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Predictive Sentence Processing: Evidence from Passive Relative Clause Processing

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ABSTRACT

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Previous studies proposed that readers engage in predictive processing by showing that the processing of expected elements is facilitated compared to unexpected elements (Frazier and d'Arcais 1989, Frazier and Clifton 1989, Stowe 1986). However, others claim that such processing facilitation can also be attributed to integration facilitation (Gibson 1998, 2000, Grodner and Gibson 2005). Using a self-paced reading experiment, this study provides evidence for predictive processing by examining the processing of passive relative clauses with pied-piped *by*-phrases. We found evidence that the processing of inanimate embedded subjects is facilitated after encountering *by*-phrases, an effect that can only be attributed to predictive processing rather than integration facilitation. Overall, this study provides further evidence that readers engage in a predictive structure-building processes ahead of encountering unequivocal bottom-up input (Phillips 2006, Staub and Clifton 2006, Wagers and Phillips 2009, Yoshida 2006, Yoshida, Dickey and Sturt 2013).

KEYWORDS

structural prediction, passive relative clause processing, pied-piping, p-stranding, animacy, integration, moving-window self-paced reading experiment

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1. Introduction and Background

1.1 Predictability in Filler-Gap Dependency

One of the most noteworthy properties of human sentence processing is that the parser is predictive, meaning that the parser constructs the upcoming structure and lexical words in accordance with what has already been encountered (Altmann and Kamide 1999, Federmeier 2007, Federmeier and Kutas 1999, Kamide et al. 2003, Kimball 1975, Lau et al. 2006, McRae et al. 2005, Phillips 2006, Staub and Clifton, 2006, Wagers and Phillips 2009, for details regarding whether such a predictive top-down mechanism follows from specific parsing strategies such as left-corner parsing strategy, refer to Abney and Johnson 1991, Crocker 1994, Sturt and Lombardo 2005). Upon hearing words and phrases in real-time, readers make predictions about the as yet encountered morphosyntactic and lexical items (Altmann and Kamide 1999, Boland 2005, DeLong, Urbach and Kutas 2005, Kamide, Altmann and Haywood 2003, Kazanina 2017) as well as syntactic structures (Phillips 2006, Staub and Clifton 2006, Wagers and Phillips 2009; Yoshida, Dickey and Sturt 2013). For example, in studies using Event-Related Potential (ERP) measures, readers anticipate certain semantic features of an upcoming lexical item in line with what has already been processed, which results in the reduced N400 ERP responses if the subsequent words are semantically associated to the preceding context (Federmeier 2007, van Berkum et al. 2005, Kutas and Federmeier 2011).

In the domain of predictive structure-building processes in the sentence processing realm, Staub and Clifton (2006) investigated predictive processing in the *either-or* construction. The word *either* requires the presence of *or* for it to be licensed (Larson 1985). In the processing of *either-or* construction, they found that once *either* is encountered, readers would predictively make hypotheses about the upcoming structure that contains the disjunctive coordination *or*, as well as the syntactic category of the disjunct followed by *or*. They presented stimuli like below where the sentence either contained *either* (1a) or not (1b) in an eye-tracking while reading experiment.

(1) a. Either Linda bought the red car or her husband leased the green one.
b. Linda bought the red car or her husband leased the green one.
Staub and Clifton (2006: 428)

In (1a), in the presence of *either*, where it sets up a strong (category) prediction about the structure downstream, the reading time facilitation was observed when what occurs after *either* and what occurs after *or* are of the same syntactic category. But in (1b), in the absence of *either*, the first NP that follows after *or* is considered as an object of the first conjunct due to the strong motivation to attach words into locally coherent syntactic structure (Frazier and Fodor 1978, Kimball 1973). This overrides the expectations about having the same syntactic category of what has appeared before *or*, leading to the detectable slowdown at the first encountered NP followed by *or* in (1b) compared to that of (1a).

Yoshida, Dickey and Sturt (2013) make similar observations about the predictive parsing in the case of sluicing, a construction with the ellipsis of a clausal element in an embedded wh-interrogative (Chung, Ladusaw and McCloskey 1995, Lasnik 2001, 2005, Merchant 2001, Ross 1969). The omission of a clause after the wh-element needs to be recovered in the second conjunct in order to achieve proper interpretation of the sentence. Thus, the content of the missing element should be recovered by referring to the first conjunct. When faced with the

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embedded wh-phrase in the second conjunct, the sentence is either compatible with the upcoming elliptical (sluicing) construction as in (2a) or the non-elliptical construction as in (2b)[1].

(2) a. John told some stories, but we couldn't remember which stories ~~(John told).~~
b. John told some stories, but we couldn't remember which stories Mary was so impressed with.

