Korean Journal of English Language and Linguistics, **Vol 26, January 2026, pp. 106-126**
DOI: 10.15738/kjell.26..202601.106

KOREAN JOURNAL OF ENGLISH LANGUAGE AND LINGUISTICS

ISSN: 1598-1398 / e-ISSN 2586-7474

http://journal.kasell.or.kr

Investigating Animacy Effects on Prepositional Phrase Attachment Ambiguity Resolution: Evidence from Self-paced Reading*

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Received: November 26, 2025
Revised: January 13, 2026
Accepted: January 13, 2026

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* This work draws upon the first author's doctoral dissertation (2026).

ABSTRACT

Li, Ziying and Nayoun Kim. 2026. Investigating animacy effects on prepositional phrase attachment ambiguity resolution: Evidence from self-paced reading. *Korean Journal of English Language and Linguistics 26*, 106-126.

This study investigates the role of animacy in guiding prepositional phrase (PP) attachment ambiguity resolution. We conducted a self-paced reading experiment, testing sentences like *the teacher recorded a student/classroom with a microphone…*, where the Prepositional Phrase is ambiguous between a noun-modifier and a verb-modifier. While previous studies have demonstrated a dominant preference for the structurally simpler verb-modifier analysis (Minimal Attachment; Frazier and Rayner 1982), subsequent research has argued that attachment decisions depend on a range of syntactic and semantic factors such as the argument status of the PP (Schütze 1995). We manipulated the animacy of the direct object preceding the PP to explore its effect on PP attachment ambiguity resolution. Upon disambiguation, reading times revealed equivalent processing costs for both animate and inanimate noun conditions. This indicates that readers first assigned the PP *with a microphone* to the verb and then performed the noun-modifier reanalysis, regardless of the animacy of the object noun. Our findings are consistent with the theory that Minimal Attachment serves as a default syntactic processing strategy (Frazier 1979). These results further indicate that the role of animacy in guiding ambiguity resolution, as observed in previous studies (e.g., Trueswell et al. 1994), may be structurally limited. Specifically, animacy appears to exert strong influences in core-argument structures, where it interacts directly with other strong syntactic-thematic constraints, such as thematic role assignment. However, this animacy influence does not extend to ambiguity resolution involving non-argument structures such as PP-attachment ambiguities.

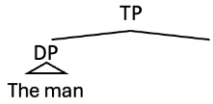
KEYWORDS

real-time sentence processing, animacy, PP-attachment ambiguity, Minimal Attachment

1. Introduction

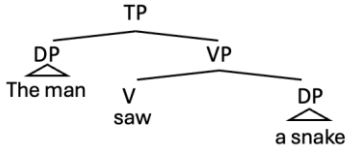
Sentence comprehension unfolds incrementally over time: readers begin to construct a syntactic structure from the first word they encounter and update it immediately with the integration of new words (Frazier 1979, Frazier and Fodor 1978, Frazier and Rayner 1982, Gibson 1998, 2000, Miller 1962). As readers start building the structure with the first word, an open syntactic dependency is established, and each incoming word is integrated to progressively resolve the dependency. For example, when structure building begins with a noun phrase (NP) "the man," which is the first input, a syntactic dependency is formed, as in (1).[1]

(1) The man…



Then, subsequent inputs will be integrated into the open structure to resolve the dependency and complete sentence comprehension. For example, when a verb phrase (VP) "saw a snake" appears next, it will be integrated into the structure in (1), serving as the main verb and forming a structure as in (2).

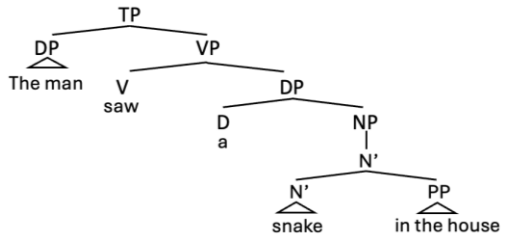
(2) The man saw a snake.



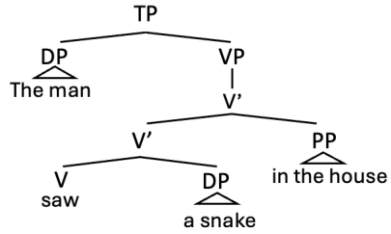
Sometimes, subsequent material permits more than one structural integration, leading to multiple potential syntactic structures and interpretations. For instance, when the prepositional phrase (PP) "in the house" appears subsequently, it can be integrated into the structure in (2) in two ways, attaching either to the NP "snake" as in (3a) or to the VP "saw" as in (3b).

(3) The man saw a snake.

a. NP-modifier reading



b. VP-modifier reading



[2]

[1] In this paper, tree abbreviations follow standard generative notation (Carnie 2021): TP (Tense Phrase), DP (Determiner Phrase), NP (Noun Phrase), VP (Verb Phrase).

[2] The syntactic trees in this paper are presented following the phrase structure rules (Chomsky 1957) for overall simplicity and

If the intended interpretation is clarified by a later input (i.e., the disambiguating input), the structural ambiguity like that in (3) is referred to as a "temporary" or "local" ambiguity (Ferreira and Henderson 1990, 1991, Frazier and Rayner 1982, MacDonald et al. 1994, Spivey-Knowlton et al. 1993, Trueswell 1996, Trueswell et al. 1994). Given that readers immediately build the syntactic structure upon encountering ambiguity, without waiting for the disambiguating input to appear (Frazier 1979, Frazier and Fodor 1978, Frazier and Rayner 1982, Miller 1962), a central question has been how the structure is initially assigned.

Over the decades, different theories have been proposed to answer this question. One of the most prominent classes of processing theories posits that readers consistently adopt the simplest structure with the fewest nodes, following a strategy known as Minimal Attachment (Ferreira and Clifton 1986, Frazier 1979, Frazier and Fodor 1978, Frazier and Rayner 1982, Rayner et al. 1983). This strategy has been demonstrated in a number of empirical studies, where readers consistently preferred the structurally simpler interpretation (e.g., 3b vs. 3a) across many ambiguity types (e.g., Clifton and Ferreira 1989, Clifton et al. 1991, Clifton et al. 2003, Ferreira and Clifton 1986, Ferreira and Henderson 1990, 1991, Frazier and Rayner 1982, Karsenti and Meltzer-Asscher 2025, Rayner et al. 1983, Staub et al. 2018).

Rayner et al. (1983) showed that comprehenders primarily adhere to the Minimal Attachment principle in contexts involving ambiguous PP attachment. They examined sentences in which pragmatic plausibility strongly favored the non-minimal attachment over the minimal attachment interpretation, as compared in (4).

(4) a. The spy saw the cop *with binoculars* but the cop didn't see him.
b. The spy saw the cop *with a revolver* but the cop didn't see him.
(Rayner et al. 1983, p. 368, (3))

The PP *with binoculars*/*with a revolver* is structurally ambiguous, as it can attach either to the noun or to the verb. Under the Minimal Attachment principle (Frazier 1979), the minimally complex VP-attachment parse is expected to be initially favored in both cases. However, relative to (4a), world knowledge renders an NP-attachment (non-minimal) analysis far more plausible for (4b).

