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BRIEF REPORT

Informativity renders a referent more accessible: Evidence from eyetracking

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Abstract The amount of information attached to a noun phrase (henceforth, NP) has been shown to enhance accessibility and increase pronominal reference in language production. However, both the effect of information quantity on the comprehension of ambiguous pronouns and the time course of any informativity effect have been left unexplored. In two eyetracking experiments, we investigated how additional information on the part of NP referents influenced the resolution of following ambiguous pronouns. The results of the first experiment revealed an informativity effect, with more looks to the informationally richer referent than to the competitor. However, the effect of additional information emerged late in time when the referent was the object of the verb. The second experiment replicated the results of the first and also showed that, consistent with the online results, an ambiguous pronoun is interpreted as referring to the informationally richer NP in an offline, explicit pronoun resolution task. The results lend support to theories of language processing that assume that explicit information increases the accessibility of the associated concept, in contrast to approaches that assume that accessibility is associated with givenness.

Keywords NP position · NP length · Informativity · Pronoun resolution · Time course

In our daily encounters with language, we are regularly faced with ambiguities that must be resolved for successful communication to take place. One ubiquitous source of linguistic ambiguity is a referring expression (such as a pronoun) that can potentially refer to more than one previously mentioned entity. For example, in Example 1 the pronoun "he" could refer to both the "wizard" and the "knight."

(1)

The wizard disagreed with the knight. He came up with a good idea to solve the problem.

Numerous psycholinguistic studies have attempted to identify the factors that guide the processing and resolution of ambiguous pronouns (e.g., Almor, 1999, 2004; Ariel, 1990, 1996; Arnold, 1998, 2001, 2010; Chafe, 1976; Givón, 1983; Gundel, Hedberg, & Zacharski, 1993; Hobbs, 1979; Kehler, Kertz, Rohde, & Elman, 2008). Although many factors, such as general attention mechanisms (e.g., Bower & Morrow, 1990; Morrow, Bower, & Greenspan, 1989), discourse coherence (Kehler & Rohde, 2013; Kehler et al., 2008), and speaker-intended cues (Goodrich & Hudson Kam, 2009; Goodrich Smith & Hudson Kam, 2012; Nappa & Arnold, 2014) have been shown to influence pronoun resolution, there is considerable consensus among researchers that "accessibility" is one of the most influential factors. *Accessibility* has been defined as the ease with which the concept associated with a noun phrase (NP) can be retrieved from memory (Bock, 1982, 1987; Bock & Irwin, 1980; Bock & Warren, 1985; Christianson & Ferreira, 2005; Kelly, Bock, & Keil, 1986; McDonald, Bock, & Kelly, 1993; Prat-Sala & Branigan, 2000). Past research has shown that a more accessible NP is more likely to be interpreted as the referent of an ambiguous pronoun (e.g., Ariel, 1990; Arnold, 2001; Brennan, 1995; Fletcher, 1984; Fukumura & Van Gompel, 2010, 2011; Givón, 1983; Gundel et al., 1993; Stevenson, Crawley, & Kleinman, 1994).

Many structural and conceptual factors have been shown to influence accessibility. For example, it has repeatedly been

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demonstrated that the NP playing the role of grammatical subject and the NP that occurs in the first linear position in a sentence are more likely to be interpreted as the referent of an ambiguous pronoun (e.g., Gernsbacher & Hargreaves, 1988; Givón, 1983; Gordon, Grosz, & Gilliom, 1993, Gundel et al., 1993). For instance, in Example 1 above, "he" is more likely to be interpreted as referring to the "wizard" than to the "knight," because the former fulfills a more prominent structural role (i.e., it is the subject as well as the first-mentioned NP). Note that, in English, the first NP in a clause tends also to be the grammatical subject, in part because of English's rigid subject–verb–object word order (as illustrated by this example). Thus, for simplicity, we will use the term "structural" throughout this article to refer to both the syntactic role and linear position, with no commitment to either source of prominence. In a series of self-paced reading experiments, Gordon et al. (1993) found that it takes significantly longer for participants to read sentences in which the subsequent realization of a structurally prominent entity is through a repeated noun (e.g., "wizard") than a pronoun (e.g., "he"), a phenomenon they termed the "repeated-name penalty." Since structural prominence has been argued to boost accessibility (Bock, 1987, 1995; Bock & Warren, 1985; McDonald et al., 1993; Prat-Sala & Branigan, 2000; Van Nice & Dietrich, 2003), these results can be interpreted as lending support to the view that accessibility constrains the processing of different forms of referring expressions.

More generally, it has been found that a less explicit referring expression (e.g., a pronoun) tends to be interpreted as referring to more accessible NPs. For example, Fletcher (1984) presented participants with discourse segments such as the one in Example 2, in which the subject of the second clause (see the underlined part) was ambiguous between two NPs present in the first clause (i.e., Pete and Sam). The level of explicitness of the referring expressions was manipulated, ranging from highly implicit and unmarked expressions (a null pronoun) to highly explicit and marked ones (a repeated noun, *the guy*).

(2)

Pete had intended to go bowling with Sam last night but *[null pronoun]/he/the guy* broke his leg.

Participants were asked to decide to which of the two preceding NPs the ambiguous subject referred. The results showed that the participants' tendency to associate the referring expression with the subject of the first sentence increased as the structural and phonological explicitness of the ambiguous subject decreased. Similarly, it has been shown that "accented" (i.e., more marked) referring expressions tend to be interpreted as coreferential with less accessible NPs, and "unaccented" (i.e., less marked) referring expressions tend to be associated with more accessible preceding NPs (Arnold, 2008; Dahan, Tanenhaus, & Chambers, 2002; Fletcher, 1984).

In addition to structural properties, semantic properties have been shown to influence the interpretation of ambiguous pronouns, as well (Pyykkönen & Järvikivi, 2010; Pyykkönen, Matthews, & Järvikivi, 2010). Some verbs allow for inferences about whether to attribute causality to either the subject or the object of the sentence. As an example, in the sentence *The man frightened the woman*, causality is attributed to the man, whereas in the sentence *The man feared the woman*, causality is attributed to the woman. Previous research has revealed that there is a tendency to interpret ambiguous pronouns as referring to the entities thought to have been the event's cause. Thus, independent of the structural roles of the event participants in a sentence, the semantic bias on the part of the verb can influence pronoun resolution (Crinean & Garnham, 2006; Fukumura & Van Gompel, 2010; Garnham, Traxler, Oakhill, & Gernsbacher, 1996; Garvey & Caramazza, 1974; Garvey, Caramazza, & Yates, 1975; Greene & McKoon, 1995; Koornneef & Van Berkum, 2006; Stewart, Pickering, & Sanford, 2000). In addition, Fukumura and Van Gompel (2011) showed that animate entities, which have been shown to be more accessible than inanimate entities (Bock & Warren, 1985; Branigan, Pickering, & Tanaka, 2008; Prat-Sala & Branigan, 2000; Rosenbach, 2008), are more likely to be interpreted as the referents of ambiguous pronouns.

Consistent with work on the comprehension of referring expressions, parallel work on the production of referring expressions has also demonstrated that accessibility affects the form of referring expressions, such that more accessible NPs tend to be realized with less explicit (or marked) referring expressions, such as pronouns, rather than by repeated nouns (Arnold, 2001; Arnold & Griffin, 2007; Fukumura & Van Gompel, 2010, 2011; Karimi, Fukumura, Ferreira, & Pickering, 2014). This is an important observation, because pronouns carry little linguistic content, and therefore using pronouns for highly accessible NPs could potentially increase the ambiguity in reference. However, since comprehenders also tend to link ambiguous pronouns to accessible NPs, most such ambiguities will be successfully resolved and will not impair comprehension.

One potential factor that could influence accessibility, and therefore the resolution of ambiguous pronouns, but that has largely been left unexplored is the amount of information attached to an NP (the potential referent). We will refer to this property as "length," because additional information is typically accomplished by adding modifiers, which make the potential referent longer than one that is less informative. Note that the length of a referring expression directly correlates with the informativity of that referring expression, because longer referring expressions are necessarily more informative. The possibility that the length of an NP might matter is grounded in previous research showing that length influences the accessibility of the associated NP. At the same time, previous research has suggested two opposing predictions as to the

potential effect of length on the resolution of ambiguous pronouns: one suggesting that length enhances accessibility, and the other indicating that it makes an NP less accessible.

