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Active nature of dependency formation: The online processing of *tough*-constructions*

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Lew, Jeongho and Nayoun Kim. 2022. Active nature of dependency formation: The online processing of *tough*-constructions. *Linguistic Research* 39(1): 127-153. Previous research has demonstrated that filler-gap dependency formation is an active process in which gap filling occurs at the earliest possible gap site, in advance of identifying the location of the actual gap (Crain and Fodor 1985; Frazier 1987; Frazier and Clifton 1989; Frazier and Flores d'Arcais 1989; Omaki et al. 2015; Stowe 1986). In this study, we investigated whether this active gap filling is at work in the processing of *tough*-constructions. In *tough*-constructions, the matrix subject has to be associated with a gap in the embedded clause (Chomsky 1977; Keine and Poole 2017; Lasnik and Fiengo 1974; Rezac 2006). However, unlike a *wh*-phrase in *wh*-questions or relative clause constructions, the matrix subject in *tough*-constructions does not guarantee the presence of a gap. The results of a self-paced reading experiment indicated that active gap filling is nonetheless operative in the processing of *tough*-constructions, providing further evidence for the active nature of dependency formation. **(Sungkyunkwan University)**

Keywords syntax, psycholinguistics, filler-gap dependency, active gap filling, *tough*-constructions, transitivity, plausibility mismatch effects, self-paced reading

1. Introduction

This study investigates the active dependency formation in real-time processing of *tough*-construction. Previous research on the processing of filler-gap dependency revealed that the parser attempts to postulate a gap at the earliest possible gap site rather than waiting for definitive evidence for the location of the gap (Crain and Fodor 1985; Frazier

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1987; Frazier and Clifton 1989; Frazier and Flores d'Arcais 1989; Omaki et al. 2015; Stowe 1986). Through a self-paced reading experiment, this study examines whether this active gap filling is operative in the processing of *tough*-constructions, in which the matrix subject has to be associated with a gap in the embedded clause (Brody 1993; Chomsky 1977; Hartman 2011; Hicks 2009; Keine and Poole 2017; Postal 1971; Rezac 2006). Although the matrix subject itself in *tough*-constructions does not tell the parser that there exists a gap somewhere in the sentence, our study reveals that the same active gap-filling strategy is also employed in the processing of *tough*-constructions.

2. Background

2.1 Active filler-gap dependency processing

An element in a sentence can be displaced from the site at which it is interpreted. *Wh*-questions like (1) constitute an example of such a case. In (1a), while the *wh*-phrase *what* appears in a clause-initial position, it cannot be interpreted in this surface position. Rather, it is understood as the theme argument of the embedded verb *ate* whose syntactic position is empty. In cases where an empty object position is filled with another element, the sentence becomes unacceptable, as in (1b). The dislocated element is often referred to as a *filler*, and the empty argument position a gap[1]. The dependency established between a filler and a gap is called *filler-gap dependency*. Since there is no limitation on the amount of material intervening between a filler and a gap, the filler can, in principle, be indefinitely distant from its gap. Such dependencies are also referred to as unbounded or long-distance dependencies.

(1) a. What did John think that Mary ate ___?
b. *What did John think that Mary ate an apple?

Previous research on filler-gap dependency processing has revealed that the parser

1 An underscore is used to represent a gap. In this study, we take a neutral position on the issue of whether filler-gap dependencies involve empty categories. That is, we are not arguing for a particular analysis of how filler-gap dependencies are represented (see McElree and Bever 1989; Nicol et al. 1994; Pickering and Barry 1991 for the debates on this issue).

attempts to postulate a gap at the earliest possible gap site even before identifying the location of the actual gap (Crain and Fodor 1985; Frazier and Clifton 1989; Frazier and Flores d'Arcais 1989; Lee 2004; Omaki et al. 2015; Stowe 1986). Evidence for this active gap filling has been provided by much work using different experimental paradigms such as a filled-gap effect and a plausibility mismatch effect (Omaki et al. 2015; Stowe 1986; Traxler and Pickering 2003, among many others). For example, Stowe (1986) examined word-by-word reading times for sentences with and without a filler-gap dependency, such as (2a) and (2b). In (2a), there is a *wh*-filler *who* and a gap after the preposition *to*, and the parser must associate the filler with the gap. By contrast, (2b) lacks such a dependency. What Stowe observed was that the direct object *us* was read slower in (2a) than in (2b), which has been called the "filled-gap effect".

(2) a. My brother wanted to know **who** Ruth will bring **us** home to ___ at Christmas.
b. My brother wanted to know **if** Ruth will bring **us** home to Mom at Christmas.

(Stowe 1986: 234)

The filled-gap effect observed in (2) may suggest that the parser had postulated a gap in the earliest direct object position in advance of encountering the actual gap in (2a), and was surprised to see the direct object position filled with the overt noun phrase (NP) *us*. This means that readers need to abandon their initial analysis with the gap, and the reanalysis process from the gap to the overt NP leads to the reading time slowdown. If the parser had associated the filler with the gap only after the identification of the actual prepositional object gap, the parser would not have been surprised upon encountering the direct object and thus there would have been no reading time slowdown at *us* in (2a). Unlike (2a), (2b) does not involve a filler-gap dependency. Given that a search for a gap does not need to be initiated in the absence of a filler-gap dependency, there is no reason for the parser to be surprised by the presence of the overt object NP, resulting in the lack of a reading time slowdown at *us* in (2b).

Additional evidence for the active gap-filling strategy was manifested by the "plausibility mismatch effect". Traxler and Pickering (1996) made a comparison between reading times for sentences such as those in (3). In both (3a) and (3b), there is a gap inside a relative clause, after the preposition *about*. Since the author can write about the

city as in (3a) and the author can write about the book in (3b), both (3a) and (3b) can be considered globally plausible. That is, after reading the sentences to the end, readers would eventually regard both sentences as semantically acceptable. Between *the city* and *the book*, however, while *the book* can be a plausible object of the verb *write*, *the city* cannot. This contrast in plausibility was reflected in reading times at the verb region (*wrote unceasingly*): the verb region was read more slowly in (3a) than in (3b). This may also suggest that the parser postulates a gap at the verb before identifying the actual gap after the preposition *about*. This phenomenon is referred to as the "plausibility mismatch effect", and is used as a diagnostic in the present study.

