# The pistol that injured the cowboy: Difficulty with inanimate subject–verb integration is reduced by structural separation

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## ARTICLE INFO

## ABSTRACT

Previous work has suggested that the difficulty normally associated with processing an object-extracted relative clause (ORC) compared to a subject-extracted relative clause (SRC) is increased when the head noun phrase (NP1) is animate and the embedded noun phrase (NP2) is inanimate, compared to the reverse animacy configuration. Two eye-tracking experiments were conducted to determine whether the apparent effects of NP animacy on the ORC–SRC asymmetry reflect distinct processes of interpretation that operate at NP2 and NP1. Experiment 1 revealed a localized difficulty interpreting the embedded action verb when the preceding NP2 was inanimate as compared to animate, but this difficulty in subject–verb integration did not extend to the broader region of words in the RC and matrix verb where difficulty was observed in processing ORCs as compared to SRCs. Experiment 2 demonstrated that the difficulty associated with integrating an inanimate NP with an action verb is reduced when the two appear in separate clauses, as in the case of an SRC.

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## Introduction

The expressive power of human language rests in part on its ability to represent multiple relationships between different entities in a single sentence with more than one clause. The process of understanding such complex sentences requires that this representation be built incrementally as the words of a sentence are read or heard, even though the relationships between the meanings conveyed by those words may not be clear until all the words of a sentence are encountered. Research investigating the cognitive processes underlying the comprehension of complex sentences has focused a great deal on sentences containing subject-extracted and object-extracted relative clauses (RCs). In a subject RC (SRC), as in (1a), the head noun phrase (NP) is the subject of the RC, whereas in an object RC (ORC), as in (1b), the head NP is the object of the RC. These two sentences contain the exact same words, just in a different order, yet ORCs have been shown to impose

greater processing difficulty than SRCs on a wide variety of tasks (e.g., Caplan, Alpert, & Waters, 1998; Caramazza & Zurif, 1976; Ford, 1983; Holmes & O'Regan, 1981; Just, Carpenter, Keller, Eddy, & Thulborn, 1996; King & Just, 1991; Wanner & Maratsos, 1978).

> 1a. The reporter that injured the senator persuaded the members of the jury.
> 1b. The reporter that the senator injured persuaded the members of the jury.

Although different types of cognitive mechanisms have been implicated as contributing to the difficulty of incremental interpretation of complex sentences (for a review see Gordon & Lowder, in press), it is clear that mechanisms that find meaningful relationships between parts of a sentence can offset complexity effects when those relationships are easy to establish. For example, King and Just (1991) demonstrated that the difficulty associated with processing an ORC sentence with arbitrary noun–verb pairings (e.g., *The robber that the fireman detested watched the program*) was substantially reduced when there were

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inherent semantic relationships between the nouns and verbs (e.g., *The robber that the fireman rescued stole the jewelry*).

The factors that facilitate establishment of meaningful relationships between parts of a complex sentence do not depend completely on there being specific relationships between nouns and verbs at the level of events that are likely to occur (as in *fireman rescued* and *robber stole* in the King and Just example). Instead, it has been argued that they include relationships at the level of thematic roles (Gennari & MacDonald, 2008, 2009; Mak, Vonk, & Schriefers, 2002, 2006; Traxler, Morris, & Seely, 2002; Traxler, Williams, Blozis, & Morris, 2005). For example, Traxler et al. (2002, 2005) varied the animacy of the two critical NPs in RC sentences, as in (2). They found that ORCs with an inanimate head NP and an animate embedded NP (2b) were as easy to process as SRCs (2c)–(2d), but that ORCs with an animate head NP and an inanimate embedded NP (2a) were more difficult than the other three conditions. This difficulty emerged not only on the relative clause itself, but also extended to the matrix verb.

2a. *The cowboy that the pistol injured was known to be unreliable.*
2b. *The pistol that the cowboy concealed was known to be unreliable.*
2c. *The cowboy that concealed the pistol was known to be unreliable.*
2d. *The pistol that injured the cowboy was known to be unreliable.*

As can be seen in (2), the experimental materials used by Traxler et al. (2002, 2005) compared conditions in which each sentence contains both an animate and an inanimate NP. This configuration is problematic because it is impossible to determine whether the greater difficulty found between the ORC sentences in (2a) and (2b) is caused by the animacy of NP1, the animacy of NP2, or a combination of both. Determining the source of the processing difficulty is complicated further by the need to use different embedded verbs in the two types of ORC sentences. While previous research on the role of animacy in RC processing has typically varied the animacy of NP1 and NP2 together, the role of the animacy of NP2 on the processing difficulty found in ORCs can be isolated by varying the animacy of NP2 and holding both NP1 and the embedded verb constant as shown in (3).

3a. *The sheriff that the cowboy injured persuaded the members of the jury.*
3b. *The sheriff that the pistol injured persuaded the members of the jury.*

The contrast between (3a) and (3b) suggests that at least part of the reason for the advantage in understanding ORCs with animate NP2s as compared to inanimate NP2s is local to the processing of the embedded clause rather than to processing the embedded clause in relation to information in the main clause. The embedded verb may be easier to interpret when there is an animate NP2 (e.g., *cowboy injured*) than when there is an inanimate NP2 (e.g., *pistol injured*). A local difference in ease of processing could arise for several reasons. For example, it has been suggested that an inanimate subject NP may force a non-prototypical assignment of thematic roles (instrument rather than agent; Cruse, 1973; Dowty, 1991; Fillmore, 1968; Schlesinger, 1989; Wolff, Jeon, Klettke, & Li, 2010; Wolff, Jeon, & Li, 2009). Difficulty might also arise from additional processing steps required for enriched composition (McElree, Traxler, Pickering, Seely, & Jackendoff, 2001; Pustejovsky, 1995; Traxler, Pickering, & McElree, 2002), or from the need to access literal interpretations prior to figurative interpretations (Grice, 1975; Searle, 1979). Thus, a variety of types of evidence suggest that local interpretation of the inanimate noun and verb paired within the embedded ORC might account for all or part of previously reported effects of animacy on the ORC–SRC asymmetry in ease of processing. However, this possibility is by no means certain, as other psycholinguistic research supports the notion that interpretations that are metaphorical (Glucksberg, 1991, 2003) or metonymic (Frisson & Pickering, 1999; Humphrey, Kemper, & Radel, 2004) are accessed as quickly as literal interpretations, an alternative that suggests that there would be no local difference in ease of processing the inanimate-noun and verb pairings within the embedded ORC.

The hypothesis that a local effect of NP2 animacy accounts for results previously attributed to the effect of animacy on relative-clause processing per se (e.g., 2a versus 2b) is challenged further by evidence that the animacy of NP1 has little or no effect on the ease of processing within SRC sentences (e.g., 2c versus. 2d). Such an effect might be expected since the head of an SRC is the subject of the embedded verb, yielding pairings of inanimate NP1 with embedded verb (see 2d) that match those found in the ORC constructions with an inanimate NP2 (see 2a). If interpretation of the pairings of inanimate nouns and verbs used in these studies imposes a local processing cost, then the absence of such an effect for the SRC sentences must be explained. A variety of types of psycholinguistic evidence indicates that the relations between different parts of a sentence are processed to varying degrees, with the depth of processing depending greatly on the structure of the sentence (Baker & Wagner, 1987; Bredart & Modolo, 1988; Ferreira, Bailey, & Ferraro, 2002; Gordon & Hendrick, 1998; Sanford & Sturt, 2002). This suggests that processing of the meanings of an NP and a verb may occur at a deeper level when the expressions are within the same clause as compared to when they are separated by a clause boundary such as when an SRC modifies an inanimate head noun (e.g., 2d).

## Experiment 1

This experiment examined the processing of ORCs when the embedded NP was animate versus inanimate. The ORCs used by Traxler et al. (2005, Experiment 3) were adapted for the current experiment so as to allow a careful examination of the locus of this difficulty. Traxler et al.'s sentences contained embedded nouns that differed in animacy, but the experimental contrasts also involved

different embedded verbs (e.g., *pistol injured* versus *cowboy concealed*; see 2a–2b) and different head nouns. Accordingly, these materials were altered so that the only difference between the two ORCs was the animacy of the embedded NP (see 4b–4c). In addition, we created an SRC version of each sentence (4a). Thus, a comparison of condition (4a) with (4b) should reveal an ORC–SRC processing difference, whereas a comparison of (4b) and (4c) allows examination of the locus of the processing difficulty associated with integrating an inanimate versus animate subject with a verb. We refer to these three conditions as SRC, ORC-Animate, and ORC-Inanimate, respectively.