Thus, if readers used this pragmatic cue to guide structural building in PP-attachment ambiguity resolution, they should favor the non-minimal (NP-)attachment instead of the VP attachment for (4b). Nevertheless, Rayner et al. (1983) found that reading times were significantly longer in (4b) than in (4a) upon disambiguation. These findings indicated that readers had first favored the structurally simpler VP-attachment parse across both sentences, despite the pragmatic implausibility in the *revolver* sentence (4b).

Further evidence was observed in Ferreira and Henderson (1990), who demonstrated that Minimal Attachment principle can even override strong lexical-syntactic cues such as verb subcategorization information to affect readers' initial attachment decisions during ambiguity resolution. They tested sentences as in (5).

(5) a. He *wished* Pam needed a ride with him.
b. He *forget* Pam needed a ride with him. (Ferreira and Henderson 1990, p. 557, Table 1)

readability. However, to accurately reflect the adjunct status of the PPs (e.g., *in the house*) in both the NP- and VP-attachment analyses (Schütze 1995), its attachment representation follows the standard X-bar convention (Chomsky 1973), where the adjunct PP is both a daughter of the upper N'/V' and a sister to the lower N'/V'.

In these sentences, the NP *Pam* is structurally ambiguous, as it can attach either as the direct object of the main verb (*wished/forgot*) or as the subject of the embedded complement clause. In line with the Minimal Attachment principle (Frazier 1979), the direct-object structure should be favored over the embedded-subject structure. However, for (5a), verb subcategorization rules out the direct-object (minimal) structure, as *wish* does not take an NP direct object and instead strongly favors an embedded complement clause. However, despite the strong verb bias in (5a), Ferreira and Henderson (1990) observed increased reading times at the point of verbal disambiguation in both conditions. These results suggest that readers first adopted the structurally minimal direct-object interpretation, even in cases where the verb's subcategorization properties made that analysis unlikely.

This strong adherence to the Minimal Attachment principle is also observed in more complex contexts. For instance, Staub et al. (2018) investigated relative clause (RC) vs. complement clause (CC) ambiguities in constructions illustrated in (6).

(6) The information that the health department provided…
a. a cure reassured the tour operators.
b. reassured the tour operators. (Staub et al. 2018, p. 27, (8))

The word string in example (6) is temporarily ambiguous between two interpretations: (i) being part of a nominal CC, as in (6a); or (ii) being part of an RC, as in (6b). From a structural standpoint, the nominal CC analysis is simpler because it attaches directly to the noun (*information*) as its complement; by contrast, the RC interpretation incurs greater structural cost because it involves computing a filler–gap dependency.[3]

Staub et al. (2018) reported a strong bias toward the structurally simpler nominal-CC analysis across three eye-tracking experiments. The reading times were faster at a nominal CC analysis disambiguation (6a) compared to an RC analysis disambiguation (6b). Crucially, this bias remained unchanged regardless of whether the head noun was compatible with a CC or whether the sequence was plausible as a relative clause. This supports readers' initial commitment to the simplest structure (i.e., the nominal-CC analysis, 6a), as predicted by Minimal Attachment (Frazier 1979).

More recent work, such as that of Karsenti and Meltzer-Asscher (2025) also provided evidence for the Minimal Attachment principle in syntactic processing. Their results showed that readers strongly favored attaching a structurally ambiguous NP to the preceding verb instead of construing it as the subject of the following clause in object/subject ambiguity contexts such as "*After the guests drank cold water…*." This preference for local attachment (cf. Phillips and Gibson 1997) reflects a tendency of readers to avoid postulating new clauses and to minimize open dependencies, consistent with the Minimal Attachment principle (Frazier 1979).

Despite the substantial evidence across numerous studies for the Minimal Attachment principle (Frazier 1979) as a primary determinant of syntactic processing (Clifton and Ferreira 1989, Clifton et al. 1991, Clifton et al. 2003, Karsenti and Meltzer-Asscher 2025, Ferreira and Clifton 1986, Ferreira and Henderson 1990, 1991, Frazier and Rayner 1982, Rayner et al. 1983, Staub et al. 2018), subsequent research has argued that this principle is not universally applied and that structural preferences are modulated by a variety of syntactic and semantic constraints (Ackerman 2015, Baek 2014, Hindle and Rooth 1993, Kwon et al. 2019, MacDonald et al. 1994, McRae et al.

[3] A "filler-gap dependency" constitutes a syntactic configuration where a displaced element (the *filler*) is connected to a downstream structural position (the *gap*) later in the sentence, where it receives its interpretation and thematic role (Chomsky 1973). The processing of such configurations is widely regarded as cognitively demanding, given that the filler has to be held in working memory until the parser identifies the gap site (Gibson 1998, 2000).

1998, Schütze 1995, Schütze and Gibson 1999, Shoghi et al. 2025, Spivey-Knowlton and Sedivy 1995, Traxler et al. 2002, Trueswell and Tanenhaus 1994, Trueswell et al. 1994).

For example, Schütze (1995) re-evaluated the VP-attachment bias for structurally ambiguous PPs predicted by Minimal Attachment (Frazier 1979), proposing that attachment decisions are determined by the argument status of the PPs. Re-examining classic studies (e.g., Clifton et al. 1991, Rayner et al. 1983, Taraban and McClelland 1988) that observed an overall preference of VP-attachment analysis for ambiguous PP during initial ambiguity resolution, Schütze (1995) noted that many experimental PPs were not distinguished by their argument-modifier status.[4]

Schütze's (1995) reanalysis showed that in contexts biased toward VP-attachment, the PP frequently constituted a plausible argument of the verb (e.g., an instrumental *with a telescope* for the verb *saw*; Rayner et al. 1983); on the other hand, in sentences showing an NP-attachment preference, the PP was often an argument for the noun head (e.g., a solution *to the problem*; Taraban and McClelland 1988). In fact, Schütze (1995) later put forward an "argument-preference hypothesis," proposing that comprehenders favor linking an ambiguous PP to whichever head, noun or verb, licenses it as an argument, rather than consistently applying Minimal Attachment (Frazier 1979).

Besides the impact of argument status on PP-attachment preference (e.g., Schütze 1995, Schütze and Gibson 1999), other studies have also highlighted the role of a range of lexical and semantic constraints in resolving syntactic ambiguity, posing a challenge to the prominence of the Minimal Attachment principle (Frazier 1979). For instance, a large body of work on ambiguity resolution has shown that animacy influences initial parsing across different types of ambiguous sentences (e.g., Traxler et al. 2002, Li and Kim 2023, Trueswell and Tanenhaus 1994, Trueswell et al. 1994). These works have largely examined contexts where the animacy of an argument NP directly informs the assignment of thematic roles (e.g., agent vs. theme) and core grammatical status/functions (e.g., subject vs. object), thereby resolving the ambiguities between active and passive interpretations (e.g., Trueswell et al. 1994) or facilitating the processing of subject/object extracted relative clauses (e.g., Traxler et al. 2002).

