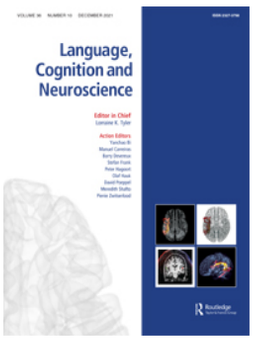
On the parsing of garden-path sentences



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On the parsing of garden-path sentences

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ABSTRACT

Previous studies have reported that temporarily ambiguous sentences sometimes cause reading disruption (garden-path effects). These studies have interpreted their finding as indicating that the human sentence processing device (the processor) initially assigns incorrect structures and subsequently attempts revision. That is a logical interpretation. However, no previous studies have demonstrated evidence of a causal relationship between garden-path effects and initial misanalysis. Besides, there is currently limited evidence regarding whether the processor conducts revision. The present study reports two self-paced reading experiments that investigated these fundamental issues about garden-path effects. Experiment 1 demonstrated that the processor initially misanalyses temporarily ambiguous sentences and consequently encounters garden-path effects and persists with initial misinterpretations. Experiment 2 similarly observed garden-path effects. Additionally, there was evidence that the processor constructs globally correct structures during revision. These findings provide evidence that garden-path effects result from initial misanalysis, and the processor conducts revision upon disambiguation.

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Garden-path effect; revision process; incremental processing; lingering misinterpretation; complement ambiguity

Introduction

In processing temporarily ambiguous sentences, the human sentence processing device (the processor) sometimes encounters reading difficulty (garden-path effects). For example, consider sentence (1) below.

(1) Mary saw the girl drank some water.

In (1), "the girl" is a temporary ambiguous phrase, as at this point, the processor can analyse it as either the complement of "saw" (Mary saw the girl) or the subordinate clause subject with a null complementiser (Mary saw ~~that~~ the girl …). The ambiguity disambiguates towards the latter structure at "drank". However, previous studies have demonstrated that garden-path effects occur at the disambiguating region (e.g. Ferreira & Henderson, 1990; Frazier & Rayner, 1982; Garnsey et al., 1997; Trueswell et al., 1993). Based on the assumption that processing costs increase when the processor has difficulty integrating an input word into the current structure, the previous studies interpreted their finding as indicating that the processor initially misanalyses the temporarily ambiguous phrase. That is a logical interpretation. However, to corroborate the interpretation, it is necessary to demonstrate a causal relationship between garden-path effects and initial misanalysis, given that garden-path effects are not direct evidence of initial misanalysis but an assumed side effect. Nonetheless, there is currently no evidence that garden-path effects result from initial misanalysis. Without such evidence, we cannot potentially exclude the possibility that garden-path effects result from other mechanisms. For example, in (1), the processing of "the girl" might be delayed until the disambiguating region, and reading difficulty might occur at "drank" because of the processor attempting to analyse "the girl" as both the direct object and the subject simultaneously due to both analyses being locally available (e.g. Tabor et al., 2004). Of course, such a processing mechanism is unlikely, given that it is against the current theory of sentence processing that the processor predictively constructs structures during sentence processing (Phillips, 2006; Staub & Clifton, 2006; Yoshida et al., 2013). However, to deny this unlikely possibility and assert that garden-path effects result from initial misanalysis, we need to provide evidence that in complement sentences as in (1), the processor incrementally analyses the temporarily ambiguous phrase as the direct object of the main clause verb. Experiment 1 of the present study addresses this issue by directly investigating the

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representation that the processor creates at the temporarily ambiguous phrase.

Another issue that the present study investigates is whether the processor conducts revision[1] during sentence processing.[2] A central assumption in the study of garden-path effects had been that upon disambiguation, the processor constructs globally correct structures. However, this assumption has been questioned by previous studies which have reported that the processor often persists with misinterpretations after disambiguation (Christianson et al., 2001, 2006; Cunnings & Fujita, 2020; Fujita & Cunnings, 2020, 2021a, 2021b; Slattery et al., 2013; Sturt, 2007; van Gompel et al., 2006). For example, in Christianson et al. (2001), participants read sentences with a subject-object ambiguity such as "While Mary dressed the girl drank some water", where "the girl" must be analysed as the main clause subject but is assumed to be initially misanalysed as the complement of "dressed". After reading such temporarily ambiguous sentences, participants answered questions referring to misinterpretations like "Did Mary dress the girl?". The correct response to this question is "no", as "Mary dressed herself", not "the girl". However, Christianson et al. observed many "yes" responses. This finding indicates that misinterpretations linger after the end of the sentence, which potentially casts doubt on the assumption that the processor conducts revision upon disambiguation. To investigate this issue, Slattery et al. (2013) recently tested sentences as in (2a/b).

(2a) After the bank manager telephoned(,) **David's father** grew worried and gave **himself** approximately five days to reply.

(2b) After the bank manager telephoned(,) **David's mother** grew worried and gave **himself** approximately five days to reply.