> 4a. *The sheriff that injured the cowboy persuaded the members of the jury.* (SRC)
> 4b. *The sheriff that the cowboy injured persuaded the members of the jury.* (ORC-Animate)
> 4c. *The sheriff that the pistol injured persuaded the members of the jury.* (ORC-Inanimate)

Based on the findings of previous work (Gennari & MacDonald, 2008; Traxler et al., 2002, 2005), we expected the ORC-Inanimate condition to be more difficult than the ORC-Animate condition. With regard to the locus of this effect, two outcomes are possible. First, it is possible that the difficulty associated with the ORC-Inanimate condition will appear in a broad region of the sentence, perhaps beginning early in the RC and continuing on to the matrix verb. This pattern would provide support for the idea that NP animacy influences RC processing, as a large body of literature has demonstrated that the difficulty associated with processing an ORC affects reading times for several words in the sentence (e.g., Ford, 1983; Gordon, Hendrick, & Johnson, 2001, 2004; Gordon, Hendrick, Johnson, & Lee, 2006; Holmes & O'Regan, 1981; Johnson, Lowder, & Gordon, 2011; King & Just, 1991; Traxler et al., 2002, 2005; see Gordon & Lowder, in press, for review). Alternatively, it is possible that the difficulty associated with the ORC-Inanimate condition is unrelated to broad RC-level effects, but instead emerges due to the local difficulty of integrating an inanimate noun with an action verb, such as *pistol injured*.

The possibility of using an inanimate noun as the subject of an action verb was noted by Fillmore (1968), who observed that an instrument that appears as part of an adjunct phrase in a causal construction (e.g., *John broke the window with a hammer*) can also often appear as the external argument of the verb (e.g., *A hammer broke the window*; see also Cruse, 1973). Inanimate NPs vary in their acceptability as "causers," and verbs vary in the ease with which they can be paired with inanimate causers. For example, Schlesinger (1989) noted that *The dishwasher cleaned the dishes* sounds more natural than *The rag cleaned the dishes*, perhaps because machines make better agents than do rags. He further noted that *The bullet killed the president* is acceptable while *The bullet murdered the president* is anomalous, because the verb *murder* requires that the subject possess intention (see also Wolff et al., 2010). Dowty (1991) proposed that the thematic roles assigned to the arguments of a verb tend to possess certain prototypical features falling into one of two broad categories, which he terms Proto-Agent and Proto-Patient. Dowty lists

several features belonging to a Proto-Agent, which include the ability to change the state of another participant and the ability to initiate movement. This perspective may help explain why certain inanimate NPs are more acceptable than others as the subject of an action verb.

In addition, the presence of an inanimate NP as the subject of an action verb might require a process of figurative interpretation. For example, in (4c), a *pistol* is incapable of performing the action *injure* on its own. Thus, one may infer here that the tool is being used as a referential expression to stand for the unnamed animate agent (e.g., *the one who used the pistol*). This suggests a type of *metonymic* construction, where some salient characteristic of an entity refers to the entity as a whole. Research on language processing provides conflicting perspectives about whether literal and figurative meanings are processed differently. While some models propose that a literal interpretation must be accessed before a figurative interpretation (e.g., Grice, 1975; Searle, 1979), others propose that literal and figurative interpretations can be accessed in parallel (e.g., Glucksberg, 1991, 2003). Although a great deal of work has been devoted to better understanding the processing of figurative language in general (e.g., Gerrig & Healy, 1983; Gibbs, 1980, 1986; Gibbs, Bogdanovich, Sykes, & Barr, 1997; Inhoff, Lima, & Carroll, 1984; Onishi & Murphy, 1993; Ortony, Schallert, Reynolds, & Antos, 1978; Shinjo & Myers, 1987), very little work has examined the processing of metonymy specifically. One prominent exception is Frisson and Pickering (1999), who measured eye movements while participants read sentences containing place-for-institution metonyms (e.g., *That blasphemous woman had to answer to the convent*) and place-for-event metonyms (e.g., *A lot of Americans protested during Vietnam*). Frisson and Pickering showed that processing these metonyms was just as easy as processing the same words when they were used in their literal sense, thus providing evidence for parallel access of the literal and figurative interpretations.

Expressions such as *pistol injured* are closer in form to what Lakoff and Johnson (1980) termed object-for-user metonyms (e.g., *The gun he hired wanted fifty grand*) than to the place-for-institution and place-for-event metonyms studied by Frisson and Pickering (1999). Object-for-user metonyms were studied by Gibbs (1990), who found greater whole-sentence reading times when the sentence subject was metonymic (e.g., *scalpel* to refer to *surgeon*) compared to both a literal condition (e.g., *doctor*) and a metaphoric condition (e.g., *butcher*), suggesting some processing cost associated with figurative interpretation. Whereas the object-for-user metonyms studied by Gibbs were constructed so that the metonym referred to a person (e.g., *The scalpel was sued for malpractice*), constructions like (4c) can be understood either by inferring that the instrument represents a person (e.g., *pistol* to refer to *shooter*), or by inferring that the instrument represents an event (e.g., *someone's shooting of the pistol*). This latter perspective has been discussed by Pustejovsky (1995) in his comparison of the two sentences presented in (5). Here, the verb *kill* specifies an action, and so it selects for an animate NP as its subject. This requirement is satisfied in (5a), but not in (5b). Specifically, Pustejovsky proposes that the

inanimate subject in (5b) represents a type of metonymic construction that requires an additional process of deep interpretation, which he called *coercion*. That is, Pustejovsky proposes that the inanimate entity in (5b) makes sense as the subject of the sentence because it is coerced from an object (e.g., *the gun*) into an event involving an animate agent (e.g., *someone's shooting of the gun*).

5a. John killed Mary.
5b. The gun killed Mary.

Evidence that coercion incurs a processing cost has been found for NPs that syntactically appear as direct objects and which refer to objects when they follow verbs that require an event complement as compared to those that take a direct object (e.g., *The author began/wrote the book*; McElree et al., 2001; Traxler et al., 2002). However, psycholinguistic evidence of coercion has not previously been reported for the conditions to be studied here – subject NPs that do not meet animacy specifications of verbs.

In sum, multiple linguistic and psycholinguistic approaches suggest that subject–verb integration should be more difficult for inanimate than animate nouns. Previous studies on animacy and relative-clause processing have provided evidence that there is difficulty associated with embedding an inanimate NP within an ORC and that this difficulty contributes to the overall processing of the RC. However, the covariation of animacy configurations and different embedded verbs used by these studies make this interpretation problematic. Experiment 1 was designed to more carefully isolate the locus of processing difficulty by comparing ORCs where the only variation across ORC conditions was in the animacy of the embedded noun.

*Method*

*Participants*

Twenty-four students at the University of North Carolina at Chapel Hill participated in this experiment in exchange for course credit. They were all native English speakers and had normal or corrected-to-normal vision.

*Materials*

Each participant was presented with 30 experimental sentences and 94 filler sentences. The 30 experimental sentences were adapted from Traxler et al. (2005, Experiment 3). These materials were modified to include a new animate noun that served as NP1 in all three versions of each sentence (e.g., *sheriff*; see 4a–4c). The embedded verb, animate NP2, and inanimate NP2 were all taken directly from Traxler et al. Importantly, Traxler et al. had carefully balanced the animate and inanimate NP2s for length and frequency. The matrix verb and the remainder of the sentence were modified such that the meaning could feasibly apply to either of the two animate NPs or the inanimate NP (see Appendix A for full set of experimental stimuli).