The authors asked whether one of the constructions between the elliptical construction or non-elliptical construction is initially preferred over another in (2a). If the elliptical construction is preferred, then this constitutes evidence that the parser builds the detailed hierarchical clausal structure that licenses ellipsis in advance of encountering the unequivocal lexical content that confirms the ellipsis structure. Making use of the Gender Mismatch Effect (Gompel and Liversedge 2003) as well as Binding Connectivity Effects, they asked what happens at the reflexive in the second conjunct. They presented stimuli like those in (3) in which an antecedent was either c-commanding the reflexive or non-c-commanding reflexive (Chomsky 1981). Examples (3c) and (3d) served as control conditions where the parallelism requirement is not satisfied, since the embedded wh-phrase constitutes a PP, and thus the content of the antecedent cannot be recovered in the ellipsis site (Merchant 2001).

(3) a. John told some stories, but I don’t know which stories about himself.
b. Mary told some stories, but I don’t know which stories about himself.
c. John told some stories, but I don’t know with which stories about himself.
d. Mary told some stories, but I don’t know with which stories about himself.
Yoshida, Dickey and Sturt (2013: 8)

Readers were slower to read gender-mismatched reflexives in (3b) than gender-matched reflexives in (3a) relative to the control conditions in (3c) and (3d). This contrast suggests that upon encountering the wh-element, readers build a hierarchical structure within the ellipsis site which is sufficiently detailed enough to license a reflexive binding relationship. Since the wh-phrase itself (e.g., *which stories*) is not associated with the ellipsis in a direct manner, the results can be explained by assuming the predictive nature of the parser calculating the sophisticated hierarchical structure that allows for the establishment of a binding relationship between the subject of the antecedent clause and the reflexive within the wh-phrase ahead of bottom-up information about the presence of the ellipsis[2]. Given that the parser could wait until the unambiguous lexical content that disambiguates the possible upcoming structure to avoid unwanted reanalysis process, the parser nevertheless builds the clausal structure that licenses ellipsis before facing unequivocal lexical information (see also Kim, Carlson, Dickey and Yoshida 2020).

Additional evidence that readers predictively build the syntactic structure based on the encountered input comes from the real-time processing of long-distance dependencies like wh-filler-gap dependencies. In the processing of wh-filler-gap dependencies, readers encounter the wh-element first and then actively look for the licensor (i.e., the gap for the wh-element) without decisive information about its position. Gaps for wh-elements are usually predictively posited by parsers at their earliest possible positions, to process of which is thought to be driven by

[1] Ellipsis is indicated by the strike through.
[2] For other central questions on Yoshida et al. (2013) regarding whether the hierarchical structure of the antecedent is built in the ellipsis, we direct readers to the paper.

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the need to maximize the grammatical interpretation or by the need to terminate the dependency to liberate the wh-filler from memory store (Frazier and d'Arcais 1989, Frazier and Clifton 1989, Stowe 1986).

(4) 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)

For example, in (4a), the gap is at an object position of the preposition *to*. Upon confronting the wh-phrase, *who*, readers immediately seek for the earliest potential gap to fulfill the grammatical analysis or to mitigate the burden of the memory store (Frazier and Clifton 1989, Frazier and d'Arcais 1989, Stowe 1986). Now consider the contrast between (4a) and (4b). In (4b), there is neither a gap nor a wh-phrase signaling a gap. Stowe (1986) found that readers were slower to read *us* in (4a) in comparison to (4b) because they fail to satisfy the prediction of the gap or the verb. The reading time slow-down in (4a) suggests that the readers initially postulate a gap at the position following the embedded verb, which turns out to be occupied by *us*. In (4b), the readers do not predictively postulate any gap due to the lack of wh-phrases signaling the existence of gaps. Therefore, there is no reading time slow-down when the readers encounter *us* in (4b).

1.2 Motivation of Our Experiment

As illustrated above, ample evidence suggests that humans engage in predictive sentence processing by postulating upcoming syntactic elements or structures before seeing unequivocal evidence for them. But the question arises to whether this predictability (processing driven by expectation) can equally be attributed to **eased integration** (De Long 2005, Gibson 1998, 2000, Grodner and Gibson 2005, Keine 2020, Warren and Gibson 2002). It is claimed that when non-local dependencies in sentences are processed, a processing cost arises when the reader links one member of a dependency to another member within the same dependency (Gibson 1998, 2000, Grodner and Gibson 2005, Keine 2020, Warren and Gibson 2002).

Integration costs are known to correlate with the distance between the dependent element and the licensor, as determined with respect to the number of intervening new discourse referents (Gibson 1998). Consider (5), where in (5b), upon encountering *attacked*, readers need to retrieve *the reporter* and the intervening new discourse referent *the senator* imposes integration costs whereas (5a) involves no intervening noun prior to the grammatical licensor that participates in the dependency resolution, and hence no concomitant processing cost is engendered (Gibson 1998, 2000, Grodner and Gibson 2005, Keine 2020, Warren and Gibson 2002).