However, much less is known whether NP animacy plays a role in non-argument ambiguity resolution such as PP-modifier ambiguities. These ambiguities differ from those previously studied in that the core thematic roles and grammatical status of the NPs are already established, and the ambiguity lies in the subsequent non-argument PP-modifier, specifically in determining which prior phrase (the VP or the NP) the PP attaches to (e.g., Clifton et al. 1991, Rayner et al. 1983, Schütze 1995, Schütze and Gibson 1999, Taraban and McClelland 1988). Furthermore, within the investigation of PP-attachment ambiguity resolution, essential studies have emphasized the influence of structural preference (e.g., Minimal Attachment; Rayner et al. 1983) and argument status (Schütze 1995, Schütze and Gibson 1999). However, whether animacy can serve as a semantic cue by licensing a possessive relation that favors NP-attachment interpretation of the subsequent PP-modifier has not yet been explored.

Addressing this gap, the present study examines whether the animacy of the preceding NP influences the VP-attachment bias posited by Minimal Attachment in resolving PP-attachment ambiguity during real-time sentence processing. Our central hypothesis is that an animate direct object NP will facilitate an NP-modifier analysis of a subsequent PP, thereby reducing or eliminating the processing cost observed in NP-attachment sentences in previous studies (e.g., Clifton et al. 1991, Rayner et al. 1983). To examine this hypothesis, we ran a self-paced reading experiment using sentences that included PPs exhibiting temporary structural ambiguity, such as *the*

[4] In syntactic theory (Radford 1988), an *argument* usually refers to a phrase that completes the meaning of a head of a phrase (e.g., **look**[head] *after the man*, a **man**[head] *in his fifties*), while a *modifier* is an optional phrase that simply adds descriptive information to the head being modified (e.g., read *in the room*, a man *with a coffee*).

teacher recorded a student/classroom with a microphone with the camera…, where the first PP *with a microphone* can be a modifier of either the preceding noun (the student/classroom has a microphone) or the verb (use a microphone to record).

Definiteness was systematically varied for both the direct object NP and PP_1 (*a* student/classroom with *a* microphone) to encourage NP-modifier attachment of the PP (Altmann and Steedman 1988, Crain and Steedman 1985, Spivey-Knowlton and Sedivy 1995). An interaction was therefore predicted: given the greater plausibility of an animate noun being a possessor (Dubois et al. 2024, Rosenbach 2008, Strunk 2005), the NP-modifier analysis of PP_1 would be facilitated for the animate NP (*student*). This would result in less processing cost when the ambiguity is resolved by the PP_2 (*with the camera*) in the animate condition as opposed to the inanimate condition (*classroom*), where the NP-attachment option is unlikely, leading the parser to default to VP attachment as predicted by Minimal Attachment (Frazier 1979).

Contrary to what we had anticipated, the reading-time results indicated no reanalysis differences between animate and inanimate NP sentences: both types of sentences showed longer reading times at the disambiguating region compared to sentences where no reanalysis was required at that point. This result is consistent with the Minimal Attachment principle (Frazier 1979): readers initially adopted the structurally simpler VP-modifier analysis for the ambiguous PP and engaged in a costly NP-modifier reanalysis upon disambiguation, regardless of the animacy of the direct object NP.

This suggests that animacy did not influence the VP-attachment preference during the PP-attachment ambiguity resolution in our experiment. The absence of animacy effect within the animate and inanimate noun sentences further indicates that its effect may be dependent on the relative strength of competing factors or limited to specific context where animacy can serve as a crucial factor in its association with other syntactic-thematic constraints (e.g., McRae et al. 1998, Li and Kim 2023, Lin and Garnsey 2010, Traxler et al. 2002, Trueswell and Tanenhaus 1994, Trueswell et al. 1994).

2. Background: The Role of Animacy in Guiding Ambiguity Resolution

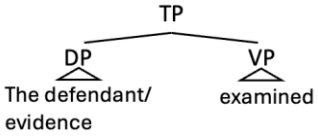
Animacy is defined as the contrast between animate and inanimate entities, which has been claimed to exert a strong influence on syntactic structure building and disambiguation. Research in psycholinguistics indicates that animacy operates as a semantic signal that works in tandem with thematic-role assignment to shape early syntactic processing in sentences with temporary ambiguity (Gennari and MacDonald 2009, McRae et al. 1998, Tabor et al. 2004, Traxler et al. 2002, Trueswell et al. 1994). Trueswell et al. (1994) illustrated this effect by examining sentences such as those in (7).

(7) a. The defendant examined by the lawyer turned out to be unreliable.
b. The evidence examined by the lawyer turned out to be unreliable.
(Ferreira and Clifton 1986, p. 352, (2))

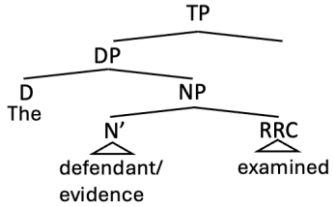
In (7), the verb *examined* is temporarily ambiguous, as it can be interpreted either as the main predicate of the clause, as shown in (8a), or as part of a reduced RC modifying the noun phrase *the defendant/evidence*, as in (8b).

(8) The defendant/evidence examined…

a. Main verb interpretation



b. Reduced relative clause interpretation



According to Minimal Attachment (Frazier and Rayner 1982), the main-verb analysis in (8a) should initially be preferred for both (7a) and (7b) because it is structurally simpler than the reduced relative clause alternative in (8b). Processing difficulty is therefore predicted at the prepositional phrase *by the lawyer*, which disambiguates against the main-verb parse and triggers a reanalysis of *examined* as a reduced relative clause (Trueswell et al. 1994).

Crucially, only (7a), which contained an animate subject NP (*defendant*), elicited processing difficulty, while (7b), with an inanimate subject (*evidence*), did not. Trueswell et al. (1994) argue that this contrast reflects the role of animacy in guiding incremental structure building: animate NPs favor an initial active subject–verb parse with verbs such as *examined*, whereas inanimate NPs weaken this bias.

As a result, (7a) and (7b) might undergo different analysis processes. For (7a), readers initially adopted the main verb interpretation (8a) but were forced to perform a costly reduced relative clause reanalysis once the initial structural interpretation conflicted with the later-arriving phrase *by the lawyer.* In contrast, for (7b), readers likely adopted the reduced relative clause interpretation (8b) prior to disambiguation due to its greater semantic plausibility, thereby encountering no processing difficulty as no reanalysis was required. This suggests that animacy, in its association with thematic roles, can override the strong preference for the simplest structure (Minimal Attachment; Frazier 1979), serving as an early disambiguating cue to guide structural building at the initial stage of ambiguity resolution (MacDonald et al. 1994, Tanenhaus et al. 1995, Trueswell et al. 1994).

