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The recruitment of knowledge regarding plurality and compound formation during language comprehension

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Abstract

Compound formation has been a major focus of research and debate in mental lexicon research. In particular, it has been widely observed that compounds with a regular plural non-head are dispreferred, and a long line of research has examined the nature of this constraint, including which morphological, semantic or phonological properties of the non-head underlie this dispreference. While it is typically assumed that this constraint in fact leads to the barring of a compound analysis to a noun-noun string which would otherwise violate the constraint, its implementation during sentence comprehension has not been thoroughly examined. Using self-paced reading, we demonstrate that knowledge of pluralization and compound formation is immediately utilized in the assignment of structure to noun-noun strings, and that the dispreference for regular plural non-heads in fact leads the parser away from the compound analysis in favor of a more complex grammatical alternative. These results provide new evidence for the online deployment of knowledge regarding pluralization and its interaction with compound formation, and inform our understanding of how morphological information is deployed during, and impacts real-time sentence comprehension.

Keywords

morphological constraints; compounding; inflection; ambiguity; parsing

Compound formation has been a major focus of research on the mental lexicon, providing an important test case for investigating issues regarding the nature of the constituents of complex words, how these constituents are combined into larger structures, and the constraints on these combinations. Some studies have examined compound formation in sentence contexts, addressing the assignment of compound structure to noun-noun sequences, the assignment of a semantic interpretation to the resulting compound, and their consequences for resolving the larger structure and meaning of the sentences carrying them (e.g., Frazier & Rayner, 1987; MacDonald, 1993; Gibson, & Tunstall, 2002, Kennison, 2005; Cunnings & Clahsen, 2007; Staub, Rayner, Pollatsek, Hyönä, & Majewski, 2007).

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Although research investigating compound formation in sentence contexts carries the potential to inform our understanding of the role of morphological units, and of how knowledge of word formation is deployed during real-time language comprehension, fundamental questions remain regarding how and to what extent word formation processes like compounding in fact unfold and affect real-time processing. While knowledge of word formation constraints such as the dispreference for regular plurals in compounds is often assumed to be actively recruited and able to guide structure assignment and interpretation during real-time language comprehension (see Kennison, 2005 for an example), this particular assumption remains largely untested. Moreover, factors including the nature of the constraint itself, evidence showing mismatches among morphological phenomena when tested in real-time processing versus other environments, evidence that morphological and semantic cues which could guide structure assignment (including the formation of compound structures) do not always do so, and evidence that external parsing pressures affect the likelihood of assigning or avoiding compound structure within a sentence, all lead to questions regarding precisely how morphological units and combinatorics in word formation are deployed and influence comprehension in real time.

It has been widely argued that regular plurals (e.g., *rats*) are dispreferred as the non-head constituent of word-word compounds (e.g., **rats eater*; Gordon, 1985). This constraint has served as a major point of focus in debates on the nature of inflection, and more broadly, on the nature, acquisition, and neural instantiation of human language. This constraint has served as a testing ground for innateness in child language acquisition (e.g., Alegre & Gordon, 1996; Clahsen, Rothweiler, Woest, & Marcus, 1992; Gordon, 1985; cf. Nicoladis & Murphy, 2004), for the acquisition of a second language in adulthood (e.g., Clahsen, 2010; Murphy & Hayes, 2010), and for probing the nature of morphological knowledge in children with language impairments including Specific Language Impairment (e.g., Oetting & Rice, 1993; van der Lely & Christian, 2000) and Williams Syndrome (e.g., Clahsen & Almazan, 2001; Zukowski, 2005).

Analyses of the constraint barring regular plural non-heads in compounds (which we will refer to as the PIC constraint) have sought to account for the general prohibition of regular plural non-heads, while also addressing attested exceptions (e.g., *parks department*) and the observation that irregular plural non-heads are typically considered more acceptable than their regular counterparts (e.g., *mice eater* vs. *rats eater*; Gordon, 1985). The constraint has been argued by some to be a constraint on morphological combinatorics (e.g., Berent & Pinker, 2007, 2008; Kiparsky, 1982; Selkirk, 1982; Siddiqi, 2009). Others have challenged this characterization, instead attempting to account for both the prohibition and its exceptions in terms of semantic and phonological constraints (e.g., Haskell, MacDonald, & Seidenberg, 2003; Seidenberg, MacDonald, & Haskell, 2007) or with recourse to distributional/frequency-based information (e.g., Hayes, Murphy, Davey, & Smith, 2003; Hayes, Smith, & Murphy, 2005; Ramscar & Dye, 2010). Evidence suggesting the dispreference for regular plurals in compounds comes primarily from their paucity in production among children (Gordon, 1985; Nicoladis, 2005; Ramscar & Dye, 2010) and adults (Lardiere & Schwartz, 1997; Murphy, 2000; van der Lely & Christian, 2000), and from evidence that they are judged poorly in experiments in which participants are

confronted with violations of the constraint (e.g., Berent & Pinker, 2007; Cunnings & Clahsen, 2007; Haskell et al., 2003). In contrast, very little research has examined whether this constraint is active during real-time sentence processing. The focus of the current study is not to tease apart these alternative characterizations of the constraint, but rather to turn our attention to examining the fundamental underlying assumption that this dispreference indeed influences real-time comprehension, resulting in the abandonment of compound structure in favor of a grammatical alternative when available. This assumption, though widely held, has not to our knowledge been put to direct test.

In the current study, we address this gap in our basic understanding of the deployment of the constraint barring regular plural non-heads in compounds. We present new evidence that noun-noun sequences for which the first noun (the potential non-head) is plural engender reading time slowdowns at the potential compound head, providing converging evidence that the dispreference for plurals in compounds is evident during sentence comprehension (see also Cunnings & Clahsen, 2007); crucially, we demonstrate that the parser then abandons the compound analysis in favor of a more complex, relative clause analysis of the noun-noun string in the construction we test. Thus, we provide evidence not only for the immediate recognition of the violation of this constraint, but also that this in fact leads to the abandonment of the dispreferred structure. We thus show that morphological information regarding pluralization and compound formation impacts the anticipation of downstream syntactic structure (in our case, a relative clause) in advance of the appearance of the disambiguating verb confirming the presence of this structure. Such research is crucial for fully understanding pluralization, compound formation, their interactions, as well as their impact on language comprehension more broadly, for a number of reasons, outlined below.