(5) a. The reporter that attacked the senator admitted the error.
b. The reporter that the senator attacked admitted the error.
(Gibson 1998: 2)

Integration costs emerge when the dependency is terminated and integrated into the current structure. Thus, the Filled-Gap Effect (Frazier and Clifton 1989, Frazier and d'Arcais 1989, Stowe 1986) which we have reviewed above, may be considered as simply reflecting the integration of the verb which leads to the increased integration costs once the filler is integrated to the grammatical licensors such as the verb or the preposition. If this is the case, this may not necessarily serve as evidence for the active prediction of the structure before the unambiguous bottom-

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up input; rather, any reading disruption may not necessarily be explained by the failure to actively predict the upcoming material in advance but caused by the costs associated with integrating words into the current structure.

In this paper, we attempt to address this tension by providing further evidence that the parser makes some fine-grained predictions about the upcoming structure in advance of the unequivocal bottom-up input. Specifically, we will make use of the wh-filler, *who* and the *by who* phrase where the wh-filler is accompanied by the preposition. We show that *by who* (Pied-piping *by*-phrase) engenders the predictions about (i) the passive verb of the relative clause and (ii) the subsequent inanimate subject as an embedded subject within a relative clause. But the wh-element, *who* does not lead readers to make such predictions about the passive verb of the relative clause and the embedded animate subject within a relative clause.

One way to test if the parser is predictive in its operations is to employ the sentence configuration below in (6), where A and B are some types of syntactic elements. Assume that there is a causal relation between the existence of A and B in a single sentence: the occurrence of A leads to the more likely occurrence of B. If the parser is predictive, it would expect the occurrence of B after observing A, leading to measurable effects (e.g., increased reading time) when the expectation is not satisfied (i.e., when B is in fact not in the sentence).

(6) …A…B…

However, this way of testing the predictive nature of the parser has a caveat. The processing facilitation observed at B in (6) can alternatively be explained as a ease of integration of B into the structure due to the presence of A, while the parser remains unpredictive. To control for this alternative explanation, we can employ an "ACB" configuration.

Consider a sentence configuration as shown below in (7), where A, B, and C all represent some types of syntactic element. Assume that there is a causal relation between the existence of A and B in a single sentence: the occurrence of A leads to the more likely occurrence of B. Further assume the same relation between B and C: the occurrence of B leads to the more likely occurrence of C. In other words, the occurrence of B suggests the presence of the C. Since A and B are not linearly close to each other, the prediction of the C element would in turn suggests that B is predicted based on A. Importantly, since there is no direct relationship between A and C, it is unlikely that the presence of A facilitates the integration of C into the structure. Therefore, the caveat of the "AB" configuration discussed above is controlled for.

(7) ….A…C…B…

The passive construction in English provides us with an "ACB" configuration shown in (7)[3]. In English passive sentences, the external argument DP in the D-structure can be expressed as part of a *by*-phrase (Baker, Johnson and Roberts 1989, Chomsky 1977, 1981, Marantz 1984). When the agent DP is a *wh*-element (e.g., in a relative clause construction where the agent DP relativized), either the *wh*-element undergoes wh-movement and strands *by*, or the entire *by*-phrase can be pied-piped together (Jaeggli 1986, Lasnik 1988). Under the latter scenario, the pied-piped *by*-phrase would precede the rest of the passivized clause. Returning to the "ACB" configuration, the pied-piped *by*-phrase would constitute the "A" component, foreshadowing the upcoming passivized verb which

[3] Using the "ACB configuration" to tease apart expectation-related and integration-related processing costs has been employed in various previous sentence processing studies. Please refer to the following references to justify our use of the "ACB configuration" experimental design (Kazanina 2017, Phillips 2006, Sloggett and Yoshida 2019, Yoshida 2006).

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constitutes the “B” component. Furthermore, the subject projected by passivized verbs usually bear the theme thematic role, and is thus more likely to be an inanimate DP (Ferreira 1994, Fredriksson 2016). Thus, passivized verbs lead to the more likely occurrence of inanimate subjects, which constitute the “C” component in an “ACB” configuration.

Now let us look at the time-course of the processing of (8), which constitutes such “ACB” configuration. In (8a), *by whom* is the pied-piped *by*-phrase with the wh-element. If the parser builds the structure predictively, the parser will anticipate the upcoming verb to be passivized. The subject projected by passivized verbs are known to bear the patient thematic roles, which is less marked being inanimate compared to agents (Dowty 1991, Grimshaw 1990, Jackendoff 1990). The expectation for a passive verb would in turn lead to the increased expectation for an inanimate subject (Ferreira 1994, Fredriksson 2016). Hence, when the inanimate subject (*the case for a doll*) is encountered, it would have already been anticipated by the parser. In comparison, when pied-piping doesn’t happen, as shown in (8b), the fronted *who* does not trigger the predictions for a passive VP. As a result, there would be no increase in the expectation for an inanimate subject. When the inanimate subject (*the case for a doll*) is encountered by the parser in (8b), greater reading disruption is predicted compared to (8a).