(3) a. We like **the city** that the author wrote unceasingly and with great dedication about ___ while waiting for a contract.
b. We like **the book** that the author wrote unceasingly and with great dedication about ___ while waiting for a contract.
(Traxler and Pickering 1996: 465)

As illustrated above, in the resolution of long-distance dependencies, it seems that readers tend to postulate a gap as soon as possible at the position where the dependency can be licensed. However, readers attempt to postulate a gap only when it is grammatically licit to license a dependency (Phillips 2006; Pickering et al. 1994; Stowe 1986; Traxler and Pickering 1996). Traxler and Pickering (1996) tested whether the plausibility mismatch effect observed in (3) also arises in (4) where the first potential gap site is inside the relative clause island. Islands refer to syntactic structures out of which syntactic movement is blocked, and relative clauses are one such structures (Chomsky 1977, 1981; Ross 1967). That is, a filler-gap dependency cannot be established between an element inside a relative clause and another element out of the relative clause. In (4), the relative clause island domain blocks the dependency between the filler *the city*/*book* and the gap inside the relative clause.[2] Therefore, if readers abide by the island constraints, they will not search for a gap inside an island domain. Accordingly, they will not attempt to link the filler with the verb inside the relative clause island, regardless of whether the filler can be a plausible object of the verb or not. Therefore, there will be no reading time difference between (4a) and (4b) at the verb region (*wrote*

2 RC refers to the relative clause, indicated by square brackets.

unceasingly) inside the relative clause island. By contrast, if active gap filling is not constrained by island constraints, the plausibility mismatch effect will also be found in (4). That is, at the critical verb region, the reading time is predicted to be longer in (4a), where the filler *the city* is implausible as an object of the verb, than in (4b), where the filler *the book* is a plausible object of the verb. The plausibility mismatch effect was not found in (4), suggesting that active gap filling is operative only in grammatically licit environments.

(4) a. We like the city that the author [RC_{island} who wrote unceasingly and with great dedication] saw ___ while waiting for a contract.
b. We like the book that the author [RC_{island} who wrote unceasingly and with great dedication] saw ___ while waiting for a contract.
(Traxler and Pickering 1996: 465)

Active gap filling also seems to be unaffected by a verb's transitivity bias. Pickering and Traxler (2003) tested whether the plausibility mismatch effect observed in (3) is also observed with verbs whose intransitive use is more frequent than transitive. It is plausible to speculate that the same effect might not arise with intransitive-biased verbs. This is because the postulation of a gap may be guided by the subcategorization frequency of verbs, in such a way that the parser does not posit a gap if the verb's intransitive use is more frequent than its transitive use.

To test this possibility, Pickering and Traxler (2003) manipulated the verb's transitivity bias as well as the plausibility between the filler and the verb as in (5). While the verb *kill* in (5a) and (5b) is a transitive-biased verb, the verb *worry* in (5c) and (5d) is an intransitive-biased verb. In (5a) and (5c), the filler-verb combinations are plausible, since a soldier can kill a general and a dog can worry a cat. However, neither *the country* in (5b) nor *the car* in (5d) can be a plausible object of *kill* and *worry*, respectively. If gap filling is affected by the verb's transitivity bias in such a way that an attempt to postulate a gap is made only when the verb is preferably transitive, no plausibility mismatch effect is expected when the verb is preferably intransitive. However, the plausibility mismatch effect was observed in both transitive-biased verb and intransitive-biased verb conditions. That is, there was a reading time slowdown at the verb in both (5b) and (5d), with the implausible filler-verb combinations.

(5) a. That's the general that the soldier killed enthusiastically for during the war in Korea.
b. That's the country that the soldier killed enthusiastically for during the war in Korea.
c. That's the cat that the dog worried compulsively about after going to the vet because of an injury.
d. That's the car that the dog worried compulsively about after going to the vet because of an injury.

(Pickering and Traxler 2003: 479)

These results, therefore, seem to suggest that whether a gap is postulated is not simply determined by the subcategorization frequency of the verbs. Rather, the results accord with the view that the parser employs the active gap-filling strategy irrespective of the verb's transitivity bias.

Omaki et al. (2015) also investigated whether active gap filling is triggered in advance of verb transitivity information. In their first experiment, they compared the reading times for sentences such as in (6), where verb transitivity and the presence of an island structure were manipulated. In (6a) and (6b), the first embedded verb is transitive, whereas in (6c) and (6d), it is intransitive. While (6a) and (6c) do not involve an island structure, in (6b) and (6d), the first embedded verb is inside the relative clause island. In transitive conditions, the matrix subject *the city* is an implausible object of the first embedded verb *wrote*. If active gap filling is operative, reading times are expected to be slower at the verb region in the transitive non-island condition (6a), when compared with the transitive island condition (6b).

As for intransitive conditions, Omaki et al. (2015) hypothesized that there are two possibilities. If the parser attempts to posit an object gap only after it is confirmed that the verb is transitive, there will be no such contrast between the intransitive non-island condition (6c) and the intransitive island condition (6d), because the parser will not actively postulate a gap in either condition. However, if the parser actively attempts to postulate a gap before verb transitivity information becomes available, there will be a reading time slowdown at the verb region in (6c), because the actual subcategorization property of the verb is at odds with the expected one.

(6) a. The city that the author wrote regularly about was named for an explorer.

b. The city that the author who wrote regularly saw was named for an explorer.
c. The city that the author chatted regularly about was named for an explorer.
d. The city that the author who chatted regularly saw was named for an explorer.

(Omaki et al. 2015: 5)

They found that in both transitive and intransitive non-island conditions (6a) and (6c), the spillover region after the verb was read slower than in their island counterpart conditions (6b) and (6d), which supports the hypothesis that the parser actively attempts to postulate a gap in advance of verb transitivity information.