First, previous research examining morphological processing in isolation versus during sentence comprehension has shown that morphological effects observed outside of sentence context are not always observed in sentence processing, and vice versa. This recommends the examination of morphological phenomena not only in isolation or in offline judgment tasks, but also in the context of real-time sentence processing. For example, Hyönä, Vainio, and Laine (2002) demonstrated complexity effects in the recognition of case-marked words in isolation which were not evident in a reading task. Bertram, Hyönä, and Laine (2000) showed a dissociation in the opposite direction: base-frequency effects were found for some Finnish inflected words during sentence processing but not when tested in isolation. Studies on the assignment of internal structure to ambiguous multi-morphemic words in isolation and those using sentential contexts have also yielded differing results (e.g., Libben, 2003; Pollatsek, Drieghe, Stockall, & de Almeida, 2010). These mismatches motivate investigating the deployment of knowledge regarding plurality and compound formation during real-time sentence comprehension.

Second, previous research on the processing of noun-noun sequences during sentence processing has shown that some types of information, which could potentially steer the processing mechanism away from assigning compound structure when it would yield anomalies, do not do so. For example, the compound analysis of a noun-noun string is, all else equal, strongly preferred over more complex analyses, as previous noun-noun/relative clause ambiguity studies (e.g., Grodner et al., 2002) have shown. Grodner et al. (2002) have

shown that this causes the parser to hold onto a compound structure assignment even when the resulting compound analysis yields an anomalous interpretation (we review Grodner et al., 2002, in more detail below). No previous research that we are aware of has tested whether or not morphological information such as that regarding pluralization of non-heads overrides this kind of structural bias in favor of a compound analysis, leaving open the question of whether morphological information regarding pluralization in compound formation, unlike semantic anomaly, may serve to guide the parser away from a compound interpretation during comprehension. A study by Kennison (2005) examined whether semantic interpretation in noun phrases is incremental or head-driven, by manipulating plural marking on the noun in more vs. less plausible phrases, such as “ancient castle(s)” versus “careful castle(s)” presented in sentence context. Kennison’s manipulation relies on the assumption that pluralization on the noun identifies it as the noun phrase head since its pluralization rules it out as the non-head constituent of a multi-word compound. Kennison’s results show a reading time slowdown for the anomalous condition only when the noun is plural, which Kennison (2005) takes to suggest that noun phrase interpretation may not occur until the head is identified (however, see Staub et al., 2007, who show effects of incremental interpretation within noun phrases even when the nouns are singular). For our purposes, Kennison’s (2005) findings provide evidence suggesting that knowledge of pluralization in compound formation may in fact influence the assignment of compound structure during real-time processing. On the other hand, there is evidence that other morphological cues which should in principle be used to guide parsing do not always do so (see e.g., Brysbaert & Mitchell, 1996, 2000, for Dutch findings suggesting that gender agreement cues are not always used to disambiguate syntactic structures). Indeed, in the parsing literature, it has been proposed that the parser may tolerate some degree of dispreferred structure in order to achieve a “good-enough” parse (Ferreira, Bailey, & Ferraro, 2002; Ferreira & Patson, 2007).

Third, investigating pluralization and compound formation during sentence comprehension will inform our understanding of the impact of morphological representations and combinations on the processing of larger structures, broadening our view of their role in comprehension, while also informing alternative models of processing at the sentence level. It is worth re-emphasizing here that the barring of regular pluralization in compounding is not exceptionless; that is, finding a regular plural on the first noun of a noun-noun sequence is not a deterministic cue ruling out the compound analysis in all cases (recall attested combinations like *parks department*); this makes plurals in compounds a particularly interesting test case for how morphological knowledge such as that of compound formation is in fact recruited for comprehension. Determining whether the apparent violation of the constraint on regular plurals inside compounds in fact leads the parser to both abandon this analysis and to anticipate a more complex, relative clause analysis for which disambiguating evidence has not yet been encountered, speaks to alternative processing models more broadly. For example, such a finding would be consistent with processing models in which structure building is strongly incremental and predictive, recruiting multiple sources of information, including information regarding compound formation and plurality, to posit linguistic structure in advance of deterministic bottom-up input (e.g., Lau, Stroud, Plesch, & Phillips, 2006; Yoshida, 2006, among others).

Fourth, gaining a measure of the online instantiation and syntactic consequences of the violation of this constraint would ultimately provide a new testing ground for determining how compounds of other types (e.g., with irregular plural non-heads, inherent plural non-heads, or singulars with phonological endings similar to plurals, like *maze*) are processed during sentence comprehension. This would provide a new testing ground for investigating what properties 'trigger' the constraint, speaking directly to issues regarding the potential roles of morphological regularity, phonological form, and semantics, which has been a major point of debate in research on plurals in compounds to date. As the first study directly probing whether even regular pluralization on the potential non-head member of a noun-noun sequence in fact leads to the abandonment of compound structure in favor of a grammatical alternative – a fundamental assumption of nearly all current approaches, which has not been confirmed – we will focus on regular pluralization, for which the phenomenon is widely agreed upon. The current study addresses this open question.

One previous sentence processing study, Cunnings and Clahsen (2007), presents eye-tracking evidence that the PIC constraint is active during online processing. Participants read sentences containing compounds with either a regular plural, irregular plural, or singular non-head. Eye-movement measures thought to reflect relatively early processing stages (e.g., first fixation duration, gaze duration), were significantly longer for the compound head for the condition with a regular plural non-head, compared to those with irregular plural or singular non-heads; the latter two did not differ in these measures. Evidence for a dispreference for irregulars emerges in measures such as regression path duration and rereading time. Cunnings and Clahsen (2007) take this evidence to reflect a morphological constraint against regular plurals in compounds, which is active prior to a later-emerging semantic constraint against semantically plural non-heads, aligning their results with structure-first models in which morphosyntactic information guides initial parsing decisions (e.g., Frazier & Clifton, 1996; cf., Altmann, Garnham, & Dennis, 1992). However, what has not yet been established using either offline or online tasks is whether the dispreference for regular non-heads in compounds results in the assignment of non-compound structure to the noun-noun string which would otherwise violate the constraint. We provide such evidence in the current study. To probe for the effects of plurality in the assignment of structure to noun-noun strings, we utilize the noun-noun/relative-clause ambiguity paradigm.