(2a/b) are temporarily ambiguous when the comma after "telephoned" is absent but unambiguous when it is present. (2a/b) contain a reflexive pronoun "himself" in the main clause. According to the principles-and-parameters theory (Chomsky, 1981), a reflexive pronoun in English is referentially dependent on a nominal expression in a local domain. In (2a/b), "himself" must co-refer with the main clause subject "David's father/mother" because "David's father/mother" c-commands "himself" (e.g. neither "David's father/mother" nor "himself" dominates the other and the mother node of "David's father/mother" (= TP) dominates "himself"), and "David's father/mother" and "himself" are in the same local domain (e.g. "David's father/mother", "himself" and its governor are in the same minimal TP; e.g. [$_{TP}$ David's father/mother [$_{T'}$ T [$_{VP}$ [$_{VP}$ grew worried] [$_{ConjP}$ and [$_{VP}$ gave [$_{PRN}$ himself]]]]]]). The antecedent either matches (2a) or mismatches (2b) the gender of the reflexive ("David's father/mother … himself"). In the unambiguous conditions, such a gender manipulation should cause longer reading times at the reflexive in gender mismatch (2b) than gender match (2a) sentences due to gender mismatch effects (Sturt, 2003). In the ambiguous conditions, if the processor revises the temporarily ambiguous phrase as the main clause subject,[3] similar gender mismatch effects should arise. However, if revision fails, that is, if the temporarily ambiguous phrase remains in the subordinate clause after disambiguation, gender mismatch effects may be absent. The reason is that the subordinate clause is outside of the reflexive's binding domain and thus does not allow "David's father/mother" to be the grammatical antecedent for the reflexive ([$_{CP}$ [$_{CP}$ After [$_{TP}$ the bank manager [$_{T'}$ T [$_{VP}$ telephoned [$_{DP}$ David's father/mother]]]]] [$_{C'}$ C [$_{TP}$ ø [$_{T'}$ T [$_{VP}$ [$_{VP}$ grew worried] [$_{ConjP}$ and [$_{VP}$ gave [$_{PRN}$ himself]]]]]]]]). In an eye-movement while reading task, Slattery et al. observed similar gender mismatch effects at the reflexive between the ambiguous and unambiguous conditions and interpreted their result as indicating that upon disambiguation, the processor constructs structures compatible with the correct interpretation of the sentence as a whole (see also Fujita & Cunnings, 2021b, which replicated the result of Slattery et al.).

The result of Slattery et al. (2013) makes a significant contribution to the theory of revision. However, it does not necessarily indicate that the processor conducts revision. For example, when encountering the disambiguating region in (2), the processor may fail to locate the main clause subject. As predicted by Slattery et al., one way to deal with this revision failure is to analyse the main clause without its subject ("After the bank manager telephoned David's father, ø grew worried and gave himself approximately five days to reply"). However, such a null-subject analysis is ungrammatical in English, and thus, the processor may avoid it. Another way for the processor to deal with the revision failure is to analyse a local nominal as the main clause subject in conformity with its general preference for local attachment (Frazier, 1979; Kimball, 1973; Sturt et al., 2002). In (2), the nominal that is closest to the disambiguating region is "David's father/mother", the grammatical main clause subject (After the bank manager telephoned(,) David's father/mother$_{[\text{temporarily ambiguous phrase}]}$ grew$_{[\text{disambiguating region}]}$ …). In this case, although revision technically fails, gender mismatch effects should arise. Fodor and Inoue (1998) similarly argued that in temporarily ambiguous sentences such as "While Mary visited the mother of John had lunch", revision fails but the processor may analyse the local

nominal "John" as the main clause subject. The present study explores this possibility, using temporarily ambiguous complement sentences as in (1). Note that Fodor and Inoue claimed that their revision approach described above applies to subject-object ambiguities but not complement ambiguities. However, the present study examined complement ambiguities for the reasons that a similar revision mechanism may operate in complement ambiguities and research on revision is limited to subject-object ambiguities (Fujita & Cunnings, 2021b; Slattery et al., 2013).

The present study

Below, I report two self-paced reading experiments that examined the mechanism underlying garden-path effects. Previous studies have demonstrated that garden-path effects occur during the processing of temporarily ambiguous sentences. However, none of them has provided evidence that garden-path effects result from initial misanalysis. Experiment 1 addressed this issue by examining the representation created at the temporarily ambiguous phrase of complement sentences. Experiment 1 also investigated whether initial misanalysis is the source of lingering misinterpretations. Previous studies have also demonstrated that the processor attempts revision during sentence processing. However, the results of these studies do not necessarily indicate that the processor conducts revision. Also, the current evidence for revision is limited to subject-object ambiguities. To address these issues, Experiment 2 investigated whether the processor constructs globally correct structures during revision by using a research design similar to the one used in Slattery et al. (2013) and testing complement ambiguities.

Experiment 1

Experiment 1 investigated whether the processor initially misanalyses temporarily ambiguous sentences and whether the initial misanalysis results in garden-path effects and lingering misinterpretations, using sentences as in (3a–d) and comprehension questions.

(3a) *Ambiguous, Gender match*

John saw the boy after washing himself in the bathroom took some time to rest from studying.