4a. *The sheriff that injured the cowboy persuaded the members of the jury*. (SRC)
4b. *The sheriff that the cowboy injured persuaded the members of the jury*. (ORC-Animate)

4c. *The sheriff that the pistol injured persuaded the members of the jury*. (ORC-Inanimate)

In addition to controlling for frequency of N2, we computed bigram (word-pair) frequencies of N2 and the embedded verb for the ORC-Animate versus ORC-Inanimate conditions (e.g., *cowboy injured* versus *pistol injured*) using two different corpora: the Corpus of Contemporary American English (COCA; Davies, 2008) and the Google Terabyte N-Gram corpus (Brants & Franz, 2006). These corpora give highly consistent estimates of the relative frequency of the critical words in the study, showing the following Spearman rank-order correlations: embedded animate nouns (rho = .92, $p < .001$), embedded inanimate nouns (rho = .89, $p < .001$), and embedded verbs (rho = .90, $p < .001$). COCA provided bigram frequencies for 25 out of the 60 critical noun–verb pairs in the materials, whereas Google N-Gram provided bigram frequencies for 39 of the 60 pairs. This difference is likely due to COCA being based on a smaller sample of text (425 million words) as compared to Google N-Gram (approximately 1,000,000,000,000 words). The fact that over one third of the noun–verb pairs were not observed even in Google N-Gram points to the limitations of using even a very large corpus, one far larger than any individual's life experience with language, to estimate the predictability of a word based on the preceding word. Transitional probabilities, defined as the probability of encountering a particular word, given the preceding word (McDonald & Shillcock, 2003), were computed from Google N-Gram. These did not differ between the ORC-Animate (.000089) and ORC-Inanimate (.000091) conditions, $[t(37) = 0.02, p > .98]$, suggesting that predictability of the verb did not vary systematically across conditions based on the animacy of the preceding noun.

Traxler et al. (2005, Experiment 3) had matched their stimuli for plausibility across conditions. In Traxler et al.'s experiment, rating data collected from 12 participants showed no significant differences in mean plausibility ratings between any of the conditions. Although our materials involved only minor changes to Traxler et al.'s materials, we nevertheless wanted to ensure that there were no differences in plausibility among our three conditions. Accordingly, we presented our stimuli, along with filler items, to 15 raters who did not participate in the eye-tracking experiment. The task was to indicate how likely they believed the events described by the sentence were on a scale from 1 (highly unlikely) to 5 (highly likely; e.g., Pickering & Traxler, 1998; Traxler & Pickering, 1996). Each rater saw the sentences in a different random order. Mean plausibility ratings were 3.3 (SRC), 3.2 (ORC-Animate), and 3.2 (ORC-Inanimate). A repeated-measures ANOVA revealed no significant differences across conditions, $F < 1$.

For the eye-tracking experiment, one version of each item was assigned to one of three lists such that no participant saw more than one version of each item. After each sentence, a true/false comprehension question appeared. For the experimental sentences, two-thirds of the comprehension questions asked about the action being described in the RC, whereas the other third asked about the action

being described in the main clause (King & Just, 1991). Half of the questions were true and half were false.

### Design and procedure

Each experimental session began with four filler sentences. After this warm-up block, the remaining 120 sentences were presented in a different random order for each participant. Participants were instructed to read at a natural pace and to press a key after reading each sentence. At this point, the comprehension question appeared, and participants pressed one key to answer "true," and another to answer "false."

Participants' eye movements were monitored using an EyeLink 1000 system (SR Research). This device records eye movements using a camera mounted on the table in front of participants, sampling pupil location at a rate of 1000 Hz and parsing the samples into fixations and saccades. After undergoing a procedure that calibrated the eye-tracker, the experimental session began. At the start of each trial, a fixation point was presented on the screen in the location where the first word of the sentence would appear. When the experimenter judged the participant's gaze to be steady on the fixation point, the experimenter pressed a button that made the fixation point disappear and the sentence appear. After reading the sentence, the participant pressed a key, which made the sentence disappear and a comprehension question appear. After the participant responded to the comprehension question, the trial ended and the fixation point for the next trial appeared.

### Results

Reading times from all trials were included, regardless of whether the comprehension question was answered correctly. Analysis of the eye-tracking data focused on three standard measures. *Gaze duration* is the sum of all initial fixations on a word or region; it begins when the region is first fixated and ends when gaze is directed away from the region, whether to the left or the right. *Regression-path duration* (also called *go-past time*) is the sum of all fixation durations beginning with the initial fixation on a particular region and ending when the gaze is directed to the right of that region. This measure incorporates both early and later stages of language comprehension and is particularly useful for measuring integration difficulties (Clifton, Staub, & Rayner, 2007). *Total time* is the sum of all fixations on a word or region. The offline measure of comprehension-question accuracy is also reported.

To assess the RC effect, we report reading times for two regions of interest: the RC and the matrix verb. We chose to analyze the RC as a single region, rather than as a series of individual words, to control for the different word orders of SRCs and ORCs. This region consisted of the three words between the complementizer and the matrix verb. At the matrix verb, the word orders of SRCs and ORCs are identical once again, so this word can be analyzed on its own. In addition to comparing reading times for the RC region and the matrix verb across the three conditions, we were able to take a more fine-grained look at the RC region for the ORC-Animate and ORC-Inanimate conditions.

**Table 1**
Eye-tracking results of relative-clause effects in Experiment 1. The RC region was defined as the three words after the complementizer and before the matrix verb.

| Region of interest | Condition | Measure (in ms) | | |
|---|---|---|---|---|
| | | Gaze | Regression-path | Total time |
| RC region | SRC | 509 | 796 | 1423 |
| | ORC-Animate | 536 | 1078 | 1814 |
| | ORC-Inanimate | 519 | 1188 | 1676 |
| Matrix verb | SRC | 284 | 467 | 594 |
| | ORC-Animate | 306 | 641 | 671 |
| | ORC-Inanimate | 301 | 624 | 672 |

Table 1 displays reading-time means relevant to RC-level effects. Specifically, we compared reading times for all three conditions at the RC and the matrix verb.

### RC region

For each of the three reading-time measures, we conducted a one-way repeated-measures ANOVA comparing the three conditions. Analysis of gaze duration on the RC region revealed no significant differences among the three conditions [$F_1(2,46) < 1$; $F_2(2,58) < 1$]. In contrast, significant differences were obtained for regression-path duration [$F_1(2,46) = 27.69$, $MSE = 35,478$, $p < .001$; $F_2(2,58) = 21.04$, $MSE = 58,416$, $p < .001$] and total time [$F_1(2,46) = 16.31$, $MSE = 58,099$, $p < .001$; $F_2(2,58) = 6.32$, $MSE = 182,402$, $p < .005$]. Follow-up comparisons indicated a robust ORC–SRC processing difference, with longer reading times for ORC-Animates compared to SRCs on regression-path duration [$F_1(1,23) = 43.86$, $MSE = 21,782$, $p < .001$; $F_2(1,29) = 33.02$, $MSE = 36,624$, $p < .001$], as well as total time [$F_1(1,23) = 36.06$, $MSE = 51,054$, $p < .001$; $F_2(1,29) = 10.64$, $MSE = 210,967$, $p < .005$]. Similar differences were observed for ORC-Inanimates compared to SRCs on regression-path duration [$F_1(1,23) = 32.29$, $MSE = 57,191$, $p < .001$; $F_2(1,29) = 35.20$, $MSE = 65,440$, $p < .001$], as well as total time [$F_1(1,23) = 16.50$, $MSE = 46,875$, $p < .001$; $F_2(1,29) = 6.59$, $MSE = 139,593$, $p < .02$]. In addition, regression-path durations showed that ORC-Inanimates were read more slowly than ORC-Animates (significant in the subject analysis) [$F_1(1,23) = 5.30$, $MSE = 27,460$, $p < .05$; $F_2(1,29) = 2.39$, $MSE = 73,185$, $p > .13$], whereas there were no significant differences for these two conditions in the total time data ($p$'s > .10). The nature of the difference between the ORC-Animate and ORC-Inanimate conditions is explored in greater detail below.