Structure assignment involving noun-noun sequences has been investigated using a number of ambiguity resolution paradigms. Results from the noun-noun/noun-verb ambiguity paradigm (e.g., *desert trains*, where *trains* may either be the compound head or main verb in a sentence) have alternatively been used to argue for a delay in assigning category (e.g., Frazier & Rayner, 1987) or its immediate assignment utilizing multiple information sources, such as plausibility and co-occurrence frequency (e.g., MacDonald, 1993). Grodner et al. (2002) examined the noun-noun/relative-clause ambiguity in English sentences such as (1) below.

(1) The alley mice run rampant in is damp and dimly lit but relatively clean.

(Grodner, et al., 2002: 279)

Grodner et al. (2002) tested whether the structural bias in favor of the compound analysis of the ambiguous noun-noun string (e.g., *alley mice*), which they attribute to a preference for storing the least amount of incomplete structure (the noun-noun reading requires only a matrix predicate, while the relative-clause reading requires the prediction of an embedded verb and NP gap site in addition to the matrix predicate), is evident even in cases in which non-structural biases favor the more complex, relative-clause analysis. If the noun-noun analysis is adopted, a garden-path slowdown is then expected upon encountering the second verb (*is*, in the example above). In a self-paced reading experiment testing both plausible and implausible potential compounds, Grodner et al. (2002, Experiment 2) showed significant slowdowns for both the plausible and implausible compound conditions by the word following the disambiguating verb. With respect to the noun-noun sequences themselves, the implausible compounds were read more slowly than the plausible compounds. Grodner et al. (2002) take these results to indicate an effect of structural complexity even in the face of contravening non-syntactic information.

Current Study

In the current study, we utilize the noun-noun/relative-clause ambiguity paradigm, manipulating number on the first noun (the potential compound non-head) to test whether a regular plural potential non-head will result in an immediate slowdown, reflecting the deployment of the dispreference for regular plurals in compounds (following Cunnings & Clahsen, 2007); we also manipulate the presence or absence of the complementizer *that* (following Grodner et al., 2002) to generate unambiguous relative clause structures (see 2a–d for examples). If knowledge of pluralization and compound formation is deployed during processing, increased reading times should be observed for the PIC-violating condition (2b) compared to (2a).

2a) At the university, the particle chemists efficiently replicated broke the container.

2b) At the university, the particles chemists efficiently replicated broke the container.

2c) At the university, the particle that chemists efficiently replicated broke the container.

2d) At the university, the particles that chemists efficiently replicated broke the container.

Crucially, these sentences ultimately resolve as non-compound, relative clause sentences. If encountering a potential violation of the PIC constraint leads to the abandonment of compound structure in favor of a grammatical alternative (the relative clause analysis), this should lead to the avoidance of a garden-path slowdown which is otherwise expected upon encountering the disambiguating verb (*broke*, in example 2). While our experimental sentences are all grammatical (and do not ultimately involve compounding), they allow tests of both whether a noun-noun string yielding a violation of the PIC constraint engenders a slowdown at the potential compound head, and whether under these conditions, the parser abandons the compound analysis in favor of a relative-clause analysis.[1] Such effects would be consistent with those of a previous study on Japanese classifier-noun mismatches

(Yoshida, 2006). In Japanese, numeral classifiers match semantically with the noun with which they associate, as is illustrated in (3a–b).

3a) san-nin-no tosioita sensee-ga

three-Cl(human)-Gen aged teacher-Nom (semantically compatible)

'three aged teachers'

3b) san-satsu-no tosioita sensee-ga

#three-Cl(books/printed matter)-Gen aged teacher-Nom (semantically incompatible)

(adapted from Yoshida, 2006: 230–231)

In example (3a), the classifier for humans, *nin*, is used with the noun *sensee* (teacher), yielding a semantically natural phrase; in example (3b), the classifier for books/printed matter, *satsu*, is used with the noun *sensee* (teacher), yielding a semantically anomalous/ uninterpretable phrase. However, the genitive numeral classifier may be separated from its associated noun by an intervening relative clause, as in example (4).

4) san-satsu-no [tosioita sensee-ga atarasii koochoo-ni yorokonde okutta] hon-o
three-Cl(books/printed matter)-Gen aged teacher-Nom new president-Dat gladly gave book-Acc

'three books that an aged teacher gladly gave to the new president'

(adapted from Yoshida, 2006: 230–231)

Yoshida (2006) used self-paced reading to examine the processing of an apparent classifier mismatch which ultimately resolves as a classifier-noun pair separated by a relative clause. The matching/mismatching classifier-noun sequences and relative clauses were presented in full sentences like (5a–b) below, adapted from Yoshida (2006):

5a) Classifier Match Condition

Tannin-wa san-nin-no tosioita sensee-ga atarasii koochoo-ni yorokonde okutta hon-o aru-seeto-ni kyoositu-de yomase-masita.

Class-teacher-Top three-Cl(human)-Gen aged teacher-Nom new president-Dat gladly gave book-Acc a-student-Dat class-room-at made-read.

'The teacher made a student read the book that three aged teachers gladly gave to the new president at the classroom.'

5b) Classifier Mismatch Condition

Tannin-wa san-satu-no tosioita sensee-ga atarasii koochoo-ni yorokonde okutta hon-o aru-seeto-ni kyoositu-de yomase-masita

[1]If the relative lack of regular plural non-heads in compounds is due not to a constraint, but to extragrammatical factors (see, e.g., Hayes et al., 2005, for a detailed discussion), it is also possible that a slowdown at the potential compound head for the plural non-head condition would be observed (e.g., reflecting its unfamiliarity) but not lead to the abandonment of that structure in favor of an alternative (and more complex) relative clause analysis.

Class-teacher-Top three-Cl(book)-Gen aged teacher-Nom new president-Dat gladly Gave book-Acc a-student-Dat class-room-at made-read.

'The teacher made a student read three books that an aged teacher gladly gave to the new president at the classroom.'

