instrument roles are obligatory for the class of verbs tested here. The data suggest that readers are likely to activate an implicit agent when they read prime sentences that explicitly mention an instrument, but are not likely to activate an instrument when they read prime sentences that explicitly mention an agent. If the structural representations that incorporate activated arguments persist, or are reactivated more quickly following an appropriate prime sentence, this could lead to facilitated processing of sentences that have the same structural configuration.

Two general questions are addressed in this article:

1. How do comprehenders represent syntactic structure information?

2. How is that information accessed and used in real time as incoming sentences are parsed and interpreted?

Autonomous syntax models of parsing propose treating words as belonging to one of several categories, such as *noun*, *verb*, *adjective*, *determiner*, and so forth. To parse a sentence, comprehenders identify the category that each word belongs to and then apply heuristic processes to determine how words in sentences relate to one another (e.g., Chomsky, 1965; Frazier, 1979; Frazier & Rayner, 1982; Rayner, Carlson, & Frazier, 1983; see Jackendoff, 2002, for a review). The overall system of heuristics minimizes the mental effort required to structure sentences. From this point of view, syntax is an autonomous level of representation connected to, but separate from, lexical access (at a lower level) and sense-semantics, reference, and situation models (at higher levels). By contrast, *constraint-based lexicalist* accounts propose that syntactic structure information is tied to individual lexical representations (e.g., Ford, Bresnan, & Kaplan, 1982; Jurafsky, 1996; MacDonald, Pearlmutter, & Seidenberg, 1994; Taraban & McClelland, 1988). In this kind of architecture, phonological, semantic, lexical, syntactic, and discourse processing are viewed as highly interactive aspects of a unified system. Interpretation is a function of patterns of activation within and across a variety of subprocessors, with the system eventually adopting interpretations that lead to stable patterns of activation across the entire system. Within this kind of architecture, activating the lexical representation of an individual word feeds activation to syntactic representations that have been tied to that individual word on the basis of the comprehender's prior experience with the language (activating the lexical representation of a word also affects the activity of other groups of processing units representing other aspects of the input).

Although the autonomous syntax and lexicalist viewpoints have some common characteristics (e.g., both of them describe syntactic representations in terms of phrase structure trees; see Frazier, 1987; MacDonald et al., 1994), they make different claims about how syntactic ambiguity is resolved, because they describe fundamentally different processing architectures. For example, autonomous syntax accounts propose that nongrammatical information—such as animacy or semantic fit with the established discourse representation—influences the choice of syntactic analysis only after an initial structure has been built and evaluated with respect to syntax-internal considerations (i.e., "Is this structure possible in the language?"); lexicalist models propose that individual word characteristics can influence the activation of syntactic alternatives from the earliest possible moment. A comprehensive treatment of autonomous syntax versus constraint-based lexicalist parsing is beyond the scope of this article, which will focus on one issue that needs to be resolved whichever parsing model one prefers: the *grain size* problem (Mitchell, Cuetos, Corley, & Brysbaert, 1995; see also Cuetos & Mitchell, 1988; Mitchell, 1987). The grain size problem arises because, in a lexicalist system, syntactic structure

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activations are tied to specific lexical entries, but (1) those lexical entries can be organized in a number of different ways, and (2) separate probability statistics can be kept at different levels of abstraction. This article will not address (2), but will try to begin solving (1).

For example, any given verb can have a variety of forms. The concept "walking" can be expressed in a simple past tense verb (*He walked* . . .), past progressive (. . . *was walking* . . .), a number of modals (. . . *could have walked*, *might walk*, *should be walking*), future tense (*will walk*), future perfect (. . . *will have walked* . . .), and so on. The likelihood of a subject–verb structure, as opposed to a subject–verb–object structure, could differ substantially across forms, so comprehenders might anticipate an intransitive continuation more robustly for *He was walking* (which might continue with *this morning*) than for *He walked* (which might continue with *the dog*). In fact, some evidence does suggest that different verbs with different subcategory preferences elicit different patterns of response when they are embedded in ambiguous contexts (Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Traxler, 2002, 2005; Trueswell, Tanenhaus, & Kello, 1993). It is still not entirely certain whether such effects occur before or after an initial structural hypothesis has been formed.

If we are to develop a model where syntactic representations are tied to lexical entries, it is critical to determine how those lexical entries are organized. In the preceding example, the lexical entries could be organized such that all of the different versions of *walk* have the same base entry, different surface forms are generated by undertaking morphological composition (e.g., Badecker & Caramazza, 1991; Clahsen, 1999; Rastle, Davis, Marslen-Wilson, & Tyler, 2000), and the same pattern of structural activation occurs no matter what surface form is present (because the underlying lexical representation would have only a single set of links to syntactic structure representations). By contrast, each of the different surface forms could have its own lexical entry, in which case the pattern of structural activations could differ depending on which surface form appeared in the input.

Different kinds of hybrid models are also possible. For example, one could compute probabilities for each of the surface forms, as well as an overall set of probabilities for the base form. These two sets of probabilities could be supplemented by language-level statistics: How often do different configurations of arguments or structures occur across all verbs in language? Different weights could be assigned to each of these probabilities, and different patterns of weightings would produce different patterns of behavior in the system. For example, a system that weighted language-level probabilities more heavily than surface form probabilities would behave more like a *garden-path* parser that ignores surface form probabilities altogether in favor of simplicity metrics (Frazier, 1979). Being able to weight probabilities at different levels of abstraction introduces a free parameter into probabilistic models that makes them difficult to test using standard psychometric methods—for example, reaction time (RT) tasks or eyetracking. How then might one attempt to discover how lexical entries are organized and how those entries are associated with syntactic structure information?

One possibility is to take advantage of *syntactic priming*. Syntactic priming occurs when structural information activated during processing of a prime sentence persists and affects processing of a subsequent sentence. Such effects are commonly observed in language production (e.g., Bock, 1986; Bock & Loebell, 1990; Branigan, Pickering, & Cleland, 2000) and, under the right circumstances, in online comprehension (Arai, van Gompel, & Scheepers, 2007; Ledoux, Traxler, & Swaab, 2007; Pickering & Traxler, 2004; Traxler & Pickering, 2005; Traxler & Tooley, in press).[1] For example, in an ERP study (Tooley, Traxler, & Swaab, 2007), reduced relative prime sentences, such as Sentences 1 and 2 below, appeared before a reduced relative target sentence, such as Sentence 3.

(1) The engineer examined by the board passed with flying colors.

(2) The engineer inspected by the board passed with flying colors.

(3) The defendant examined by the lawyer was found guilty.

The P600 or *syntactic positive shift* has been shown to be sensitive to syntactic processes, with increased amplitude of the P600 indexing greater syntactic complexity or processing load (Friederici, Hahne, & Mecklinger, 1996; Friederici, Hahne, & Saddy, 2002; Friederici & Mecklinger, 1996; Hagoort, Brown, & Groothusen, 1993; Kaan & Swaab, 2003; Osterhout & Holcomb, 1992).[2] In this ERP study, reductions in the amplitude of the P600 were observed when prime sentences like Sentence 1, above, preceded the target. By contrast, prime sentences like Sentence 2 had no effect on the amplitude of the P600 component during processing of the disambiguating word *by* in the target sentence. These ERP results reinforce findings from eyetracking studies showing that primes like Sentence 1 facilitate target sentence processing, but primes like Sentence 2 do not (Pickering & Traxler, 2004; Traxler & Pickering, 2005). The difference between prime sentences like Sentence 1 and prime sentences like Sentence 2 is that critical lexical material is repeated across primes and targets in the former but not in the latter.

It is possible to exploit this priming paradigm to explore the way syntactic and lexical representations are organized. The basic assumption is that priming should occur when two representations have some elements in common. For example, in word-level priming, two words may prime each other because they share phonological representations—for instance, *plain* and *plane*—or elements of meaning—for instance, *pig* and *pork* (Balota, Yap, & Cortese, 2006; Humphreys, Evett, & Taylor, 1982; Meyer & Schvaneveldt, 1971). Shared representations are also thought to be responsible for cross-language syntactic priming in bilingual language production. In one such experiment, Spanish–English bilinguals were more likely to produce passive sentences in English after hearing a passive sentence in Spanish than after hearing either

active or intransitive sentences in Spanish (Hartsuiker, Pickering, & Veltkamp, 2004). Hartsuiker and colleagues concluded that the bilingual speakers must have accessed the same syntactic representations for both the English and Spanish passive voices. If Spanish and English syntax were represented separately, Spanish-language prime sentences would have no influence on the production of English passives.

Similar logic applies to within-language syntactic priming. If the structure of one sentence primes the processing of a subsequent sentence, those two sentences must share elements of representation at some level. Further, if one sentence is a more effective prime than another, the more effective sentence must be more closely related to the target sentence than to the less effective prime sentence. The experimental paradigm used in the present study capitalizes on these two properties to investigate whether the parser treats different kinds of prepositional phrases (PPs) as freely interchangeable, or whether the parser reacts differently to different kinds of PPs. This provides an opening to begin to address the grain size problem. If the parser treats all PPs the same, then any probability statistics that are kept will have to be tied to a generic PP representation. In this case, the representation of a verb might include the information that it takes an NP object 60% of the time, is intransitive 20% of the time, and takes a PP object 15% of the time. If, instead, the parser respects a distinction between different PP types, the representation of that same verb might include the information that it takes an *agent* PP 10% of the time (e.g., *The apple was cut by the baker*) and an *instrument* PP 5% of the time (e.g., *The apple was cut with the knife*; of course, other types, such as *locatives*, are also possible; see Liversedge, Pickering, Branigan, & van Gompel, 1998).