(8) a. John met the carpenter by whom the case for a doll was made at the party.
b. John met the carpenter who the case for a doll was made by at the party.

Crucially, there is no direct association between *by whom* and an inanimate subject inside the relative clause and thus the lower processing cost of the inanimate subject in the embedded clause (reflected by faster reading time) cannot be simply regarded as the result of facilitation caused by the integration of the inanimate subject into the structure.

2. Experiment

2.1 Experiment

In this experiment, we directly test the reading time-course for passive relative clauses with inanimate subjects using a self-paced reading paradigm (as shown earlier in (8)). This type of sentences, as discussed in the previous section, provides an “ACB” configuration for us to test if predictive processing is employed by the readers in the filler-gap dependencies. It is predicted that after reading a pied-piped *by*-phrase containing a wh-element (the “A” element in the “ACB” configuration), the readers would have higher expectation for a passive embedded verb (the “B” element in the “ACB” configuration), which in turn predicts the existence of an inanimate subject DP (the “C” element in the “ACB” configuration). As a result, the processing of the inanimate relative clause subject is facilitated in sentences with pied-piped *by*-phrase compared to sentences with only the wh-element fronted. This should be reflected by a reading time difference at the inanimate relative clause subject position.

2.1.1 Participants

Participants were 94 native speakers of English with no language or reading disorders, and were recruited from Prolific Academics online platform (https://prolific.co/). We employed a screening process that is standard in online linguistic experiments using crowdsourcing platforms (e.g., MTurk, Prolific, etc.); participants had to meet

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the following criteria: (i) their self-reported first language must be English (ii) their IP-address should be in the United States and (iii) they should have no reading or language-related disorders. If they had not met any of the criterions stated above, they were not eligible to participate in the study. Furthermore, after the completion of the experiment, they were instructed to follow the link, and provide the code number in order to make sure they have successfully completed the experiment.

Participants took part in this experiment online via a link deployed on the IbexFarm, which is the web-based presentation platform for experiments (Drummond 2013). All participants provided informed consent and received compensation of approximately $4 for the completion of the experiment. The experiment took around 20 minutes.

2.1.2 Materials and Procedure

The first test condition, shown below as (9a), involves a passive relative clause with pied-piped *by*-phrase. The second test condition, shown below as (9b), involves a passive relative clause with stranded *by*. To control for any potential contrast between relative clauses with P-stranding and Pied-piping that is not the result of predictive processing triggered by a fronted *by*-phrase, we include two control conditions as shown in (9c) and (9d). In the control conditions, the wh-element is embedded in a PP, but the P head is *for* rather than *by*. The embedded subject within the relative clause was always inanimate (e.g., *the interesting case*) and was followed by the PP (e.g., *for a doll*) where the effects are likely to surface in resulting from the nature of the self-paced reading experiment mode (Vasishth and Lewis 2006). Overall, we have a 2X2 within-subjects design with two factors: Movement Type (Pied-piping vs. P-stranding) and PP Type (*by*-phrase vs. *for*-phrase)[4].

(9) a. John met the carpenter **by whom** the interesting case for a doll was made at the dinner party.
[Pied-piping, *by*-phrase]
b. John met the carpenter **who** the interesting case for a doll was made **by** at the dinner party.
[P-stranding, *by*-phrase]
c. John met the carpenter **for whom** the interesting case for a doll was made at the dinner party.
[Pied-piping, *for*-phrase]
d. John met the carpenter **who** the interesting case for a doll was made **for** at the dinner party.
[P-stranding, *for*-phrase]

The experimental stimuli were distributed across four different lists following Latin Square counterbalancing methodology. In each list, a total of 64 fillers were combined with the critical conditions in a pseudo-randomized manner, in such a manner that the critical experimental items were not adjacent to each other. None of the filler sentences contained manipulations relevant to the current experiment items.

[4] An anonymous reviewer suggested using *to*-phrase and *of*-phrase as a good baseline as well. Furthermore, as noted by an anonymous reviewer, the investigation of the corpus studies might be helpful. But for the current purpose, we think the (offline) acceptability rating experiment by native speakers would suffice to state that the sentences with *by whom* and *for whom* were rated similarly (at least their judgment given ample time to reflect on the sentences).