(adapted from Yoshida, 2006: 230–231)

The apparent mismatch among the classifier and the first-encountered noun (*sensee* 'teacher' in 5b) caused a slowdown at the noun, and led to the reduction of the garden path effect otherwise encountered at the embedded verb which resolves the structure grammatically as a relative clause. If the detection of a violation of the PIC constraint likewise is both instantiated online and leads the parser to posit an alternative, relative clause continuation, then we expect an initial slowdown upon detection of the constraint violation, and a concomitant amelioration of the garden path effect upon encountering the verb which definitively disambiguates the sentence as containing a relative clause.

In Experiment 1, we present an acceptability judgment experiment, verifying that the particular compounds to be used in Experiment 2 are rated as less acceptable when the non-head is pluralized. In Experiment 2, we report a self-paced reading experiment showing both the immediate application of the PIC constraint, and that its violation leads to the abandonment of the compound structure in favor of a relative-clause structure.

Experiment 1: Acceptability Judgment Task

To ensure that our compounds are dispreferred when the initial noun is pluralized, we first tested their acceptability as compounds in brief sentences (following Cunnings & Clahsen, 2007; Haskell et al., 2003, among others). Since this constraint is not exceptionless, it is particularly important to verify whether the compounds to be tested in our self-paced reading study (Experiment 2) are judged less acceptable when their non-head is pluralized.

Method

Participants—Thirty-eight undergraduate students from the University of Kansas provided their written informed consent to participate in this experiment. The participants were all native speakers of American English with normal or corrected-to-normal vision. Participants were offered course credit or paid for their participation.

Stimuli—All 24 noun-noun compounds tested have non-heads with regular plural forms. To avoid potential effects of existing multi-word concatenations, we tested only novel noun-noun combinations (all had a zero co-occurrence rate in the Corpus of Contemporary American English; Davies, 2009). Moreover, the potential non-head nouns were all plural biased; for each noun, we ensured that it appeared more often in its plural form than in its singular form, using the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995). This reduces the likelihood of obtaining slowdowns at the non-head itself due to the rarity of the noun in its plural form (see Lau, Rozanova, & Phillips, 2007, for reading time slowdowns for plural forms of singular-biased, but not plural-biased nouns). This also minimizes the likelihood that the compounds with plural non-heads are dispreferred because of the rarity of

the non-head in its plural form. The compounds were presented in short sentences (see 6a–b).

6a) The pole welders worked through the night. (Singular non-head condition)

6b) The poles welders worked through the night. (Plural non-head condition)

The compound was bolded and underlined in each sentence. The 24 target compounds were presented with either a singular or plural non-head, in a Latin Square design, together with 24 filler sentences. Twelve fillers included compounds with singular non-heads, six included irregular plural non-heads (e.g., *teeth examiners*), and six included inherent plural non-heads (e.g., *pliers holders*). All compounds had a plural head noun, since they also appear in this way in Experiment 2, as is necessary for the string to be used in a noun-noun/relative-clause ambiguity paradigm.

Procedure—Participants rated the acceptability of the compound in each sentence, on a 7-point (1 = least acceptable, 7 = most acceptable) scale. Participants were instructed that a relatively unacceptable compound would be one that struck them as awkward/"off" (following Haskell et al., 2003). The target sentences were divided into two counterbalanced lists, such that each participant rated every compound, but no participant judged a given compound with both a singular and a plural non-head. The 24 target sentences and 24 fillers were presented in a different randomized order for each participant. Mean ratings for the singular and plural non-head versions of the target compounds were analyzed to verify whether the plural non-head version of the compounds is dispreferred. If these compounds pattern similarly to those tested in previous studies, we expect that they will be rated less acceptable when the non-head appears with a regular plural than when it appears in singular form.

Results

The target compounds were judged significantly less acceptable (M = 2.8) when their non-head was plural than when the non-head was singular (M = 5.5), $t_1(37) = 14.708$, $p < 0.001$; $t_2(23) = 18.919$, $p < 0.001$; two-tailed, paired t-test). This pattern held for each compound tested.

Discussion

These results confirm that our compounds are rated less acceptable when the non-head is pluralized, consistent with a range of previous findings (e.g., Berent & Pinker, 2007; Cunnings & Clahsen, 2007; Haskell et al., 2003). In Experiment 2, we provide a direct test for whether this dispreference leads the parser away from a compound analysis, something that is not straightforward to conclude solely based on acceptability ratings or reading time slowdowns upon encountering a violation of this constraint.

Experiment 2: Self-Paced Reading

Method

Participants—Forty-eight undergraduate students from the University of Kansas provided their written informed consent to participate in this experiment. The participants were all

native speakers of American English with normal or corrected-to-normal vision. Participants were offered course credit for their participation.

Stimuli—The target stimuli consisted of 24 sentence sets, in a 2 × 2 design with the factors Number (singular vs. plural potential non-head) and Ambiguity (presence vs. absence of the relativizer *that*). See Table 1 for examples. The first four words of the sentence were identical within each set, as were all of the words following the potential compound head.

The potential compounds are those described in Experiment 1. The disambiguating verb was an unambiguous past tense verb, in order to minimize the likelihood that this verb would instead be taken as a potential modifier. In addition to the 24 target sentences, 72 filler sentences were constructed. The fillers varied in length from 10–14 words and varied in syntactic structure. The target to filler ratio in this experiment was 1:4.

Following Grodner et al. (2002), we conducted a pretest using an offline, pencil-and-paper survey in which participants rated the plausibility of sentence onsets containing a compound, as in *At the university, the particle chemists* or a relative clause, as in *At the university, the particle that chemists efficiently replicated*, on a 5-point scale (1 = least plausible, 5 = most plausible). Two list versions were comprised of half compound and half relative clause onsets, such that no participant saw both versions of the same stimulus. Thirty-six native English speaking participants received extra credit for completing this pretest; none participated in the self-paced reading experiment or Experiment 1. All sentence onsets containing compounds were rated as more plausible than their relative clause counterparts. The mean rating difference between the compound onsets (M = 4.14) and relative-clause onsets (M = 3.36) was confirmed, $t(23) = 6.791$, $p < 0.001$; two-tailed, paired t-test by items. Thus, both complexity and plausibility encourage a compound analysis of the ambiguous noun-noun strings.