On the one hand, on the basis of theories of reference associated with some functional approaches to language (e.g., Ariel, 1990, 1996; Givón, 1983), referring expressions serve as markers of the degree of accessibility of the associated referents in discourse. According to this view, referring expressions implicitly convey the discourse status of their associated referents. In terms of Ariel's theory of accessibility (Ariel, 1988, 1990, 1991), three universal principles guide the linguistic encoding of referring expressions: informativity, rigidity, and phonological size. *Informativity* refers to the amount of information that the referring expression provides about its associated referent: The more informative a referring expression, the less accessible the associated referent is presumed to be in the addressee's mental model (as assessed by the speaker). For example, both *The lady who was tall and good-looking* and *The lady* may refer to the same person in the world, but the former is more informative and should be used when the speaker thinks that the referent is less accessible to the addressee (otherwise, the additional information about the person is unnecessary, and its inclusion violates the Gricean maxim of quantity: Grice, 1975; see also Engelhardt, Bailey, & Ferreira, 2006). *Rigidity* refers to the extent to which a referring expression excludes potential alternative referents that the addressee may entertain when processing the referring expression. More rigid (i.e., less ambiguous) referring expressions should be used to refer to less accessible referents, so that the addressee has an easier job identifying the correct referent. For example, *The animal* is a less rigid referring expression than *The horse*, and as such the latter should be used when the referent is deemed to be less accessible to the addressee. Finally, *phonological size* refers to the length of the referring expressions (keeping informativity constant) and the degree of stress used in the pronunciation of the referring expression. Longer and more phonologically pronounced (or accented) referring expressions mark lower degrees of accessibility, and therefore should be used to refer to referents that are deemed to be less accessible to the addressee, and vice versa. For example, *The US* is shorter than *The United States of America*, and therefore marks a higher degree of accessibility.

On the basis of these three principles, a long NP should mark a less accessible referent in comparison to a short NP, because a long NP is more informative, more rigid, and phonologically heavier. Conversely, a short NP should mark a more accessible referent, because it is less informative, less rigid, and less phonologically sizable (see Ariel, 1990, 1996; Givón, 1983, 1988, 1989; Gundel et al., 1993). On the basis of Ariel's (1990) accessibility hierarchy, then, the referents of long definite descriptions, such as *the first woman selected to be on the team of an American spaceship*, are less accessible than the referents of short, definite descriptions, such as *the woman* or pronouns (*she*). Crucially, if language comprehenders are sensitive to speakers' choices of referring expressions, they should pick up on these signals to infer the level of accessibility of the referents in discourse. Thus, the prediction from this functional approach to reference is that shorter NPs should make comprehenders infer that the associated referents are more accessible in the speakers' model of discourse than the referents of longer NPs. If this inference shapes comprehenders' own discourse model, the referent of a short NP should be more accessible to comprehenders than the referent of a long NP. As such, given a long and a short NP and a pronoun that can potentially refer to either, language comprehenders should prefer to interpret the ambiguous pronoun as being coindexed with the short NP, because the referent associated with it is more accessible.

In contrast, research on memory and recall suggests that the more information that is attached to a word, the more deeply that word will be encoded in memory, which then results in facilitated retrieval (e.g., Craik & Tulving, 1975; Fisher & Craik, 1980; Marks, 1987). In addition, research on language production has shown that longer NPs are more accessible, due to the richness of their semantic representations. For example, Yamashita and Chang (2001) showed that longer NPs are assigned to more prominent structural roles or positions in sentences than are shorter NPs (Hakuta, 1981; Yamashita & Chang, 2001; cf. Arnold, Wasow, Losongco, & Ginstrom, 2000; Francis, 2010; Stallings, MacDonald, & O'Seaghdha, 1998).

The greater accessibility of longer NPs over shorter NPs is also predicted by the information load hypothesis (Almor, 1999). This hypothesis assumes that the processing of referring expressions is driven by the information load imposed on the language comprehension system during establishment of the referential dependency; the lower the information load, the more easily the referring expression will be processed (Almor, 1999, 2004). Almor (1999) defined information load in terms of the semantic or conceptual distance between the referent and the referring expression, as well as the conceptual interference caused by that distance. A more specific referent is assumed to be conceptually more distant from a general (less explicit) referring expression (such as a pronoun), leading to less conceptual interference, less information load, and therefore facilitated referential processing. In contrast, a more general referent would be conceptually closer to the same referring expression, and thus more likely to produce interference and confusion (Almor, 1999, 2004). Under this account, it is easier to comprehend *bird* as being a referring expression for *ostrich* than to comprehend *bird* as being a referring expression for *robin*. This is because *ostrich* is more specific, and therefore more conceptually distant from *bird*, than is *robin* (Almor, 1999). The relevance of the information load hypothesis to the question of how NP length affects interpretations is

that length necessarily results in a more specific NP (Almor, 2004). As such, this hypothesis predicts that ambiguous pronouns should preferentially be interpreted as referring to longer NPs.

Consistent with the predictions of the information load hypothesis, Hofmeister (2011) found that in long-distance dependencies involving a moved constituent and the site where that constituent originated, longer NPs resulted in faster reading times at that site than did shorter NPs. The assumption in this work is that the information in the moved constituent is retrieved when the comprehender encounters the original site. Employing sentences such as Example 3, in which *the communist* is retrieved and associated with *banned*, Hofmeister found faster reading times for the words immediately following *banned* in Example 3b than in Example 3a, suggesting that the representations associated with longer NPs are retrieved from memory faster than those associated with shorter NPs.

(3)

a. It was a communist who the members of the club banned from ever entering the premises.
b. It was an alleged Venezuelan communist who the members of the club banned from ever entering the premises.

Since both the processing of long-distance dependencies and reference processing require memory retrieval of the associated referent (Ariel, 1990; Gernsbacher & Hargreaves, 1988; Hofmeister, 2011; McKoon & Ratcliff, 1980), these results suggest that long NPs would result in greater accessibility at retrieval, leading to more pronoun use in language production and a preference to associate an ambiguous pronoun with the longer NP during comprehension.

We had examined the first of these predictions—that a longer NP should result in more pronominal reference in production—in our previous work (Karimi et al., 2014). In three sentence continuation experiments, we manipulated the length of potential referent NPs, producing experimental items such as Example 4 in three conditions: a long–short condition (Example 4a) in which NP1 was lengthened with a relative clause, a short–long condition (Example 4b) in which the same relative clause was attached to NP2, and a short–short condition (Example 4c) in which both NPs were unmodified.

(4)

a. The actor who was frustrated and visibly upset about the night's disastrous performance walked away from the actress.
b. The actor walked away from the actress who was frustrated and visibly upset about the night's disastrous performance.
c. The actor walked away from the actress.

We replicated the well-established finding that pronouns were used more often to refer to NP1 (the subject) than to NP2 (a verbal or prepositional object). More importantly, we also found that this effect was modulated by NP length, such that the bias to refer to NP1 with a pronoun (rather than a repeated noun) was stronger when NP1 was longer than NP2 (Example 4a) than when it was shorter (Example 4b) than NP2. Similarly, the tendency for pronominal references to NP2 was significantly enhanced when it was longer (Example 4b) than when it was shorter (Example 4a).

What we do not yet know is how length affects accessibility (which can also be described as *ease of retrieval from memory*), and how pronoun interpretation during online language comprehension is affected as a consequence. That is, are ambiguous pronouns more likely to be interpreted as referring to longer NPs, as a general-accessibility account would suggest, or to shorter NPs, as is predicted by some functional approaches to reference? Much previous work has been by nature silent about the time course of the effects of length, because offline tasks were employed. Sentence generation and completion tasks cannot tell us how any length effect emerges incrementally. The time course of pronoun resolution is crucial to an adequate theory of reference processing, because it reveals how different sources of information (e.g., structural vs. semantic or contextual prominence) interact with one another (Arnold, 2013).

To answer these questions, we conducted two visual-world experiments in which we tracked participants' eye movements while they listened to sentences and simultaneously watched related images on a computer screen, allowing us to investigate pronoun processing as it unfolded in real time. To preview the results, our experiments showed that ambiguous pronouns are more likely to be interpreted as being coreferential with longer NPs. In addition, time-course analyses revealed that the length effect emerges early for the NP that occurs in the preferred initial sentence position (NP1), but later for an NP mentioned in the less-preferred later position (NP2).

Experiment 1

Method

Participants Thirty-six undergraduate students were recruited from the participant pool of the University of South Carolina. All were native speakers of American English and had normal or corrected-to-normal vision. They took part in the experiment in exchange for course credit.

Materials Forty-two experimental items were created. Each item consisted of two separate sentences. Sentence 1 introduced two human characters (NP1 and NP2) related by a transitive verb. The manipulations occurred in Sentence 1 by

means of a relative clause that was attached either to NP1, creating a long–short condition, or to NP2, creating a short–long condition, or to neither, producing a short–short (baseline) condition. Sentence 2 always started with an ambiguous pronoun that could potentially refer to either of the critical NPs introduced in Sentence 1. Sentence 2 was made as neutral as possible with regard to any semantic bias to refer to either of the critical NPs in Sentence 1. A sample experimental item is show in Example 5; all of the experimental items are listed in the Appendix.