### Matrix verb

Analysis of gaze durations on the matrix verb showed no significant differences between the three conditions, [$F_1(2,46) < 1$; $F_2(2,58) = 1.25$, $p > .25$]. There was, however, a significant difference between the three conditions at the matrix verb for regression-path duration [$F_1(2,46) = 7.02$, $MSE = 31,566$, $p < .01$; $F_2(2,58) = 5.35$, $MSE = 46,103$, $p < .01$] and a significant difference for total time in the subject analysis, but not in the item analysis [$F_1(2,46) = 4.73$, $MSE = 10,197$, $p < .05$; $F_2(2,58) = 1.87$, $MSE = 30,497$,

$p > .15$]. Follow-up comparisons revealed longer reading times for ORC-Animates compared to SRCs for regression-path duration [$F_1(1,23) = 8.64$, $MSE = 42,054$, $p < .01$; $F_2(1,29) = 9.33$, $MSE = 44,517$, $p < .01$], and a similar pattern in the subject analysis for total time [$F_1(1,23) = 5.36$, $MSE = 13,314$, $p < .05$; $F_2(1,29) = 2.50$, $MSE = 35,354$, $p > .10$]. Likewise, there were significant differences between the ORC-Inanimates and the SRCs for regression-path duration [$F_1(1,23) = 17.48$, $MSE = 17,060$, $p < .001$; $F_2(1,29) = 4.90$, $MSE = 65,015$, $p < .05$], and a similar pattern in the subject analysis for total time [$F_1(1,23) = 8.52$, $MSE = 8593$, $p < .01$; $F_2(1,29) = 2.55$, $MSE = 32,489$, $p > .10$]. In contrast to the ORC–SRC difference, there were no differences between the ORC-Animate and ORC-Inanimate conditions at the matrix verb for either regression-path duration or total time ($p$'s > .60).

### Words in the ORC

As noted above, there was a significant difference between the two ORC conditions for regression-path duration on the RC region as a whole. Because these two conditions have identical word orders, it was possible to isolate the locus of this effect with a more fine-grained, word-by-word analysis of the RC region (see Table 2). Comparing regression-path duration for ORC-Animates and ORC-Inanimates at these individual words revealed no differences at the determiner [$F_1(1,23) < 1$; $F_2(1,29) < 1$], nor at the embedded noun [$F_1(1,23) < 1$; $F_2(1,29) < 1$]. Critically, however, the two conditions differed significantly at the embedded verb, such that ORC-Inanimates were slower than ORC-Animates [$F_1(1,23) = 8.23$, $MSE = 19,026$, $p < .01$; $F_2(1,29) = 4.05$, $MSE = 55,971$, $p = .05$]. This pattern of effects is depicted graphically in Fig. 1.[1]

Analysis of gaze durations and total times for each word in the RC revealed no significant differences between the ORC-Inanimate and ORC-Animate conditions.

### Comprehension-question accuracy

Comprehension questions following four of the sentences had overall accuracy rates lower than 50%. A closer look at these items revealed that the questions were worded ambiguously. These four questions were omitted from the analysis. A one-way repeated-measures ANOVA showed that accuracy rates differed by condition, although this effect was only significant by subjects [$F_1(2,46) = 4.86$, $MSE = 105$, $p < .05$; $F_2(2,50) = 2.06$, $MSE = 191$, $p > .13$]. Follow-up comparisons indicated that responses to questions following SRCs were significantly more accurate (93%) than

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[1] To assess whether the observed animacy difference at the embedded verb could be explained by differences in noun–verb bigram frequency, we conducted a Spearman rank-order correlation comparing mean regression-path durations at the verb and transitional probabilities (see Method section) for the 39 bigram pairs for which Google N-gram contained frequency data. The correlation was not significant (rho = −.19, $p > .25$). Even so, a closer examination of the data revealed that this non-significant effect was being driven by two items (*burglar shot* and *revolver shot*), both of which had transitional probabilities over twice as large as any of the other items. Removing these two items completely erased any hint of a correlation (rho = −.05, $p > .77$). Thus, we did not find any evidence for the hypothesis that differences in bigram frequency of N2 and the embedded verb were contributing to the observed differences in reading times at the embedded verb for animate versus inanimate nouns.

**Table 2**
Eye-tracking results of animacy effects in Experiment 1.

| Word | Condition | Measure (in ms) | | |
|------|-----------|------|------|------|
| | | Gaze | Regression-path | Total time |
| Determiner | ORC-Animate | 234 | 392 | 564 |
| | ORC-Inanimate | 206 | 386 | 586 |
| Embedded noun | ORC-Animate | 234 | 444 | 782 |
| | ORC-Inanimate | 230 | 444 | 678 |
| Embedded verb | ORC-Animate | 298 | 518 | 847 |
| | ORC-Inanimate | 305 | 633 | 805 |

questions following ORC-Animates (87%) [$F_1(1,23) = 6.41$, $MSE = 66$, $p < .05$, $F_2(1,28) = 4.41$, $MSE = 137$, $p < .05$]. There was no difference in accuracy rates between ORC-Animates (87%) and ORC-Inanimates (84%) [$F_1(1,23) = 1.07$, $MSE = 113$, $p > .31$; $F_2(1,26) < 1$].

### Discussion

The results of Experiment 1 showed greater processing difficulty for ORCs compared to SRCs, as indicated by longer regression-path durations and total times at the RC region of the sentence and at the matrix verb. Also, responses to comprehension questions were less accurate for ORCs than SRCs. These findings are consistent with previous demonstrations of the ORC–SRC processing difference. Comparing regression-path durations on the RC region for the ORC-Animate and ORC-Inanimate conditions initially suggested that there might be greater RC-related processing difficulty for ORC-Inanimates; however, a word-by-word analysis of this region revealed that this effect emerged entirely at the embedded verb (see Fig. 1). In fact, there was no hint of an animacy effect at the matrix verb in any of the three eye-tracking measures used to analyze the data. This pattern shows that integrating an inanimate subject with a verb imposes a local processing cost, but does not contribute to the difference in processing ORCs versus SRCs, as might have been demonstrated by effects on the embedded noun and the matrix verb, in addition to the difference we observed on the embedded verb. These results are consistent with our hypothesis that subject–verb integration is difficult when an inanimate NP must combine with an action verb; however, the results are inconsistent with a view that RC processing is made easier by altering the animacy configuration of the critical nouns (Gennari & MacDonald, 2008, 2009; Traxler et al., 2002, 2005).

The results of Experiment 1 differ from previous studies on RC processing that have found that the animacy of the embedded noun affects processing of the matrix verb (Gennari & MacDonald, 2008; Mak et al., 2002, 2006; Traxler et al., 2002, 2005). One possible reason for this discrepancy has to do with the choice of comparison condition. In our experiment, the two ORC conditions differed only at the embedded noun (e.g., *The sheriff that the cowboy injured...* versus *The sheriff that the pistol injured...*). In contrast, the two ORC conditions that previous studies have used differed in their head nouns, embedded nouns, and
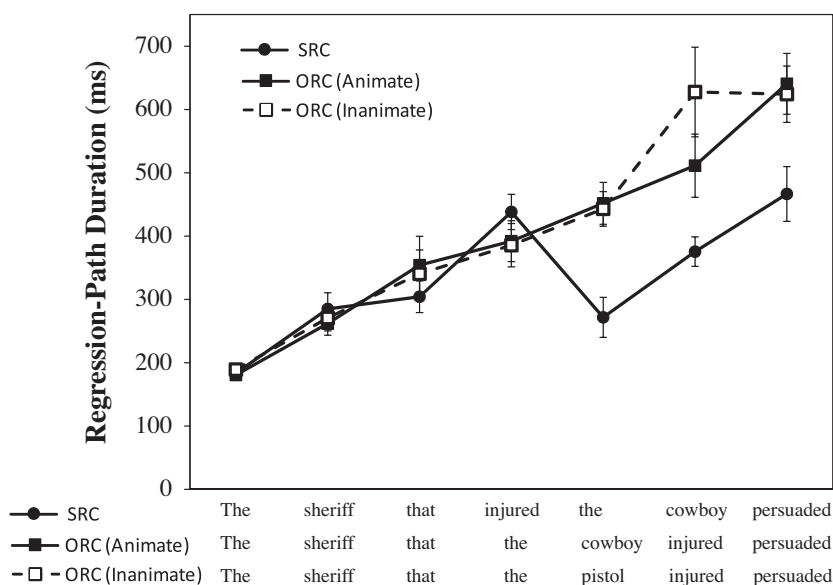
**Fig. 1.** Mean regression-path durations for the three conditions in Experiment 1. Error bars represent the standard error of the mean.

embedded verbs (e.g., *The pistol that the cowboy concealed...* versus *The cowboy that the pistol injured...*). Accordingly, differences at the matrix verb found by previous studies may have been influenced by differential spillover onto the embedded matrix verb from the preceding words. Overall, these differences in stimulus materials may help explain the conflicting findings between the work presented here and the results of previous studies.