We believe that acceptability judgment data (with which we provide below along with the online processing data) provides a better and more direct measurement of construction markedness than corpus distribution. There are cases where a grammatically marked construction may have high corpus frequency (e.g., English sentences with resumptive pronouns, see Ferreira and Swets (2005)), and there are also cases where a grammatically well-formed and perfectly acceptable construction have low corpus frequency (e.g., parasitic gaps). To avoid such confounds, we believe that it is better to directly probe the acceptability of test sentences in norming studies

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The experiment was deployed on the IbexFarm online platform designed for web-based experiments (Drummond 2013). Participants took part in the experiment remotely on their own laptops by clicking the link distributed to them. The standard word-by-word moving window self-paced reading design was employed: sentences were masked by dashed lines on the display, and the parts of the sentences were unmasked one-by-one as the participant pressed the spacebar. The reading time at each region is recorded. A comprehension question was asked after each sentence. Comprehension questions were designed to ask various parts within the sentence, and an example of a comprehension questions was “Was the prize given at the party?”. Participants were instructed to answer the comprehension questions as accurately as they can by pressing the F-key and J-key that signal “Yes” and “No” respectively, and were immediately notified if their answers were inaccurate. The average mean accuracy for the comprehension questions in experimental items was 82%.

2.1.3 Prediction

There are two critical regions of interest; the first critical region is the embedded subject of the relative clause (*an interesting case*), and the second critical region is the passivized verb (*was made (by/for)*). At the first critical region, we predict facilitation effects only at the [Pied-Piping, *by*-phrase] conditions, but not in [P-stranding, *by*-phrase] conditions. If readers predict the passive structure based on the [Pied-Piping, *by*-phrase] filler in advance of the confirmatory bottom-up input that supports the passivized verb (e.g., *was made*), we expect to observe faster reading times for [Pied-Piping, *by*-phrase] filler followed by inanimate embedded subject compared to *who* filler. But no comparable differences should be detected between [Pied-Piping, *for*-phrase] and [P-stranding, *for*-phrase] conditions[5]. At the second critical region (at the passivized verb), we expect the [Pied-Piping, *by*-phrase] sentences to be read significantly faster than the [P-stranding, *by*-phrase] sentence[6].

2.1.4 Analysis

A linear mixed effects regression model (Baayen et al. 2008) using the lme4 package in R version 3.2.3 was employed to analyze the results. All models involved the maximal random effects structure (Baayen 2008, Baayen

[5] An anonymous reviewer suggested that the fronted *for who* phrase could lead to non-trivial predictions about the type of verb that follows. A pied-piped *for*-phrase could suggest that the following embedding verb needs to have a particular argument structure that is compatible with a *for*-phrase argument (e.g., a beneficent argument). However, as far as we know, such verbs, unlike passive verbs, do not have an inanimate subject bias. Therefore, we believe that the choice of *for whom* condition as a control condition is warranted.

[6] We ran an acceptability rating experiment on 16 participants (refer to Mahowald, Graff, Hartman and Gibson 2016, and Sprouse and Almeida 2017 for the justification of the small number of participants for the well-controlled acceptability rating experiment) who were undergraduate students at Northwestern University. They participated in the study in exchange for course credit and participated in the sound-proof lab. They were instructed to read the sentences presented on a desktop PC using Linger software (Rohde 2003) and rate the sentence from 1 to 7 based on the naturalness (1 indicating totally unacceptable, and 7 totally acceptable). The mean ratings were [Pied-piping, *by*-phrase] :4.30 (SE = 0.16), [P-stranding, *by*-phrase]: 4.04 (SE = 0.14), [Pied-piping, *for*-phrase]: 4.53 (SE = 0.16), and [P-stranding, *for*-phrase]: 3.81 (SE = 0.15) where all the conditions were judged to be higher than 3.5. Statistical analyses of the linear mixed effect models revealed a main effect of *Movement Type* (Estimate: 0.47, SE = 0.13, t = 3.69) and an interaction between *Movement Type* and *PP Type* (Estimate: -0.53, SE = 0.26, t = -2.06). But crucially, the pair-wise comparison revealed no main effect of *Movement Type* between [Pied-piping, *by*-phrase] and [P-stranding, *by*-phrase] conditions (Estimate: 0.22, SE = 0.19, t = 1.17). The norming acceptability rating study revealed no differences between the two conditions in the *by*-phrase, suggesting they were read similarly.

For the current purpose, we believe the acceptability rating experiment would suffice. But we leave rigorous corpus study investigation on the Pied-Piping and P-stranding depending on different kinds of preposition types for the future research.

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Davidson and Bates 2008, Bates, Maechler, Bolker and Walker 2014, Jaeger 2008). For every model, it included sum-coded fixed effects of *Movement Type* (Pied-piping vs. P-stranding) and *PP Type* (*by*-phrase vs. *for*-phrase), and their interaction. All models involved the maximal random effects structure, which includes by-item and by-participant random intercepts and slopes for both fixed effects and their interaction in cases where it converged (Barr, Levy, Scheepers and Tily 2013). In cases where the model did not converge, the random effects with the least variance were removed in a stepwise manner (Arnett and Wagers 2017, Kim, Brehm, Sturt and Yoshida 2020, among many others). Statistical analyses were carried out on log-transformed reading times for each region for the sake of normality assumptions without the necessity to implement residualization to control for the word length (Box and Cox 1964). Participants whose comprehension accuracy was above 50% were included (resulting in the exclusion of seven participants out of 104 participants), yielding total 94 participants[7]. Reading times read extremely fast and slow (faster than 3000ms and slower than 80ms) were excluded prior to the analysis, following previous studies (e.g., Arnett and Wagers 2017).