Procedure—The sentences were presented word-by-word in a non-cumulative, moving-window self-paced reading paradigm (Just, Carpenter, & Wooley, 1982). Each sentence is initially presented with all words replaced by dashes; participants are instructed to hit the left mouse button to reveal each subsequent word. As the participant advances through each subsequent word, the previous word is re-masked by dashes. Following the final word of the sentence, participants were presented with a yes/no comprehension question. Participants were instructed to hit a key labeled Y for *yes* and a key labeled N for *no*. Stimuli were presented on a desktop PC with CRT monitor. Stimulus presentation was controlled by Paradigm (Tagliaferri, 2005). Following a practice session with 5 practice sentences, the 24 sets of target sentences were presented in a Latin Square design and randomized with the 72 filler sentences.

Data Analysis

Reading times for sentences for which a given participant answered incorrectly and those with reading times outside a threshold of 3 standard deviations from a participant's mean reading time in that region across conditions (1.9% of the datapoints) were excluded from analysis (Ratcliff, 1993). The remaining data were carried forward for statistical analysis via

a 2×2 (Number [singular, plural) X Ambiguity [ambiguous, unambiguous]) repeated-measures analysis of variance (ANOVA).

If the PIC constraint is instantiated during real-time processing, we predict a larger slowdown upon encountering the potential head of the noun-noun sequence when it is preceded by a non-head with a regular plural, compared to when it is preceded by a singular. Thus, we predict a Number x Ambiguity interaction at Region 7, reflecting especially long reading times for the second noun in the Ambiguous-Plural condition (e.g., *particles chemists*), following Cunnings and Clahsen (2007). If the detection of a violation of this constraint leads to the abandonment of compound structure in favor of a more complex, relative clause analysis, then we expect an amelioration of the garden-path effect upon encountering the verb which disambiguates the structure as a relative clause for the condition in which the potential compound non-head had been in its regular plural form. Thus, we predict a Number x Ambiguity interaction, reflecting especially long reading times for the Ambiguous-Singular condition, which we expect to emerge by the word following the disambiguating second verb (Region 11), following Grodner et al. (2002).

Results

Comprehension Question Accuracy—Mean comprehension question accuracy was high (M = 96 %; Range = 95%–97% across conditions). No significant accuracy differences across conditions were observed.

Self-Paced Reading Times—Below, we present analyses of the reading time results, focusing first on the noun-noun string, in order to investigate the online instantiation of the PIC constraint, and second on the disambiguating second verb and its spillover region, to investigate the syntactic consequences of this constraint. Mean reading times for the Singular, Ambiguous, Plural Ambiguous, Singular, Unambiguous, and Plural Unambiguous conditions are reported in Figure 1.

Dispreference for Plurals in Compounds

Region 7: Potential compound head: Reading times at the critical region containing the potential compound head (Region 7) showed a significant effect of Ambiguity both by participants and items, $F_1(1, 47) = 28.218$, $MSE = 23099.716$, $p < 0.001$; $F_2(1, 23) = 65.086$, $MSE = 4998.090$, $p < 0.001$. The effect of Number was marginal by participants, though not by items, $F_1(1, 47) = 3.151$, $MSE = 15430.873$, $p < 0.083$; $F_2 < 1$, $p > 0.352$. Crucially, the Ambiguity x Number interaction was significant by participants and items, $F_1(1, 47) = 4.212$, $MSE = 17193.718$, $p < 0.047$; $F_2(1, 23) = 5.140$, $MSE = 6037.237$, $p < 0.034$. The main effect of Ambiguity reflects overall slower reading times for ambiguous conditions relative to the unambiguous conditions. The crucial Ambiguity x Number interaction reflects the particularly large slowdown for the plural condition when ambiguous (i.e., when a PIC constraint violation) compared to the singular condition. This increased slowdown reflects the online instantiation of the PIC constraint.[2] This pattern is also reflected in the following paired comparisons. Reading times did not differ among the two unambiguous conditions, $t_1(47) < 1$, $p > 0.669$, $t_2(23) < 1$, $p > 0.793$, while the plural, ambiguous condition showed longer reading times than the singular, ambiguous condition in the by-participants analysis

and approached significance in the by-items analysis, $t_1(47) = 2.139$, $p < 0.039$, $t_2(23) = 1.525$, $p < 0.142$.

Regions 8–9: Regions following potential compound head: The effect of Ambiguity remained significant for both participants and items in Region 8, $F_1(1, 47) = 24.077$, $MSE = 9671.053$, $p < 0.001$; $F_2(1, 23) = 6.568$, $MSE = 15874.693$, $p < 0.018$. The main effect of Ambiguity again reflects slower reading times for ambiguous conditions relative to the unambiguous conditions. There was also a significant effect of Number by participants, $F_1(1, 47) = 5.676$, $MSE = 9558.047$, $p < 0.022$; $F_2 < 1$, $p > 0.429$, reflecting overall slower reading times for the plural conditions, and no evidence of an interaction, all $F < 1$, $p > 0.333$.

In Region 9, there was no longer an effect of Ambiguity, all $F < 1$, $p > 0.765$. The effect of Number was marginal by participants, $F_1(1, 47) = 3.527$, $MSE = 16882.200$, $p < 0.068$, although not by items, $F_2 < 1$, $p > 0.336$. This reflects slower reading times for the plural conditions. There was no Ambiguity x Number interaction by participants or items, $F_1(1, 47) = 1.867$, $MSE = 30477.866$, $p < 0.179$; $F_2(1, 23) = 2.589$, $MSE = 11561.554$, $p < 0.122$.

Syntactic Consequences of the PIC Constraint

Region 10: Second verb: Reading times in Region 10, the verb which disambiguates the sentence in favor of a relative-clause analysis, showed a significant effect of Ambiguity both by participants and by items, $F_1(1, 47) = 11.629$, $MSE = 21764.820$, $p < 0.002$; $F_2(1, 23) = 14.014$, $MSE = 8399.441$, $p < 0.002$. The effect of Number was significant by participants, $F_1(1, 47) = 5.254$, $MSE = 5499.173$, $p < 0.027$, though not by items, $F_2 < 1$, $p > 0.243$. There was no significant interaction of Ambiguity and Number by participants or items, all $F < 1$, $p > 0.553$. The main effect of Ambiguity reflects overall slower reading times for ambiguous conditions relative to the unambiguous conditions, and the main effect of Number indicates an overall faster reading time for plurals than singulars.