In their second experiment, Omaki et al. (2015) also compared the reading times for sentences such as in (7), whose difference between (6) lies in the fact that the matrix subject *the book* is a plausible object of the first embedded verb *wrote* in the transitive conditions (7a) and (7b). It is thus predicted that there will be no reading time difference between (7a) and (7b) at the verb region, but there will be a contrast between the intransitive non-island condition (7c) and the intransitive island condition (7d) due to the transitivity mismatch effect.

(7) a. The book that the author wrote regularly about was named for an explorer.
b. The book that the author who wrote regularly saw was named for an explorer.
c. The book that the author chatted regularly about was named for an explorer.
d. The book that the author who chatted regularly saw was named for an explorer.

(Omaki et al. 2015: 9)

The prediction was borne out, which again provides supporting evidence for the hypothesis that pre-verbal information triggers active gap filling. Taken together, it seems that active gap filling is widely employed in the processing of long-distance dependency constructions, but the active search for the gap is constrained by grammatical constraints

(Phillips 2006; Pickering et al. 1994; Stowe 1986; Traxler and Pickering 1996).

If active gap filling is widely employed in the processing of long-distance dependency constructions, then the question of what the underlying motivation for active dependency formation is needs to be addressed. There are several possibilities that may account for the active nature of dependency formation. First, it may be the need to resolve a dependency as soon as possible that derives active gap filling. Alternatively, the need to satisfy grammatical requirements, such as thematic role assignment, may derive active gap filling. In this case, different possibilities arise depending on whose requirements are responsible for active gap filling; it can be requirements of a filler, or those of a gap-hosting verb. It is also possible that the need to satisfy the grammatical requirements of both a filler and a gap-hosting verb derives active gap filling.

In fact, Aoshima et al. (2004) attempted to distinguish between the possibilities that may guide the active dependency formation (active filler strategy, verb-driven, and the full-constraint-driven approaches). While the need to posit a gap as soon as possible is assumed to drive the processing of filler-gap dependencies under the Active Filler Strategy approach, under the other two approaches, the grammatical requirements, such as thematic role assignment, are assumed to drive the establishment of such dependencies (Aoshima et al., 2004). What distinguishes the two is the element whose requirements should be satisfied; while it is a verb in the verb-driven approach, it is any element according to the full constraint-driven approach.

They tested whether a fronted *wh*-phrase is associated with an embedded clause whose verb is encountered earlier than that of the main clause in Japanese *wh*-fronting constructions, even though the earliest potential gap site in the main clause precedes the embedded clause. Since the earliest potential gap site is in the main clause, if it is the need to postulate a gap as soon as possible that derives active gap filling, the parser will associate the fronted *wh*-phrase with the main clause. However, it turned out that the parser links the fronted *wh*-phrase to the embedded clause, suggesting that active gap filling is not derived simply due to the need to postulate a gap as soon as possible. Aoshima et al. (2004) also tested whether the association between the *wh*-phrase and the embedded clause takes place before or after the embedded verb is processed. They found that the association occurs prior to encountering the embedded verb, which suggests that active gap filling cannot be solely attributed to the verb's need to satisfy its grammatical requirements. Overall, Aoshima et al.'s (2004) findings suggest that active gap filling is not driven simply because a gap needs to be postulated as soon as possible, nor solely

because a verb's grammatical requirements need to be satisfied. Rather, the findings suggest that a gap is postulated at the earliest position at which a filler can be thematically interpreted and thus support the hypothesis that active dependency formation results from the need to satisfy the grammatical requirements of any element in a sentence.

2.2 *Tough*-constructions

In the present study, we investigate whether readers actively hypothesize the tail of the dependency in the processing of *tough*-constructions. *Tough*-constructions can be considered a type of long-distance dependency construction, because the matrix subject in *tough*-constructions is displaced from the position where it receives its interpretation.

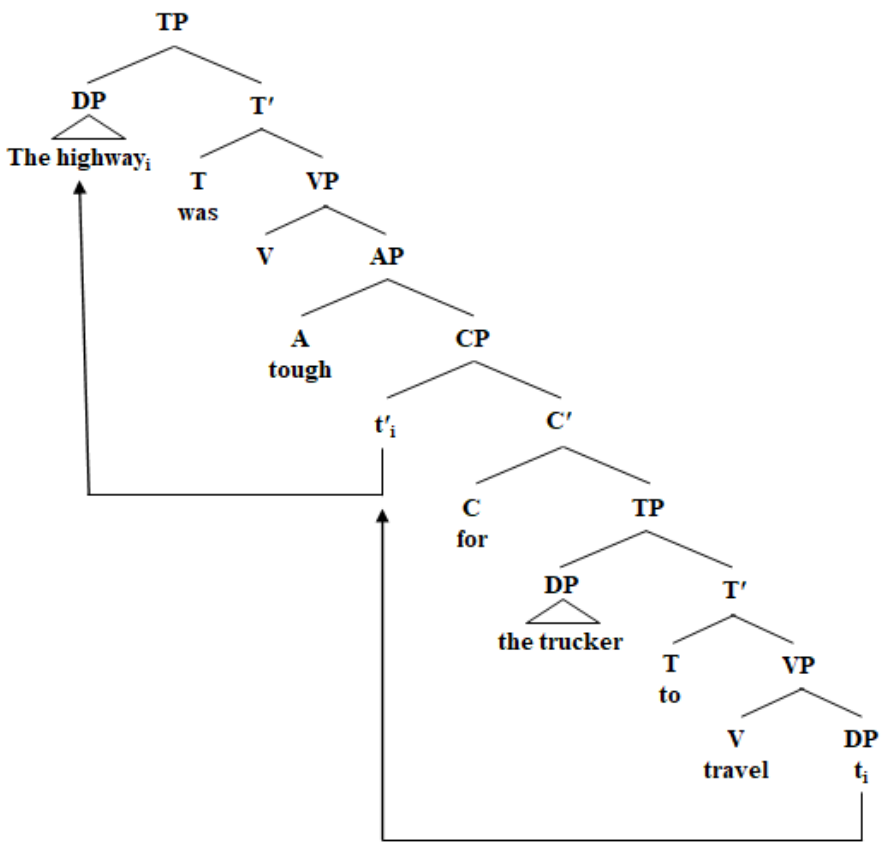
(8) a. **The highway** was tough for the trucker to **travel** ___.
b. **The highway** was tough for the trucker to travel **toward** ___.