Furthermore, our findings are consistent with the notion that the integration of an inanimate subject NP with an action verb represents a form of enriched composition or metonymic interpretation, which requires additional processing compared to the integration of an animate NP with a verb. For example, Pustejovsky (1995) has proposed that inanimate subject–verb pairs, such as *gun killed,* can only be properly understood via a process of coercion, where the noun is type-shifted from an object to an event. Several previous studies have demonstrated a processing cost associated with complement coercion, where the meaning of an expression is coerced from an object to an event (e.g., McElree et al., 2001; Traxler et al., 2002), as in *began the book* being interpreted as *began reading the book*. The current experiment is the first to demonstrate such a coercion cost for subject–verb integration.

## Experiment 2

Experiment 1 demonstrated a local cost associated with integrating an inanimate subject with a verb, which was independent of the broader cost associated with processing an ORC as compared to a matched SRC. This demonstration of a local cost for integrating an inanimate noun with a verb raises the question of why such an effect was not observed in the SRC sentences on which the stimuli for Experiment 1 were based (Traxler et al., 2005, Experiment 3).

A possible explanation of these differing results is that for the sentences used in Experiment 1 the inanimate sub-

ject NP and the verb that had to be integrated appeared together in the same clause, whereas in Traxler et al.'s (2005) SRCs, the inanimate NP was the head which was modified through its integration with a verb that only appeared overtly in a different clause. On several accounts of human language comprehension, the relations between different parts of a sentence are processed to varying degrees, with the depth of processing depending greatly on the structure of the sentence (e.g., Ferreira et al., 2002; Gordon & Hendrick, 1998; Sanford & Sturt, 2002). Direct evidence that information in a relative clause is processed less deeply in relation to the head than information in a main clause comes from Baker and Wagner (1987), who showed that false information is less likely to be detected by readers when the critical NP and verb phrase are presented in two different clauses, as in (6a), compared to when they appear in the same clause, as in (6b).

6a. *The liver, which is an organ found only in humans, is often damaged by heavy drinking.*
6b. *The liver, which is often damaged by heavy drinking, is an organ found only in humans.*

This work suggests that noun–verb pairs are not integrated as fully when they are separated by a clause boundary as when they appear together overtly in the same clause. This finding is particularly relevant to the current study, as it raises the possibility that a subject–verb pair such as *pistol injured* may be processed in very different ways, depending on whether the noun and verb appear in the same clause or in different clauses.

Accordingly, Experiment 2 explores whether the magnitude of the animacy effect depends on the syntactic structure of the sentence by examining the processing of subject–verb relations between the head NP of an SRC and the embedded verb. We predicted that the difficulty associated with integrating an inanimate subject and verb

would be reduced when these constituents appeared in two separate clauses, compared to when they were in the same clause. This hypothesis was driven in part by Traxler et al.'s (2002, 2005) finding that there was no difference in processing times for SRCs with an animate versus an inanimate head NP (i.e., no difference between 2c and 2d). However, based on the results of our Experiment 1, one might expect greater difficulty for (2d; *pistol injured*) compared to (2c; *cowboy concealed*). Finding no difference between these two sentences might suggest that the relations between the semantic properties of a subject and verb have reduced relevance when the verb is part of an embedded clause.

## Method

### Participants

Thirty-two students at the University of North Carolina at Chapel Hill participated in this experiment in exchange for course credit. They were all native English speakers and had normal or corrected-to-normal vision.

### Materials, design, and procedure

Each participant was presented with 40 experimental sentences and 84 filler sentences. The 40 experimental sentences were adapted from Traxler et al. (2005, Experiment 3). The SRCs from Traxler et al.'s experiment comprised two of our conditions (7a and 7c). Our other two conditions were created by dropping the complementizer of the SRCs and rewriting the end of the sentence such that the embedded verb was now the main verb of the sentence (7b and 7d). These changes allowed us to fully cross animacy (i.e., animate versus inanimate head NP) with syntax (i.e., SRC versus simple sentence; see Appendix B for full set of stimuli).

> 7a. The cowboy that concealed the pistol was known to be unreliable. (Animate-SRC)
> 7b. The cowboy concealed the pistol last night in the saloon. (Animate-Simple)
> 7c. The pistol that injured the cowboy was known to be unreliable. (Inanimate-SRC)
> 7d. The pistol injured the cowboy last night in the saloon. (Inanimate-Simple)

Fifteen participants who did not participate in the eye-tracking experiment rated these sentences for plausibility. As in Experiment 1, the task was to indicate how likely they believed the events described by the sentence were on a scale from 1 (highly unlikely) to 5 (highly likely). Each rater saw the sentences in a different random order. Mean plausibility ratings were 3.7 (Animate-SRC), 3.9 (Animate-Simple), 3.4 (Inanimate-SRC), and 3.6 (Inanimate-Simple). Analysis of these plausibility ratings revealed a significant main effect of syntax $F(1, 14) = 8.18$, $p < .05$, indicating higher ratings for simple sentences than SRCs. In addition, there was a significant main effect of animacy $F(1, 14) = 7.84$, $p < .05$, indicating higher ratings for sentences with animate versus inanimate NP1s. Critical to our hypothesis, however, there was no hint of an interaction between syntax and animacy, $F < 1$. Thus, any read-

ing-time effects demonstrating reduced processing difficulty for inanimate subject NPs when they appear in an SRC compared to a simple sentence cannot be attributed to plausibility differences.

For the eye-tracking experiment, one version of each item was assigned to one of four lists such that no participant saw more than one version of each item. All other aspects of the design and procedure were identical to Experiment 1.

### Results

As in Experiment 1, we report results for gaze duration, regression-path duration, total time, and comprehension-question accuracy. Reading times are presented in Table 3. In our analyses, we focused on the verb as our target region (i.e., main verb for simple sentences, embedded verb for SRCs), as this was the word where processing difficulty emerged for inanimate subjects in Experiment 1. The design of Experiment 2 allowed us to test for the presence of an interaction at this target region to determine whether the animacy effect depends on the syntactic structure of the sentence. For this analysis, a contingent-expansion technique (Rayner & Duffy, 1986) was implemented for the SRC conditions, such that for trials where the target word was skipped but the complementizer was fixated, processing time on the complementizer was used in place of the target word.[2]

### Verb

Analysis of gaze durations showed no main effect of animacy at the verb [$F_1(1, 31) = 1.12$, $MSE = 1831$, $p > .25$; $F_2(1, 39) = 1.14$, $MSE = 5028$, $p > .25$]. There was a main effect of syntax, such that simple sentences were read more slowly than SRCs [$F_1(1, 31) = 13.64$, $MSE = 3441$, $p < .01$; $F_2(1, 39) = 20.07$, $MSE = 3254$, $p < .001$]. Of primary importance, there was a significant interaction between syntax and animacy [$F_1(1, 31) = 6.33$, $MSE = 2867$, $p < .05$; $F_2(1, 39) = 9.08$, $MSE = 3821$, $p < .01$]. This interaction was probed further using two sets of contrasts: one holding syntax constant and one holding animacy constant. These analyses revealed that the Inanimate-Simple condition was more difficult than the Animate-Simple condition [$t_1(31) = 2.57$, $p < .05$; $t_2(39) = 2.20$, $p < .05$], but that there was no difference between the Inanimate-SRC condition and the Animate-SRC condition [$t_1(31) = 1.34$, $p > .19$; $t_2(39) = 1.16$, $p > .25$]. Furthermore, there was a large difference between the Inanimate-Simple and Inanimate-SRC conditions [$t_1(31) = 4.25$, $p < .001$; $t_2(39) = 4.86$, $p < .001$], but no difference between the Animate-Simple and Animate-SRC conditions [$t_1(31) = 1.08$, $p > .28$; $t_2(39) = .91$, $p > .36$].

Analysis of regression-path durations at the verb revealed a pattern of effects identical to the findings obtained for gaze durations. Again, there was no main effect of animacy [$F_1(1, 31) < 1$; $F_2(1, 39) < 1$], but there was a main ef-

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[2] There was no difference between animacy conditions in percentage of trials that went into the contingent expansion: animate head NP: 13%, inanimate head NP: 14%, $F_1(1, 31) < 1$; $F_2(1, 39) < 1$.