(5)

Sentence 1:

a) *Short–short:* The wizard disagreed with the knight.
b) *Long–short:* The wizard who was confused and depressed by the irreparable situation disagreed with the knight.
c) *Short–long:* The wizard disagreed with the knight who was confused and depressed by the irreparable situation.

Sentence 2:

He suddenly came up with a good idea to solve the problem.

Sentence 2 was the same for all versions of Sentence 1. All experimental items were recorded by a female native speaker of American English who was blind to the purposes of the study. The two sentences of an experimental item were recorded consecutively but in separate audio files.

Each experimental item was matched with a visual display such as that in Fig. 1, containing the corresponding images for NP1, NP2, and a random distractor. The positions of the images were randomized on each trial.

Sixty filler items were also created. The fillers differed from the experimental items in one or more of the following features: They had only one NP in the first sentence, the NPs were animal or inanimate entities, or the NPs were all short. However, some fillers were lengthened with either a relative clause or a prepositional phrase, to superficially match the properties of the experimental items.

Finally, to encourage participants to pay attention to the sentences, we added 20 comprehension questions to the items. Eight of these questions were tagged to experimental items and 12 to fillers. The questions about the experimental items were general, but those for the fillers were more specific (see the Appendix for the comprehension questions tagged to the experimental items).

Design We manipulated NP position (NP1 vs. NP2) and NP length (short–short, long–short, and short–long), producing a 2 × 3 design. NP1 was always mentioned first and was the subject of the sentence, and NP2 was always the second-mentioned human character and was the object of the sentence. The order of the two human NPs in Sentence 1 was counterbalanced, such that in a second version of each experimental item the structural properties of the two NPs were swapped. For example, in the second version of Example 5, *the knight* was NP1 and *the wizard* was NP2. However, since this counterbalancing variable was of no theoretical interest, we collapsed over it. The images corresponding to the two NPs were randomized on each trial.

Fig. 1 Example visual display for Experiment 1

Apparatus Eye movements were recorded using an SR Research EyeLink 1000 eyetracker sampling at 1000 Hz. We tracked the right or the left eye, depending on which gave the least error on calibration. The experiment was programmed with the SR Research Experiment Builder software. The eyetracking equipment was interfaced with a 1,024 × 768 CRT display monitor (refresh rate of 75 Hz) and a 3.40-GHz Pentium 4 PC, which controlled the experiment and recorded the position of the eye throughout the experiment.

Procedure The participants were seated in front of a computer and wore headphones. They were told that they would hear "mini-stories while some related images are simultaneously displayed on the computer screen," and that their job as a participant was to "simply listen and watch!" At the beginning of each trial, a drift correction dot appeared on the screen, and participants pressed the space bar to initiate the trial. Upon pressing the space bar, the three images corresponding to an experimental item appeared on the screen, and, after a 250-ms delay, Sentence 1 was played. After Sentence 1 was completed, the visual display disappeared and a fixation cross appeared in the center of the screen for 500 ms, to take participants' looks away from either of the two critical NPs. Then the

visual display reappeared on the screen and Sentence 2 was played.

Results

Prior to running any analyses, we removed fixations shorter than 80 ms and longer than 1,500 ms (4.6 %). We also then removed trials in which the participants did not look at the cross when it was on the screen (21.3 %). Figure 2 shows the fixation proportions on each NP in each of the three length conditions. We ran statistical analyses on the time window beginning from the onset of the ambiguous pronoun until 3,000 ms afterward. The highlighted sections in Fig. 2 show the windows of analysis.

For all of the models reported in this article, we used logit mixed models to analyze the data (Baayen, 2008; Baayen, Davidson, & Bates, 2008; Barr, 2008; Jaeger, 2008) with NP position (NP1 and NP2) and NP length (short–short, long–short, and short–long) as well as their interaction as fixed effects, and subjects and items as random effects. We performed two types of analyses to capture both the main effects and interactions of our predictors, as well as to follow how the effects changed over time: full-window analyses and time-course analyses. For the full-window analyses, we first ran model comparisons to find out whether NP position, NP length, or their interaction significantly contributed to explaining variance in the probabilities of looks. We began by building a base model with Intercept as the fixed factor as well as random intercepts for subjects and items. We then sequentially added NP position and NP length, as well as their interaction, to the base model as fixed effects. If the added predictor significantly improved the model fit, we concluded that it accounted for a significant amount of variation in the dependent variable—that is, that it had a main effect on the probability of fixation. Model improvement was assessed by the log-likelihood ratio tests provided by the lme4 package in R, which uses a chi-square test to determine model improvement as a function of an additional predictor (Bates, Maechler, & Dai, 2008). If the interaction between NP position and NP length significantly improved the model fit above and beyond the two main effects, we followed up the model comparisons by outputting the full-predictor model (i.e., with NP position, NP length, and their interaction as fixed effects) and looking at the Wald statistic to assess whether the coefficient associated with the interaction term differed significantly from zero (Agresti, 2002). Thus, the full-window analyses allowed us to evaluate whether any of the predictors had a significant effect on the probability of fixations over the entire time window (i.e., 3,000 ms). For the time-course analyses, we followed the effect of a significant predictor over time by dividing the 3,000-ms time window into three 1,000-ms windows and examined the effect of that predictor within a single time window. These three time windows are shown in Fig. 2. Below we describe these two analyses for Experiment 1. In all of our analyses throughout this article, we always centered NP position so that its effect would be interpretable as in standard analyses of variance.

Full-window analyses Model comparisons on the data from Experiment 1 revealed that sequentially adding NP position,

Fig. 2 Experiment 1: Fixation proportions by NP position and NP length. "W" and "Dist" stand for "Window" and "distractor," respectively

NP length, and the interaction significantly improved the model fits [$\chi^2(1) = 7.85$, $p < .01$; $\chi^2(2) = 10.19$, $p < .01$; and $\chi^2(2) = 6.37$, $p < .05$, respectively], suggesting that all three predictors significantly influenced the probability of fixating on the critical images over the entire time window. The output of the full-predictor model (with NP position centered) revealed a significant interaction between NP position and the long–short versus the short–long conditions ($\beta = 0.11$, $SE = 0.04$, $z = 2.46$, $p < .05$), but no interaction between NP position and the long–short versus short–short conditions ($\beta = 0.03$, $SE = 0.05$, $z = 0.73$, $p = .46$), nor between NP position and the short–short versus short–long condition ($\beta = 0.08$, $SE = 0.04$, $z = 1.68$, $p = .09$). It is important to mention that with regard to the random-effects specification in this model, the maximal, the no-correlation, and the slopes-only models all failed to converge (most likely because our dependent variable was binomial), and we therefore included only random intercepts in the model (see Barr, Levy, Scheepers, & Tily, 2013).

Next, we followed up the interaction by looking at the effect of NP position within each level of NP length. NP position was always centered, and the models included random intercepts for subjects and items as well as by-subjects and by-items random slopes for NP position. The results of these analyses revealed that the effect of NP position (i.e., more looks to NP1 than to NP2) approached significance ($\beta = –0.06$, $SE = 0.03$, $z = –1.73$, $p = .08$) in the short–short condition, was fully significant in the long–short condition ($\beta = –0.11$, $SE = 0.03$, $z = –3.11$, $p < .01$), but was not significant in the short–long condition ($\beta = 0.01$, $SE = 0.03$, $z = 0.47$, $p = .63$) across the full time window.

Time-course analyses We then analyzed how the effect of NP position within each level of NP length changed over time by examining the NP position effect within each of the 1,000-ms time windows. Table 1 summarizes the coefficients of each of the three analyses. In Window 1, as can be seen in Table 1, we found no NP position effect in the short–short condition, but this effect was significant in the long–short and short–long conditions, with significantly more looks to NP1 than to NP2. In Window 2, NP position had no significant effect on fixations in the short–short and short–long conditions, but its influence approached significance in the long–short condition. In Window 3, there was a significant NP position effect in the short–short condition but not in the long–short condition. Importantly, there was also a significant NP position effect in the short–long condition, but here we found a pattern opposite to the one we have observed previously—namely, more looks to NP2 than to NP1.

Discussion

Consistent with previous research (Ariel, 1990; Arnold, 2001; Brennan, 1995; Fletcher, 1984; Fukumura & Van Gompel, 2010, 2011; Givón, 1983; Gundel et al., 1993; Stevenson et al., 1994), this experiment revealed a significant NP position effect, with more looks to NP1 than to NP2 across the entire time window, suggesting that the structurally more prominent and therefore more accessible NP (i.e., NP1) attracts more looks than the less structurally prominent and accessible NP (i.e., NP2).