To investigate whether the parser treats PPs as generics, two types of prime sentences and two types of target sentences were used. The two types of prime sentences contained reduced relative clauses, as in Sentences 4 and 5:

(4) The deer shot by the hunter was only slightly injured.

(5) The deer shot with the rifle was only slightly injured.

In Sentence 4, the PP *by the hunter* is an *agent* PP, because the noun in the PP represents the initiator of the action *shot*. In Sentence 5, the PP *with the rifle* is an *instrument* PP, because the noun in the PP represents the object used (by an unnamed agent) to perform the action *shot*.[3] Previous experiments have shown that sentences with agent PPs prime reduced relative target sentences with agent PPs (Ledoux et al., 2007; Pickering & Traxler, 2004; Tooley et al., 2007; Traxler & Pickering, 2005; Traxler & Tooley, in press). The question that this experiment was designed to address was: Will agent and instrument sentences facilitate each other as much as they facilitate themselves?

The answer to this question will help address the grain size problem for this sentence type. If the parser treats all PPs as generic members of the same class, agent PPs should prime agent PPs as much as instrument primes do, and agent PPs should prime instrument PPs as much as instrument PPs do. On this account, processing a reduced relative prime sentence will enhance the activation of a NOUN–RC(PP)–MAIN VERB structure, and any target sentence that matches at this level of description will be facilitated. If so, it will not matter whether the prime and target have the same subtype of PP or not. Alternatively, the parser may react differently to different subtypes of PPs. If so, the representation of the prime sentence could be something like NOUN–RC[PP(AGENT)]–MAIN VERB or NOUN–RC[PP(INSTRUMENT)]–MAIN VERB. Alternatively, as noted by Boland and Blodgett (2006, p. 387), there may be differences in the structural representations of different kinds of PPs, depending on whether the PP is an argument or an adjunct of a preceding verb. If there is no overlap in the representations of the agent and instrument subtypes, or if the parser does not recognize the overlap, there may be no priming across subtypes. If the architecture is a hybrid—that is, the representations are organized at the level of generic PPs and at a subordinate level based on semantic properties—there should be some crosstype priming, but greater priming should be observed within than between types.

Including the instrument PPs also tests whether the processing of such sentences can be primed at all. Any positive finding would represent the first time priming effects have been observed in the online processing of reduced relative sentences containing instrument PPs.

EXPERIMENT

This experiment was designed to test whether reduced relative prime sentences facilitate processing of PP modifiers generally, or whether priming is restricted to a specific type of modifier (e.g., agent PPs). Alternatively, priming effects might be larger within than between modifier types. The results of this experiment will help illuminate the representational system underlying syntactic priming in comprehension. A finding of greater priming within than across types would indicate either that semantic category information (e.g., *agent* vs. *instrument*) influenced priming, or that individual lexical items had separate connections to structural elements encoding different types of prepositional phrases. To the extent that semantic type information enhances priming (as suggested by Frazier, Munn, & Clifton, 2000), greater facilitation should be observed within than between PP types.

Method

Participants. Forty-eight participants from the University of California, Davis participated in return for course credit. All of the participants were native speakers of English with normal, uncorrected vision and hearing. One participant was removed from the analysis because of excessive numbers of trials with missing data; therefore, the statistics reported below include data from only 47 participants.

Stimuli. There were 28 sets of items like 6A–6D below; all of the items appear in the Appendix.

(6A) The director watched by the cop was in a bad part of town. (agent PP)

(6B) The director watched with the binoculars was in a bad part of town. (instrument PP)

6C. The lifeguard watched by the swimmer had a deep dark suntan. (agent PP)

6D. The lifeguard watched with the telescope had a deep dark suntan. (instrument PP)

In half of the items, the modifier consisted of an agent PP, as in 6A and 6C. In the other half, the modifier consisted of an instrument PP, as in 6B and 6D. Crossing prime and target sentence types produces four types of targets: agent targets following agent primes, agent targets following instrument primes, instrument targets following agent primes, and instrument targets following instrument primes.

The verbs (e.g., *watched*) were always repeated across prime and target sentences, because priming in online processing has been observed previously only under these conditions for this sentence type (Ledoux et al., 2007; Pickering & Traxler, 2004; Tooley et al., 2007; Traxler & Pickering, 2005; for the double-object/dative alternation, see Arai et al., 2007).

By rotating items across eight lists, each prime sentence on one list served as a target sentence on a different list. Thus, prime–target comparisons were made across exactly the same sentences. This eliminates concerns about the length and frequency of the individual words as well as possible effects of additional ambiguities beyond the reduced relative-main clause ambiguity. In other words, the estimates of the priming effects were based on measuring readers' responses to a sentence like *The director watched by the cop was in a bad part of town* when it was preceded by unrelated material (i.e., a filler sentence), and then seeing whether that exact sentence was processed faster when it was preceded by either an agent or an instrument prime sentence.

Items were assigned to lists in a pseudorandom manner, so that equal numbers of each type appeared on each list and participants were only exposed to one version of each item. So, any given participant saw 28 prime–target pairs (56 experimental sentences in all), 7 of each prime–target type (7 agent prime–agent target, 7 agent prime–instrument target, 7 instrument prime–agent target, and 7 instrument prime–instrument target). Prime–target pairs were assigned to lists in a pseudorandom manner, so that participants could not predict what kind of prime–target pair would appear on any given trial. The prime–target pairs were rotated across lists, so that all four types of prime–target pair appeared at each serial position. So, for example, Item 1 on List 1 was an agent prime–agent target pair. On the next list, Item 1 was an agent prime–instrument target pair. On List 3, Item 1 was an instrument prime–agent target pair. On List 4, Item 1 was an instrument prime–instrument target pair. On Lists 5–8, the order of the sentences within a prime–target pair was reversed (primes were changed to targets and targets were changed to primes).

The counterbalancing therefore accomplished the following goals: (1) Every prime sentence (on one list) served as a target sentence (on a different list); (2) a participant read any particular sentence exactly once; (3) there were equal numbers of each kind of prime–target pair on every list; and (4) the order of presentation was counterbalanced across lists to distribute training effects and any filler sentence effects evenly across conditions.

Agent and instrument target sentences always followed the prime sentences immediately; that is, no material appeared between the prime sentence and the subsequent target sentence, so readers always read two critical sentences one right after the other: first the prime, then the target.

The experimental sentences were displayed along with 59 filler sentences of various types. At least 1 filler sentence intervened between each prime–target pair. Although the proportion of ambiguous sentences was high, previous priming experiments with this sentence type have shown that priming effects are abolished when even one sentence with a different verb than the target appears prior to the target (Pickering & Traxler, 2004; Tooley et al., 2007). Hence, even a single intervening filler sentence should lead to essentially "normal" reading times for the prime sentence. Further, if there were any carryover effects from preceding trials, they would, if anything, lead to a lowered estimate of any possible priming effects; and because all types of items appeared in all serial positions involving experimental trials, such effects would be distributed evenly across conditions.

None of the filler items had verbs used in the prime–target pairs. None of the filler items had reduced relative clauses, but two of the filler items had full relative clauses—for instance, *The garbage man brought home a couch that he found on the sidewalk*. Seven of the filler items had PPs modifying nouns—for instance, *The grocery store stocked dozens of different kinds of beer*. Seven of the filler items had PPs modifying verbs—for instance, *Tony forgot his homework on the bus*. In two of those seven cases, the PP was part of a passive and included an agent—for instance, *The airline confirmed that the reservations were approved by the manager*. In one case, the passive was immediately followed by another filler sentence: *The policeman stopped the speeding motorist*. In the other case, the passive was sometimes followed by an agent prime sentence (on four of the eight lists; the rest of the time it was followed by an instrument prime). It is unlikely that this passive filler led to speeded processing of the agent prime sentence, because the filler and the prime had different verbs.

Eye-movement monitoring procedure. A Fourward Technologies dual-Purkinje image eyetracker monitored participants' eye movements while they read the test sentences. The tracker has an angular resolution of 10′ of arc. The tracker monitored only the right eye's gaze location. A PC displayed materials on a VDU 70 cm from participants. Participants' gaze location was sampled every millisecond, and the PC software recorded the tracker's output to establish the sequence of eye fixations and their start and finish times. Before the experiment, the experimenter seated the participant at the eyetracker and used a bite plate and headrests to minimize head movements. After the tracker was aligned and calibrated, the experiment began. After reading each sentence, the participant pressed a key. After 14 of the filler sentences, the participant responded to a comprehension question. Participants did not receive feedback on their responses. Between each trial, a pattern of squares appeared on the computer screen along with a cursor that indicated the participants' current gaze locations. If the tracker was out of alignment, the experimenter recalibrated it before proceeding with the next trial.

Analyses. Four standard eye-movement measures were computed for each participant. *First-pass time* is the sum of all fixation durations, beginning with the first fixation in a region until the reader's gaze leaves the region, left or right. *First-pass regressions* is the number of eye movements that crossed a region's left-hand boundary immediately following a first-pass fixation. *Regression-path time* includes all fixation durations from the first fixation in a region until the reader's gaze crosses the right-hand boundary of the region. This measure includes refixations of preceding regions and the target region itself. *Total time* is the sum of all fixation durations in a region, regardless of order.