However, as can be observed in Figure 1, encountering the disambiguating verb in Region 10 appears to yield a slowdown for the singular, ambiguous condition that is not present in the preceding region, while the difference between plural, ambiguous and plural, unambiguous conditions at Region 10 is qualitatively similar to the reading time difference already evident in the pre-disambiguation Region 9. We further examined this using a Region by Ambiguity analysis (following Grodner et al., 2002) for each condition, comparing the effect of Ambiguity at the pre-disambiguation Region 9 and at the disambiguating word in Region 10. In this analysis, a significant interaction among Region and Ambiguity, with an Ambiguity effect evident only in the disambiguating region (Region 10) but not earlier, would suggest a garden path effect engendered at disambiguation. For the Singulars, there was a marginal main effect of Ambiguity by participants, $F_1(1, 47) = 2.891$, $MSE = 11.007$, $p < 0.097$, $F_2(1, 23) = 1.226$, $MSE = 10047.089$, $p < 0.281$, and,

[2]Since we manipulated number in Region 5 (the potential compound non-head), we tested this region to ensure that no differences emerged before the potential head. There was no significant effect of Ambiguity, Number, or their interaction by participants or items (all $F < 1$, all $p > 0.340$). Moreover, no differences emerged at the relativizer *that* (Region 6 of the unambiguous conditions), all $t < 1$, all $p > 0.657$.

crucially, an interaction of Ambiguity and Region ($F_1(1,47) = 5.118$, MSE = 29538.426, $p < 0.029$), $F_2(1, 23) = 9.596$, $MSE = 7995.109$, $p < 0.006$, reflecting the emergence of an Ambiguity effect in Region 10 (singular, unambiguous reading time 420 ms, singular, ambiguous 502 ms) that was not present in Region 9 (singular, unambiguous reading time 486 ms, singular, ambiguous 456 ms). This interaction is reflected in the following *t*-tests: singular, unambiguous and singular, ambiguous did not differ in Region 9, $t_1(47) = 1.132$, $p < 0.264$, $t_2(23) = 1.297$, $p < 0.209$, while they did in Region 10, $t_1(47) = 2.629$, $p < 0.013$, $t_2(23) = 2.765$, $p < 0.012$. For the plurals, in contrast, there were effects of Region, $F_1(1,47) = 5.822$, $MSE = 39168.141$, $p < 0.021$, $F_2(1, 23) = 13.849$, $MSE = 9404.881$, $p < 0.002$, and Ambiguity $F_1(1,47) = 6.747$, $MSE = 18451.297$, $p < 0.013$, $F_2(1, 23) = 7.438$, $MSE = 11049.386$, $p < 0.013$, reflecting overall faster reading times in Region 10, and overall slower times for plural, ambiguous than plural, unambiguous. Crucially, however, there was no interaction among Ambiguity and Region, $F_1 < 1$, $p > 0.464$, $F_2 < 1$, $p > 0.907$, suggesting that the appearance of the disambiguating word did not cause any garden-path slowdown for the plural, ambiguous condition.

Region 11: Spillover region following second verb: Reading times in Region 11 again showed a significant effect of Ambiguity for both participants and items, $F_1(1, 47) = 39.342$, $MSE = 17220.849$, $p < 0.001$; $F_2(1, 23) = 42.216$, $MSE = 8016.918$, $p < 0.001$. There was also a significant effect of Number by participants and items, $F_1(1, 47) = 8.711$, $MSE = 15762.995$, $p < 0.006$; $F_2(1, 23) = 8.269$, $MSE = 8980.811$, $p < 0.010$. Crucially, there was also a significant Ambiguity x Number interaction by participants and items, $F_1(1, 47) = 11.174$, $MSE = 15245.593$, $p < 0.003$; $F_2(1, 23) = 10.636$, $MSE = 7771.587$, $p < 0.004$. The main effect of Ambiguity reflects overall slower reading times for ambiguous conditions relative to the unambiguous conditions, while the effect of Number reflects overall slower reading times for singulars. The critical Ambiguity x Number interaction reflects the particularly large slowdown for the singular, ambiguous condition compared to the plural, ambiguous condition. This pattern is also reflected in the following paired comparisons. Reading times did not differ among the two unambiguous conditions, $t_1(47) <1$, $p > 0.539$, $t_2 < 1$, $p > 0.825$, while the singular, ambiguous condition showed longer reading times than the plural, ambiguous condition, $t_1(47) = 3.271$, $p < 0.003$, $t_2(23) = 3.291$, $p < 0.004$.

When examining Region 11, a small but significant slowdown for the plural, ambiguous versus plural, unambiguous condition was also evident ($t_1(47) = 3.772$, $p < 0.001$; $t_2(23) = 3.411$, $p < 0.003$). This might suggest that there was a garden-path effect even for the plural, ambiguous condition, although significantly reduced compared to the singular, ambiguous condition. However, as noted in the discussion of the Region 10 results, the plural ambiguous and unambiguous conditions differed before disambiguation. Thus, we examined whether the slowdowns for the plural, ambiguous condition and the singular, ambiguous condition indeed emerged following disambiguation, using a Region by Ambiguity interaction analysis (following Grodner et al., 2002). The comparison of reading times in Region 11 to those in either Region 9 (the region prior to the appearance of the disambiguating second verb) or Region 10 (the disambiguating second verb) revealed an interaction effect among Ambiguity and Region only for the singulars. This effect is significant by participants and items comparing Regions 9 versus 11, $F_1(1, 47) = 16.486$,