Importantly, we also observed a significant interaction between NP position and NP length across the whole time window, indicating that the effect of structural prominence is modulated by the length (and, consequently, the informativity) of the NP. Following up this interaction, we found significantly more looks to NP1 than to NP2 in the long–short condition, but not in the short–short and short–long conditions, suggesting that informativity on the part of NP1 renders it more accessible, and informativity on the part of NP2 neutralizes the baseline preference to look at NP1.

However, when we consider the time course of the effects by examining the three 1-s time windows separately, we observed a more nuanced pattern. First, in the baseline short–short condition, the preference for NP1 emerged only in the third time window. Conversely, in the long–short condition, NP position influenced the probability of fixations on the corresponding images in the first and second time windows, suggesting that additional information causes the effect of NP position to emerge earlier and to last longer (about 2,000 ms). Interestingly, there was a significant NP position effect only in the first and third time windows in the short–long condition, but they went in opposite directions: There were more looks to NP1 in the first time window, and more looks to NP2 in the third. This pattern of results for the short–long condition suggests that the additional information about NP2 eventually overrides the preference for NP1 over NP2, but this influence emerges late in time (after 2,000 ms).

The early bias (seen in the first time window) to look at the object corresponding to NP1 rather than to NP2 in the short–long condition is intriguing. Given that there were also significantly more looks to NP1 than to NP2 in the long–short but not in the short–short condition, we speculate that this might be due to the complexity created by adding more information to the given sentence (regardless of which NP the extra information was attached to). Specifically, it seems that when faced with a complex sentence (i.e., in the long–short or the short–long conditions), people initially rely on structural prominence rather than length and informativity to resolve the pronoun. However, the effects of informativity emerge later in time if they are at odds with structural biases such as the preference for NP1 as the referent of the ambiguous pronoun. And when the sentence is simple and contains no additional modifiers (the short–short condition), we do not see an early bias for NP1 (i.e., no more looks to NP1 than to NP2 in the first time window), but a preference for NP1 that emerges later in time.

Table 1 Experiment 1: The effect of NP position within each NP length level and in each 1,000-ms time window

NP Length	Window Number	Predictor	β	SE	Z	p
Long–short	Window 1	(Intercept)	–2.30	0.07	–29.68	<.001
		NP position	–0.17	0.06	–2.72	<.01
	Window 2	(Intercept)	–2.18	0.07	–29.10	<.001
		NP position	–0.11	0.06	–1.76	.07
	Window 3	(Intercept)	–2.18	0.07	–30.43	<.001
		NP position	–0.03	0.06	–0.06	.54
Short–long	Window 1	(Intercept)	–2.18	0.06	–36.04	<.001
		NP position	–0.15	0.06	–2.57	.01
	Window 2	(Intercept)	–2.04	0.05	–35.78	<.001
		NP position	0.05	0.05	0.91	.36
	Window 3	(Intercept)	–2.12	0.06	–30.57	<.001
		NP position	0.13	0.06	2.17	<.05
Short–short	Window 1	(Intercept)	–2.26	0.06	–32.91	<.001
		NP position	0.01	0.06	0.24	.81
	Window 2	(Intercept)	–2.29	0.07	–31.24	<.001
		NP position	–0.09	0.06	–1.41	.15
	Window 3	(Intercept)	–2.31	0.08	–27.19	<.001
		NP position	–0.14	0.06	–2.25	<.05

The pattern of interplay between structural prominence and contextual information in the long–short and short–long conditions is consistent with the good-enough approach to language processing, which distinguishes between "fast-and-frugal" heuristics and deep, algorithmic processing during language processing (e.g., Ferreira, Bailey, & Ferraro, 2002). Using the good-enough approach, the language-processing system processes information using simple heuristics (i.e., in a shallow manner) and turns to deeper processing only if necessary. In fact, there is recent evidence that heuristic processing precedes algorithmic processing (Dwivedi, 2013). Perhaps, then, if a sentence is more difficult to process because it contains more information (i.e., the long–short and short–long conditions), pronoun resolution primarily proceeds through a simple "NP1-is-the-referent" heuristic (hence, a greater probability of looking to NP1 in the first time window), and the influences from semantic or contextual information exert their impact only later in time, perhaps because information about linear order and structural position is available more quickly (e.g., Frazier & Fodor, 1978; Friederici, 2002).

Experiment 2

Although the findings from the first experiment suggest that length increases the probability of looking at the associated NP, it remains unclear how (and even whether) the participants eventually resolved the ambiguous pronoun. Thus, in this experiment, we aimed to replicate the length effect, but we also asked a yes/no comprehension question that explicitly tapped into the resolution of the ambiguous pronoun after each trial. In addition, to avoid losing data due to participants not fixating on the center cross when the sentence containing the pronouns was played out, the procedure was changed to require participants to fixate the cross for at least 250 ms before the second sentence would play and the visual scene would reappear. Finally, in line with recent arguments about the importance of replication studies (e.g., Braver, Thoemmes, & Rosenthal, 2014; Makel, Plucker, & Hegarty, 2012), we sought to ensure that the patterns observed in Experiment 1 would be found in a new experiment with different participants, conducted at a different point in the academic year.

Method

Participants Thirty-six participants were recruited from the participant pool of the University of South Carolina, none of whom had participated in Experiment 1. As before, they were compensated with course credit.

Materials All the visual displays and the sentences (i.e., Sentence 1 and Sentence 2) were identical to those used in Experiment 1. The only changes we made were the following: First, the presentation of Sentence 2 and the reappearance of the visual scene were contingent on the participants fixating the central fixation cross for at least 250 ms. Second, participants answered a comprehension question on each trial (including fillers), and all of the questions following the experimental items explicitly queried the participants' resolution of

the ambiguous pronoun. The comprehension question was presented in the form an "*It*-cleft" statement (e.g., "It was the wizard who discovered a solution for the problem"; see the Appendix), and participants had to indicate whether the statement was consistent with the story they had just heard.

Design, apparatus, and procedure The design and the equipment were the same as in the previous experiment. The experimental procedure was also the same, except that after each trial the participants used a button box to answer the comprehension question. The buttons were labeled "Yes" (the right button), "No" (the left button), and "Next trial" (the middle button). The participants had to press "yes" if the statement was consistent with the story, and "no" if it was not, with their answer presumably being based on how they had interpreted the ambiguous pronoun. The participants pressed "next trial" to move on to the next trial after answering the comprehension question.

Results

As in the previous experiment, we first removed fixation durations that were shorter than 80 ms and longer than 1,500 ms (4.48 %). We then analyzed the data in the full 3,000-ms time window to see whether NP length interacted with NP position across the full time window, and then looked at the three 1,000-ms time windows separately to assess whether and how the effect of NP position interacted with length over time. Figure 3 shows the fixation proportions by NP position and NP length, with the time windows highlighted. We also report the results for the comprehension questions.

Full-window analyses Model comparisons revealed that adding NP position significantly improved the model fit [$\chi^2(1) = 9.71$, $p < .01$], but adding NP length did not [$\chi^2(2) = 1.79$, $p = .40$]. Importantly, however, the addition of the interaction between NP position and NP length did significantly improve the model fit [$\chi^2(2) = 9.50$, $p < .01$], suggesting that, in the full time window, the effect of NP position depended on the levels of NP length for influencing the probability of looks. The output of the full-predictor model showed a significant interaction between NP position and the long–short versus the short–long conditions ($\beta = 0.12$, $SE = 0.04$, $z = 3.01$, $p < .01$), a significant interaction between NP position and the long–short versus short–short conditions ($\beta = 0.09$, $SE = 0.04$, $z = 2.13$, $p < .05$), but no interaction between NP position and the short–short versus short–long conditions ($\beta = 0.03$, $SE = 0.04$, $z = 0.88$, $p = .37$). As in the first experiment, we attempted to run this model with maximal, no-correlation, and slopes-only random structures, but since all of them failed to converge, we eventually included only random intercepts in the model (see Barr et al., 2013).

Next, we followed up the significant interaction by looking at the effect of NP position within each level of NP length. NP position was always centered, and the models had random intercepts for both subjects and items as well as by-subjects and by-items random slopes for NP position. Consistent with the first experiment, the results of these analyses revealed that NP position had a significant effect on the probability of looks only in the long–short condition ($\beta = –0.12$, $SE = 0.03$, $z = –3.69$, $p < .001$), but not in the short–short or short–long conditions ($\beta = –0.04$, $SE = 0.03$, $z = –1.38$, $p = .16$, and $\beta = 0.00$, $SE = 0.03$, $z = –0.22$, $p = .824$, respectively).