Three scoring regions were analyzed. The *verb* region consists of the verb inside the relative clause—for instance, *watched* in 6A–6D. The *PP* region consisted of the prepositional phrase—for instance, *by the cop*/ *with the binoculars* in 6A–6B. The PP region was analyzed as a whole because it is a linguistically defined unit that has been used in previous priming studies (e.g., Pickering & Traxler, 2004) and previous studies involving the reduced relative sentence type that did not involve priming manipulations (e.g., Clifton et al., 2003). The *post-PP* region consisted of the two words immediately following the PP region. Data are reported for the post-PP region primarily to provide a more complete picture (since no significant main effects or interactions were observed there). Including data for this region also helps determine whether or not effects are localized to the repeated verb and PP regions.

Prior to determining fixation durations, an automatic procedure incorporated fixations of less than 80 msec into the largest fixation within one character. In the next stage, the procedure eliminated all individual fixations greater than 1,000 msec and less than 80 msec. Subsequently, first-pass, regression-path, and total times of less

than 120 msec were excluded from the analyses. Finally, first-pass, regression-path, or total times exceeding 3,000 msec were excluded. These procedures together led to 3.7% of the data being excluded.

Because the PP region differed in length across the agent and instrument PP conditions, the analyses reported below for the PP region are for length adjusted (or *residual*) reading times. To calculate these times, the data from the PP region in the prime sentences were subjected to a correlational analysis. Length of the region in characters was entered as the regressor, and the dependent measures (first-pass time, first-pass regressions, regression-path time, and total time) were entered as the criterion. Only prime sentence data were used for this analysis, because outcomes for the target sentences were influenced by the experimental manipulation (see below).[4] These correlational analyses yielded predicted reading times based on length. In the next step, predicted values were subtracted from the observed values for each trial for each participant to obtain the residual reading times. Condition means by participants and items were then calculated for these residual reading times and entered into the statistical tests. Residual reading times were computed for the PP region only; the other two scoring regions were identical across conditions. The correlational analysis did not show a relationship between the length of the PP region and the percentage of regressions from that region; so, for this dependent measure, the raw data were used in all of the analyses.

Results

Table 1 presents mean values for the four dependent measures by condition for each of the three scoring regions. Table 2 presents mean residual reading times for the three reading time measures (but not first-pass regressions; see above) for the PP scoring region. Figures 1 and 2 present residual first-pass and total time, respectively, for the PP scoring region.

Did prime sentences lead to facilitated target processing? To determine whether any priming occurred, data from each scoring region were first subjected to 2 (sentence type: prime vs. target) × 2 (prime type: agent vs. instrument) × 2 (target type: agent vs. instrument) repeated measures ANOVAs, with all factors treated as within-participants and items. Main effects of sentence type (prime vs. target) would indicate whether the target sentences were processed more rapidly than the prime sentences. Main effects of sentence type occurred in the total time data from the verb region [$F_1(1,46) = 38.0$, $p < .0001$, $MS_e = 4{,}820$; $F_2(1,27) = 11.3$, $p < .01$, $MS_e = 8{,}380$] and in all four dependent measures from the PP region [residual first-pass, regression-path, and total time as well as raw first-pass regressions, all Fs > 7.6, all ps $< .01$. Residual first-pass time: $F_1(1,46) = 7.67$, $p < .01$, $MS_e = 11{,}148$; $F_2(1,27) = 8.18$, $p < .01$, $MS_e = 5{,}992$. First-pass regressions: $F_1(1,46) = 25.1$, $p < .0001$, $MS_e = 138.5$; $F_2(1,27) = 18.0$, $p < .001$, $MS_e = 112.6$. Residual regression-path time: $F_1(1,46) = 37.2$, $p < .0001$, $MS_e = 19{,}505$; $F_2(1,27) = 27.0$, $p < .0001$, $MS_e = 14{,}618$. Residual total time: $F_1(1,46) = 39.3$, $p < .0001$, $MS_e = 13{,}829$; $F_2(1,27) = 35.4$, $p < .0001$, $MS_e = 9{,}612$]. None of the dependent measures from the post-PP region indicated faster processing in the target sentences relative to the prime sentences [all $F_1 < 1$, n.s.; all $F_2 < 2.6$, n.s.]. These findings indicate that substantial facilitation occurred during processing of the prepositional phrases when the target sentences were processed. Notably, these effects do not represent spillover effects from the repeated verb, because priming effects were observed there only in the total time measures.

Did priming occur to an equal extent for all types of prime–target pairs? No. Different amounts of priming were observed for different prime–target pairs. First, in the PP region, three-way interactions of sentence type (prime

Table 1
Mean Values for First-Pass Time, First-Pass Regressions, Regression-Path Time, and Total Time to Prime and Target Sentences by Region and Condition

	Verb Region		PP Region		Post-PP Region	
Condition (Prime–Target)	Prime	Target	Prime	Target	Prime	Target
			First-Pass Time			
Agent–agent	345	331	592	533	445	424
Agent–instrument	345	324	559	688	397	425
Instrument–agent	337	339	716	544	441	412
Instrument–instrument	347	338	690	637	433	414
			First-Pass Regressions			
Agent–agent	10.9%	8.5%	14.0%	10.0%	10.6%	13.7%
Agent–instrument	10.9%	9.7%	20.7%	9.7%	15.8%	13.7%
Instrument–agent	11.6%	8.5%	15.5%	12.8%	11.9%	13.7%
Instrument–instrument	11.2%	7.3%	16.4%	9.7%	15.2%	15.8%
			Regression-Path Time			
Agent–agent	409	380	713	610	530	537
Agent–instrument	417	387	755	805	522	560
Instrument–agent	393	400	874	656	548	544
Instrument–instrument	425	385	860	734	547	517
			Total Time			
Agent–agent	475	432	777	691	560	537
Agent–instrument	494	435	790	885	515	555
Instrument–agent	474	471	928	704	566	530
Instrument–instrument	495	423	904	771	573	534

Table 2
Mean Values for Residual First-Pass Time, Residual Regression-Path Time, and Residual Total Time to Prime and Target Sentences by Condition

Condition	Prime	Target
Residual First-Pass Time		
Agent–agent	−5.0	−51.3
Agent–instrument	−48.6	22.8
Instrument–agent	44.0	−47.2
Instrument–instrument	4.8	−49.8
Residual Regression-Path Time		
Agent–agent	−33.7	−122
Agent–instrument	−5.03	−25.1
Instrument–agent	35.5	−81.7
Instrument–instrument	3.7	−122
Residual Total Time		
Agent–agent	−20.5	−92.0
Agent–instrument	−19.9	14.9
Instrument–agent	50.7	−83.4
Instrument–instrument	11.5	−122

vs. target), prime type (agent vs. instrument), and target type (agent vs. instrument) occurred in residual first-pass time [$F_1(1,46) = 5.35$, $p < .03$, $MS_e = 7{,}229$; $F_2(1,27) = 4.12$, $p = .05$, $MS_e = 6{,}330$] and in the by-participants analysis of the residual total times [$F_1(1,46) = 5.22$, $p < .03$, $MS_e = 12{,}568$], although this was not significant in the by-items analysis [$F_2(1,27) = 2.41$, $p = .13$, $MS_e = 10{,}936$].

To assess the amount of priming, tests for simple effects were conducted comparing reading time in the prime sentences with reading time in the target sentences. Note that these comparisons used data from all of the prime sentences of the appropriate type; so, to estimate processing time for the agent prime sentences, data from both the agent–agent and agent–instrument conditions were used. These means comparisons indicated that significant priming effects occurred in only three of the four prime–target pairs. Agent and instrument primes both facilitated agent targets to about the same degree, but instrument primes had a greater effect on instrument targets than agent primes did. This pattern is clearly illustrated in Figures 1 and 2.

First consider what happened when agent targets followed agent primes. Although there was a savings of about 25 msec in the target sentence over the prime in residual first-pass time, this did not lead to a significant result in the means comparisons [$F_1(1,46) = 2.60$, $p = .11$; $F_2(1,27) = 2.02$, $p = .17$]. There was a reduction in the proportion of first-pass regressions from the PP region, however, for agent targets following agent primes [$F_1(1,46) = 10.2$, $p < .01$; $F_2(1,27) = 13.0$, $p < .01$]. A similar savings was observed in the residual regression-path time [$F_1(1,46) = 19.3$, $p < .0001$; $F_2(1,27) = 17.0$, $p < .001$] and residual total time [$F_1(1,46) = 12.9$, $p < .001$; $F_2(1,27) = 7.52$, $p = .01$]. So, there was robust priming for agent targets when they followed agent primes.

Next, consider what happened when agent targets followed instrument primes. Once again, the residual first-pass data failed to show a significant savings relative to the baseline [$F_1(1,46) = 1.78$, n.s.; $F_2(1,27) < 1$, n.s.]. However, the first-pass regressions data did indicate that there were fewer regressions from the PP region in the target than in the baseline condition [$F_1(1,46) = 3.97$, $p = .05$; $F_2(1,27) = 5.11$, $p < .05$]. This effect also occurred in the residual regression-path time [$F_1(1,46) = 7.13$, $p = .01$; $F_2(1,27) = 5.46$, $p < .03$] and residual total time data [$F_1(1,46) = 9.95$, $p < .01$; $F_2(1,27) = 6.74$, $p < .02$]. There was, therefore, robust priming for agent targets when they followed instrument primes.