MSE = 31719.574, $p < 0.001$; $F_2(1, 23) = 25.096$, *MSE* = 10677.317, $p < 0.001$. The effect is significant by participants and marginal by items comparing Regions 10 versus 11, $F_1(1, 47) = 5.235$, *MSE* = 21350.881, $p < 0.028$; $F_2(1, 23) = 4.187$, *MSE* = 13830.270, $p < 0.053$. These interactions are reflected in the following *t*-tests: singular, unambiguous and singular, ambiguous did not differ in Region 9, $t_1(47) = 1.132$, $p < 0.264$, $t_2(23) = 1.297$, $p < 0.209$, while they did in both Region 10, $t_1(47) = 2.629$, $p < 0.013$, $t_2(23) = 2.765$, $p < 0.012$ and Region 11, $t_1(47) = 5.363$, $p < 0.001$, $t_2(23) = 5.595$, $p < 0.001$, with the difference increasing region to region. In contrast, no interaction is evident for the plurals in any comparison (*Regions 9 vs. 11:* all $F < 1$, all $p > 0.56$; *Regions 10 vs. 11:* all $F < 1$, all $p > 0.883$). That is, only the singulars, and not the plurals, showed a garden-path effect in Region 11 that was not present pre-disambiguation. This analysis suggests that the difference between plural ambiguous and unambiguous conditions at Region 11 reflects the continuation of a difference that emerged before the disambiguating verb, while that for the singulars reflects a slowdown in Region 11 that was not present before disambiguation (and was larger in the spillover Region 11 than in the disambiguating Region 10 itself).

General Discussion

The data presented here show that knowledge of pluralization and compound formation is deployed online, and crucially, that knowledge of the dispreference for plurals inside compounds leads to the adoption of a more complex, relative-clause resolution of the noun-noun/relative-clause ambiguity. These effects were evident both in the increased slowdown at the potential head position for noun-noun strings with a plural, compared to a singular, potential non-head, and in the reversal of this pattern following the disambiguating second verb. The latter effect suggests that the presence of pluralization on the first noun of the noun-noun string indeed led the processing mechanism away from a compound analysis of the noun-noun string in favor of a more complex, relative-clause analysis, despite both structural and non-structural biases favoring the compound analysis. These results are convergent with the eye-tracking findings of Cunnings and Clahsen (2007), showing a reading time slowdown immediately upon encountering a noun-noun string that violates the PIC constraint (see also Cunnings and Clahsen, 2008, regarding plurals in derived nominals). These results are also in line with a wide range production and acceptability judgment studies suggesting that regular plural compound non-heads are disfavored. Our findings crucially extend those of the Cunnings & Clahsen (2007) eye-tracking study, and the findings from offline tasks such as acceptability judgments (e.g., Berent & Pinker, 2007; Cunnings & Clahsen, 2007; Haskell et al., 2003, among others) in showing that when assigning a compound structure to a noun-noun sequence would result in a plural non-head, the processing mechanism indeed attempts to assign a non-compound analysis to the structure.

The garden-path slowdown for the singular, ambiguous condition is consistent with previous findings that a compound analysis, and not a more complex relative-clause analysis, is initially adopted for noun-noun strings. This finding is consistent with processing models in which the relative complexity of alternative structures influences structure assignment in real-time, with the compound analysis of a noun-noun string in a noun-noun/relative clause ambiguous structure strongly preferred (e.g., Grodner et al., 2002). While Grodner et al.

(2002) suggest that compound structure is preferred even when the resulting compound is semantically anomalous, our findings suggest that morphological information – specifically, the presence of pluralization on the first noun of the noun-noun sequence, does serve to rule out the compound analysis in favor of the more complex, relative clause analysis. This result provides support for the assumption that (at least regular) pluralization on nouns is deployed as an indicator that the noun is not a non-head constituent of a multi-word compound (see, e.g., Kennison, 2005 for this assumption, and for converging evidence that plural marking is deployed for head identification). Thus, despite the structural bias toward the compound resolution of the noun-noun/relative clause structural ambiguity, and the observation that the barring of regular plurals in compounds is not exceptionless, the presence of pluralization on the potential compound non-head steers the processing mechanism away from a compound analysis; at least in this domain, the parsing mechanism appears to avoid accepting a violation of this morphological constraint, rather than tolerating this anomaly (cf., Brysbaert & Mitchell, 1996, 2000 for underuse of gender cues; see, e.g., Ferreira, Bailey, & Ferraro, 2002; Ferreira & Patson, 2007 for one example of a parsing model in which some degree of dispreferred structure may be tolerated under some circumstances).

That the presence of pluralization led the processing mechanism away from this analysis, and thus ameliorated the garden-path slowdown that otherwise occurs when the structure is disambiguated as a relative-clause, is broadly convergent with the findings of Yoshida (2006) which demonstrated that a classifier-noun mismatch can engender the prediction of a relative clause in advance of encountering other information indicating that such a clause has begun. These results are consistent with approaches to sentence comprehension positing highly incremental, predictive parsing mechanisms (Altmann & Kamide, 1999; Gibson, 1998; Yoshida, 2006). Indeed, our analyses revealed no garden-path for the plurals when pre-disambiguating region differences in reading times among the ambiguous and unambiguous plural conditions is taken into account, consistent with an interpretation of the findings in which the relative clause has been predicted (as argued for the classifier-mismatch/relative clause ambiguity results in Yoshida, 2006, for example), rather than an interpretation in which the plural aids in reanalysis of the ambiguity upon encountering the disambiguating verb.

As noted in the Results, analysis of reading times at the spillover region (Region 11) did show a significant slowdown for plural, ambiguous compared to plural, unambiguous, which appears to reflect some level of garden-path for the plural condition, though reduced compared to the singular condition, as evidenced by the significant Ambiguity by Number interaction; this would potentially challenge the interpretation of our disambiguation findings as reflecting predictive processing rather than reanalysis. Thus, additional discussion of this effect is warranted. This difference might have emerged because compounds with a regular plural non-head were occasionally pursued, regardless of the dispreference for compounds with regular plural non-heads. Recall that the constraint is not exceptionless, although all of our compounds with plural non-heads were judged to be worse than their singular counterparts. However, there are other accounts for such a slowdown that do not necessarily involve adopting a compound analysis for the PIC-violating strings. For example, while we utilize an overt complementizer/relativizer (*that*) to generate our