Time-course analyses We then analyzed how the effect of NP position interacted with NP length over time by examining the effect of NP position within each level of NP length and each of the 1,000-ms time windows. Table 2 summarizes the coefficients associated with each of the three analyses. As can be seen in Table 2, in Window 1 no NP position effect is apparent in the short–short condition, but consistent with Experiment 1, we did find a significant position effect in the long–short and short–long conditions, with significantly more looks to NP1 than to NP2. In Window 2, we found a significant effect of NP position in the long–short condition, but not in the short–short and short–long conditions. And in Window 3, NP position did not have a significant effect in the short–short and long–short conditions. Importantly, however, and again consistent with the first experiment, we observed a significant NP position effect in the short–long condition, but the pattern was that there were more looks to NP2 than to NP1, consistent with the idea that the additional information attached to NP2 made it a more attractive referent for the pronoun than the typically default NP1.

Analyses of comprehension questions The questions assessed how the participants resolved the pronominal ambiguity. Figure 4 shows the preferences for NP1 interpretations of the ambiguous pronoun in the short–short, short–long, and long–short conditions.

We first examined whether NP length influenced the tendency to interpret the ambiguous pronoun as referring to NP1. We compared a base model with only an intercept and with subjects and items as random factors to a model in which NP length was added as the predictor. The result of this model comparison revealed that adding NP length significantly improved the model fit [$\chi^2(2) = 122.07$, $p < .001$]. We then ran a mixed-effects model with NP length as the predictor and with random intercepts for both subjects and items, as well as by-subjects and by-items random slopes for NP length, to obtain the coefficients. The results showed more overall NP1 interpretations of the ambiguous pronoun in the long–short than in the short–long condition ($\beta = 1.50$, $SE = 0.19$, $z = 7.84$, $p <$

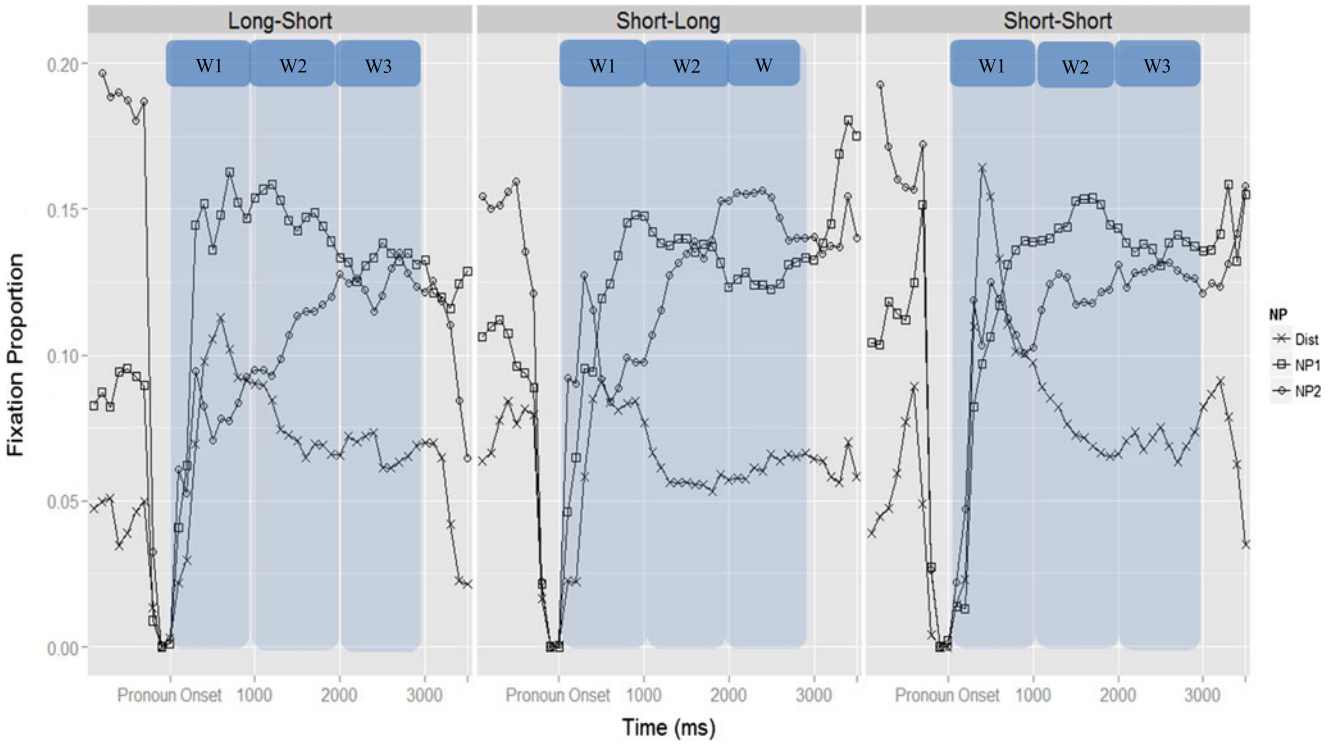

Fig. 3 Experiment 2: Fixation proportions by NP position and NP length. "W" and "Dist" stand for "Window" and "distractor," respectively

.001), and more overall NP1 interpretations in the short–short condition than in the short–long condition ($\beta = 1.28$, $SE = 0.18$, $z = 6.80$, $p < .001$). However, no significant difference in preferences emerged for an NP1 interpretation of the ambiguous pronoun between the short–short and long–short conditions ($\beta = 0.21$, $SE = 0.17$, $z = 1.99$, $p = .23$). These question-answering data are consistent with the eyetracking results and suggest that NP1 is the preferred NP for the pronoun, a bias that changes only when NP2 is made longer and more informative than NP1.

Table 2 Experiment 2: The effect of NP position within each NP length level and in each 1,000-ms time window

NP Length	Window Number	Predictor	β	SE	Z	p
Long–short	Window 1	(Intercept)	–2.04	0.07	–26.72	<.001
		NP position	–0.29	0.05	–5.06	<.001
	Window 2	(Intercept)	–1.80	0.05	–32.31	<.001
		NP position	–0.12	0.05	–2.33	<.05
	Window 3	(Intercept)	–1.77	0.05	–34.05	<.001
		NP position	–0.00	0.05	–0.04	.96
Short–long	Window 1	(Intercept)	–1.97	0.08	–23.94	<.001
		NP position	–0.15	0.06	–2.44	<.05
	Window 2	(Intercept)	–1.69	0.05	–31.03	<.001
		NP position	0.00	0.05	0.01	.98
	Window 3	(Intercept)	–1.77	0.05	–34.3	<.001
		NP position	0.10	0.05	2.11	<.05
Short–short	Window 1	(Intercept)	–1.96	0.07	–26.30	<.001
		NP position	–0.06	0.05	–1.22	.22
	Window 2	(Intercept)	–1.76	0.05	–34.24	<.001
		NP position	–0.04	0.05	–0.92	.35
	Window 3	(Intercept)	–1.74	0.05	–34.11	<.001
		NP position	–0.00	0.05	–0.05	.95

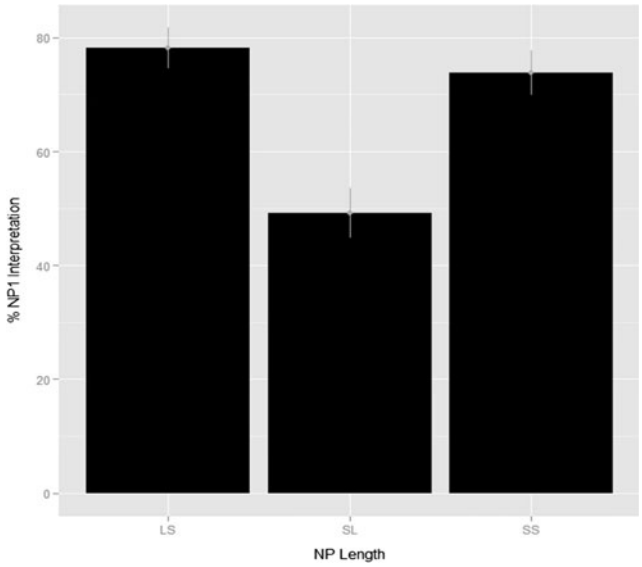

Fig. 4 Experiment 2: NP1 interpretation of the ambiguous pronoun, by NP length

Discussion

Overall, this experiment replicated the results from Experiment 1: Across the full time window, the structurally more prominent NP (NP1) attracted more fixations than the one that was less prominent (NP2). Also, consistent with Experiment 1, NP position and NP length interacted across the whole time window, such that more looks were directed to NP1 than to NP2 only in the long–short condition, suggesting that the accessibility of NP1 is enhanced when it is longer and more informative. One inconsistency in the results across experiments is that, in the short–short condition, NP position had a significant effect in the third time window in Experiment 1 but not in Experiment 2. We will return to this point in the "General discussion".