The role of animacy information in affecting syntactic processing is further demonstrated by Traxler et al. (2002), who conducted eye-tracking experiments comparing subject-relative clauses (SRCs) and object-relative clauses (ORCs). It has been well-established that ORCs impose greater processing difficulty than SRCs (Frazier and Fodor 1978, Frazier and Clifton 1989, Gibson 1998, 2000, Traxler et al. 2002, Wanner and Maratsos 1978).[5] Nevertheless, Traxler et al. (2002) showed that animacy systematically modulates the processing cost incurred by ORCs: ORC costs were markedly reduced when an inanimate main-clause subject co-occurred with an animate embedded

[5] Theories have offered different explanations for why ORCs (ia) are more difficult to process than SRCs (ib).

(i) a. The *lawyer* that ___ irritated the banker filed a lawsuit. (SRC)
b. The *lawyer* that the banker irritated ___ filed a lawsuit. (ORC) (Traxler et al. 2002, p. 73, (1))

Syntax-oriented theories (e.g., Frazier and Clifton 1989, Frazier and Fodor 1978) explain the greater processing cost of ORCs in terms of their heightened structural complexity: SRCs retain a parallel subject–verb–object order across clauses, whereas ORCs interrupt this pattern by positioning the object ahead of the subject in the embedded clause, which lengthens the dependency. In contrast, memory-based approaches (e.g., Gibson 1998, 2000, Gibson et al. 1996) maintain that ORCs are more demanding because readers must temporarily store the extracted object noun phrase until it can be integrated into its syntactic position and thematic role. Intervening noun phrases increase the difficulty of establishing long-distance dependencies, a frequent property of ORCs.

subject, as in (9a), but were amplified when the animacy configuration was reversed, as in (9b).

(9) a. The movie$_{[inanimate]}$ that the director$_{[animate]}$ watched received a prize at the film festival.
b. The director$_{[animate]}$ that the movie$_{[inanimate]}$ pleased received a prize at the film festival.
(Traxler et al. 2002, p. 79, (3))

Under the so-called Active Filler strategy (e.g., Frazier and Clifton 1989), the complementizer *that* leads comprehenders to anticipate a dependency between the relative-clause subject position and a preceding filler. In an effort to satisfy this dependency as rapidly as possible, comprehenders initially assume that the main-clause subject (e.g., *the movie/director*) will also serve as the subject of the relative clause. When this expectation is violated because the embedded subject position is occupied by a different noun phrase, the parser must relinquish its initial commitment and undertake a costly reinterpretation, yielding the well-documented processing difficulty associated with object relative clauses (Frazier and Clifton 1989, Frazier and Fodor 1978, Gibson 1998, 2000, King and Just 1991, Traxler et al. 2002, Wanner and Maratsos 1978). Importantly, however, the magnitude of this reanalysis cost differed between (9a) and (9b).

Traxler et al. (2002) attribute this asymmetry to animacy and its association with thematic roles. The grammatical subject is commonly associated with an animate entity bearing an agent role (Bever 1970, Branigan et al. 2008, Ferreira 1994, MacWhinney et al. 1984). However, in (9a), the inanimate main-clause subject (*the movie*) is not a plausible agent. This semantic implausibility weakens the initial subject-bias analysis in the relative clause, allowing for an easier reanalysis when the animate and highly agentive NP *the director* appears at the embedded subject position.

By contrast, in (9b), the animate main-clause subject *the director* is a highly plausible agent, reinforcing the initial subject-bias analysis in the relative clause both syntactically and semantically. This leads reader to make a stronger commitment to the incorrect initial structure. Consequently, the subsequent appearance of the inanimate NP *the movie* in the embedded subject position creates a syntactic conflict with readers' initial analysis, leading to a costly reanalysis. In addition, the inanimate NP *the movie* may incur extra cognitive cost by conflicting with comprehenders' bias toward an agentive subject interpretation. The interaction of this semantic incongruity with syntactic disruption thus accounts for the greater processing difficulty found in (9b) as opposed to (9a).

Li and Kim (2023) further explored constructions exhibiting the classic object–subject ambiguity, exemplified by *While the police was investigating the detective/evidence examined by the lawyer...*, where the ambiguous NP (*the detective/evidence*) is expected to be preferentially analyzed as an object (Karsenti and Meltzer-Asscher 2025, Phillips and Gibson 1997). However, upon encountering a subsequent NP (e.g., *an officer*), readers showed processing difficulty at sentences when the ambiguous NP was animate (e.g., *detective*). These findings indicate that readers had already revised their parse to treat *the detective* as the subject of the subsequent verb *examined*, thereby forming a locally coherent active configuration (cf. Tabor et al. 2004). The results therefore imply that animacy can function as a powerful cue that overrides initial structural biases during ambiguity resolution.

Earlier studies have shown that animacy significantly modulates structure-building processes and sentence comprehension (e.g., Tabor et al. 2004, Traxler et al. 2002, Trueswell et al. 1994, Gennari et al. 2012). Yet these studies have largely examined configurations in which animacy is tightly coupled with thematic-role assignment and directly informs grammatical-function interpretation. The current study targets a different environment: a downstream PP-attachment ambiguity, where animacy is not diagnostic of core thematic roles but may instead cue possessive plausibility (Dubois et al. 2024, Rosenbach 2008, Strunk 2005). We test whether this semantic factor

can weaken the strong VP-attachment bias predicted by Minimal Attachment (Frazier 1979), predicting reduced disambiguation costs when the direct object NP is animate rather than inanimate.

3. Self-paced Reading Experiment

Building on previous findings demonstrating that semantic cues such as animacy can guide ambiguity resolution and sentence comprehension (Gennari and MacDonald 2009, McRae et al. 1998, Tabor et al. 2004, Traxler et al. 2002, Trueswell et al. 1994), the present study investigated whether animacy, insofar as it serves as a cue to possessive plausibility (Dubois et al. 2024, Rosenbach 2008, Strunk 2005), can override the VP-attachment bias posited by the Minimal Attachment principle (Frazier 1979) when resolving PP-attachment ambiguities (e.g., The teacher recorded a student/classroom *with a microphone…*).

While the Minimal Attachment principle (Frazier 1979) suggests a structural bias for the VP-attachment analysis of the PP *with a microphone*, the use of indefinite NPs (*a student/classroom with a microphone*) can create a competing bias for NP-attachment (Altmann and Steedman 1988, Crain and Steedman 1985). Therefore, we predicted that an animate direct object NP (*student*), by increasing the plausibility of a possessive relation (Dubois et al. 2024, Rosenbach 2008, Strunk 2005), would further reinforce this NP-attachment interpretation of the following PP, and consequently attenuate processing costs at the point of disambiguation relative to an inanimate NP (*classroom*).

3.1 Participants

Sixty-four native speakers of English (aged 20–45) recruited from *Prolific* (Palan and Schitter 2018) participated in the experiment. They were paid approximately £9.00/h for participation, following *Prolific*'s payment guidelines.