Next, consider what happened when instrument targets followed instrument primes. Here, the reduction in processing difficulty in the target sentence relative to the prime sentence was significant in all four dependent measures. In

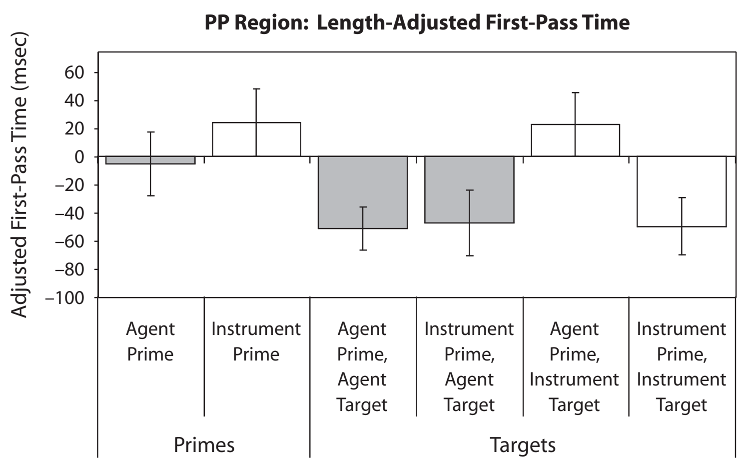

Figure 1. Length-adjusted first-pass time. The two leftmost bars represent mean residual first-pass time for the agent prime sentences (leftmost bar) and the instrument prime sentences (next bar to the right). The next four bars represent residual first-pass time for the agent and instrument target sentences when they follow agent and instrument prime sentences. Error bars represent standard errors.

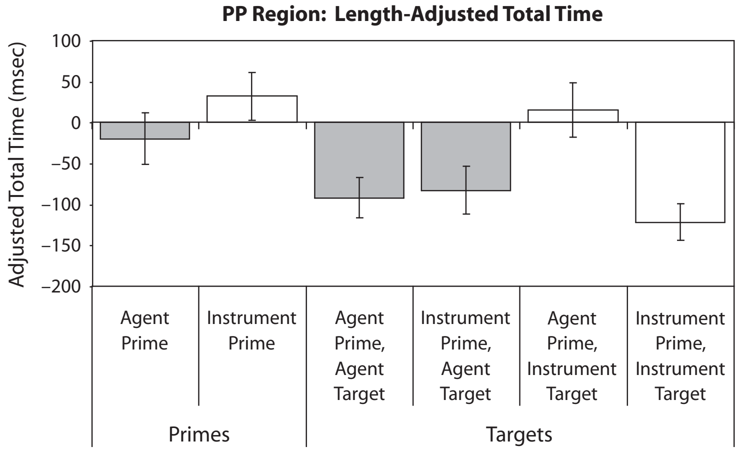

Figure 2. Length-adjusted total time. The two leftmost bars represent mean residual total time for the agent prime sentences (leftmost bar) and the instrument prime sentences (next bar to the right). The next four bars represent residual total time for the agent and instrument target sentences when they follow agent and instrument prime sentences. Error bars represent standard errors.

the residual first-pass time, the savings was about 75 msec [$F_1(1,46) = 23.9, p < .0001$; $F_2(1,27) = 15.8, p < .001$]. There were about one third fewer first-pass regressions in the target sentences than in the prime sentences [16% vs. 9.7%; $F_1(1,46) = 7.41, p < .01$; $F_2(1,27) = 9.73, p < .01$]. There were about 140 msec of savings in the residual regression-path time data [$F_1(1,46) = 36.8, p < .0001$; $F_2(1,27) = 31.1, p < .0001$]. There was a savings of about 150 msec in the residual total time data [$F_1(1,46) = 58.4, p < .0001$; $F_2(1,27) = 39.7, p < .0001$]; so there was robust priming for instrument targets when they followed instrument primes.

Finally, consider what happened when instrument targets followed agent primes. Here, none of the residual reading-time analyses showed differences between the instrument target sentences and the same sentences when they appeared as primes. Residual first-pass time for the PP region of instrument sentences was about 24 msec, the savings in processing when an agent prime preceded an instrument target was about 1 msec [$F_1(1,46) = 0.01$, n.s.; $F_2(1,27) = 0.002$, n.s.]. Residual regression-path time was about 20 msec for instrument primes and about −25 msec for instrument primes following agent targets [$F_1(1,46) = 3.67, p = .06$; $F_2(1,27) = 2.81, p = .11$]. Residual total time was about 31 msec in instrument prime sentences and about 15 msec for instrument targets following agent primes [$F_1(1,47) = 0.65$, n.s.; $F_2(1,27) = 1.52$, n.s.]. There were fewer regressions from instrument targets following agent primes relative to the baseline [9.7% vs. 16%; $F_1(1,47) = 7.41, p < .01$; $F_2(1,27) = 9.73, p < .01$]; so there was some indication that an agent prime might affect early processing of instrument targets. The agent prime appeared to make participants less likely to regress from the PP region in the instrument target. However, the total time data indicated that there was no overall savings in processing time when an instrument target followed an agent prime.

Evidence for differential effects of agent and instrument primes on instrument targets can be found in analyses focusing on target sentence processing. To determine whether agent and instrument targets were processed equally quickly when they followed agent or instrument primes, a series of 2 (prime type: agent vs. instrument) × 2 (target type: agent vs. instrument) ANOVAs were performed on the data from the target sentences. Significant interactions would show that some prime types had greater facilitative effects on some target types than on others.

Analyses of the residual first-pass data from the PP region of the target sentences indicated a prime × target type interaction [$F_1(1,46) = 8.64, p < .01, MS_e = 8{,}013$; $F_2(1,27) = 6.43, p < .02, MS_e = 7{,}035$]. This interaction occurred because—although there was no difference in processing times for agent targets that followed agent or instrument primes [$F_1(1,46) = 0.051$, n.s.; $F_2(1,27) = 0.13$, n.s.]—instrument targets had shorter residual first-pass time when they followed instrument primes than when they followed agent primes [$F_1(1,46) = 15.4, p < .001$; $F_2(1,27) = 10.4, p < .01$].

The first-pass regressions data from the target did not indicate an interaction of prime and target types [$F_1(1,46) = 0.74$, n.s., $MS_e = 119$; $F_2(1,27) = 0.77$, n.s., $MS_e = 65.3$].

The residual regression-path time data did indicate a prime × target type interaction in data from the PP region of the target sentences [$F_1(1,46) = 11.4, p < .01, MS_e = 19{,}380$; $F_2(1,27) = 18.7, p < .001, MS_e = 7{,}234$]. As in the residual first-pass time data, this interaction reflects the fact that agent targets had equivalent residual regression-path time regardless of prime type [$F_1(1,46) = 1.97$, n.s.; $F_2(1,27) = 3.70, p = .07$], but instrument targets had shorter residual regression-path time when they followed instrument primes than when they followed agent primes [$F_1(1,46) = 11.4, p < .01$; $F_2(1,27) = 17.6, p < .001$].

The residual total time data also indicated a prime × target type interaction in the PP region of the target sentences [$F_1(1,46) = 15.6$, $p < .001$, $MS_e = 15,907$; $F_2(1,27) = 8.20$, $p < .01$, $MS_e = 13,602$]. As in the other reading-time measures, the interaction occurred because agent targets were processed equally quickly when they were preceded by agent primes or instrument primes [$F_1(1,46) = 0.11$, n.s.; $F_2(1,27) = 0.013$, n.s.], but residual total times were shorter when instrument targets were preceded by instrument primes than when they were preceded by agent primes [$F_1(1,46) = 27.7$, $p < .0001$; $F_2(1,27) = 15.5$, $p < .001$].

Two facts emerge from the overall pattern of results. (1) Processing of agent and instrument targets can be primed; the disambiguating region of both types of targets was processed faster than was the same region of the same sentences when those sentences appeared as prime sentences. (2) The degree of priming depends on both the kind of prime sentence that came before and the kind of target sentence that is being processed. Agent target sentences were about equally difficult to process, whether an agent prime or an instrument prime appeared immediately beforehand; and in both cases, the target sentences were easier to process than were the prime sentences. However, instrument target sentences were processed differently, depending on what kind of prime preceded them. Robust priming was observed when an instrument prime preceded an instrument target, but there was little evidence that agent primes facilitated processing of targets containing an instrument PP. There appeared to be fewer regressions from the PP region when the instrument target was preceded by an agent prime, but this difference did not lead to an overall savings in processing time for instrument targets following agent primes (as indicated by the residual total time results). To sum up, results from the PP region indicate that agent targets are primed about equally by either agent or instrument primes, but instrument targets are primed more by instrument primes than by agent primes.

Results for the verb and post-PP regions are included for completeness, and are as follows.

Verb region. The omnibus 2 (sentence type) × 2 (prime type) × 2 (target type) ANOVAs showed a significant main effect of sentence type (prime vs. target) only in the total time data [$F_1(1,46) = 38.0$, $p < .0001$, $MS_e = 4,820$; $F_2(1,27) = 11.3$, $p < .01$, $MS_e = 8,380$]. This main effect reflects a savings of approximately 44 msec in the target sentences relative to the prime sentences. The three-way interaction of sentence, prime, and target types was not significant for any of the dependent measures.