Importantly, and consistent with what we observed in the first experiment, time-course analyses revealed that, in the first time window, the probability of fixating on NP1 was significantly greater in the long–short and the short–long conditions, but not in the short–short condition, suggesting that length (informativity) on the part of NP1 causes the NP position effect to emerge earlier, and also that having a long NP leads to more looks to NP1 (regardless of which NP is longer). In the second time window, the probability of fixating NP1 was greater only in the long–short condition, but not in the short–short and short–long conditions, suggesting that extra information on the part of NP1 causes the NP position effect to last longer. Finally, in the third time window, we found no NP position effect in the short–short and long–short conditions, but the probability of fixating on NP2 was greater than the probability of fixating on NP1 in the short–long condition, suggesting that informativity eventually overrides structural prominence. This pattern of results in the short–long condition is consistent with that observed in the first experiment, and it seems to suggest that in the short–long condition, comprehenders are biased to look at NP1, perhaps due to a fast-acting "NP1-is-the-referent" heuristic that comes into play when the sentence is difficult to process (Dwivedi, 2013; Ferreira et al., 2002). However, over time, the prominence brought about by the extra information attached to a longer NP2 becomes available and eventually is strong enough to override the structural prominence of NP1.

In line with the online eyetracking data, the behavioral results also showed an effect of NP length on how the ambiguous pronoun was interpreted: There was a significantly stronger preference for NP1 interpretations of the ambiguous pronoun in the short–short condition than in the short–long condition, suggesting that when the structurally less prominent NP (NP2) is made more informative (i.e., lengthened), it becomes less likely that comprehenders will interpret the pronoun according to the structural bias for NP1. We also found significantly more NP1 interpretations in the long–short condition than in the short–long condition, suggesting that a relatively longer and more informative NP is more likely to be interpreted as the referent of an ambiguous pronoun. Finally, there was no reliable difference in how the ambiguous pronoun was interpreted between the short–short and long–short conditions, probably because the prominence of NP1 in the long–short conditions was at ceiling, perhaps due to the combination of structural prominence and enhanced informativity.

General discussion

The two experiments that we have presented were designed to show how comprehenders use information about structural prominence and informativity to choose among potential referents for an ambiguous pronoun. Taken together, the two experiments in our study replicated previous findings in showing a clear and consistent effect of NP position, such that the probability of fixating on NP1 (the structurally more prominent NP) was greater than the probability of fixating on NP2 (the structurally less prominent NP), which we interpreted to indicate a preference for NP1 as the pronoun referent. Note that since syntactic role and linear position were always conflated in our experimental sentences (see the Design of Experiment 1 and the Appendix), our design could not allow us to distinguish between the effect of syntax and that of linear position, which have been shown to be independent of each other (Järvikivi, van Gompel, Hyönä, & Bertram, 2005; Kaiser & Trueswell, 2008).

In addition, across the full 3-s time period, this preference for NP1 interacted with length such that the object corresponding to NP1 received more fixations in the long–short condition, suggesting that more information makes it easier to retrieve the associated concept from memory, and thus

makes it more accessible across the entire time window. Most importantly, looking at the effects of NP position across the three length conditions and within each 1,000-ms time window showed that length reliably increases the probability of fixating on the associated NP; when NP1 was longer and more informative, the NP position effect emerged earlier (in the first time window) and lasted longer (for about 2,000 ms), as compared with the baseline (short–short) condition. Conversely, when NP2 was longer, the probability of fixating NP2 was greater than the probability of fixating NP1, but this effect emerged later in time (in the third time window).

Interestingly, in the short–long condition, we observed an initial bias to look at NP1 (in the first time window) but by the end of the sentence, the effect of the longer NP2 outweighed the structural preference. Given that there was also a bias to look at NP1 in the long–short condition but not in the short–short condition, it seems that attaching extra information to either NP1 or NP2 initially causes a bias in favor of NP1. This could be due to the fact that length increases the overall complexity of the given sentence, and it could be that when a sentence becomes more difficult to encode and retain in memory, the processor relies on a simple structural heuristic to make its referential decision. Thus, the referent of the ambiguous pronoun is initially assumed to be the first-mentioned subject NP, which provides a quick and simple resolution of the pronominal ambiguity. However, in the short–long condition, the effect of length on the part of NP2 eventually emerges when enough time has elapsed. In other words, the reason why the effect of length appears late in the short–long condition could be that the NP length effect contradicts the NP position effect and that the NP position effect takes priority. This explanation is in line with predictions from the "online cognitive equilibrium" approach to language processing, according to which a complex sentence should produce more disequilibrium in the language comprehension system, and should thereby enhance the need to resolve any ambiguity so that equilibrium can be achieved as soon as possible (see Karimi & Ferreira, 2015).

One argument that could be leveled against the effect of length in the short–long condition is that although NP2 was the object in the main clause, it was always the subject of the *embedded, subordinate* clause in the experimental sentences (see the Appendix). As such, the greater accessibility of NP2 in the short–long condition could still have stemmed from NP position rather than from NP length and informativity. However, such an interpretation is based on the assumption that the subjects of subordinate clauses are more accessible than the subjects of main clauses. If anything, the subjects of main clauses are syntactically more prominent, and should therefore be more (not less) accessible than the subjects of subordinate clauses. Moreover, this alternative explanation cannot explain the whole pattern of results in our experiments. First, if subjecthood is the only influential factor and informativity plays no role in pronoun processing, we should have observed more looks to NP1 than to NP2 in the short–short condition. However, more looks to NP1 were observed only in the third time window in Experiment 1, and were not observed in Experiment 2 at all. Thus, the fact that informativity modulated the probability of looks to the associated NPs in the long–short and short–long conditions suggests that informativity did exert an influence. Second, this alternative explanation cannot capture the time course of the effects: If subjecthood results in an early bias to look at the associated NP, as was indicated by the early bias to look at NP1 in the long–short condition, then the effect of subjecthood (on the part of NP2) would not have arisen late in the short–long condition. Finally, this interpretation cannot explain the pattern of results in the behavioral data. Specifically, on the basis of this explanation, we should have observed significantly more NP1 interpretations in the long–short than in the short–short condition. This is because in the long–short condition, NP1 was the subject of both the main and the subordinate clauses, but it was only the subject of the main clause in the short–short condition (in fact, there was no subordinate clause in the short–short condition). However, we found no significant difference between the long–short and short–short conditions with regard to preference for NP1 interpretations of the ambiguous pronoun.

Our results are in line with our previous work on the effect of length on the production of referring forms, showing that longer NPs are more likely to be referred to with pronouns than with repeated nouns, which in turn implies greater accessibility for longer NPs (Karimi et al., 2014). The present article extends our previous results to language comprehension in general, and ambiguous pronoun resolution in particular. Tapping into online (as opposed to offline) language processing, our results also provide important insights into the mechanism of the length effect. Specifically, our results show that the resolution of pronominal ambiguity in simple discourses like the ones we used is primarily driven by structural properties of the NP, and that information-based influences such as length can override that effect, given enough processing time. Thus, our results are in line with theories of language processing postulating that length increases the semantic richness and, as a result, the accessibility of the associated NP (Hofmeister, 2011; Yamashita & Chang, 2001). Our results are also consistent with the information load hypothesis, in that longer NPs, which are necessarily more specific than shorter NPs, were more likely to be interpreted as the referents of ambiguous pronouns. According to the information load hypothesis, ambiguous pronouns should be interpreted as coindexed with longer rather than shorter NPs because pronouns are nonspecific. Such an interpretation minimizes the conceptual distance, and therefore the interference between the referentially dependent expression (the pronoun) and the referent (Almor, 1999, 2004). However, our results run

counter to the assumption embodied in some functionalist views of language processing, which maintain that shorter NPs should be perceived to be more "given," and therefore should be more accessible in discourse and more likely to be linked to a pronoun (Ariel, 1990, 1996; Givón, 1988, 1989; Gundel et al., 1993). It is important to mention, nonetheless, that functional approaches typically account for reference resolution in situations of more natural language use, in which interlocutors (are assumed to) draw inferences about each other's current mental states on the basis of the produced utterances. In our case, this would mean that our participants would attempt to use length as an indicator of the accessibility of the associated NP in the speaker's mind. Given that there was no natural dialogue in our study, we acknowledge that the present setup of our experiments was perhaps not the most adequate way to evaluate the functional–linguistic approaches. Further research with more natural experimental paradigms would be required.