In *tough*-constructions like (8), a matrix subject has to fill an object gap in the embedded infinitival clause. In (8a), the object of the verb *travel* is missing, and the matrix subject, *the highway*, should be associated with this verbal object gap. In (8b), there is no overt object of both the verb *travel* and the preposition *toward*. However, since the verb *travel* can be used as an intransitive verb and thus can stand alone without any object, whereas the preposition *toward* cannot, the actual gap in (8b) is the prepositional object gap. Therefore, the matrix subject must be associated with the prepositional object gap.

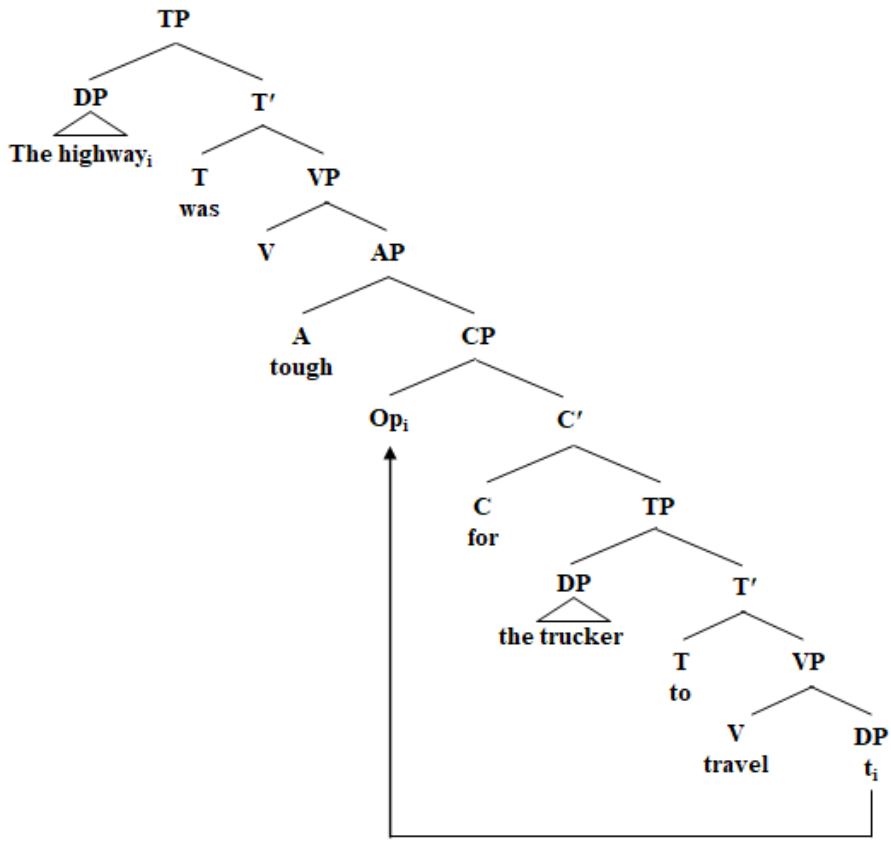
Broadly speaking, there have been two accounts of *tough*-constructions that explain the generated position of the matrix subject. In one account, the matrix subject is generated in the object position in the embedded infinitival clause and moves to the matrix subject position, via the specifier position of the embedded CP, as exemplified in (9a) (Brody 1993; Hartman 2011; Hicks 2009; Hornstein 2000; Postal 1971). The second account assumes that the matrix subject is not moved from the embedded clause, but base-generated in the matrix clause. Instead, it is the null operator coreferential with the matrix subject that base-generated in the object position of the embedded infinitival verb, as exemplified in (9b) (Chomsky 1977; Keine and Poole 2017; Rezac 2006).

In (9a), since the matrix subject is base-generated at the complement position of the embedded verb, a dependency is directly established between the matrix subject and the embedded verb. In (9b), however, the matrix subject is not moved from the complement position of the embedded verb. Rather, the matrix subject is indirectly linked with the embedded verb by means of a null operator (Chomsky 1977; Keine and Poole 2017; Lasnik and Fiengo 1974), although thematic interpretation of the matrix subject becomes available at the embedded verb. However, regardless of whether the dependency between the matrix subject and the embedded verb is direct or indirect, in order for the sentence to be interpreted, the gap in the embedded clause must be filled with a displaced element in both accounts, as in other long-distance constructions.

(9) a.



b.


TP
DP
T′
The highway$_i$
T
was
VP
V
AP
A
tough
CP
Op$_i$
C′
C
for
TP
DP
the trucker
T′
T
to
VP
V
travel
DP
t$_i$

The real-time processing of *tough*-constructions resembles that of *wh*-filler-gap dependency which is one type of long-distance dependency. In the *wh*-filler-gap dependencies in (10), the position after *drink* is the potential gap site where the gap can, in principle, be grammatically licensed. However, the actual gap is at the complement of the preposition *with*.

(10) What did Paul drink the beer with?

What relative clauses without an overt *wh*-phrase like (3b) (repeated here as (11)) and *tough*-constructions like (8b) (repeated here as (12)) have in common is that they both involve a filler-gap dependency, but the filler itself does not guarantee the parser the existence of the dependency.

(11) We like the book that the author wrote unceasingly and with great dedication about ___ while waiting for a contract.
(12) The highway was tough for the trucker to travel toward ___.

The head noun *the book* in (11) itself does not indicate that there is a gap somewhere in the sentence, nor does the matrix subject *the highway* in (12). However, the study by Traxler and Pickering (1996) revealed that the parser actively attempts to postulate a gap at the earliest potential gap site when processing relative clauses without an overt *wh*-phrase. They found evidence showing that the parser makes an attempt to posit a gap at the verb *wrote* before identifying the actual gap after the preposition *about* in (11). Similarly, in (12), while the actual gap site is located after the preposition *toward*, the earliest possible gap site is the object position of the verb *travel*. If the parser attempts to postulate a gap in *tough*-constructions in the same way it does for other long-distance dependency constructions such as *wh*-questions or relative clause constructions, the gap is predicted to be initially postulated at the verb *travel* in the online processing of (12).