**Table 3**
Eye-tracking results of Experiment 2.

| Region of interest | Condition | Measure (in ms) | | |
|---|---|---|---|---|
| | | Gaze | Regression-path | Total time |
| Determiner 1 | Animate SRC | 193 | | 217 |
| | Animate Simple | 201 | | 247 |
| | Inanimate SRC | 195 | | 221 |
| | Inanimate Simple | 196 | | 226 |
| Noun 1 | Animate SRC | 272 | 295 | 551 |
| | Animate Simple | 250 | 274 | 526 |
| | Inanimate SRC | 258 | 300 | 534 |
| | Inanimate Simple | 256 | 304 | 630 |
| Complementizer | Animate SRC | 247 | 315 | 446 |
| | Inanimate SRC | 252 | 293 | 443 |
| Verb | Animate SRC | 269 | 343 | 547 |
| | Animate Simple | 287 | 379 | 640 |
| | Inanimate SRC | 256 | 322 | 571 |
| | Inanimate Simple | 312 | 415 | 734 |
| Determiner 2 | Animate SRC | 214 | 259 | 318 |
| | Animate Simple | 224 | 301 | 314 |
| | Inanimate SRC | 223 | 267 | 327 |
| | Inanimate Simple | 225 | 296 | 332 |
| Noun 2 | Animate SRC | 232 | 311 | 389 |
| | Animate Simple | 240 | 353 | 381 |
| | Inanimate SRC | 259 | 343 | 439 |
| | Inanimate Simple | 255 | 328 | 422 |



**Fig. 2.** Mean regression-path durations for the four conditions in Experiment 2. Error bars represent the standard error of the mean.

fect of syntax with simple sentences overall causing more difficulty than SRCs [$F_1(1,31) = 10.00$, $MSE = 12,362$, $p < .01$; $F_2(1,39) = 12.41$, $MSE = 12,474$, $p < .01$]. This main effect was qualified by the significant interaction between syntax and animacy [$F_1(1,31) = 5.97$, $MSE = 5311$, $p < .05$; $F_2(1,39) = 5.35$, $MSE = 12,528$, $p < .05$]. Follow-up contrasts revealed greater difficulty with the Inanimate-Simple condition than the Animate-Simple condition [$t_1(31) = 2.04$, $p = .05$; $t_2(39) = 1.92$, $p < .07$], but no difference between the Inanimate-SRC condition and the Animate-SRC condition [$t_1(31) = 1.54$, $p > .13$; $t_2(39) = 1.45$, $p > .15$]. In addition, there was a large difference between the Inanimate-Simple and Inanimate-SRC conditions [$t_1(31) = 4.11$, $p < .001$; $t_2(39) = 4.02$, $p < .001$], but no difference between the Animate-Simple and Animate-SRC conditions [$t_1(31) = 1.27$, $p > .20$; $t_2(39) = 0.87$, $p > .38$]. This pattern of effects is depicted graphically in Fig. 2.

Finally, total times on the verb showed a significant main effect of syntax [$F_1(1,31) = 32.13$, $MSE = 17,302$, $p < .001$; $F_2(1,39) = 24.66$, $MSE = 24,769$, $p < .001$] and a main effect of animacy that was significant in the subjects analysis and marginal in the item analysis [$F_1(1,31) = 5.33$, $MSE = 18,200$, $p < .05$; $F_2(1,39) = 3.23$, $MSE = 44,388$, $p < .09$]. Also, there was a marginally significant interaction between syntax and animacy [$F_1(1,31) = 3.05$, $MSE = 15,866$, $p < .10$; $F_2(1,39) = 3.42$, $MSE = 30,153$, $p < .08$]. In line with the pattern of results obtained for gaze duration and regression-path duration, the total time data showed longer reading times on the verb for the Inanimate-Simple condition compared to the Animate-Simple condition [$t_1(31) = 2.75$, $p < .05$; $t_2(39) = 2.17$, $p < .05$], but no difference between the Inanimate-SRC condition and the Animate-SRC condition [$t_1(31) = .50$, $p > .60$; $t_2(39) = .28$, $p > .75$]. In addition, there was a large difference between
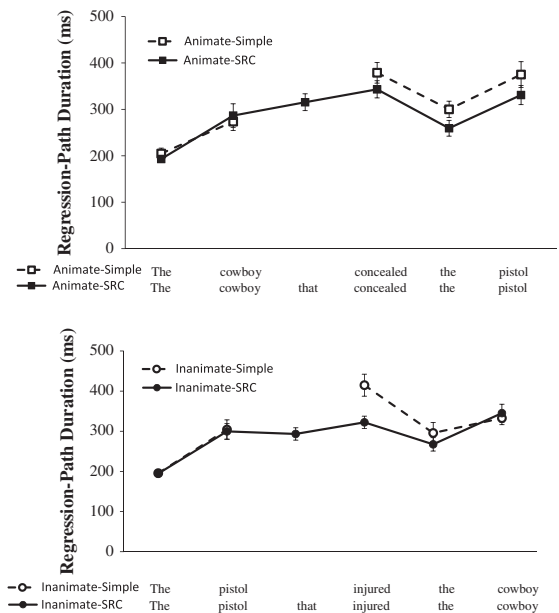
the Inanimate-Simple and Inanimate-SRC conditions [$t_1(31) = 5.19$, $p < .001$; $t_2(39) = 4.19$, $p < .001$], which replicated the gaze duration and regression-path duration findings. Unlike these other two measures, however, the total time data also showed longer reading times for the Animate-Simple condition compared to the Animate-SRC condition [$t_1(31) = 2.95$, $p < .01$; $t_2(39) = 2.28$, $p < .05$].

*Additional reading-time effects*

Gaze duration and regression-path duration on N1 showed no effects; however, analysis of the total time data on this word revealed an interaction between syntax and animacy that was significant in the item analysis and marginally significant in the subject analysis [$F_1(1,31) = 3.24$, $MSE = 35,308$, $p < .09$; $F_2(1,39) = 6.10$, $MSE = 27,698$, $p < .02$]. Follow-up contrasts showed longer total reading times on N1 for the Inanimate-Simple condition compared to the Animate-Simple condition [$t_1(31) = 2.29$, $p < .05$; $t_2(39) = 2.57$, $p < .05$], but no difference between the Inanimate-SRC condition and the Animate-SRC condition [$t_1(31) = .51$, $p > .60$; $t_2(39) = .39$, $p > .65$]. There were also marginally longer reading times on N1 for the contrast comparing the Inanimate-Simple condition to the Inanimate-SRC condition [$t_1(31) = 1.93$, $p < .07$; $t_2(39) = 1.87$, $p < .07$], but no hint of a difference between the Animate-Simple condition and the Animate-SRC condition [$t_1(31) = .68$, $p > .50$; $t_2(39) = 1.03$, $p > .30$]. The inflated total times on N1 in the Inanimate-Simple condition reflect readers' tendency to go back and reread earlier parts of the sentence after encountering difficulty at the verb. As such, these effects are in line with the pattern of results found at the verb in further demonstrating the difficulty associated with the Inanimate-Simple condition relative to the other conditions.

At the determiner following the verb, we observed a main effect of syntax in regression-path duration, such

that there were significantly longer reading times for simple sentences compared to SRCs, regardless of animacy [$F_1(1,31) = 4.20$, $MSE = 8870$, $p < .05$; $F_2(1,39) = 6.75$, $MSE = 13,682$, $p < .05$]. This finding may reflect general facilitation with processing an object NP when it is embedded in an RC compared to when it is in the same clause as the subject NP. On the other hand, the overall high skipping rates of this word (i.e., over 50% for all conditions) combined with the fact that this effect did not emerge on N2 make it difficult to interpret this effect on the article.

We did, however, observe significant main effects of animacy on N2, such that there was greater difficulty for sentences that had an inanimate sentence subject compared to sentences that had an animate sentence subject, regardless of syntax. This effect was significant in gaze duration [$F_1(1,31) = 10.40$, $MSE = 1330$, $p < .005$; $F_2(1,39) = 5.26$, $MSE = 3411$, $p < .05$] and in total time (significant in the subject analysis, marginal in the item analysis) [$F_1(1,31) = 7.70$, $MSE = 8620$, $p < .01$; $F_2(1,39) = 2.91$, $MSE = 21,025$, $p < .10$]. Together with the findings obtained on the verb, these results suggest that the difficulty associated with the Inanimate-Simple condition begins early and extends to N2, whereas difficulty with the Inanimate-SRC condition does not emerge until after the verb.