Another limitation of our study was that we manipulated length only through relative clauses. It could be the case that other ways of lengthening an NP, such as through premodifiers, could yield different results. In fact, evidence from processing garden-path sentences has indicated that the sheer length of the ambiguous region is not what influences recovery from the misanalysis of a garden-path sentence, but rather the distance of the head noun from the disambiguating word (Ferreira & Henderson, 1991). In the same manner, premodifiers, which necessarily result in a shorter distance of the head noun from the ambiguous pronoun, might influence pronoun processing differently. Another limitation pertains to the way in which the relative clauses might have been interpreted by the participants. Specifically, they could be interpreted as "restrictive," in which case they would contribute to the singling out of a particular referent from among other potential referents, or as "unrestrictive," in which case they would only add information to the head noun but not necessarily contribute to reference. Although the unrestrictive interpretation of the relative clause would usually require a comma or pause between the head noun and relative clause, and there was no such pause in the recordings of our materials, further direct investigation of this issue could shed more light on the effect of length on ambiguous pronoun resolution.

The question that we address now is how length increases the accessibility of the associated concept. One possibility is that the extra information attached to the longer phrase renders it more predicable; that is, more properties can be predicated of longer NPs (Bock, 1982; Keil, 1979). More specifically, *predicability* refers to the number of available pathways for retrieving a concept from memory. For example, the greater accessibility of animate concepts than of inanimate concepts has been attributed to the fact that more ideas can be predicated of animate entities than of inanimate entities (Keil, 1979). Additional information, in the form of a modifier attached to an NP, might make it easier (at least temporarily) to predicate more ideas of the concept denoted by the head noun, rendering it more accessible than a short NP. This view seems to be consistent with the semantic-richness account, because semantically richer NPs necessarily have more information attached to them, which renders them more predicable. Another reason why longer NPs might be more accessible than shorter NPs could be that in order for a modifier to be attached to an NP, it must be reactivated in memory for efficient integration of information (Hofmeister, 2011; Lewis & Vasishth, 2005). As such, in the case of longer NPs, the head NP will be reactivated many times over the course of processing the attached relative clause, whereas the shorter NP (which is composed of only a head NP) will be activated perhaps only once. As a result, the longer NP could have been more robustly encoded in memory, and therefore more rapidly accessed at retrieval.

From a more general perspective, our results are consistent with previous research showing that less explicit referring expressions tend to be interpreted as referring to more accessible NPs. Specifically, a pronoun is an unmarked referring expression, and given a choice, it should refer to the relatively more accessible preceding NP, which is what our results showed. An important question that arises here is why there should be an inverse relationship between the explicitness of referring expressions and the accessibility of associated NPs in the first place. In other words, why should ambiguous pronouns tend to be coreferential with more accessible NPs, and vice versa? One potential explanation comes from uniform information density (UID; Jaeger, 2010). According to UID, the human language-processing system tends to maintain a uniform distribution of information over the linguistic signal, to optimize smooth and efficient transmission of information. Under this account, "information" is defined in terms of probabilistic predictability, with more predictable content carrying less information, and less predictable content carrying more information. A uniform distribution of information over a linguistic signal is achieved if more predictable words are realized with less explicit linguistic signals, and less predictable words are realized with more explicit linguistic signals. This is because if words that carry less information are realized with less explicit linguistic signal (and vice versa), a constant ratio of information over the linguistic signal will be obtained. Although UID defines information in terms of predictability, the definition could potentially be extended to accessibility, as well (note that these two notions are generally highly correlated and are sometimes used interchangeably; see Arnold, 2010). Thus, by extension, it could be that more-accessible NPs carry less information and less-accessible NPs carry more information. If this is true, then UID may provide a reasonable explanation for our results. Specifically, on the basis of UID, it could be argued that because a pronoun carries little linguistic signal, it should preferentially refer to the more accessible

(i.e., longer) NP to maintain a constant signal-to-information ratio.

One notable observation across Experiments 1 and 2 was the somewhat variable NP position effect in the short–short condition: In Experiment 1, more looks to NP1 than to NP2 occurred only in the third time window, and in Experiment 2, there was no NP position effect in the short–short condition. Although this observation is somewhat surprising, it is in line with previous research showing that in the visual-world paradigm, people distribute their gazes almost evenly on all antecedents when processing referentially ambiguous anaphoric expressions (Chambers, Tanenhaus, Eberhard, Filip, & Carlson, 2002; Sedivy, Tanenhaus, Chambers, & Carlson, 1999; Spivey, Tanenhaus, Eberhard, & Sedivy, 2002). It is reasonable to assume that in the short–short condition, the two NPs were more equally accessible than in the long–short or the short–long condition, in which additional information increased the accessibility difference between them, leading to more equal distributions of fixations to the two potential referents.

Another related reason for the tendency to leave the pronoun free in the short–short condition may be that many of the verbs that we employed to create our experimental stimuli were symmetrical predicates such as hugged (see the Appendix), in which the action makes the two NPs equally prominent. As such, again, the two NPs might have been more equally accessible in the short–short than in the long–short and short–long conditions, in which length tilted the balance in favor of one of the NPs, resulting in more balanced looks to both NPs. However, note that the behavioral data from Experiment 2 showed a clear preference to interpret the ambiguous pronoun as being coreferential with NP1 rather than NP2 in the short–short condition (74 % vs. 26 %). This offline preference for NP1 seems to suggest that, in the short–short condition, the referent of the ambiguous pronoun might not be established until an explicit question is asked about it.

From a more general standpoint, failure to identify a referent for a pronoun is compatible with previous research showing that language comprehenders sometimes fail to identify the referents for pronouns even when the pronouns are unambiguous (Greene, McKoon, & Ratcliff, 1992; Love & McKoon, 2011), consistent with theories of language processing postulating that discourse representations might sometimes remain underspecified (e.g., Ferreira, 2003; Ferreira et al., 2002; Ferreira & Patson, 2007; Sanford & Sturt, 2002; Swets, Desmet, Clifton, & Ferreira, 2008). Interestingly, however, adding more information to either of the NPs resulted in earlier resolution of the pronominal ambiguity in favor of NP1 (i.e., in the earliest time window in the long–short and short–long conditions). This could be because the extra information enhances the accessibility of the already preferred NP1 and increases the probability of resolution.

Our results suggest that some aspects of pronoun resolution take time to emerge. For instance, the NP position effect in the short–short condition emerged in the third time window in Experiment 1. Similarly, the NP length effect emerged in the third time window for the short–long conditions in both experiments. This finding is in line with research showing that the resolution of ambiguous pronouns is often delayed. For instance, MacDonald and MacWhinney (1990) showed that pronouns facilitate retrieval of the referent but inhibit retrieval of the nonreferent. More importantly, MacDonald and MacWhinney also found that this facilitation effect is substantially delayed when the pronoun is ambiguous. Similarly, employing self-paced reading-time paradigm, Stewart, Holler, and Kidd (2007) showed that the resolution of ambiguous pronouns is delayed, whereas the processing of unambiguous pronouns is not. Specifically, they showed that there is no initial and automatic commitment to a certain interpretation of an ambiguous pronoun, and that the processing system waits for additional, disambiguating information before fully resolving the pronominal ambiguity.

In conclusion, our results demonstrate that adding information to a potential referent increases the likelihood that an ambiguous pronoun will be interpreted as coreferential with it. This preference occurs because additional information increases the accessibility of a potential referent—that is, makes it easier to retrieve the associated representation from memory. In support of this account, we observed more looks to the relatively longer NPs than to NPs that were shorter, a pattern that is further reinforced by offline data showing that listeners interpreted pronouns as being coreferential with the longer NP. Taken as a whole, these findings suggest that accessibility affects comprehension via familiar and independently postulated memory mechanisms linking accessibility to retrievability (e.g., Lewis, Vasishth, & Van Dyke, 2006): As a phrase becomes more informative, it also becomes more accessible because the additional information makes the concept easier to retrieve. Greater accessibility, in turn, increases the chances that an NP will be chosen as the referent of an anaphoric expression such as a pronoun. This study, then, adds to the body of work demonstrating important links between the memory and language systems during online and offline processing.

Appendix: Experimental items for Experiments 1 and 2

Only the items for the long–short condition are listed. The items for the short–long and the short–short conditions can be recovered by attaching the relative clause in Sentence 1 to the second (instead of the first) noun phrase and by removing the relative clause altogether, respectively. Comprehension questions

tagged to the eight experimental items in Experiment 1, as well as those tagged to all of the experimental items in Experiment 2, are shown below each item.