What makes *tough*-constructions interesting from the perspective of online sentence processing lies in the fact that the matrix subject NP in *tough*-constructions does not provide any signal indicating the presence of a gap. In *wh*-questions or relative clause constructions with an overt *wh*-phrase, a fronted *wh*-phrase itself guarantees that there is a verb or preposition that hosts a gap somewhere in a sentence, since it cannot be interpreted at its surface position. Therefore, an active search for a gap can be initiated

as soon as the *wh*-phrase is identified in these constructions. However, in *tough*-constructions, even though the matrix subject must be eventually associated with a verb or a preposition in the embedded clause regardless of whether the dependency between them is direct or indirect, the matrix subject itself does not indicate the presence of a gap-hosting verb or preposition[3]. In the present study, we investigated whether an active search for a gap nonetheless takes place in the processing of *tough*-constructions, as in other long-distance dependency formation.

2.3 Predictions for the experiment

In all conditions, the object of the preposition in the embedded clauses is missing, and the embedded infinitival verb is optionally transitive. Therefore, for the sentences to be grammatical, between what follows the embedded verb and what follows the preposition, the latter must be the actual gap site to which the matrix subject is linked. However, since the preposition comes later than the embedded verb, what follows the embedded verb constitutes the earlier potential gap site. That is, in all the sentences in (13), the earliest potential gap site is located after the infinitival verb. However, the actual gap site is located after the preposition *about* in (13a/b), and after the preposition *behind* in (13c/d).

Because all the sentences in (13) are globally plausible, if the parser attempts to fill a gap only after the actual gap is identified, no plausibility mismatch effect is expected at the verbal object gap (*read*/*land*). However, if the parser actively attempts to posit a gap in the processing *tough*-constructions, a reading time slowdown will be observed at the embedded infinitival verb when the matrix subject is implausible as an object of the embedded infinitival verb, compared to when the matrix subject is plausible as an object of the verb. That is, reading times will be slower at the infinitival verb region (*read*) in (13b) than in (13a). If active gap filling is operative irrespective of the verb's transitivity bias, the same plausibility mismatch effect will also be observed in Intransitive-biased conditions. That is, the infinitival verb region (*land*) will be read more slowly in (13d) than in (13c). If active gap filling is guided by the subcategorization frequency of verbs in such a way that a gap is not posited if the verb's intransitive use

3 We direct readers to Tollan (2019) and Tollan and Clemens (2021) for the discussion on the differences in the processing of A'-movement and A-movement.

is more frequent than its transitive use, a plausibility mismatch will be observed only in Transitive-biased conditions (13a/b), but not in Intransitive-biased conditions (13c/d).

(13) a. *Transitive-biased*, *Plausible*
The article was hard for the editor to read carefully and meticulously about in the office.
b. *Transitive-biased*, *Implausible*
The burglar was hard for the editor to read carefully and meticulously about in the office.
c. *Intransitive-biased*, *Plausible*
The plane was difficult for the pilot to land smoothly and safely behind in the fog.
d. *Intransitive-biased*, *Implausible*
The truck was difficult for the pilot to land smoothly and safely behind in the fog.

3. Experiment

3.1 Participants

Sixty one participants (Age range: 21~45) recruited from Prolific took part in our self-paced reading experiment. They self-reported themselves as native speakers of English and identified English as their first and dominant language. The experiment took about 20 minutes, and the participants were paid about 4 dollars for their participation.

3.2 Materials

The experimental materials consisted of 16 sets of sentences like those in (13). *Transitivity* (transitive-biased verb vs. intransitive-biased verb) and *Plausibility* (plausible vs. implausible) were manipulated in a 2×2 factorial design, yielding four conditions. The manipulation of *Transitivity* concerned whether the embedded verb was transitive-biased or intransitive-biased, while the manipulation of *Plausibility* concerned whether the matrix subject could be a plausible object of the embedded verb.

Most of the experimental items for this study were created by modifying the materials from Pickering and Traxler (2003). We selected 12 transitive-biased verbs and 13 intransitive-biased verbs from their materials. We changed Pickering and Traxler's original sentences into *tough*-constructions like those in (14), all of which contained a prepositional object gap in the embedded infinitival clause. Plausibility was manipulated between the matrix subject and the embedded infinitival verb. For *tough*-predicates, we used 14 different adjectives selected from the list of *tough*-predicates in Gluckman (2021). In the experimental sentences, a matrix clause containing a *tough*-predicate was followed by a non-finite embedded clause. In the embedded clause, the critical infinitival verb was preceded by a *for*-phrase, and followed by two adverbs connected by *and*. After the second adverb was a gap-hosting preposition, which was followed by a prepositional phrase. Since there was only one adverb between the earliest possible gap site and the actual gap site in Pickering and Traxler's (2003) original materials, we added *and* and an additional adverb in order to detect a plausibility mismatch effect that can be delayed and appear later than expected.

The 16 experimental items as well as 48 experimental fillers were pseudo-randomized for each participant. The experimental fillers were unrelated to the manipulations of the current experiment.

(14) a. *Transitive-biased*, *Plausible*
The article was hard for the editor to read carefully and meticulously about in the office.

b. *Transitive-biased*, *Implausible*
The burglar was hard for the editor to read carefully and meticulously about in the office.

c. *Intransitive-biased*, *Plausible*
The plane was difficult for the pilot to land smoothly and safely behind in the fog.

d. *Intransitive-biased*, *Implausible*
The truck was difficult for the pilot to land smoothly and safely behind in the fog.

3.3 Procedure

The participants recruited from Prolific were given a link to the experiment created using Ibex Farm, through which they could participate in the experiment online any time they wanted to with their own computer. They were informed that the experiment should be conducted in a quiet setting without distractions, and that they could not participate using a mobile phone. The participants were asked to read sentences in a self-paced reading paradigm. Materials were presented word by word on a computer screen. In each trial, words were initially masked by dashes, and participants had to press the spacebar to reveal each word of a sentence. As the next word appeared, the previous word was again masked by a dash. Half of the experimental sentences and half of the filler sentences were followed by a content-related yes/no question. Questions like "Was the word 'pilot' mentioned?" were asked, in which various parts of the sentence were targeted. Experimental items were divided into four lists following a Latin Square design, so that no more than two target sentences and two filler sentences appeared in succession.