There were no additional significant main effects or interactions.

*Comprehension-question accuracy*

Analysis of comprehension-question accuracies revealed a main effect of syntax, such that responses following simple sentences (96%) were significantly more correct than responses following SRCs (89%), $F_1(1,31) = 16.63$, $MSE = 78$, $p < .001$; $F_2(1,39) = 8.24$, $MSE = 216$, $p < .01$. There was no main effect of animacy, $F_1(1,31) = 1.10$, $MSE = 38$, $p > .30$; $F_2(1,39) < 1$, nor was there a syntax by animacy interaction, $F_1(1,31) < 1$; $F_2(1,39) < 1$.

*Discussion*

Experiment 2 replicated the finding from Experiment 1 that there is greater processing difficulty for inanimate compared to animate subject–verb pairs when the two words appeared together in the same clause. Whereas Experiment 1 had demonstrated this greater difficulty when the noun and verb both appeared in the embedded relative clause, Experiment 2 showed that this pattern is also observed when the noun and verb both appear in the main clause. Crucially, Experiment 2 further demonstrated that this processing difficulty was significantly reduced when integration occurred across the boundary created by an SRC. This finding is consistent with the notion that the depth at which the words of a sentence are processed depends critically on the structure of the sentence.

## General discussion

Together, the two experiments reported in this paper demonstrate that the difficulty of integrating an inanimate subject with a verb depends on the syntactic structure of the sentence. Experiment 1 showed that subject–verb integration was difficult for inanimate subjects, compared to animate subjects, when the two constituents appeared together in the same clause. This difficulty emerged entirely at the verb, indicating that the animacy manipulation had no effect on processing times for any other part of the sentence. Experiment 2 showed that inanimate subject–verb integration was just as easy as animate subject–verb integration when the subject and verb appeared in two different clauses.

Our comparison of ORCs versus SRCs in Experiment 1 demonstrated that the processing difficulty occurs over a broad region of the sentence, encompassing the RC as well as the matrix verb. This finding is consistent with a large literature showing that the difficulty associated with processing an ORC is not confined to a single word (e.g., Ford, 1983; Gordon et al., 2001, 2004, 2006; Holmes & O'Regan, 1981; Johnson et al., 2011; King & Just, 1991; Traxler et al., 2002, 2005). In contrast, our comparison of ORCs with an animate versus an inanimate embedded NP showed that the animacy manipulation influenced reading times only at the embedded verb. Accordingly, these results provide no evidence that NP animacy influences RC processing per se. Instead, the difficulty associated with integrating an inanimate subject with a verb seems to be a localized effect.

A variety of linguistic and psycholinguistic accounts have previously proposed that integration of an inanimate subject NP with an action verb is difficult (Cruse, 1973; Dowty, 1991; Fillmore, 1968; Pustejovsky, 1995; Wolff et al., 2009, 2010). Depending on the nature of the particular subject–verb pair, this difficulty may stem from needing to access a metaphorical or metonymic sense of the noun (Frisson & Pickering, 1999; Gibbs, 1990), coercing the noun from an object to an event (Pustejovsky, 1995), or perceiving a mismatch between the semantic properties of the noun and the thematic properties specified by the verb (Dowty, 1991). The inanimate noun–verb pairs used in the current experiments were taken directly from previous research (Traxler et al., 2005; Experiment 3) so as to facilitate comparison of current results to those obtained previously. The heterogeneity of those inanimate noun–verb pairs in that research makes it difficult to identify the exact source or sources of the local processing difficulty in inanimate subject–verb integration.

Critically, the difficulty associated with integrating an inanimate subject NP with an action verb depended on syntactic structure, with the effect disappearing when the two constituents were in different clauses. This finding is in line with several theoretical accounts suggesting that the depth of sentence processing depends to a large extent on the structure of the sentence (e.g., Ferreira et al., 2002; Gordon & Hendrick, 1998; Sanford & Sturt, 2002). Specifically, work by Ferreira and colleagues (Christianson, Hollingworth, Halliwell, & Ferreira, 2001; Ferreira, 2003; Ferreira, Christianson, & Hollingworth, 2001; see Ferreira & Patson, 2007, for a review) has demonstrated that participants who are presented with garden-path sentences or passive sentences that contain noncanonical agent-patient roles frequently misinterpret the meaning of the sentence. Similarly, Sanford and colleagues (Sanford, Sanford, Filik, &

Molle, 2005; Sturt, Sanford, Stewart, & Dawydiak, 2004) have used a change-detection paradigm to demonstrate that readers are more likely to notice that a target word has changed from one presentation of the text to the next if the word is linguistically focused by the sentence structure or is highlighted by a prior discourse context. Although this previous work provides compelling evidence that linguistic representations are often inaccurate or incomplete, the measures used combine the influences of both online linguistic processing and offline memory-based retrieval of the linguistic information. In contrast, the current work shows that the online processing time associated with integrating an inanimate subject–verb combination is reduced when the two constituents appear in separate clauses, showing that the process of interpretation depends critically on the structure of the sentence.

There is previous empirical support for the perspective that sentence structure can have a powerful impact on how linguistic representations are processed. As discussed above, Baker and Wagner (1987) demonstrated that readers are less likely to detect false information embedded in a sentence when the information appears as part of a subordinate clause, rather than as part of the main clause (see also Bredart & Modolo, 1988). Although the combination of an inanimate subject with an action verb does not constitute false information per se, our findings extend Baker and Wagner's results in demonstrating an online disruption in processing that is reduced by structural separation.

Focusing on sentence structure as it relates to the current experiments, it is important to note that the purpose of an RC is either to restrict the identity of the head noun or to modify its meaning. In other words, the RC is a modifying clause—an adjunct—and it has been argued that adjuncts do not depend heavily on the specifics of the head they modify (e.g., Schütze & Gibson, 1999). From this perspective, then, the semantic properties of a subject have a stronger influence on subject–verb integration when that subject NP is an argument of the verb, compared to when the verb is part of an adjunct phrase. This finding can be explained by acknowledging that an RC typically conveys information that is presupposed, or given by the previous discourse context (Fox & Thompson, 1990; Gordon & Hendrick, 2005). Under this view, the RC grounds the head NP in information that is presumed to already be familiar to the comprehender, while less familiar information is presented in the main clause. In the case of subject-extracted RCs, such as the ones used in Experiment 2, NP1 serves as the subject of both the embedded verb and the main-clause verb, thus introducing two subject–verb relationships. Because the language comprehension system is limited, attentional resources must be allocated efficiently. For this reason, we believe that language processing focuses attention on the relationship between the head noun and the main verb of the sentence at the expense of the relationship between the head noun and the RC verb because such expressions typically convey presumed or contextual information.

In sum, this work demonstrates that there is a processing cost associated with integrating an inanimate subject with an action verb, but that this cost does not contribute to the higher-level syntactic difficulty associated with processing an ORC. Importantly, the magnitude of this processing difficulty depends on the structure of the sentence—it is larger when the inanimate noun is an argument of the action verb compared to when the action verb appears as part of an relative clause that identifies or modifies the meaning of the inanimate noun. We believe that this occurs because the depth at which people process relations between parts of a sentence is determined by its structure.

## Acknowledgments

## A. Appendix

The stimuli from Experiment 1 are shown below in their object-extracted forms with both animate and inanimate embedded NPs. Each stimulus was also presented in its subject-extracted form, as described in the text.