2.1.5 Results

Average word-by-word log-transformed reading times for all four conditions are plotted in Figure 1. At the first critical region (embedded inanimate subject: *the interesting case*), there were no main effects as well as an interaction between *Movement Type* X *PP Type*. At the spillover region right after the embedded inanimate subject, there was a main effect of *Movement Type* such that pied-piping sentences were read significantly faster than the p-stranding sentences (Estimate: –0.04, SE = 0.02, t = -2.63). Further subset analysis revealed that there was a significant difference between the [Pied-piping, *by*-phrase] condition and the [P-stranding, *by*-phrase] condition: the former was read significantly faster at the embedded inanimate subject region than the latter (Estimate: -0.05, SE = 0.02, t = -2.01). Critically, no such difference was observed between the [Pied-piping, *for*-phrase] condition and the and the [P-stranding, *for*-phrase] condition at the first critical region (Estimate: -0.04, SE = 0.02, t = -1.65). Furthermore, the subset analysis revealed that there was no main effect of PP Type regardless of the *Movement Type*, both in Pied-Piping construction (Estimate: -0.03, SE = 0.02, t = -0.96) as well as in P-stranding construction (Estimate: -0.01, SE = 0.02, t = -0.46).

At the second critical region (*was made by/for*), there was a main effect of *Movement Type* such that such that pied-piping sentences were read significantly faster than the p-stranding sentences (Estimate: -6.10, SE = 0.02, t = -6.36). Further subset analysis revealed that there was a significant difference between the [Pied-piping, *by*-phrase] condition and the [P-stranding, *by*-phrase] condition: the former was read significantly faster than the latter at the second critical region (Estimate: -0.08, SE = 0.02, t = -3.65). The subset analysis also revealed that there was a significant difference between [Pied-piping, *for*-phrase] condition and [P-stranding, *for*-phrase] condition was also observed such that the former is read significantly faster than the latter (Estimate: -0.13, SE = 0.02, t = -5.27).

At the spillover region of the second critical region, there was a main effect of *Movement Type* (Estimate: -0.06, SE = 0.01, t = -4.49). Importantly, there was a significant difference between the [Pied-piping, *by*-phrase] condition and the [P-stranding, *by*-phrase] condition such that the former is read faster than the latter (Estimate: -0.07, SE = 0.02, t = -4.04). There was also a significant difference between the [Pied-piping, *for*-phrase] condition and the [P-stranding, *for*-phrase] such that the former is read faster than the latter (Estimate: -0.05, SE = 0.03, t = -2.33).

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[7] The mean accuracy prior to the exclusion was 80%.

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Table 1. Summary of Fixed Effects from the Linear Mixed Effects Model

	Estimate	SE	t	p-value
Critical Region (*the interesting case*)				
Intercept	6.54	0.05	119.39	**<0.001*** **
Movement Type	-0.02	0.02	-0.88	>0.05
PP Type	-0.01	0.02	-0.30	>0.05
Movement Type X *PP Type*	0.04	0.04	0.89	>0.05
Spillover region after the Critical Region (*for*)				
Intercept	6.27	0.03	225.64	**<0.001*** **
Movement Type	-0.04	0.02	-2.63	**<0.05***
PP Type	-0.02	0.02	-0.93	>0.05
Movement Type X *PP Type*	-0.01	0.03	-0.29	>0.05
Second Critical Region (*was made by/for*)				
Intercept	6.28	0.04	143.63	**<0.001*** **
Movement Type	-0.10	0.02	-6.36	**<0.001*** **
PP Type	-0.03	0.02	-1.72	>0.05
Movement Type X *PP Type*	0.05	0.03	1.48	>0.05
Spillover region after the Second Critical Region (*at*)				
Intercept	6.13	0.03	212.06	**<0.001*** **
Movement Type	-0.06	0.01	-4.48	**<0.001*** **
PP Type	-0.02	0.01	-1.52	>0.05
Movement Type X *PP Type*	-0.02	0.03	-0.89	>0.05