3.4 Analysis

Participants whose comprehension accuracy was above 72% were included prior to the analysis. Reading times read extremely fast and slow (faster than 3000ms and slower than 50ms) were excluded prior to the analysis as well. Data analysis was performed with linear mixed-effects regression models (Baayen et al. 2008) using lme4 package (Bates et al. 2015). Whenever possible, maximal random effects structure (Barr et al. 2013) were adopted, and when it failed to converge, we simplified the model by removing random effects that had a least variance (Bates, Kliegl, Vasishth and Baayen 2015). Statistical analyses were conducted on log-transformed reading times for each region (Box and Cox 1964).

3.5 Results

Linear mixed-effects regression results are summarized in Table 1[4] and the mean

4 We ran an acceptability rating experiment with 55 participants who were native speakers of English recruited from Prolific (Similar procedure and analyses were employed as in an online experiment). In an acceptability rating experiment, there was no main effect of *Plausibility* (Estimate: 0.17, SE= 0.15, t=1.15), *Transitivity*

reading times at the critical region as well as spillover regions in Table 2. Log-transformed reading times by region and condition are plotted in Figure 1 (Transitive-biased) and Figure 2 (Intransitive-biased). The mean accuracy for the comprehension questions was 94%. The analysis of log reading times revealed a main effect of *Plausibility* at the second spillover region (*and*). That is, reading times were slower in implausible conditions than in plausible conditions regardless of *Transitivity* (Estimate: -0.08, SE= 0.02, t=-4.14). Neither a main effect of *Transitivity* (Estimate: 0.00, SE= 0.02, t=-0.24) nor an interaction between *Transitivity* and *Plausibility* were observed (Estimate: 0.01, SE= 0.04, t=0.21). This suggests that readers attempted to associate the filler with the embedded verb after which is the earliest possible gap site, regardless of whether the verb is biased toward transitive or intransitive use. After the first spillover region (*carefully*/*smoothly*), we added *and* and an additional adverb, and the effect was observed only at the second spillover region, two words after the critical region (*and*). This is not surprising, given that in a self-paced reading experiment, the effect may not appear at the critical region, but can be delayed and appear at subsequent spillover regions (Vasishth and Lewis 2006). At the actual gap spillover region (*the* after *in*), no effects were observed[5].

(Estimate: 0.10, SE= 0.23, t=0.44) nor an interaction between *Transitivity* X *Plausibility* (Estimate: 0.19, SE= 0.22, t=0.84), suggesting that the sentences in four conditions were judged as almost equally acceptable. This served as a sanity check prior to running an online experiment.

5 At the actual gap region and the subsequent regions, we predicted that the recovery from the early dependency formation at the potential gap site to construct a new dependency upon the encountering real gap would be costly, contributing to the slower reading times at the Plausible conditions relative to Implausible conditions (see Giskes and Kush 2021, which reveals the parser's persistent search for the suitable antecedent when the first predictions regarding the position of the gap is disconfirmed). Our results, however, revealed no significant effects at this particular region, contrary to our predictions. For now, we don't have definite answers as to why this particular effects would not appear, provided that early gap-filling did show up. We thank an anonymous reviewer for bringing this point into our attention, and leave this interesting puzzle for our future research.

Table 1. Summary of results of linear mixed-effects regression by region. Effects were considered significant if the absolute value of t-value was greater than 2

	Estimate	SE	t-value	p-value
Critical Region (*read*/*land*)				
(Intercept)	6.05	0.03	173.10	
Transitivity	0.03	0.02	1.40	0.161
Plausibility	0.00	0.02	0.11	0.916
Transitivity X Plausibility	-0.00	0.04	-0.02	0.982
Spillover region after the Critical Region (*carefully*/*smoothly*)				
(Intercept)	6.17	0.05	136.49	
Transitivity	0.02	0.02	0.71	0.475
Plausibility	-0.02	0.02	-0.84	0.403
Transitivity X Plausibility	-0.01	0.05	-0.17	0.863
Spillover region two words after the Critical Region (*and*)				
(Intercept)	6.10	0.04	161.11	
Transitivity	-0.00	0.02	-0.24	0.811
Plausibility	-0.08	0.02	-4.14	3.841e-05 ***
Transitivity X Plausibility	0.01	0.04	0.21	0.831

Table 2. Mean reading times in ms (SE) for the critical region, one word after the critical region (Spillover Region 1), and two words after the critical region (Spillover Region 2)

	Critical Region	Spillover Region1	Spillover Region2
Transitive-biased, Plausible	470.15 (18.23)	533.66 (20.17)	461.18 (12.71)
Transitive-biased, Implausible	449.18 (12.43)	540.00 (20.46)	505.83 (15.47)
Intransitive-biased, Plausible	469.63 (14.13)	538.22 (19.14)	464.71 (14.65)
Intransitive-biased, Implausible	485.72 (19.39)	556.59 (21.36)	520.46 (20.42)

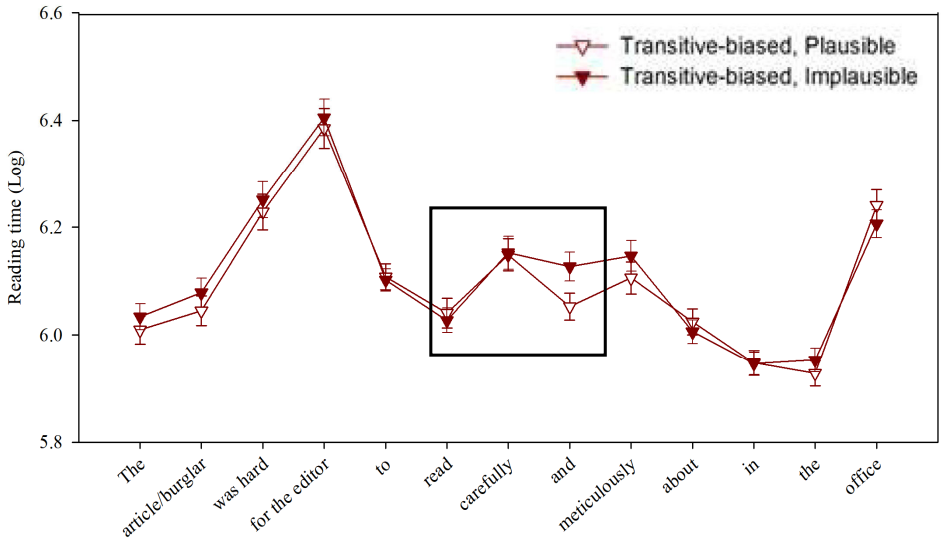


Figure 1. Reading times at the critical region (*read*), verb spillover region (*carefully*), and two words after the critical region (*and*) in the Transitive-biased conditions