3.2 Materials

We employed a 2 × 2 factorial design, where *NP Animacy* (animate object vs. inanimate object; Region 3) and *PP-Attachment Ambiguity* (temporarily attachment ambiguous PP vs. attachment unambiguous PP; Region 4) were manipulated as independent factors. Table 1 illustrates an example of the experimental items with four conditions.

In Conditions A and B, the first PP *with a microphone* (Region 4) is temporarily ambiguous between an NP-modifier (e.g., a student/classroom that has a microphone) and a VP-modifier (e.g., to record using a microphone). This ambiguity is resolved by the following PP_2 *with the camera* (Region 5), which is inconsistent with a VP-modifier interpretation of PP_1. Under standard phrase-structure assumptions, a verb cannot syntactically license two adjacent instrumental *with*-PPs in the absence of an overt conjunction (Carnie 2021, Huddleston et al. 2021). As a result, PP_2 *with the camera* is predicted to compel an analysis in which PP_1 is attached to the NP, while PP_2 modifies the VP, yielding the ultimate interpretation "using the camera to record a student/classroom that has a microphone."[6]

[6] A potential alternative analysis is that PP_2 could be attached as a modifier to the noun within PP_1 (e.g., interpreting "a microphone with the camera" as a local structure). To eliminate this potential confound and guarantee that PP_2 syntactically enforces an NP-modifier analysis for PP_1, we constructed our stimuli so that PP_2 was semantically incompatible with modifying

Table 1. Example Items Used in the Self-paced Reading Experiment

Region 1	Region 2	Region 3	Region 4	**Region 5 (Disambiguation)**	Region 6	Region 7	Region 8
A. Animate NP, Ambiguous PP-attachment							
The teacher	recorded	a student	with a microphone	**with the camera**	during	the training	observation session.
B. Inanimate NP, Ambiguous PP-attachment							
The teacher	recorded	a classroom	with a microphone	**with the camera**	during	the training	observation session.
C. Animate NP, Unambiguous PP-attachment							
The teacher	observed	a student	with a microphone	**and a camera**	during	the training	observation session.
D. Inanimate NP, Unambiguous PP-attachment							
The teacher	observed	a classroom	with a microphone	**and a camera**	during	the training	observation session.

Note. For analytical purposes, each sentence was segmented into eight phrasal regions, as summarized in Table 1. Region 5 (e.g., *with/and the/a camera*) constituted the primary area of interest, because it served as the disambiguation point at which PP_1 could be reanalyzed. Regions 6 (e.g., *during*) and 7 (e.g., *the training*) were treated as spillover regions in order to detect any delayed processing effects (Rayner et al. 1983, Staub 2015).

In Conditions A and B, the first PP *with a microphone* (Region 4) is temporarily ambiguous between an NP-modifier (e.g., a student/classroom that has a microphone) and a VP-modifier (e.g., to record using a microphone). This ambiguity can be resolved by the subsequent PP_2 *with the camera* (Region 5), which is incompatible with the VP-modifier analysis of PP_1. Under standard phrase-structure assumptions, a verb is not syntactically permitted to select two adjacent instrumental *with*-PPs in the absence of an overt conjunction (Carnie 2021, Huddleston et al. 2021). Accordingly, the appearance of PP_2 (*with the camera*) is predicted to compel a parse in which PP_1 attaches to the NP, while PP_2 modifies the verb phrase, leading to a final interpretation "using the camera to record a student/classroom that has a microphone."[7]

We also controlled for the definiteness of the direct object NPs (e.g., *a student/classroom*; Region 3) and PP_1. Definite NPs are known to carry a presupposition of identifiable reference; without prior context, the NP-modifier analysis can increase cognitive load, thereby biasing readers toward a VP-modifier analysis (Altmann and Steedman 1988, Crain and Steedman 1985, Schneider and Janczyk 2020, Schumacher 2009). To create a context more conducive to examining the role of animacy, we used indefinite articles for the object NP and PP_1 (e.g., *a student/classroom with a microphone*; Region 3 and 4). Establishing a baseline NP-attachment preference for PP_1 (Altmann and Steedman 1988, Crain and Steedman 1985, Spivey-Knowlton and Sedivy 1995), allows any processing differences between the ambiguous conditions (A and B) to be attributed more directly to animacy.

Conditions C and D functioned as unambiguous control conditions. These conditions used verbs (e.g., *notice*, *observe*) that do not license an instrumental interpretation of the subsequent PP (e.g., **use a microphone to observe*). To maintain sentence naturalness, Conditions C and D use a conjoined structure in the post-nominal PP (e.g., *with a microphone and a camera*; Regions 4 and 5).

Finally, Conditions A and C included animate direct-object noun phrases (e.g., *student*; Region 3), which readily

the noun in PP_1.

[7] A potential alternative analysis is that PP_2 could be attached as a modifier to the noun within PP_1 (e.g., interpreting "a microphone with the camera" as a local structure). We avoided this confound by making PP_2 semantically implausible as a modifier of the noun in PP_1, thereby forcing NP attachment of PP_1.

support a possessive interpretation, whereas Conditions B and D featured inanimate direct objects (e.g., *classroom*; Region 3), which are less compatible with such a role (Dubois et al. 2024, Rosenbach 2008, Strunk 2005). We manipulate the animacy of the object to explore whether and how it influences the initial syntactic analysis of the subsequent attachment ambiguous PP_1.

Alongside the 24 sets of experimental items, we incorporated 40 filler sentences that were unrelated to the current experimental design.

3.3 Procedure

The experiment was created and hosted on the web-based platform *PCIbex Farm* (Zehr and Schwarz 2018). Participants recruited through *Prolific* accessed the experiment via a unique link generated by *PCIbex Farm*. The session began with an informed consent form, after which participants received the task instructions. Prior to the main task, participants completed four practice trials with feedback in order to become accustomed to the self-paced reading procedure.

During the main session, participants read 64 sentences, including 24 critical items and 40 fillers. Critical items were distributed using a Latin-square design so that each participant encountered only one condition per item. Sentences were presented in a noncumulative, phrase-by-phrase self-paced reading format, and participants advanced through each region by pressing the spacebar without knowing the sentence length in advance. Reading times for all regions were collected for analysis.

Each trial was followed by a simple yes/no comprehension question (e.g., "Was the word *decorate* included in the sentence?") designed to ensure participants' engagement. Data were analyzed only for participants whose accuracy on these questions surpassed 70%. The entire experiment took roughly 12 minutes.

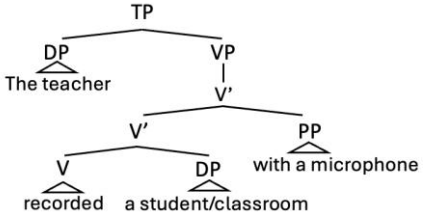
3.4 Predictions

Two opposing predictions arise concerning the extent to which animacy affects PP-attachment preference in online ambiguity resolution.