unambiguous conditions, it has been argued that distributional patterns of complementizer use in relative clauses may be affected by properties of the relative clause, and that comprehenders may be sensitive to these distributional patterns (e.g., Jaeger & Wasow, 2006; Race & MacDonald, 2003; Walter & Jaeger, 2008). Moreover, Jaeger and Wasow (2006) reported a corpus analysis showing that non-subject relative clauses with plural referents have a higher likelihood of a relativizer than those with a singular referent. Thus, it is possible that the slowdown for the plural, ambiguous condition may reflect a dispreference for a relative clause with a plural object which lacks an overt complementizer. On the other hand, our analyses examining whether the ambiguity effect indeed showed up following disambiguation suggested that the slowdown for plural, ambiguous compared to plural, unambiguous was already present in the pre-disambiguating region and did not change following disambiguation. In these analyses, there is no evidence for a garden path for plurals, arguably obviating a need to posit any of these alternative explanations. While additional research examining the slowdown for plurals observed in Region 11 is called for, we emphasize that the interaction among Ambiguity and Number in Region 11 nevertheless demonstrates an amelioration of the garden path following a plural non-head potential compound compared to a singular non-head compound. This effect makes recourse to the status of the compound. It cannot be solely due to preferences for complementizer use in relative clauses with plurals, since if the only difference among the conditions were in the preference for an overt complementizer for relative clauses with plurals, this would then predict a *larger* slowdown for the plural condition in Region 11 than for the singular condition, the opposite of which was in fact observed.

The interpretation that we propose for the slowdown at the potential compound head is that it reflects the deployment of knowledge regarding the PIC constraint, which indeed raises the question of why that analysis should be in play at the head, and not immediately at the non-head carrying the plural marking, in a strongly incremental and predictive parser. One reason for this could relate to timing; that is, it has been argued in some incremental/predictive processing models, including those in which a single parse is pursued rather than maintaining multiple options, that predictions relying on different information sources operate on different time courses (see, e.g., Friederici, 1995; Lau et al., 2006, among many others). It is common in those models to posit that the fastest-evident effects of prediction are those that can be engendered by word category alone. If so, it is possible that in the current study (in which the readers spent only around 400 ms on average on the non-head) there was simply not enough time to detect the emergence of a prediction that takes into account not only the category of the root morpheme but also its number marking and the implications that this has for compound formation; this may account for why the effect emerges at the second noun (which is again consistent at the word category level with the compound analysis which is favored by the bias toward compound over relative-clause structure shown in Grodner et al., 2002). However, it is not possible with this dataset to rule out the possibility that the prediction had in fact been generated immediately at the potential non-head, and that the processing cost observed at the potential head is instead related to pursuing an alternate analysis (or specifically, the relative-clause analysis). For example, it could represent a cost associated with projecting the relative-clause structure, for identifying which grammatical alternative(s) are available, or potentially even for the violation of an

expectation for an overt complementizer to follow. While this underscores that there are alternative explanations for what the initial slowdown represents, and raises interesting questions regarding precisely how knowledge of the PIC is deployed and whether it indeed originates at the potential non-head or the potential head, for our purposes we would like to emphasize that all of these explanations involve (i) online deployment of knowledge regarding pluralization in compound formation, evident at least as soon as the potential head is encountered (converging with Cunnings & Clahsen, 2007), and (ii) evidence from within the same sentences, at the disambiguating second verb, that before disambiguation, the deployment of this knowledge indeed led to the abandonment of the compound structure in favor of the grammatical alternative, the relative clause, which had not been probed for or shown before.

Summary

The current study demonstrates the deployment of knowledge regarding pluralization and compounding during real-time sentence comprehension, establishing that violations of this constraint lead to the abandonment of compound structure in favor of a more complex, relative clause analysis. These findings contribute to the growing literature regarding morphological processing in sentential context, and regarding the mechanisms and information sources utilized during incremental sentence processing, suggesting a way forward in probing the nature of morphological knowledge and the ways in which this knowledge informs real-time sentence comprehension.

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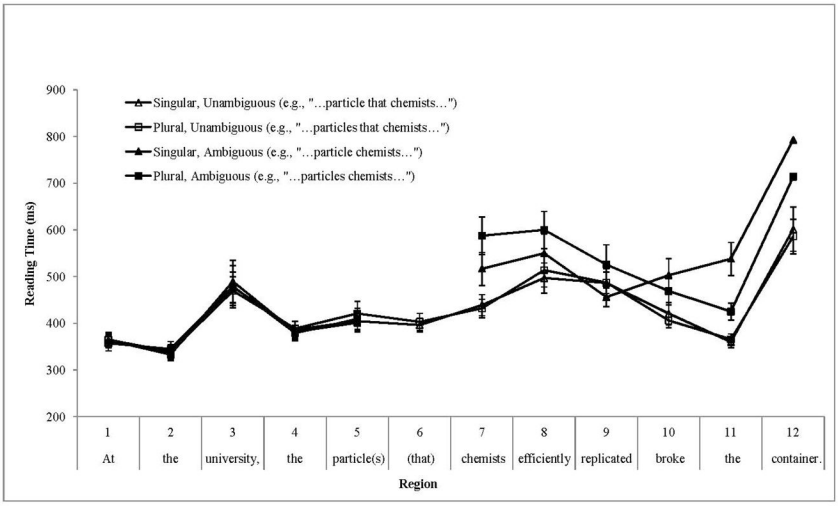

Figure 1.

Figure 1 shows mean reading times in milliseconds, for each region and condition. Error bars show Standard Error for each region, for each condition. A sample sentence is included to illustrate the content of each region.

Table 1

Sample item set

Condition	Sample sentence (regions are indicated using subscript numbers)
Singular, Ambiguous	At$_1$ the$_2$ university$_3$, the$_4$ particle$_5$ chemists$_7$ efficiently$_8$ replicated$_9$ broke$_{10}$ the$_{11}$ container$_{12}$.
Plural, Ambiguous	At$_1$ the$_2$ university$_3$, the$_4$ particles$_5$ chemists$_7$ efficiently$_8$ replicated$_9$ broke$_{10}$ the$_{11}$ container$_{12}$.
Singular, Unambiguous	At$_1$ the$_2$ university$_3$, the$_4$ particle$_5$ that$_6$ chemists$_7$ efficiently$_8$ replicated$_9$ broke$_{10}$ the$_{11}$ container$_{12}$.
Plural, Unambiguous	At$_1$ the$_2$ university$_3$, the$_4$ particles$_5$ that$_6$ chemists$_7$ efficiently$_8$ replicated$_9$ broke$_{10}$ the$_{11}$ container$_{12}$.