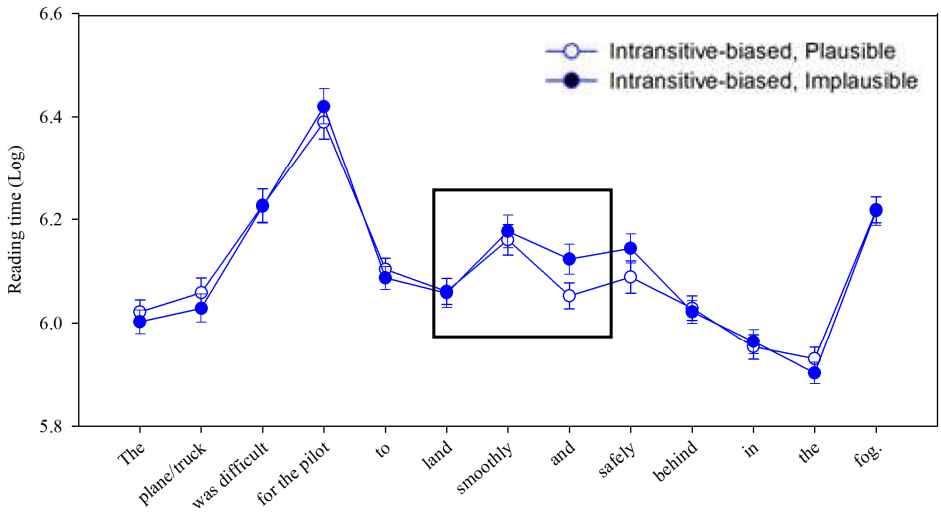


Figure 2. Reading times at the critical region (*land*), verb spillover region (*smoothly*), and two words after the critical region (*and*) in the Intransitive-biased conditions

4. Discussion

This study aimed to test whether active gap filling is operative in the processing of *tough*-constructions, in which the matrix subject has to be associated with a gap in the embedded clause. It has been argued that an active search for a gap is immediately initiated once the parser recognizes a filler (Crain and Fodor 1985; Frazier 1987; Frazier and Clifton 1989; Frazier and Flores d'Arcais 1989; Omaki et al. 2015; Stowe 1986). In *wh*-filler-gap dependency constructions, a fronted *wh*-filler itself indicates the presence of a gap. However, in *tough*-constructions, the matrix subject, which serves as a filler, does not guarantee that there is a gap in the embedded infinitival clause. Therefore, unlike in *wh*-filler-gap dependency constructions, when the matrix subject is encountered, an active search for a gap may not be immediately initiated in *tough*-constructions. However, we found experimental evidence that readers employ the active gap-filling strategy when processing *tough*-constructions.

In this study, we conducted a self-paced reading experiment using the plausibility mismatch paradigm (Traxler and Pickering 1996), in which the plausibility between the matrix subject and the embedded infinitival verb in *tough*-construction sentences and the transitivity bias of the infinitival verb was manipulated. In the experimental sentences, while the object of the infinitival verb was not filled overtly, the actual host of the gap was the preposition that came after the infinitival verb. We observed that reading times were slower at the infinitival verb spillover region, when the matrix subject was implausible as an object of the infinitival verb, compared to when the matrix subject was a plausible object of the infinitival verb. The plausibility mismatch effect was found not only when the infinitival verb was preferably transitive, but also when it was preferably intransitive. These findings suggest that the parser attempts to form a dependency in an active manner in the processing of *tough*-constructions.

A question that arises here is what drives this active gap filling in the processing of *tough*-constructions. As Aoshima et al. (2004) points out, active filler effects can be interpreted as being motivated by the need to meet grammatical constraints, such as case or thematic role requirements. If this is the case, there is a possibility that active filler effects observed in *tough*-constructions are due to a predicate, not a filler. That is, it may be that only after the parser encounters the embedded verb is a search for a filler initiated. However, there is another possibility. Even though the matrix subject itself cannot guarantee the presence of a gap before encountering the embedded verb, the parser

may notice that it is a *tough*-construction that involves a gap in the embedded infinitival clause. This is because the fact that the matrix subject cannot receive its thematic role in the matrix clause can become available to the parser before the embedded verb is encountered. For example, in (15a), at the point where *tough* is encountered, being tough can be initially understood as the attribute of the matrix subject *the traitor*. However, such an interpretation is no longer available with the following string *for the courier*, and it becomes clear that the matrix subject cannot be interpreted in the matrix clause. In (15b), this happens even earlier than in (15a), because the association of the matrix predicate with the matrix subject results in a semantic anomaly.

(15) a. The traitor was tough for the courier to communicate secretly and securely about to the spy.
b. The house was impossible for the architect to teach clearly and concisely about to the students.

Therefore, it is possible that the parser can recognize the matrix subject as a filler whose interpretation is dependent on the upcoming gap before reaching the embedded verb. In such a case, it is the grammatical requirement of the filler (i.e., the matrix subject) that drives active dependency formation. Although the current results cannot tease apart between the two possibilities, it is clear that the parser does not wait for definitive evidence for the location of the actual gap in the processing of *tough*-constructions. Rather, the parser attempts to form a dependency at the earliest possible gap site, even though it is risky in that the earliest possible gap site may not be the actual gap site.