	Sentence 1	Sentence 2
1	The actor who was frustrated and visibly upset about the night's poor performance had a walk with the cameraman.	He realized it was getting late and took a taxi home.
	It was the actor who took a taxi home. (Exp. 2)	
2	The bridesmaid who had enjoyed the wedding ceremony and was getting ready to leave had a conversation with the choirgirl.	She started to feel hungry after a while because she had had a very small breakfast.
	Who was feeling hungry and why? (Exp. 1)	
	It was the bridesmaid who started to feel hungry. (Exp. 2)	
3	The cowboy who was nervous and terribly distressed because of a recent bitter argument sat next to the boxer.	He was waiting for a friend of his to come to the bar.
	It was the cowboy who was waiting for a friend. (Exp. 2)	
4	The nurse who had time off work and was traveling in Europe went to a karaoke bar with the secretary.	She really liked to sing but did not have a good voice.
	It was the nurse who liked singing very much. (Exp. 2)	
5	The monk who was getting seriously worried about lack of religious education argued with the priest.	He really did not have any logical case to make.
	It was the monk who did not have a logical case. (Exp. 2)	
6	The boy who was extremely unpopular at school because of uncontrollable impulsiveness had a meeting with the teacher.	He was speaking in a low but unrestful voice.
	It was the boy who was speaking nervously. (Exp. 2)	
7	The spy who had formerly served in the American army during the first Gulf War greeted the sniper.	He was famous among all his friends for being intelligent.
	It was the spy who was famous for being very smart. (Exp. 2)	
8	The mermaid who was adventurous and was determined to find the lost city accompanied the angel.	She believed it would take at least 6 months to get to the location.
	It was the mermaid who estimated the amount of time to get to the lost city. (Exp. 2)	
9	The stewardess who had experienced many long flights and could foresee the hazards agreed with the tourist.	She started to get worried because the fluttering was getting more and more violent.
	What caused her to get worried? (Exp. 1)	
	It was the stewardess who was worried about the wing fluttering. (Exp. 2)	
10	The wizard who was confused and depressed by the irreparable situation disagreed with the knight.	He suddenly came up with a good idea to solve the problem.
	It was the wizard who discovered a solution for the problem. (Exp. 2)	
11	The chef who was made fully aware of the volatile market conditions negotiated with the shepherd.	He decided to think more before making a final decision.
	It was the chef who needed more time to make up his mind. (Exp. 2)	
12	The fisherman who was an ardent patriot opposing foreign interference in the waters bordering the country quarreled with the sailor.	He never thought the quarrel would eventually end in a fist fight.
	It was the fisherman who did not predict the fight. (Exp. 2)	
13	The ballerina who was outgoing and was very well connected in society watched TV with the cheerleader.	She thought it would be a good idea to invite some friends over for a small party.
	It was the ballerina who wanted to invite a few friends over. (Exp. 2)	
14	The detective who had been travelling to police stations as an undercover investigator kept in touch the policeman.	He was sure the truth will finally be revealed.
	It was the detective who was confident that the truth would be revealed. (Exp. 2)	
15	The colonel who was becoming increasingly powerless and had failed to prevent the war betrayed the prince.	He was seriously considering suicide but changed his mind in the very last moment.
	Why was he considering suicide? (Exp. 1)	
	It was the colonel who was considering suicide. (Exp. 2)	
16	The policewoman who was wise and highly considerate of the diverse problems in society wrote to the nun.	She was about to move to another city the next month.
	It was the policewoman who was about to move another city. (Exp. 2)	
17	The hunter who had discovered the cause of the repeated fires in the forest called the farmer.	He felt sorry for all the animals that had lost their lives
	It was the hunter who felt sorry for the dead animals. (Exp. 2)	
18	The deliveryman who was impatient and terribly irate about the mistake reached a compromise with the milkman.	He was so surprisingly stingy and always wanted to make more money
	It was the deliveryman who was very stingy and greedy. (Exp. 2)	
19	The babysitter who was deeply happy and relieved after hearing the final verdict hugged the lawyer.	She was a very kind person and everyone loved her very much.
	It was the babysitter who was very nice and lovely. (Exp. 2)	
20	The lady who had escaped from the city because of the extreme oppression and intimidation trusted the princess.	She was extremely worried and didn't know what the future held for her.
	It was the lady who was very worried and uncertain about the future. (Exp. 2)	
21	The model who was lazy and disorganized and had forgotten about the appointment misunderstood the hairdresser.	She was standing near the door and had and indifferent look on her face.
	It was the model who was standing near the door with an indifferent face. (Exp. 2)	
22	The maid who was lively and energetic and was running in	

the park smiled to the schoolgirl. | She was enjoying the nice weather because it was not very common in the city.

It was the maid who was enjoying the nice weather. (Exp. 2)

23 The witch who was standing next to a tree and was holding a long spear fought with the heroine. | She knew very well that speed was of utmost importance in that fight.

It was the witch who was aware of the importance of speed. (Exp. 2)

24 The dancer who came from Russia and was very experienced dined with the gymnast. | She had a sharp sense of humor and everyone liked her company.

Why did everyone like her? (Exp. 1)

It was the dancer who had a sharp sense of humor. (Exp. 2)

25 The mountaineer who was walking on the cliff and looking at the shore below waved for the skier. | He was starting to feel cold because he'd been out since early in the morning.

It was the mountaineer who was starting to feel cold. (Exp. 2)

26 The cook who had recently been sick and had missed a lot of shifts went to the movies with the waitress. | She enjoyed the movie a lot because it was directed by her favorite director.

Why did she like the movie? (Exp. 1)

It was the cook who enjoyed the movie a lot. (Exp. 2)

27 The clown who loved his job and always tried to find ways to make progress lived with the magician. | He had the bigger room in the house but was also paying more.

It was the clown who had the bigger room of the house. (Exp. 2)

28 The Indian who was recently invited to play the lead role of a new action movie cooperated with the Mexican. | He had a few suggestions to improve the scenario that he was going to share with the producer.

It was the Indian who had some suggestions for improving the scenario. (Exp. 2)

29 The scientist who was ambitiously trying to invent a radically different type of car consulted with the engineer. | He definitely needed to put everything to test to find out potential shortcomings.

It was the scientist who needed to test things to find potential faults. (Exp. 2)

30 The runner who had spent the last six months practicing very intensively challenged the champion. | She got changed and started warming up and stretching while her coach was giving her advice.

It was the runner who started warming up and stretching. (Exp. 2)

31 The violinist who really wanted to provide an unforgettable experience at the Christmas celebrations shook hands with the guitarist. | She was so talented that she could improvise at any time she wanted.

It was the violinist who was very talented and could easy improvise. (Exp. 2)

32 The postman who came from a different culture and was feeling a bit insecure exchanged telephone numbers with the Scotsman. | He was going to call him either the next day or the day after that.

It was the postman who was looking for his son. (Exp. 2)

33 The gardener who was a lover of nature and always tried growing new types of plants chatted with the botanist. | He had never seen nor heard of a flower to bloom in the winter.

What caused him to feel he needs to talk to someone? (Exp. 1)

It was the gardener who was surprised by the flower. (Exp. 2)

34 The painter who was surprisingly creative and endorsed post-modern philosophy talked to the photographer. | She was going to write a book and make her experiences public.

It was the painter who was going to write a book. (Exp. 2)

35 The singer who was rich and successful and was going to open a recording company reasoned with the flutist. | She was invited to New York to attend a concert.

It was the singer who was going to attend a concert in New York. (Exp. 2)

36 The politician who was trying to accumulate wealth through investing in the real estate market advised the judge. | He was not going to attend the meeting in the afternoon.

It was the politician who was not going to attend a meeting. (Exp. 2)

37 The surgeon who had a lot of good ideas for research and was very hardworking had a question for the pharmacist. | He was a prolific writer and had published in many prestigious journals.

It was the surgeon who was a prolific writer with many publications. (Exp. 2)

38 The robber who had totally changed and was determined to start a whole new life debated with the pirate. | He was a bit worried that people could hear them.

It was the robber who was afraid that they could be heard. (Exp. 2)

39 The plumber who was struggling to earn a living due to the financial crisis had a drink with the mechanic. | He loved sitting on the porch and watching the waves on Sunday afternoons.

It was the plumber who liked sitting in the porch and watching the ocean waves. (Exp. 2)

40 The warrior who was tired and slightly wounded and had returned to the camp swapped memories with the archer. | She had lost her father and one of her brothers in the battle.

It was the warrior who had lost her dad and brother in the battle. (Exp. 2)

41 The reporter who was persistent to reveal the dirty trick of the government to the press telephoned the columnist. | She had really important information that could affect the upcoming elections.

Why was the information important? (Exp. 1)

It was the reporter who had some important information. (Exp. 2)

42 The banker who was wealthy and well-known and was going to start a new business met the accountant. | She wanted to see an overview of the plan before they start discussing things in detail.

Why didn't they discuss the details? (Exp. 1)

It was the banker who wanted to see an overview of the plan. (Exp. 2)

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