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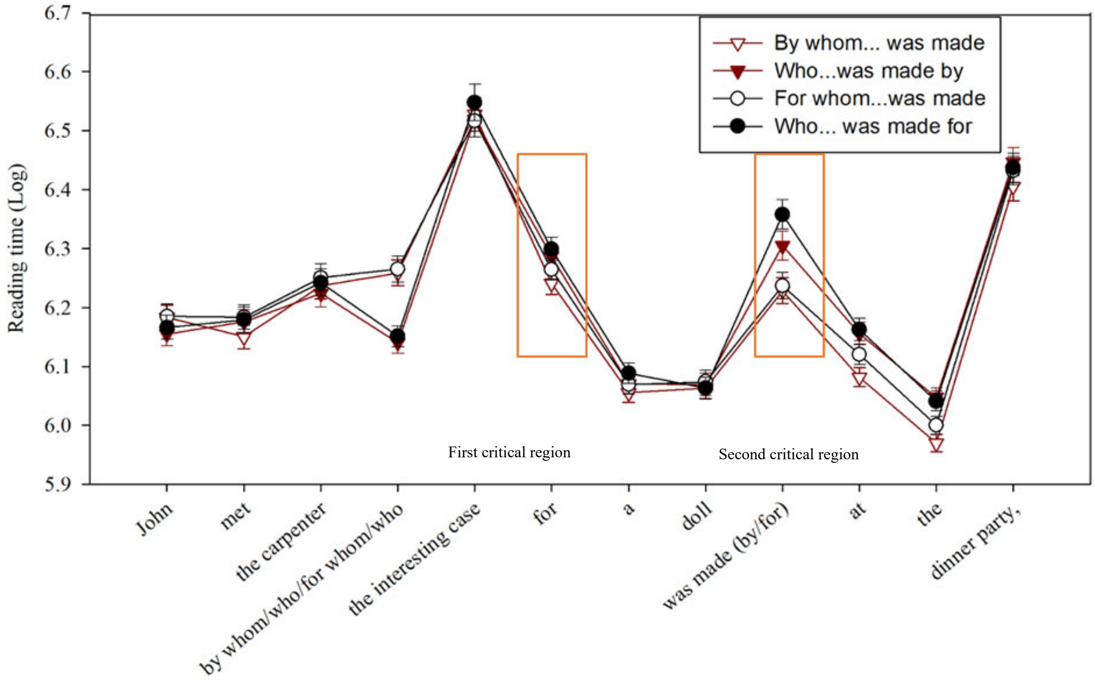

Figure 1. Average Word-by-Word Reading Times for Each Region (Error Bars Represent the Standard Error.)

3. Discussion

The goal of this study is to examine whether readers engage in predictive processing (i.e., whether they postulate future syntactic items or structures beyond what has been encountered). Specifically, we tested the processing of passive relative clauses with the relativized elements originating in *by*-phrases. Based on the hypothesis that people engage in predictive processing, the pied-piped *by*-phrases should lead to readers' expectation for a passive verb, which in turn leads to a higher expectation for an inanimate relative clause subject. In comparison, when only the wh-element *who* is fronted and *by* is stranded, the fronted wh-element should not lead to increased expectation for a passive verb. As a result, the expectation for a passive verb should be lower when *by* is stranded compared to when *by*-phrase is pied-piped. More importantly, readers' expectation for inanimate embedded subjects would also be lower when *by* is stranded compared to when *by*-phrase is pied-piped, given that inanimate subject is known to be marked in active but not passive environments (Ferreira 1994, Fredriksson 2016). These contrasts should be reflected by processing facilitations at the passivized verb position and the inanimate subject position when the *by*-phrase is pied-piped compared to when *by* is stranded.

Based on the reading time results, we see that at the passivized verb position (the second critical region as well as the spillover region right after the second critical region in our design: *was made by/for* and *at*), the [Pied-piping, *by*-phrase] condition was read faster than the [P-stranding, *by*-phrase] condition as expected. However, as explained in earlier sections, since there is a direct dependency relation between the *by*-phrase and the passivized verb, the processing facilitation at the passivized verb could be the result of a lower integration cost (Gibson 1998,

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2000, Grodner and Gibson 2005, Keine 2020, Warren and Gibson 2002). That is, the fronted *by*-phrase facilitates the integration of the verb into the structure. This alternative explanation does not require the parser to be predictive.

Moving on to the comparison at the inanimate subject position (the spillover region right after the first critical region in our design; *for*). We observed that the [Pied-piping, *by*-phrase] condition was read faster than the [P-stranding, *by*-phrase] condition at this position. This comparison utilizes the "ACB" configuration which can control for potential confounds introduced by differences in structural integration costs (Gibson 1998, 2000, Grodner and Gibson 2005, Keine 2020, Warren and Gibson 2002). Since there is no direct syntactic relation between the fronted *by*-phrase and the inanimate subject, the faster reading time at the inanimate subject cannot be the result of the *by*-phrase facilitating the integration of the subject DP into the structure. Rather, the faster reading time supports our hypothesis that the readers postulate the passive verb as soon as they encounter the fronted *by*-phrase, and the passive verb leads to the processing facilitation at the inanimate subject. This adds further support to the parsers' ability to predictively build detailed syntactic structure in advance of unequivocal confirmatory input (Phillips 2006, Staub and Clifton 2006, Wagers and Phillips 2009, Yoshida, Dickey and Sturt 2013).