Next, consider the processing of the verb region in the target sentences. No main effects or interactions occurred in the first-pass, first-pass regressions, or regression-path time data from the verb region. An interaction of prime and target types occurred in the total time data from the verb region [significant by participants, with $F_1(1,46) = 8.03$, $p < .01$, $MS_e = 3,763$; and nearly significant by items, with $F_2(1,27) = 3.64$, $p = .07$, $MS_e = 4,089$]. This interaction occurred because total time was longer in the instrument prime–agent target condition than in the other three types [instrument prime–agent target vs. agent prime–agent target, 471 msec vs. 432 msec: $F_1(1,46) = 9.32$, $p < .01$, $MS_e = 3,763$; $F_2(1,27) = 3.42$, $p = .08$, $MS_e = 4,089$; instrument prime–agent target vs. agent prime–instrument target, 471 msec vs. 435 msec: $F_1(1,46) = 7.81$, $p < .01$, $MS_e = 3,763$; $F_2(1,27) = 2.53$, NS, $MS_e = 4,089$; instrument prime–agent target vs. instrument prime–instrument target, 471 msec vs. 423 msec, $F_1(1,46) = 14.1$, $p < .001$, $MS_e = 3,763$; $F_2(1,27) = 5.95$, $p < .05$, $MS_e = 4,089$].

Post-PP region. There were no significant main effects or interactions in either the omnibus ANOVAs or the target sentence analyses for data from the post-PP region.

Additional Contrasts

A further way to assess the magnitude of the cross-category priming effects is to contrast the size of the priming effects in the instrument–agent condition with the size of the priming effects in the agent–instrument condition. So, for example, one would compare the 60-msec priming effect in the total time data from the PP region for the instrument–agent condition with the 15-msec priming effect in the agent–instrument condition (the comparable values for first-pass time, first-pass regressions, and regression-path time would be 25 vs. 2, 4.7% vs. 6%, and 100 vs. 45, respectively). Orthogonal contrasts did not produce significant results for any of these contrasts (all *t*s < 1.4). These results will be taken up in the General Discussion.

GENERAL DISCUSSION

This experiment was designed to determine whether prime sentences containing agent or instrument primes would facilitate processing of target sentences with the same or different PP types. Differences between processing times for prime sentences and the same sentences when they appeared as target sentences indicate that reading a prime sentence with the same verb and same global structure facilitated processing of the target sentences. This basic pattern replicates behavioral (Pickering & Traxler, 2004; Traxler & Tooley, in press) and neurophysiological (Ledoux et al., 2007; Tooley et al., 2007) results for the same sentence type. Three-way interactions of sentence type (prime vs. target), prime type (agent vs. instrument), and target type (agent vs. instrument) in the first-pass and total time data provide evidence that some kinds of primes had greater effects on some kinds of target sentences than they had on others. Further evidence for differential effects of different prime–target combinations can be found in significant interactions of prime and target types in the data from the target sentences. First-pass and total time from the PP scoring region showed that agent targets were about equally facilitated, whether the prime contained an agent or instrument PP. However, there was little evidence that agent primes facilitated processing of instrument targets. The first-pass regressions data from the PP region did show that instrument targets had fewer regressions, compared with baseline, when the instrument targets were preceded by agent primes. A similar, though more marginal, effect occurred in the residual regression-path time data. Note, however, that this difference in regressions did

not lead to an overall decrease in processing load in instrument targets following agent primes. The total time data did not indicate savings over baseline when the instrument targets followed agent primes, and instrument targets following instrument primes were processed faster than the same sentences when they followed agent primes. These differences started to emerge in first-pass time in the PP scoring region and carried forward through regression path and total time. In the verb region, total time (but not the other measures) provided further evidence that agent targets were about equally facilitated by either prime type, but that instrument targets were facilitated more strongly by instrument primes than by agent primes.

Before interpreting these results, it may be useful to discuss a couple of potential artifacts. First, is it possible that these results reflect strategic adaptation to the experimental context? In other words, because a reduced relative target sentence always appeared immediately after every reduced relative prime sentence, could the results reflect readers' predicting the upcoming reduced relative and adjusting their parsing processes accordingly? This is unlikely, for at least the following two reasons.

First, this possibility has been addressed for the reduced relative in a set of separate studies (Tooley et al., 2007; Traxler & Tooley, in press). In a pair of eyetracking experiments, the validity of different strategic cues was systematically manipulated to show that priming would occur in the absence of strategic cues and would fail to occur in the presence of valid strategic cues. In one experiment, valid strategic cues were established by having overlapping subject nouns in prime–target pairs like those tested here (but where all of the PPs were of the agent type). This experiment showed that the repeated noun could be primed, but not the disambiguating by-phrase. In a second experiment, the validity of the overlapping verb cue was eliminated by having overlapping verbs in a majority of the filler sentences. This second experiment indicated that priming of the disambiguating by-phrase occurred in the absence of valid strategic cues. Also, in the original online syntactic priming studies (Pickering & Traxler, 2004), a repeated verb was just as likely to cue a change in structure (from main clause to reduced relative, or vice versa) as it was to cue a repeated structure. Here, too, priming was observed, despite the absence of valid strategic cues. Hence, priming has been shown to be independent of strategic cues: It occurs in the absence of valid cues and fails to occur in their presence. Also, although it is possible that readers in the present experiment might have predicted the reduced relative on some proportion of trials, such predictions would not have allowed them to predict whether an agent or instrument modifier would appear in the disambiguating position, since each alternative was equally likely in the experimental context. Thus, we can discount strategic predictions as a major factor in participants' performance.

Second, could the priming effects be caused by lexical priming based on overlapping prepositions? This too is possible, but unlikely. First, note that priming effects in the agent targets were just as large in the instrument–agent condition (where there was no overlapping preposition) as in the agent–agent condition (where there was a repeated preposition). Further, in previous eyetracking studies on this sentence type (Pickering & Traxler, 2004; Traxler & Pickering, 2005), priming has occurred without overlapping prepositions and has failed to occur in the presence of overlapping prepositions (Traxler & Tooley, 2007). For example, a *short relative*, such as *The defendant who was examined lied to the jury*, will prime the by-phrase in *The engineer examined by the board passed*, even though there is no preposition in the prime. By contrast, *The defendant challenged by the lawyer* does not prime *The engineer examined by the board*, even though they share a preposition (presumably because the verbs in the prime and target are different). The available data suggest that preposition overlap is neither necessary nor sufficient for priming to occur. Thus, it is unlikely that preposition overlap contributed much to the priming effects observed in this experiment. It is likely, however, that repeated prepositions are registered at some level of processing, if only at the level of visual patterns. The fact that repetition at this level does not appear to affect eye movements involved in reading and interpreting sentences in any noticeable way could be interpreted as supporting some degree of modularity in language processing; that is, the parser appears to be blind to some aspects of the visual input, and does not use repeated function words in the same way in which it appears to use repeated content words (see also Rayner & Pollatsek, 1989, for a discussion of experiments where capital and lowercase letters are reversed during saccades).

This raises another question relating to the outcome of this experiment and similar priming experiments. If preposition overlap does not materially affect priming, why should any other form of lexical overlap, including verb overlap, play a role in syntactic priming? The answer could be that verbs play a greater role in establishing dependencies among words than prepositions do. But why should there be a difference between the two classes of words? First, verbs are usually very weighty in terms of their semantic impact, with Korean and similar languages being a possible exception (Jackendoff, 2002). Second, verbs affect the syntactic form that sentences take, because they specify different numbers and kinds of semantic and syntactic arguments. Hence, some theories of syntactic representation and parsing (e.g., Boland & Blodgett, 2006; Ford et al., 1982; MacDonald et al., 1994; Vosse & Kempen, 2000) emphasize the online effects of structural information tied to specific verbs, and use it to explain, for example, why readers experience different amounts of difficulty with a particular sentence type on the basis of which particular verbs appear in critical positions. By contrast, prepositions are semantically lighter than verbs are, and in many cases are essentially arbitrary placeholders (for example, we say "*on* the plane" but "*in* the car" to describe two modes of transporting people inside metal objects). In the present experiment, the preposition *with* was always used to introduce an instrument, but this need not be the case in general; it could introduce something else (e.g., *The doctor visited with his friend*). Assuming that the parser does respect some degree of difference between agent and instrument PPs, and assuming that it

has an agent preference (see below), it may be unwilling or unable to change the relative weights of different structural possibilities on the basis of overlap at only the level of prepositions. Of course, none of this rules out the possibility that the parser *could* react to repeated prepositions the way it appears to react to repeated verbs. It is just that, to date, there are no priming results that suggest that it does.

The results therefore suggest that, although different PP types can prime each other, greater priming occurs within than between types. This may indicate multiple connections between each verb and different modifier types, and that activating one connection may have little effect on the others. Additionally, having different connections to different types of modifiers opens up the possibility that different lexical items could have different strengths of connection between different types of modifiers, and that, for instance, some verbs could prefer instrument modifiers over agents.

But what about the nonsignificant results for the instrument–agent and agent–instrument contrasts? Does this not suggest that equivalent priming occurs within and across PP types? The null results in these contrasts are certainly consistent with the proposition that there is full equivalence between agent and instrument PPs. On the basis of these results, one might therefore conclude that agent primes and instrument primes are interchangeable and have comparable effects on sentences containing the other type of PP. However, the full pattern of results is difficult to reconcile with this position. If agent and instrument primes were treated as equivalent by the parser, one would expect to see equivalent priming across the board for all four prime–target conditions—agent–agent, agent–instrument, instrument–agent, and agent–agent. This prediction is supported for agent targets, but not for instrument targets. If agent and instrument primes were interchangeable and had equivalent effects, then instrument and agent primes should have been equally effective for instrument targets. But the data suggest that agent primes were not nearly as effective as instrument primes for instrument targets.