Since the current study cannot tell us whether it is the matrix subject or the embedded predicate that derives the active dependency formation in *tough*-constructions, a follow-up study is required to answer the question of what triggers active gap filling. Omaki et al. (2015) showed that reading disruption occurs at the intransitive verb in a relative clause whose syntactic position is supposed to be the earliest potential gap site, and argue that this suggests that active dependency formation is triggered before reaching the verb. If the same effects are observed in *tough*-constructions in which the embedded infinitival verb is solely intransitive, it would support the view that it is the matrix subject that derives the active dependency formation in *tough*-constructions.

We previously discussed that there are two possible dependency representations of

tough-constructions, which are generated in terms of different syntactic operations. While a semantic relationship is eventually established between the initial NP and the embedded verb in both (9a) and (9b), the surface structural position of the initial NP does not determine its grammatical status or its semantic role. The two initial NPs in (9a) and (9b) share the commonality of bearing a theme role, of which is dependent on a verb (see Baker 2009; Kratzer 1996, 2002). However, they differ in their grammatical status. While the initial NP in (9a) is the complement of the embedded verb, the initial NP in (9b) is not, as the null operator serves as the complement of the verb (Chomsky 1977; Keine and Poole 2017; Rezac 2006). That is, an NP's status as a theme does not necessarily mean that it is the complement of the verb. Consequently, depending on the representation, active dependency formation in *tough*-constructions may be derived either by the thematic saturation requirement or by the syntactic selection requirement.

Our study revealed that despite the presence of a decisive cue that the *tough*-construction exists somewhere downstream, the matrix subject or the predicate entertains the possibility of constructing a dependency upon encountering the earliest potential gap. But from the parsing point of view, the parser may not realize the existence of the *tough*-construction until one encounters the predicate. Even when the predicate is encountered, the *tough*-construction may not be expected (compare *the steak was tough* vs. *the steak was tough to cook properly*).

In the *wh*-filler-gap dependency, as soon as the *wh*-filler is identified, the parser recognizes the existence of the dependency, and attempts to postulate a gap at the earliest syntactic position to discharge the wh-filler from memory. One of the motivations behind this is because retaining the wh-filler in memory imposes a burden on memory resources (Gibson 1998). Unlike in the *wh*-filler-gap dependency, in the *tough*-construction, the presence of the gap is only optional for a much longer span of the sentence. Thus, the desire to terminate the dependency as soon as possible, and a strong bias towards a shorter dependency does not seem to be crucial, as it is not evident that a gap is located somewhere downstream.

But our results revealed that the parser attempts to posit the gap at the earliest syntactic position, and this suggests that the parser picks the parse that involves a movement compared to the parse that does not involve a movement. It looks like a movement dependency is involved (A-movement; Chomsky 1977; Keine and Poole 2017; Lasnik and Fiengo 1974; Rezac 2006) because an initial NP gets the thematic interpretation in a different clause than where it shows in the surface position within a

sentence, and the parser entertains the parse with such dependency.

An anonymous reviewer asked whether our results can be explained in terms of the retrieval-based accounts (Lewis, Vasishth, and Van Dyke 2006). It is likely that both the active-filler gap strategy as well as the memory retrieval mechanism (Lewis, Vasishth, and Van Dyke 2006) are operative to achieve a successful parse in the processing of *tough*-construction. If the memory retrieval mechanism is at play, then the verb triggers the retrieval of the already processed linguistic contents in memory. On the other hand, if an active-filling underlies the processing of *tough*-construction, the relevant point is that an active gap filling occurs prior to the position of an actual gap (after the preposition in our stimuli). Thus, the possible scenario is that the parser actively attempts to find a gap that needs to subsequently be retrieved from memory. In other words, it could be the case that the active-filling parsing strategy and the memory retrieval process are not mutually exclusive.

Since the parser tries to establish a dependency at a position before the bottom-up evidence, but does it after the parser recognizes that there has to be some dependency somewhere (after encountering, *read*/*land*), it is reasonable to assume that active filling (attempt to integrate into syntactic position) and memory retrieval are both involved in the processing of *tough*-construction (Tollan and Clemens 2021). We would like to further examine whether both mechanisms should be involved in the processing of *tough*-construction, by means of more complicated experimental design in our future study.

Finally, future work is needed to test whether the plausibility mismatch effect observed in the current study can be replicated under conditions that control for the frequency of the filler items, cloze probability, and the semantic relatedness of the filler and the (in)transitive verb. Neal et al. (2021) found that a plausibility mismatch effect was replicated in filler-gap dependency constructions when potential confounding factors were controlled for. However, such an effect was not observed in relative clause islands where a gap is not permitted. If plausibility mismatch effects are retained in *tough*-constructions after controlling for the factors illustrated above, it will serve as stronger evidence for the argument that the plausibility mismatch effect observed regardless of the verb's transitivity bias is truly due to the plausibility mismatch between the matrix subject and the embedded verb, which in turn suggests that active gap filling is operative in the processing of *tough*-constructions. We leave this for future research.

5. Conclusion

This study investigated whether the parser employs the active gap-filling strategy in the processing of *tough*-constructions (Crain and Fodor 1985; Frazier 1987; Frazier and Clifton 1989; Frazier and Flores d'Arcais 1989; Omaki et al. 2015; Stowe 1986). We conducted a self-paced reading experiment employing the plausibility mismatch paradigm to examine whether the parser attempts to form a dependency upon encountering the earliest potential gap site, or waits for conclusive evidence for the actual gap site. In the experiment, experimental items involved a *tough*-construction in which the actual gap site was located after the preposition in the embedded clause, which was preceded by the infinitival verb (Chomsky 1977; Keine and Poole 2017; Lasnik and Fiengo 1974; Rezac 2006). We manipulated the plausibility between the matrix subject and the infinitival verb in the embedded clause and the transitivity bias of the infinitival verb. We observed that reading times were longer at the infinitival verb spillover region in conditions where the matrix subject was plausible as an object of the infinitival verb, than in conditions where the matrix subject was implausible as an object of the infinitival verb, irrespective of the verb's transitivity bias. These findings indicate that the parser makes an attempt to posit a gap as soon as possible, even before the location of the actual gap site is identified. This study provides further evidence for the active nature of dependency formation.

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