An anonymous reviewer asked whether the processing difficulty caused by *who* can be explained in terms of *who* being frequently predicted as a subject. Upon realizing that *who* is the object (instead of the predicted subject), the concomitant reanalysis can occur (Lee 2004, Staub 2007). But if this is the case, we would expect to see a contrast between [Pied-piping, *for*-phrase] and [P-stranding, *for*-phrase] conditions at the first critical region (embedded subject position) and at the spillover region of the first critical region: the lone wh-element *who* is subject-biased and thus leads to processing difficulty in the embedded subject position, which is not present in the when the entire PP *for who* is pied-piped. However, we do not see such an effect (Estimate: -0.04, SE = 0.02, t = -1.65). The reading time contrast between Pied-piping condition and P-stranding condition at the embedded subject position is only present when the pied-piped wh-PP is a *by*-phrase.

Furthermore, at the spillover region right after the first critical region (*for*), there was no significant difference between the [Pied-piping, *for*-phrase] control condition and the [P-stranding, *for*-phrase] control condition. This suggests that the contrast between the [Pied-piping, *by*-phrase] and the [P-stranding, *by*-phrase] conditions is specific to *by*-phrases rather than general to pied-piping. This is consistent with our hypothesis that the fronted *by* prompts the readers to predictively postulate a passive structure[8].

There is, however, a contrast between the two *for*-phrase control conditions at the passive verb position (the second critical region in our design): the [Pied-piping, *for*-phrase] condition was read faster than the [P-stranding, *for*-phrase] condition. This contrast could be the result of a difference in the structural integration cost for the verb: although the fronted *for*-phrase does not lead the readers to postulate a passive verb, it somehow facilitates the integration of the passive verb into the current structure once it is encountered (Gibson 1998, 2000, Grodner and Gibson 2005, Keine 2020, Warren and Gibson 2002)[9].

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[8] If the different corpus frequency of *by whom* and *for whom* leads to processing cost difference, such difference should show up in reading time of the fronted wh-phrase region. However, we observed differences between the two conditions in the embedded inanimate subject position. Such effect cannot be reduced to merely the lexical frequency difference between the two wh-phrases, but rather suggests that the two different types of fronted wh-phrases lead to different predictions of how likely the embedded subject is inanimate. We leave rigorous corpus study investigation on the Pied-Piping and P-stranding with regard to different kinds of preposition types for the future research.

[9] An anonymous reviewer asked whether this is because the Pied-Piping constructions are more marked relative to the P-stranding ones. But if the participants consider the pied-piping version as the marked version in comparison with the p-stranding

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Another possibility is that the fronted *for*-phrase results in an increased expectation in verbs with argument structure frames that are compatible with a *for*-phrase. This would lead the readers to predictively postulate such verb frames when encountering a pied-piped *for*-phrase, resulting in the processing facilitation at the verb position. Crucially, since verbs with argument structure frames compatible *for*-phrases are not necessarily passive verbs, encountering a *for*-phrase would not lead to higher expectation for inanimate subjects.

Note that in our experiment, the second critical region represents the "B" component in an "ACB" configuration. Processing cost at the "B" component is confounded by potential integration facilitation due to the previous encounter with "A", which is exactly why we need to examine the "C" component rather than the "B" to isolate prediction-induced facilitation from integration facilitation. In contrast, the first critical region (embedded subject position) represents the "C" component in the "ACB" configuration. At this region, there is no effect in the for-phrase control comparison, but a significant difference between the *by*-phrase conditions. This further confirms that the effect at the second critical region is confounded by potential integration facilitation.

In conclusion, using a self-paced reading experiment, this study provides evidence for predictive processing by examining the processing of passive relative clauses with pied-piped *by*-phrases. We found evidence that the processing of inanimate embedded subjects is facilitated after encountering *by*-phrases, an effect that can only be attributed to predictive processing rather than integration facilitation. Overall, this study provides further evidence that readers engage in a predictive structure-building processes ahead of encountering unequivocal bottom-up input (Phillips 2006, Staub and Clifton 2006, Wagers and Phillips 2009, Yoshida, Dickey and Sturt 2013).

4. Conclusion

Using a self-paced reading experiment, this study examines the processing of passive relative clauses with the relativized element originating in *by*-phrases. We found evidence that readers predictively postulate passive verbs as soon as they encounter the fronted *by*-phrases. This process does not happen when only the wh-element is fronted and *by* is stranded. We also showed that structure integration facilitation (Gibson 1998, 2000, Grodner and Gibson 2005, Keine 2020, Warren and Gibson 2002) cannot explain such contrast. Overall, this study provides further evidence that readers engage in a predictive real-time processing ahead of encountering unequivocal bottom-up input (Phillips 2006, Staub and Clifton 2006, Wagers and Phillips 2009, Yoshida, Dickey and Sturt 2013).

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condition, the former should be read slower than the latter, which is the reversed direction of the effect mentioned by the reviewer. This suggests that the effect cannot be reduced to the markedness of pied-piping.

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

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