Why should agent and instrument primes have different effects on agent and instrument targets? The pattern of priming could result from a kind of suppression or displacement of the agent structure by the (less preferred) instrument structure during processing of the prime. If the preferred agent interpretation has to be suppressed in order for the less preferred instrument interpretation, construction of the correct agent-modifier structure when the target sentence was processed would potentially be delayed, and would resemble similar effects that occur in lexical disambiguation (Duffy, Henderson, & Morris, 1989; Rayner & Duffy, 1986). However, because there was no evidence that an instrument prime sentence led to slower processing of agent target sentences (the opposite pattern was actually observed), instrument primes probably do not lead to the suppression of agents.

Alternatively, the pattern priming could reflect differential activation of implicit argument structure information by agent and instrument PPs. Argument structures reflect the ways in which verbs can combine with other kinds of words to express relationships between actors and objects. For example, the argument structure for an intransitive verb needs only one slot, for an agent (e.g., *walked*: *He walked*) or a theme or experiencer (e.g., *melted*: *The ice cream melted*). A transitive verb requires an additional slot for an object; this would typically also be a theme or an experiencer (e.g., *He walked the dog*.) Argument structures influence online processing because comprehenders incorporate the constituents specified by argument structure into their representations of sentences. For example, in a set of experiments, Mauner, Tanenhaus, and Carlson (1995) demonstrated that purpose clauses (e.g., *to collect the insurance money*) were read more rapidly when they followed such verb forms as *was sunk* that allow an implicit agent than when they followed such verb forms as *sank* that do not. The semantics of the situation are not critical, because both sentences describe the same action or scenario. What is critical is that the active form *sank* does not require an external agent, but the passive form *was sunk* does.

The same principles may also apply to agent and instrument PPs. Consider again Sentence 6D, repeated here:

(6D) The lifeguard watched with the telescope had a deep dark suntan.

The sentence explicitly mentions a patient, *lifeguard*, and the instrument of the *watching* action. Logically, there must be a watcher, but that watcher is not mentioned in the sentence. Mauner et al.'s (1995) findings indicate that readers will include an implicit agent in their representation of the sentence when a verb's argument structure calls for such an agent, whether or not the sentence explicitly mentions the agent. It is likely, therefore, that readers will include an implicit agent for the kinds of verbs used in the present experiment. That is, when readers encounter *watched* in Sentence 6D, the argument structure representation includes a slot for an agent but that slot is left unfilled by the sentence; so the sentence is interpreted as if it said *The lifeguard watched by someone with the telescope had a deep dark suntan*.[5] So, when an instrument prime precedes an agent target, the argument structure that has been activated for the prime includes the agent in the canonical position, and this argument structure closely matches the argument structure and syntax necessary to encode the target. By contrast, there is no reason to believe that an agent prime would activate the argument structure necessary to incorporate an instrument (although this is logically possible). The reason for this is that a *telescope* is not necessary to engage in an act of *watching*. Similarly, the actions described by the verbs in this experiment (e.g., *sketched*, *examined*, *recorded*, *scratched*; see the Appendix) either do not require instruments or do not require particular instruments; therefore, activating the verbs' lexical representations would not necessarily entail activating an instrument PP slot. However, when the prime sentence explicitly mentions an instrument, this structural relationship would be activated and associated with the particular verb in the prime sentence. When that same verb appeared

in the target, residual activation or speeded reactivation of this configuration of arguments could facilitate processing of the target.

Note, however, that although the majority of the test sentences have fairly clear instruments, not all of the *instrument* sentences fit neatly within this semantic category. For example, *The baby delighted with the new toy* and *The child delighted with the magic show* do not require or imply additional agents (although *magic show* would seem to imply the existence of one or more magicians). The item containing the verb *bored* also likely does not imply an external agent when the verb is followed by *with*. It is not likely that the inclusion of these two items led to the pattern of priming obtained in the full data set, and there are too few such items to make it possible to determine whether they behave differently from other items that clearly imply an agent. Further work will be necessary to determine whether the class of PPs that begins with *with* in English can be fractionated into further subclasses that produce different patterns of priming effects. A situation in which instrument primes containing verbs like *watched* were more effective than primes containing verbs like *delighted* for agent targets would be straightforwardly compatible with the processing account sketched above. It may turn out, however, that the same pattern of priming effects occurs for sentences containing verbs like *watched*, which require an agent, and psych-perception verbs like *delighted* and *bored*, which do not. If this happened, the argument structure hypothesis might have to be revised. If the latter pattern of priming were obtained, it might indicate that the agent form is transiently activated whenever a *with-PP* is present, whether or not the specific verb in the sentence allowed an agent in the PP position. If so, this might indicate that language-level statistical information was contributing to the processing effects, which might in turn indicate a hybrid architecture.

The *agent–instrument* distinction resembles the *adjunct–argument* distinction incorporated in some parsing models (e.g., Frazier & Clifton's, 1996, *construal* account; see also Boland and Blodgett, 2006; Koenig, Mauner, & Bienvenue, 2003). On these accounts, the parser gives priority to argument relations over adjunct relations. For example, the sequence *The salesman interested the man* . . . could continue with . . . *in a wallet*, which is an argument of the verb *interested*. The sequence could also continue with . . . *in the menswear department*, which is typically interpreted as a locative and hence as an adjunct of the noun *man*. Readers take less time to process material that represents arguments than they do to process material that represents adjuncts (see, e.g., Clifton, Speer, & Abney, 1991; see also Kennison, 2002; Liversedge et al., 1998). As in many subareas within sentence processing research, there is a debate about whether arguments receive immediate priority in the parsing process (see Boland & Blodgett, 2006, for a highly coherent summary of this issue). There is a growing body of evidence suggesting that the lexical representation of verbs like *interested* incorporates information about what kinds of arguments the verbs take, that this information is activated when those verbs are accessed, and that this information supports processing of constituents representing those arguments (Jackendoff, 2007; MacDonald et al., 1994; Traxler & Tooley, in press).

What do these results imply, therefore, about parsing models in general? Most obviously, the results appear to favor accounts that incorporate distinctions between different types of modifiers. *By-phrase* agent PPs appear to be treated differently than *with-phrase* instrument PPs. This is certainly consistent with parsing models that treat arguments differently than adjuncts (Boland & Blodgett, 2006; Frazier & Clifton, 1996; Traxler & Tooley, in press). The results are also compatible with constraint-based lexicalist parsing accounts, which describe differences in parsing preferences as resulting from differences in the likelihood of different configurations. Agent PPs probably appear more frequently than instrument PPs for the kinds of verbs used in this experiment. If so, the lexicalist account would predict an overall preference for the agent PPs over the instrument PPs (in fact, length-adjusted RTs for the agent PPs were shorter than for the instrument PPs; see also Liversedge et al., 1998). A generic lexicalist account does not make an a priori prediction that instruments will prime agents, but such an effect could be accommodated within this framework if we assumed that the instrument primes activated argument structure and syntactic information, tied to individual verbs, that led to the activation of the preferred agent structural configuration. The lexicalist account would appear to predict differences in processing time for instrument and agent PPs, on the basis of how often those subtypes occur in combination with specific verbs. Because the present results suggest that the parser responds differently to agent and instrument PPs, it is likely that different statistics will be stored in the lexicon for the different PP types, represented as different connection strengths between the verb's base entry and the different phrase types.

One final point should be addressed—namely, whether effects like those obtained in the present experiment reflect semantic or syntactic processes. There are at least two different ways in which semantic effects could have affected the results. One way that semantic effects could have contributed to the priming effects is by semantic or cooccurrence association between the nouns in the prime sentence and the nouns in the target sentence; that is, if *binoculars* appeared in the prime sentence, *telescope* might be primed in the target sentence, and this would have nothing to do with syntactic priming. Another way in which semantic factors could contribute to the priming effects might be because the prime and target sentences contained the same verbs: Given that these verbs select for specific arguments or specific classes of arguments, processing the prime might have activated a set of arguments that included the nouns that appeared in the target PP.

The first semantic account would presumably assume that agent primes are more similar to agent targets than they are to instrument targets, and that instrument targets are more semantically similar to instrument targets than they are to agent targets. Thus, a simple semantic priming account would predict that both agent and instrument

primes would be more effective at priming other sentences of the same type than they would be at priming sentences of the opposite type. However, the experiment showed that instrument primes were just as effective as agent primes at facilitating agent targets, despite the fact that instrument primes are semantically less similar to agent targets than agent primes are. Given that there may be some correlation between semantic types and grammatical structure (McKoon & Ratcliff, 2003; Merlo & Stevenson, 2000; Stevenson & Merlo, 1997), semantic similarity may account for some of the speeded processing of targets in this experiment (e.g., if semantic and structural overlap were manipulated independently, semantic similarity might cause target sentences to be processed faster, whether or not there was syntactic overlap).