3.4.1 Prediction 1: Animacy does not influence PP attachment, consistent with the Minimal Attachment account (Frazier 1979)

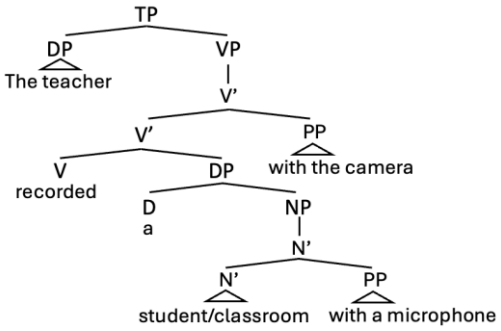
If readers follow Minimal Attachment rigidly (Frazier 1979), they should initially adopt the structurally minimal VP-attachment parse for the ambiguous PP_1 (*with a microphone*), independent of whether the preceding noun phrase is animate (*student*) or inanimate (*classroom*), as shown in (10).

(10) *Step 1* (for both A and B): Readers initially perform VP-attachment analysis for PP_1 *with a microphone*.



Encountering the disambiguating PP_2 (*with the camera*) should prompt readers to revise their initial parse and construe PP_1 as modifying the noun phrase, as illustrated in (11).

(11) *Step 2* (for both A and B): Forced by PP_2, readers perform the NP-attachment reanalysis for PP_1 *with a microphone*.

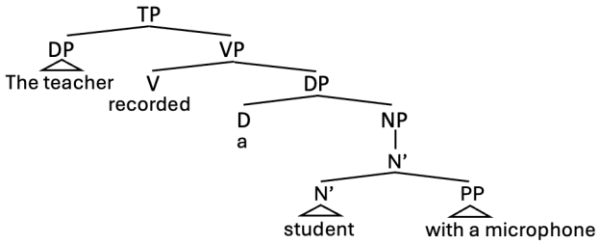


This reanalysis process would induce greater processing cost in conditions involving PP-attachment ambiguity (A and B) compared to the unambiguous conditions (C and D).[8] Critically, under the Minimal Attachment principle (Frazier 1979), no processing cost difference should be observed between the animate ambiguous condition (A) and inanimate ambiguous condition (B).

3.4.2 Prediction 2: Under a constraints-based framework, animacy is predicted to influence PP-attachment decisions (Trueswell et al. 1994).

By contrast, if animacy modulates preferences in PP attachment, processing differences should emerge between the two PP-ambiguous conditions (A and B). In particular, an animate noun phrase (e.g., *a student*) constitutes a more plausible possessor for a subsequent PP_1 (e.g., *with a microphone*) than does an inanimate noun phrase (e.g., *a classroom*). We therefore predict that the initial structural analysis of PP_1 will diverge in the animate ambiguous condition (A), as exemplified in (12), but not in the inanimate ambiguous condition (B), illustrated in (10).

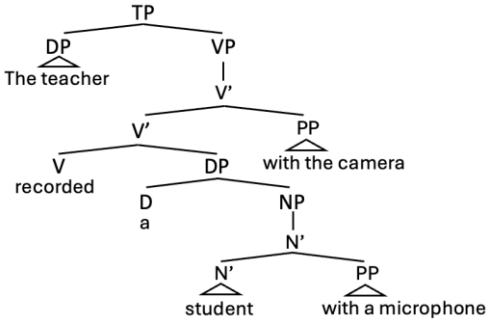
(12) *Step 1 (for A)*: Readers initially perform the NP-attachment analysis for PP_1 *with a microphone*.



[8] Assuming a strictly serial account, readers may initially favor a VP-attachment analysis for PP_1 in conditions C and D due to a bias toward minimal syntactic structure (Ferreira and Henderson 1990, Frazier and Rayner 1982, Rayner et al. 1983). Yet, semantic implausibility would prompt rapid revision before the conjunction and *a camera*, yielding no processing difficulty at that region in these conditions.

Then when the disambiguating PP_2 (*with the camera*) is encountered, it should be naturally attached to the VP, as in (13).

(13) *Step 2 (for A)*: Readers perform the VP-attachment analysis for PP_2 *with the camera*.



If this is the case, we should observe no reanalysis processing cost in the animate ambiguous condition (A), relative to the inanimate ambiguous condition (B). Even if animacy exerts its influence only at a later stage, we would nevertheless expect faster reading times in the post-disambiguation regions in Condition A relative to Condition B.

No comparable processing differences are predicted for the PP-attachment unambiguous conditions (C and D), since the conjunction (e.g., *and a camera*; Region 5) does not trigger structural revision.

3.5 Analysis & Results

We removed extremely short (<80 ms) and long (>3000 ms) reading times. Reading times in the critical region (Region 5) and two spillover regions (Regions 6 and 7) were then log-transformed to address nonnormality and satisfy model assumptions (Box and Cox 1964). Separate linear mixed-effects models were fitted for each region, with NP *Animacy* (animate vs. inanimate; coded +0.5/–0.5), *PP-Attachment Ambiguity* (ambiguous vs. unambiguous; coded +0.5/–0.5), and their interaction as fixed effects. Random slopes for Ambiguity by participant and random intercepts for items were included to capture participant- and item-level variability (Baayen et al. 2008, Barr et al. 2013).

Models were estimated using the *lmer* function from the *lme4* package (Bates et al. 2015), with p-values for fixed effects obtained through the Satterthwaite approximation (Kuznetsova et al. 2017) implemented in the *lmerTest* package. Fixed-effect summaries for all three regions are reported in Table 2.

At the disambiguation region 5 (*with/and the/a camera*), we found a significant main effect of *Ambiguity* (β = 0.175, SE = 0.021, t = 8.55, $p < 0.001$). Sentences with temporarily ambiguous PP-attachment (Conditions A and B) were read more slowly than those with unambiguous PP-attachment (Conditions C and D). No significant main effect of *Animacy* was observed ($\beta = -0.009$, $SE = 0.018$, $t = -0.51$, $p = 0.61$), and no significant interaction effect between *Animacy* and *Ambiguity* ($\beta = -0.042$, $SE = 0.036$, $t = -1.17$, $p = 0.24$).

The same pattern was observed at Region 6 (*during*), which also showed a significant main effect of *Ambiguity* ($\beta = 0.054$, $SE = 0.017$, $t = 3.18$, $p < 0.01$), such that sentences with ambiguous PP attachment (Conditions A and B) elicited slower reading times than the unambiguous controls (Conditions C and D). Again, we observed no significant main effect of *Animacy* ($\beta = -0.020$, $SE = 0.014$, $t = -1.44$, $p = 0.15$) nor was there a significant interaction between *Animacy* and *Ambiguity* ($\beta = 0.031$, $SE = 0.028$, $t = 1.11$, $p = 0.27$).

Finally, at Region 7 (*the training*), we found no significant main effect of *Ambiguity* ($\beta = 0.010$, $SE = 0.015$, $t = 0.65$, $p = 0.52$) or *Animacy* ($\beta = -0.018$, $SE = 0.015$, $t = -1.17$, $p = 0.24$), nor did we find significant interaction effect between the two factors ($\beta = 0.007$, $SE = 0.030$, $t = 0.22$, $p = 0.82$). Table 2 reports the results of linear mixed-effects models with log-transformed reading times in three regions.