1. The guide that the {hikers/avalanche} buried appeared on the six o'clock news.
2. The peasant that the {farmer/tractor} ran over assisted with the harvest every year.
3. The sheriff that the {cowboy/pistol} injured persuaded the members of the jury.
4. The bicyclist that the {woman/accident} crippled caused a number of serious injuries.
5. The intruder that the {plumber/wrench} bruised remained near the back door.
6. The policeman that the {burglar/revolver} shot remained in the bedroom.
7. The hobo that the {boys/church} sheltered looked very shabby.
8. The neighbors that the {kids/pizza} fed stayed in the basement all night.
9. The maiden that the {farmer/crops} fed died after the early frost.
10. The toddlers that the {girls/feathers} tickled came from South Africa.
11. The journalist that the {senator/article} accused caused a scandal after the election.
12. The foreigner that the {student/school} taught requested financial support.
13. The acrobats that the {people/train} carried traveled to several major cities last year.
14. The captain that the {pilot/helicopter} carried died on the way to the hospital.
15. The commander that the {engineer/rocket} lifted continued to assist NASA for many years.
16. The gladiator that the {warrior/spear} impaled attracted the attention of the crowd.
17. The manager that the {worker/machine} injured cost the company time and money.
18. The teenager that the {woman/water} scalded irritated everyone in the kitchen.

19. The lady that the {actress/jewelry} decorated received a lot of attention at the party.
20. The officer that the {punk/knife} wounded became an important part of the trial.
21. The rebels that the {soldiers/camp} housed covered a large part of the forest.
22. The vagrant that the {leper/medicine} treated made several others sick.
23. The architect that the {expert/machinery} assisted detected a flaw in the metal.
24. The citizen that the {cowboy/rope} hanged became a symbol of the revolution.
25. The villain that the {actor/razor} shaved appeared in several horror movies.
26. The supervisor that the {prospector/metal} poisoned arrived from Texas last year.
27. The technician that the {scientist/chemical} sickened worried many others in the lab.
28. The spies that the {soldiers/fort} protected saved the city from the enemy.
29. The gangsters that the {wrestlers/tattoos} covered intimidated everyone in the bar.
30. The employee that the {executive/airplane} transported flew to Chicago once a year.

## B. Appendix

1. The {hikers that fled the avalanche/avalanche that buried the hikers} appeared on the six o'clock news.
   The {hikers fled the avalanche/avalanche buried the hikers} on the side of the mountain.
2. The {farmer that washed the tractor/tractor that ran over the farmer} was standing next to the barn.
   The {farmer washed the tractor/tractor ran over the farmer} next to the barn.
3. The {cowboy that concealed the pistol/pistol that injured the cowboy} was known to be unreliable.
   The {cowboy concealed the pistol/pistol injured the cowboy} last night in the saloon.
4. The {woman that triggered the accident/accident that crippled the woman} caused a number of serious injuries.
   The {woman triggered the accident/accident crippled the woman} on the busy highway.
5. The {plumber that gripped the wrench/wrench that bruised the plumber} was found near the back door.
   The {plumber gripped the wrench/wrench bruised the plumber} near the back door.
6. The {burglar that found the revolver/revolver that shot the burglar} was in the bedroom.
   The {burglar found the revolver/revolver shot the burglar} in the bedroom.
7. The {boys that vandalized the church/church that sheltered the boys} looked very shabby.
   The {boys vandalized the church/church sheltered the boys} several times last winter.
8. The {girls that climbed the trees/trees that shaded the girls} were in the back yard.
   The {girls climbed the trees/trees shaded the girls} in the back yard.
9. The {chef that measured the flour/flour that covered the chef} won a prize at the state fair.
   The {chef measured the flour/flour covered the chef} during the competition at the state fair.
10. The {kids that ate the pizza/pizza that fed the kids} stayed in the basement all night.
    The {kids ate the pizza/pizza fed the kids} in the basement all night.
11. The {farmer that planted the crops/crops that fed the farmer} died after the early frost.
    The {farmer planted the crops/crops fed the farmer} after the early frost.
12. The {girls that gathered the feathers/feathers that tickled the girls} were from South Africa.
    The {girls gathered the feathers/feathers tickled the girls} in the African village.
13. The {gangster that concealed the acid/acid that dissolved the gangster} came up during the trial.
    The {gangster concealed the acid/acid dissolved the gangster} in the abandoned warehouse downtown.
14. The {senator that skimmed the article/article that accused the senator} was forgotten after the election.
    The {senator skimmed the article/article accused the senator} before the scandal unfolded.
15. The {student that attended the school/school that taught the student} was visited by the governor.
    The {student attended the school/school taught the student} for several years.
16. The {patients that chewed the pills/pills that healed the patients} were mentioned in the medical journal.
    The {patients chewed the pills/pills healed the patients} in the hospital downtown.
17. The {people that rode the train/train that carried the people} arrived at the station early.
    The {people rode the train/train carried the people} to every circus performance.
18. The {drug dealer that damaged the street light/street light that illuminated the drug dealer} stood on the corner of Oak and Jefferson.
    The {drug dealer damaged the street light/street light illuminated the drug dealer} on the corner of Oak and Jefferson.
19. The {pilot that flew the helicopter/helicopter that carried the pilot} crashed near the grocery store.
    The {pilot flew the helicopter/helicopter carried the pilot} into a dangerous wind storm.
20. The {engineer that designed the rocket/rocket that lifted the engineer} flew over the wildlife preserve.
    The {engineer designed the rocket/rocket lifted the engineer} several days ahead of schedule.

21. The {warrior that hurled the spear/spear that impaled the warrior} was photographed by the historian.
    The {warrior hurled the spear/spear impaled the warrior} during the fight at the Coliseum.
22. The {worker that repaired the machine/machine that injured the worker} cost the company time and money.
    The {worker repaired the machine/machine injured the worker} several months ago.
23. The {woman that prepared the water/water that scalded the woman} stayed in the bathtub for hours.
    The {woman prepared the water/water scalded the woman} in the bathtub.
24. The {actress that purchased the jewelry/jewelry that decorated the actress} got a lot of attention at the movie premiere.
    The {actress purchased the jewelry/jewelry decorated the actress} at the movie premiere.
25. The {punk that brandished the knife/knife that wounded the punk} was hidden under the stairs.
    The {punk brandished the knife/knife wounded the punk} in a dark alley downtown.
26. The {soldiers that built the camp/camp that housed the soldiers} covered a large part of the forest.
    The {soldiers built the camp/camp housed the soldiers} in another part of the forest.
27. The {leper that swallowed the medicine/medicine that treated the leper} stayed in the operating room.
    The {leper swallowed the medicine/medicine treated the leper} in the operating room.
28. The {secretary that drove the car/car that crushed the secretary} cost the insurance company a fortune.
    The {secretary drove the car/car crushed the secretary} on the icy roads.
29. The {expert that operated the machinery/machinery that assisted the expert} detected a flaw in the metal.
    The {expert operated the machinery/machinery assisted the expert} without causing any accidents.
30. The {cowboy that held the rope/rope that hanged the cowboy} was strong and tough.
    The {cowboy held the rope/rope hanged the cowboy} in the center of the town.
31. The {actor that bought the razor/razor that shaved the actor} appeared in the horror movie.
    The {actor bought the razor/razor shaved the actor} in the very first scene of the horror movie.
32. The {prospector that mined the metal/metal that poisoned the prospector} didn't harm the animals.
    The {prospector mined the metal/metal poisoned the prospector} in the dark cavern.
33. The {scientist that patented the chemical/chemical that sickened the scientist} came from Australia.
    The {scientist patented the chemical/chemical sickened the scientist} at an office in Australia.
34. The {soldiers that occupied the fort/fort that protected the soldiers} saved the city from the enemy.
    The {soldiers occupied the fort/fort protected the soldiers} to save the city from the enemy.
35. The {campers that built the fire/fire that warmed the campers} burned down the cabin.
    The {campers built the fire/fire warmed the campers} near the middle of the campgrounds.
36. The {tourist that brought the electric fan/electric fan that cooled the tourist} was a nuisance for the maid.
    The {tourist brought the electric fan/electric fan cooled the tourist} on the African safari.
37. The {mechanic that changed the oil/oil that splashed the mechanic} left a stain on the front seat.
    The {mechanic changed the oil/oil splashed the mechanic} at the garage around the corner.
38. The {technician that replaced the brake fluid/brake fluid that soaked the technician} filled the can next to the hoist.
    The {technician replaced the brake fluid/brake fluid soaked the technician} next to the hoist.
39. The {wrestlers that displayed the tattoos/tattoos that covered the wrestlers} were as ugly as they could be.
    The {wrestlers displayed the tattoos/tattoos covered the wrestlers} as part of a publicity stunt.
40. The {executive that borrowed the airplane/airplane that transported the executive} vanished into thin air.
    The {executive borrowed the airplane/airplane transported the executive} and was never seen again.

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