The second semantic account would seem to require a fairly high degree of sentence constraint—at least in the case of the agent PPs—since the verbs would seem to select only for animate agents rather than for particular subtypes of agents (e.g., nearly any person or any animal can initiate an action of *finding*). If the sentences are not particularly constraining in terms of agents, it would seem that the number of potentially anticipated nouns would be too large to support significant priming effects. A stronger case could be made for the instrument PPs, because a verb like *stabbed* would seem to strongly favor a very small class of instruments (i.e., only a very small number of instruments come to mind, with *knife* likely being the dominant response). Note, however, that this account also does not neatly explain why *stabbed with the knife* would prime *stabbed by the bartender* where there does not appear to be any preexisting association between *knife* and *bartender* to support the effect. Note, however, that it is certainly very likely that the combination of arguments (e.g., *gangster* and *drug addict* for *stabbed*) contributed to processing effects within sentences. That is, the combination of *gangster* and *stabbed* likely led to faster reading times for *drug addict* than if *drug addict* had appeared in the context of *The actor filmed by the drug addict* . . . . However, this kind of intrasentence priming effect would be equally represented in the prime sentences and in the target sentences (since these were identical), and so should not have contributed to the estimation of the between-sentence priming effects (i.e., the prime–target comparisons). If anything, intrasentence priming effects would lead to lowered estimates of the syntactic priming effects by virtue of decreasing baseline reading times. The details of the results therefore do not seem to be consistent with an account that says that semantic similarity is responsible for all of the observed facilitation.

CONCLUSION

In this experiment, sentences containing agent or instrument PPs were used to prime target sentences containing the same or different PP types. The results indicated that both instrument and agent primes led to facilitated processing of agent targets. However, instrument primes led to greater reductions than did agent primes in overall processing difficulty associated with instrument targets. This can be explained by an account under which obligatory constituents are stored and accessed with the lexical entry for the verbs in question. If this is correct, and if structural probabilities are lexically encoded, it is likely that separate probability statistics are kept for agent PPs and instrument PPs. Thus, the present results represent an important step toward a description of how structural information is organized and tied to other types of information in the lexicon.

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REFERENCES

Arai, M., van Gompel, R. P. G., & Scheepers, C. (2007). Priming ditransitive structures in comprehension. *Cognitive Psychology*, **54**, 218-250.

Badecker, W., & Caramazza, A. (1991). Morphological composition in the lexical output system. *Cognitive Neuropsychology*, **8**, 335-367.

Balota, D. A., Yap, M. J., & Cortese, M. J. (2006). Visual word recognition: The journey from features to meaning (a travel update). In M. J. Traxler & M. A. Gernsbacher (Eds.), *The handbook of psycholinguistics* (2nd ed., pp. 285-375). London: Elsevier.

Bock, J. K. (1986). Syntactic persistence in language production. *Cognitive Psychology*, **18**, 355-387.

Bock, [J.] K., & Loebell, H. (1990). Framing sentences. *Cognition*, **35**, 1-39.

Boland, J. E., & Blodgett, A. (2006). Argument status and PP-attachment. *Journal of Psycholinguistic Research*, **35**, 385-403.

Branigan, H. P., Pickering, M. J., & Cleland, A. A. (2000). Syntactic co-ordination in dialogue. *Cognition*, **75**, B13-B25.

Branigan, H. P., Pickering, M. J., & McLean, J. F. (2005). Priming prepositional-phrase attachment during comprehension. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **31**, 468-481.

Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.

Clahsen, H. (1999). Lexical entries and rules of language: A multidisciplinary study of German inflection. *Behavioral & Brain Sciences*, **22**, 991-1060.

Clifton, C., Jr., Speer, S., & Abney, S. P. (1991). Parsing arguments: Phrase structure and argument structure as determinants of initial parsing decisions. *Journal of Memory & Language*, **30**, 251-271.

Clifton, C., Jr., Traxler, M. J., Mohamed, M. T., Williams, R. S., Morris, R. K., & Rayner, K. (2003). The use of thematic role information in parsing: Syntactic processing autonomy revisited. *Journal of Memory & Language*, **49**, 317-334.

Cuetos, F., & Mitchell, D. C. (1988). Cross-linguistic differences in parsing: Restrictions on the use of the late closure strategy in Spanish. *Cognition*, **30**, 73-105.

Duffy, S. A., Henderson, J. M., & Morris, R. K. (1989). Semantic facilitation of lexical access during sentence processing. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **15**, 791-801.

Ford, M., Bresnan, J., & Kaplan, R. (1982). A competence based theory of syntactic closure. In J. Bresnan (Ed.), *The mental representation of grammatical relations* (pp. 727-796). Cambridge, MA: MIT Press.

FRAZIER, L. (1979). *On comprehending sentences: Syntactic parsing strategies*. Bloomington: Indiana University Linguistics Club.

FRAZIER, L. (1987). Sentence processing: A tutorial review. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 559-586). Hillsdale, NJ: Erlbaum.

FRAZIER, L., & CLIFTON, C., JR. (1996). *Construal*. Cambridge, MA: MIT Press.

FRAZIER, L., MUNN, A., & CLIFTON, C., JR. (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.

FRIEDERICI, A. D., HAHNE, A., & MECKLINGER, A. (1996). Temporal structure of syntactic parsing: Early and late event-related brain potential effects. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **22**, 1219-1248.

FRIEDERICI, A. D., HAHNE, A., & SADDY, D. (2002). Distinct neurophysiological patterns reflecting aspects of syntactic complexity and syntactic repair. *Journal of Psycholinguistic Research*, **31**, 45-63.

FRIEDERICI, A. D., & MECKLINGER, A. (1996). Syntactic parsing as revealed by brain responses: First-pass and second-pass parsing processes. *Journal of Psycholinguistic Research*, **25**, 157-176.

GARNSEY, S. M., PEARLMUTTER, N. J., MYERS, E., & LOTOCKY, M. A. (1997). The contributions of verb bias and plausibility to the comprehension of temporarily ambiguous sentences. *Journal of Memory & Language*, **37**, 58-93.

HAGOORT, P., BROWN, C., & GROOTHUSEN, J. (1993). The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language & Cognitive Processes*, **8**, 439-483.

HARTSUIKER, R. J., PICKERING, M. J., & VELTKAMP, E. (2004). Is syntax separate or shared between languages? Cross-linguistic syntactic priming in Spanish–English bilinguals. *Psychological Science*, **15**, 409-414.

HUMPHREYS, G. W., EVETT, L. J., & TAYLOR, D. E. (1982). Automatic phonological priming in visual word recognition. *Memory & Cognition*, **10**, 576-590.

JACKENDOFF, R. (2002). *Foundations of language*. Oxford: Oxford University Press.

JACKENDOFF, R. (2007). A parallel architecture perspective on language processing. *Brain Research*, **1146**, 2-22.

JURAFSKY, D. (1996). A probabilistic model of lexical and syntactic access and disambiguation. *Cognitive Science*, **20**, 137-194.

KAAN, E., & SWAAB, T. Y. (2003). Repair, revision, and complexity in syntactic analysis: An electrophysiological differentiation. *Journal of Cognitive Neuroscience*, **15**, 98-110.

KENNISON, S. M. (2002). Comprehending noun phrase arguments and adjuncts. *Journal of Psycholinguistic Research*, **31**, 65-81.

KOENIG, J.-P., MAUNER, G., & BIENVENUE, B. (2003). Arguments for adjuncts. *Cognition*, **89**, 67-103.

KUTAS, M., VAN PETTEN, C., & KLUENDER, R. (2006). Psycholinguistics electrified II (1994-2005). In M. J. Traxler & M. A. Gernsbacher (Eds.), *The handbook of psycholinguistics* (2nd ed., pp. 659-724). London: Elsevier.

LEDOUX, K., TRAXLER, M. J., & SWAAB, T. Y. (2007). Syntactic priming in comprehension: Evidence from event-related potentials. *Psychological Science*, **18**, 135-143.

LIVERSEDGE, S. P., PICKERING, M. J., BRANIGAN, H. P., & VAN GOMPEL, R. P. G. (1998). Processing arguments and adjuncts in isolation and context: The case of by-phrase ambiguities in passives. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **24**, 461-475.

LUKA, B. J., & BARSALOU, L. W. (2005). Structural facilitation: Mere exposure effects for grammatical acceptability as evidence for syntactic priming in comprehension. *Journal of Memory & Language*, **52**, 436-459.

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

MAUNER, G., TANENHAUS, M. K., & CARLSON, G. N. (1995). Implicit arguments in sentence processing. *Journal of Memory & Language*, **34**, 357-382.

MCKOON, G., & RATCLIFF, R. (2003). Meaning through syntax: Language comprehension and the reduced relative clause construction. *Psychological Review*, **110**, 490-525.

MERLO, P., & STEVENSON, S. (2000). Lexical syntax and parsing architecture. In M. W. Crocker, M. J. Pickering, & C. Clifton, Jr. (Eds.), *Architectures and mechanisms for language processing* (pp. 161-188). New York: Cambridge University Press.

MEYER, D. E., & SCHVANEVELDT, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, **90**, 227-234.

MITCHELL, D. C. (1987). Lexical guidance in human parsing: Locus and processing characteristics. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 601-618). Hillsdale, NJ: Erlbaum.

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 (nonlexical) statistical records. *Journal of Psycholinguistic Research*, **24**, 469-488.

OSTERHOUT, L., & HOLCOMB, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory & Language*, **31**, 785-806.

PICKERING, M. J., & TRAXLER, M. J. (2004, March). *Grammatical repetition and garden path effects*. Paper presented to the 6th Annual CUNY Sentence Processing Conference, College Park, MD.

RASTLE, K., DAVIS, M. H., MARSLEN-WILSON, W. D., & TYLER, L. K. (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language & Cognitive Processes*, **15**, 507-537.

RAYNER, K., CARLSON, M., & FRAZIER, L. (1983). The interaction of syntax and semantics during sentence processing: Eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning & Verbal Behavior*, **22**, 358-374.