Table 2. Results of Linear Mixed-Effects Models with LogRTs in Three Regions

	Estimate	SE	*t*-value	*p*-value
Disambiguation Region 5 (*with the camera*)				
(Intercept)	6.603	0.054	122.690	
NP Animacy	–0.009	0.018	–0.507	0.613
PP-Attachment Ambiguity	0.175	0.021	8.546	2.47e-12***
Animacy × Ambiguity	–0.042	0.036	–1.174	0.241
Region 6 (*during*)				
(Intercept)	6.362	0.034	185.509	
NP Animacy	–0.020	0.014	–1.436	0.151
PP-Attachment Ambiguity	0.054	0.017	3.181	0.00222**
Animacy × Ambiguity	0.031	0.028	1.105	0.269
Region 7 (*the training*)				
(Intercept)	6.308	0.040	157.331	
NP Animacy	–0.018	0.015	–1.168	0.243
PP-Attachment Ambiguity	0.010	0.015	0.645	0.519
Animacy × Ambiguity	0.007	0.030	0.222	0.824

Note. "***" indicates $p < 0.001$, "**" indicates $p < 0.01$

Mean log-transformed reading times across four conditions for three regions are presented in Figures 1, 2, and 3, respectively.

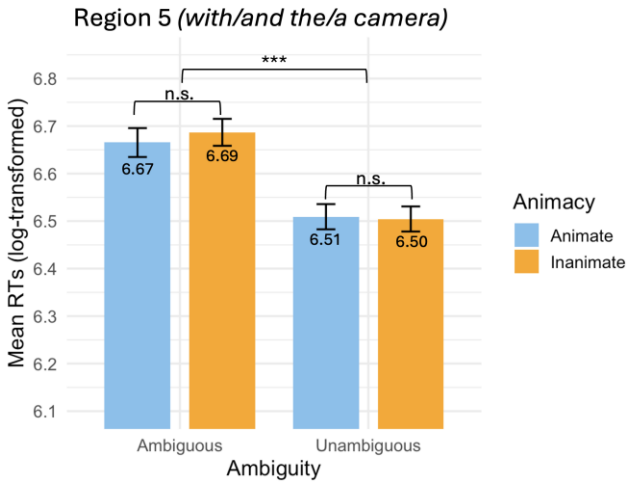


Figure 1. Mean Reading Times at Region 5 (e.g., *with/and the/a camera*)

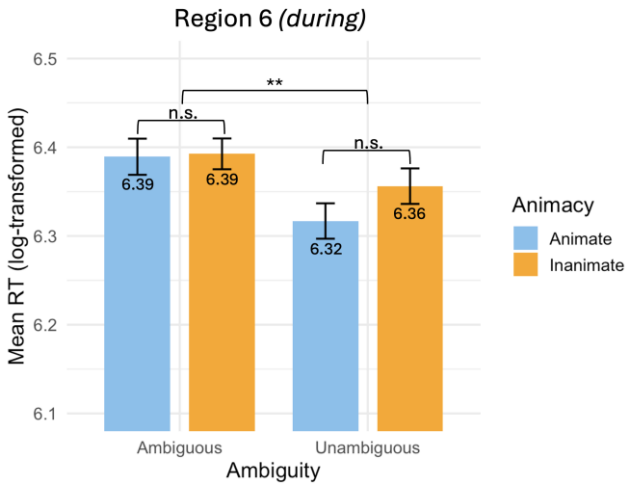


Figure 2. Mean Reading Times at Region 6 (e.g., *during*)

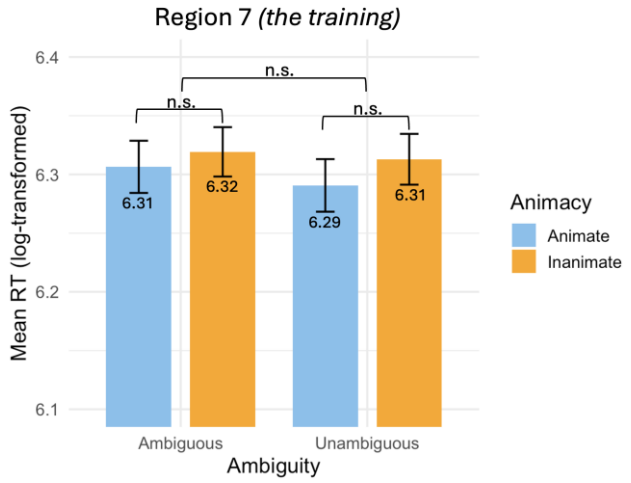


Figure 3. Mean Reading Times at Region 7 (e.g., *the training*)

4. Discussion

According to the "Minimal Attachment" principle (Frazier 1979), readers tend to adopt the least complex syntactic structure when confronted with multiple alternatives (Clifton and Ferreira 1989, Clifton et al. 1991, Clifton et al. 2003, Ferreira and Clifton 1986, Ferreira and Henderson 1990, 1991, Frazier and Rayner 1982, Karsenti and Meltzer-Asscher 2025, Rayner et al. 1983, Staub et al. 2018). Nevertheless, a large body of subsequent work has called into question the universality of this principle, arguing instead that syntactic parsing is shaped by multiple syntactic and semantic constraints (e.g., Lin and Garnsey 2010, Li and Kim 2023, McRae et al. 1998, Traxler et al. 2002, Trueswell and Tanenhaus 1994, Trueswell et al. 1994).

Some studies report that PP-attachment preferences depend on the PP's argument status rather than on Minimal Attachment (Schütze 1995, Schütze and Gibson 1999), whereas other work has shown that animacy is a central

factor in syntactic interpretation and sentence comprehension (e.g., Gennari et al. 2012, Li and Kim 2023, Tabor et al. 2004, Traxler et al. 2002, Trueswell et al. 1994). However, in previous studies, animacy has primarily been examined in constructions where it directly informs thematic role assignment. In such contexts, animacy strongly biases the structural analysis by indicating the thematic-syntactic function (e.g., agent vs. theme) or grammatical status (subject vs. object) of a structurally ambiguous NP.

The current study explores animacy effects when animacy is not relevant to thematic-role assignment but instead provides information about possessive plausibility (Dubois et al. 2024, Rosenbach 2008, Strunk 2005) to guide the subsequent PP-attachment ambiguity resolution. Using a phrase-by-phrase self-paced reading paradigm, we measured reading times for sentences containing a structurally ambiguous PP, which can be attached either to the preceding noun (NP-modifier) or to the verb (VP-modifier), reproduced here as in (14).

(14) The teacher recorded *a student/classroom with a microphone* with the camera during the training observation session.