RAYNER, K., & DUFFY, S. A. (1986). Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition*, **14**, 191-201.

RAYNER, K., & POLLATSEK, A. (1989). *The psychology of reading*. Englewood Cliffs, NJ: Prentice-Hall.

STEVENSON, S., & MERLO, P. (1997). Lexical structure and parsing complexity. *Language & Cognitive Processes*, **12**, 349-399.

TARABAN, R., & MCCLELLAND, J. L. (1988). Constituent attachment and thematic role assignment in sentence processing: Influences of content-based expectations. *Journal of Memory & Language*, **27**, 597-632.

TOOLEY, K. M., TRAXLER, M. J., & SWAAB, T. Y. (2007). *Electrophysiological evidence of syntactic priming in sentence comprehension*. Manuscript submitted for publication.

TRAXLER, M. J. (2002). Plausibility and subcategorization preference in children's processing of temporarily ambiguous sentences: Evidence from self-paced reading. *Quarterly Journal of Experimental Psychology*, **55A**, 75-96.

TRAXLER, M. J. (2005). Plausibility and verb subcategorization preference in temporarily ambiguous sentences: Evidence from self-paced reading. *Journal of Psycholinguistic Research*, **34**, 1-30.

TRAXLER, M. J., & PICKERING, M. J. (2005, March). *Syntactic priming in comprehension*. Paper presented to the 17th Annual CUNY Sentence Processing Conference, Tucson, AZ.

TRAXLER, M. J., & TOOLEY, K. M. (2007). Lexical mediation and context effects in sentence processing. *Brain Research*, **1146**, 59-74.

TRAXLER, M. J., & TOOLEY, K. M. (in press). Priming in on-line sentence comprehension: Strategic or syntactic? *Language & Cognitive Processes*.

TRUESWELL, J. C., TANENHAUS, M. K., & KELLO, C. (1993). Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden-paths. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **19**, 528-553.

VOSSE, T., & KEMPEN, G. (2000). Syntactic structure assembly in human parsing: A computational model based on competitive inhibition and lexicalist grammar. *Cognition*, **75**, 105-143.

NOTES

1. Branigan and colleagues demonstrated priming for the final interpretation of *high–low* attachment ambiguities, but these effects do not

illuminate the processes that comprehenders used to arrive at those final interpretations (Branigan, Pickering, & McLean, 2005). Luka and Barsalou (2005) showed effects of exposure on offline acceptability judgments, but here too there is no indication whether processing a prime sentence facilitates processing of a target with similar structural properties.

2. There is an ongoing debate about whether the P600 indexes only syntactic processing problems; and ERP provides other indicators of syntactic processing difficulty, such as the LAN or ELAN (Kutas, van Petten, & Kluender, 2006).

3. Sentences 4 and 5 contain additional ambiguities beyond the main verb-reduced relative structure. For example, at the word *by*, the PP could be agent or locative. In Sentence 5, the preposition *with* could indicate an upcoming instrument or an adverbial modifier (e.g., *with glee*). Because each target sentence serves as its own control, however, the observed priming effects will not be affected by these extraneous variables.

4. The results of the length correlations are as follows. First-pass time = 137 msec + 27.7 msec × length. Length effect $t = 19.1$, $p < .0001$. Regression-path time = 186 msec + 33.7 msec × length. Length effect $t = 18.0$, $p < .0001$. Total time = 302 msec + 29.8 msec × length. $t = 18.1$, $p < .0001$. The first-pass regressions analysis did not show a significant relationship between region length; % regressions = 18.3% − 0.097% × length; $t = -0.296$, n.s.

5. See McKoon and Ratcliff (2003) for a critical review of this interpretation of reduced relative syntax and semantics.

APPENDIX

The woman sketched by the artist was very beautiful.
The woman sketched with the chalk was very beautiful.
The student sketched by the painter had a mole on her hip.
The student sketched with the black pencil had a mole on her hip.

The patient examined by the physician had a rare disease.
The patient examined with the stethoscope had a rare disease.
The football player examined by the team trainer had a torn ligament.
The football player examined with the x-ray machine had a torn ligament.

The man recorded by the secretary could not be understood.
The man recorded with the new microphone could not be understood.
The singer recorded by the studio had a nasty reputation.
The singer recorded with the four-track system had a nasty reputation.

The director watched by the cop was in a bad part of town.
The director watched with the binoculars was in a bad part of town.
The lifeguard watched by the swimmer had a deep dark suntan.
The lifeguard watched with the telescope had a deep dark suntan.

The woman scratched by the cat was barely injured.
The woman scratched with the pin was barely injured.
The child scratched by the thorn bush was looking for her ball.
The child scratched with the stick was looking for her ball.

The rebels battled by the security forces fled into the jungle.
The rebels battled with the aircraft fled into the jungle.
The soldiers battled by the guerillas triumphed in the end.
The soldiers battled with the poison gas triumphed in the end.

The lifeguard splashed by the kids laughed out loud.
The lifeguard splashed with the water laughed out loud.
The woman splashed by the painter had to take a shower.
The woman splashed with the paint had to take a shower.

The hiker found by the rescue dog had a broken leg.
The hiker found with the rescue dog had a broken leg.
The aircraft found by the air traffic controller was way off course.
The aircraft found with the new radar system was way off course.

The child frightened by the burglar ran outside.
The child frightened with the monster mask ran outside.
The baby frightened by the noise was shaking uncontrollably.
The baby frightened with the puppet shook uncontrollably.

The comedian toasted by the emcee told a few jokes.
The comedian toasted with the champagne told a few jokes.
The scientist toasted by the dean was a little embarrassed.
The scientist toasted with the white wine was a little embarrassed.

The college student entertained by the musician applauded loudly.
The college student entertained with the video game applauded loudly.
The teenagers entertained by the performers stayed out late.
The teenagers entertained with the puzzles stayed out late.

APPENDIX (Continued)

The miners rescued by the paramedics recovered slowly.
The miners rescued with the heavy equipment recovered slowly.
The hikers rescued by the fisherman appeared on the 6 o'clock news.
The hikers rescued with the helicopter appeared on the 6 o'clock news.

The girl tickled by her uncle tried to get away.
The girl tickled with the feather tried to get away.
The boy tickled by the girl told her to stop.
The boy tickled with the flower told the girl to stop.

The gangster stabbed by the drug addict was rushed to the emergency room.
The gangster stabbed with the stiletto was rushed to the emergency room.
The prowler stabbed by the bartender lost a lot of blood.
The prowler stabbed with the kitchen knife lost a lot of blood.

The baby delighted by the clown giggled constantly.
The baby delighted with the new toy giggled constantly.
The child delighted by the magician clapped her hands.
The child delighted with the magic show clapped her hands.

The intruder detected by the guard was arrested and sent to jail.
The intruder detected with the surveillance equipment was arrested and sent to jail.
The aircraft detected by the radar operator landed safely.
The aircraft detected with the early warning system landed safely.

The secretary spotted by the manager returned the stolen office supplies.
The secretary spotted with the security camera returned the stolen office supplies.
The tiger spotted by the hunter ran off through the jungle.
The tiger spotted with the binoculars ran off through the jungle.

The snake charmed by the old man didn't bite anyone.
The snake charmed with the flute didn't bite anyone.
The manager charmed by the employees gave everyone the day off.
The manager charmed with the bouquet gave everyone the day off.

The grandfather bored by the grandchildren told stories of his youth.
The grandfather bored with the newspaper told stories of his youth.
The waitress bored by the author turned on the TV.
The waitress bored with the novel turned on the TV.

The diver impressed by the swimmer learned to do the butterfly.
The diver impressed with the facilities learned to do the butterfly.
The senator impressed by the constituent sent a letter of apology.
The senator impressed with the petition sent a letter of apology.

The guard attacked by the prisoner was badly injured.
The guard attacked with the knife was badly injured.
The soldier attacked by the criminal had to go to the hospital.
The soldier attacked with the bayonet had to go to the hospital.

The spectator assaulted by the drunk fell to the ground.
The spectator assaulted with the pepper spray fell to the ground.
The trespasser assaulted by the home owner fled the house.
The trespasser assaulted with the baseball bat fled the house.

The accident victim treated by the paramedic felt better in a few days.
The accident victim treated with the painkillers felt better in a few days.
The patient treated by the new doctor recovered quickly.
The patient treated with the new medicine recovered quickly.

The veterinarian paid by the client saved the cat's life.
The veterinarian paid with the credit card saved the cat's life.
The mechanic paid by the lawyer did a fine job.
The mechanic paid with the check did a fine job.

The politician confronted by the reporter lied and lied and lied.
The politician confronted with the facts lied and lied and lied.
The criminal confronted by the detective confessed to the crime.
The criminal confronted with the evidence confessed to the crime.

APPENDIX (Continued)

The celebrity photographed by the tourists had just released a new movie.
The celebrity photographed with the zoom lens had just released a new movie.
The tourist photographed by the policeman hadn't committed any crime.
The tourist photographed with the digital camera hadn't committed any crime.

The computer accessed by the hacker had a million social security numbers.
The computer accessed with the password had a million social security numbers.
The program accessed by the manager kept track of the inventory.
The program accessed with the secret code kept track of the inventory.

The space alien blasted by the robots disappeared in a blinding flash.
The space alien blasted with the laser cannon disappeared in a blinding flash.
The wizard blasted by the sorcerer turned into a black toad.
The wizard blasted with the magic spells turned into a black toad.

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