We varied the definiteness of the direct-object NP and PP_1 (*a* student/classroom with *a* microphone) to create an NP-modifier baseline (Altmann and Steedman 1988, Crain and Steedman 1985, Spivey-Knowlton and Sedivy 1995). We expected animacy to additionally bias attachment toward the NP in the animate condition (Condition A), producing shorter reading times at disambiguation than in the inanimate condition (Condition B).

The experiment revealed equivalent processing difficulty for the two PP-attachment ambiguous conditions (A and B), independent of animacy. Reading times increased at the disambiguating Region 5 (PP_2 *with the camera*) and the following Region 6 (*during*) compared to unambiguous sentences (C and D). This pattern implies that readers initially favored a VP-modifier parse associated with PP_1 *with a microphone* and then engaged in reanalysis upon encountering PP_2 *with the camera*. By Region 7 (*the training*), the difficulty had subsided, indicating recovery from the initial misinterpretation.

Importantly, neither an animacy main effect nor an interaction was observed in any region. This pattern indicates that readers adopted the Minimal Attachment strategy in resolving PP-attachment ambiguity, despite contextual manipulations intended to favor the non-minimal analysis (Clifton et al. 2003, Ferreira and Clifton 1986, Frazier 1979, Frazier and Rayner 1982, Rayner et al. 1983).

Beyond the central role typically ascribed to Minimal Attachment (Frazier 1979), the absence of animacy effects may instead reflect the influence of factors such as PP argument status (e.g., Boland and Blodgett 2006, Clifton et al. 1991, Schütze 1995, Schütze and Gibson 1999) and the well-documented tendency of action verbs to license instrumental *with*-PPs (e.g., Spivey-Knowlton and Sedivy 1995). Previous studies indicate that PPs functioning as arguments are more readily attached to their heads than adjunct PPs; for example, in *I thought about his interest in the Volvo* (Schütze 1995, p. 97, (4)), the NP-attached reading of *in the Volvo* is favored over the VP-attached adjunct reading. In our materials, PP_1 could modify both the object noun phrase and the main verb. Although definiteness manipulations were intended to promote NP-modifier attachment, this effect may have been overridden by strong verb-based VP-attachment biases (Spivey-Knowlton and Sedivy 1995), leaving animacy insufficient to shift readers away from a VP-modifier analysis.

The syntactic–thematic environment may also play a crucial role. Previous demonstrations of immediate animacy effects largely involve core argument structures, where NP animacy guides thematic-role assignment (e.g., Li and Kim 2023, McRae et al. 1998, Trueswell and Tanenhaus 1994, Trueswell et al. 1994). For instance, animate subjects often bias readers toward active interpretations, whereas inanimate subjects discourage such readings. In these contexts, animacy facilitates disambiguation in temporary main-verb/reduced-relative or SRC/ORC

ambiguities. In our materials, however, animacy contrasts occurred in object NPs that were not thematically licensed by the verb but instead participated in possessive relations with a following ambiguous PP. This pattern suggests that animacy exerts its strongest influence in argument-structure ambiguities (e.g., Lin and Garnsey 2010, McRae et al. 1998, Traxler et al. 2002, Trueswell and Tanenhaus 1994, Trueswell et al. 1994), while being less effective for non-argument ambiguities such as adjunct or modifier attachment.

The present findings indicate that animacy did not contribute to the resolution of temporary PP-attachment ambiguities. Instead, readers' behavior in the self-paced reading task is best captured by theories positing early reliance on Minimal Attachment during syntactic structure building (Ferreira and Clifton 1986, Ferreira and Henderson 1990, 1991, Frazier and Rayner 1982, Rayner et al. 1983). These results further corroborate recent demonstrations of robust structure-first parsing strategies (Staub et al. 2018). Notably, this structural bias outweighed both lexical tendencies and plausibility effects: minimal VP attachment dominated discourse-level definiteness manipulations (Altmann and Steedman 1988, Crain and Steedman 1985) as well as animacy cues that have elsewhere been shown to shape parsing in core-argument contexts (Trueswell et al. 1994).

Our findings are also consistent with serial parsing accounts, which propose that early ambiguity resolution relies primarily on syntactic information, with semantic cues such as animacy entering only at later stages to evaluate or revise an initial parse (Frazier 1979, Frazier and Rayner 1982, Rayner et al. 1983). The similar processing delays found across the two ambiguous conditions (A and B) indicate that readers first converged on the least complex VP-attachment parse and that animacy-based information was not incorporated at this early point in processing.

5. Conclusion

This study investigated whether and how animacy may affect the resolution of non-argument (adjunct) structural ambiguities such as PP-attachment ambiguity. A self-paced reading study was conducted to investigate PP-attachment ambiguities in sentences like *The teacher recorded a student/classroom with a microphone….* A well-established observation is that readers initially show an early bias toward VP attachment of the PP *with a microphone*, in accordance with the Minimal Attachment account (Frazier 1979, Frazier and Rayner 1982, Rayner et al. 1983). However, a critical question has been the strength and generality of this structural principle, i.e., whether it applies universally to all types of structural ambiguities and is strong enough to override other non-syntactic constraints such as semantic plausibility and noun animacy (Ferreira and Clifton 1986, Ferreira and Henderson 1990, 1991, Frazier 1979, Rayner et al. 1983, Staub et al. 2018).

Previous work has demonstrated robust animacy effects in resolving argument structure ambiguities through association with thematic and grammatical roles assignment (e.g., Traxler et al. 2002, Trueswell et al. 1994). By comparison, the effects of this factor in non-argument structures like adjunct PP attachment have received limited attention. This study explores whether animacy is strong enough to override Minimal Attachment (Frazier 1979) during the resolution of these ambiguities.

Based on previous observations on the role of animacy in sentence comprehension and ambiguity resolution (e.g., Gennari and MacDonald 2009, Li and Kim 2023, Tabor et al. 2004, Traxler et al. 2002, Trueswell et al. 1994), we predicted that an animate NP would promote NP attachment of the following PP by supporting a possessive interpretation (Dubois et al. 2024, Rosenbach 2008, Strunk 2005). Contrary to our hypothesis, the self-paced reading results indicated a consistent bias toward VP attachment across all conditions, in line with predictions from the Minimal Attachment account (Frazier 1979).

These findings indicate that animacy may play little role in initial structural decisions during PP-attachment ambiguity resolution, despite our efforts to induce an NP-attachment preference through definiteness (Altmann and Steedman 1988, Crain and Steedman 1985, Spivey-Knowlton and Sedivy 1995). This provides additional evidence that animacy effects may depend on structural configuration. While previous studies have demonstrated animacy effects in core-argument structures involving thematic and grammatical role assignments (e.g., Li and Kim 2023, Traxler et al. 2002, Trueswell et al. 1994), the absence of animacy effects in PP-attachment ambiguity resolution in our study indicates that its effect may not be universal and may not extend to non-argument structures where it conflicts with other constraints (e.g., syntactic principles, Frazier 1979; or lexical bias, Spivey-Knowlton and Sedivy 1995).

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Examples in: English
Applicable Languages: English
Applicable Level: Tertiary