(3b) *Ambiguous, Gender mismatch*

John saw the girl after washing himself in the bathroom took some time to rest from studying.

(3c) Unambiguous, Gender match

John saw that the boy after washing himself in the bathroom took some time to rest from studying.

(3d) *Unambiguous, Gender mismatch*

John saw that the girl after washing himself in the bathroom took some time to rest from studying.

Question: Did John wash in the bathroom?
Regions: John saw (that) | the boy/girl | after washing | himself | in the bathroom | took | some time to rest | from studying.

(3a/b) are temporarily ambiguous sentences while (3c/d) are unambiguous sentences due to the absence or presence of the complementiser "that". In (3a–d), a temporal adjunct control containing a phonetically null anaphoric subject ("after PRO washing") and reflexive ("himself") modifies the subordinate clause. Syntactically, the PRO subject is bound by the subject of the predicate that the temporal adjunct control modifies (Kwon & Sturt, 2014; Parker et al., 2015; Williams, 1992), and a reflexive co-refers with an antecedent within its binding domain (Chomsky, 1981). Thus, in (3a/b), the PRO subject and reflexive's antecedent should be controlled by the subordinate clause subject ("John$_i$ saw (that) the boy/girl$_j$ after PRO$_{*i/j}$ washing himself$_{*i/j}$ took some time to rest from studying"). In (3a/c), the subordinate clause subject matches the reflexive's gender ("the boy … himself"), whereas in (3b/d), it does not ("the girl … himself"). The main clause subject ("John") matches the reflexive's gender across (3a–d). In the unambiguous conditions (3c/d), reading times should be longer at the reflexive in gender mismatch than gender match sentences due to gender mismatch effects (Sturt, 2003). In the ambiguous conditions (3a/b), if the processor initially misanalyses the temporarily ambiguous phrase, gender mismatch effects should be absent. The reason is that if the temporarily ambiguous phrase is misanalysed, the temporal adjunct control modifies the main clause ("John$_i$ saw the boy/girl$_j$ after PRO$_{i/*j}$ washing himself$_{i/*j}$."), and thus, the PRO subject is bound by the main clause subject ("John") that matches the reflexive's gender in both (3a) and (3b) ("John … himself"). This initial misanalysis should cause longer reading times at the disambiguating region ("took") in the ambiguous (3a/b) than unambiguous (3c/d) conditions due to garden-path effects (Frazier & Rayner, 1982).

The comprehension question refers to the initial misinterpretation. If the processor initially misanalyses the temporarily ambiguous phrase and persists with the misanalysis after disambiguation (Christianson et al., 2001), comprehension accuracy rates should be lower in the ambiguous than unambiguous conditions.

Participants

Eighty native English speakers (mean age 21; range 18–60) from the University of Reading community, participated in Experiment 1 for course credit. The participants were recruited via the SONA system managed by the University of Reading and completed the experiment online.

Materials

Experimental materials consisted of 24 sets of sentences like (3a–d) paired with comprehension questions referring to initial misinterpretations. The experiment also contained 72 filler sentences, of which 24 filler sentences consisted of object relative clauses. Half of the 24 filler sentences were ungrammatical due to the violation of subject-verb number agreement. The other 48 filler sentences were all grammatical and consisted of a variety of syntactic structures. A comprehension question followed two-thirds of the filler sentences. Experimental sentences were constructed with four counterbalanced presentation lists in a Latin square design. The full set of experimental sentences used in the present study is available at https://osf.io/aw8t3.

Procedure

The experiment was administered, using a non-cumulative, phrase-by-phrase self-paced reading task in the IbexFarm (http://spellout.net/ibexfarm). Each trial began with a series of dashes masking a whole sentence. Participants pressed the space bar to read each phrase of the sentence. After participants read the last phrase, the sentence disappeared, and either the next trial or the concomitant comprehension question appeared. When answering each comprehension question, participants pressed either the "1" key if they thought the correct answer was "yes" or the "2" key if "no". The experimental and filler sentences were pseudo-randomised to make some filler sentences appear between each experimental sentence. The experiment began with four practice trials.

Data analysis

I conducted data analysis in R (R Core Team, 2020) by fitting Bayesian linear mixed models, using the package, *brms* (Bürkner, 2017). The dependent variables were reading times for four regions and comprehension accuracy rates. The regions included the reflexive ("himself") and post-reflexive ("in the bathroom") regions to test for gender mismatch effects, and the disambiguating ("took") and post-disambiguating ("some time to rest") regions to test for garden-path effects. Reading times were reciprocally transformed following prior predictive checks. Reduced reciprocal reading times indicate an increase in raw reading times. The models fit a Gaussian distribution to reading times and a Bernoulli distribution to comprehension accuracy rates. Before data analysis, reading times shorter than 100 milliseconds or longer than 10 s were removed, which affected less than 1% of the data. The independent variables were sum-coded (-.5/.5) main effects of ambiguity (ambiguous/unambiguous), gender (gender match/gender mismatch), region (reflexive/post-reflexive region and disambiguating/post-disambiguating region) and their interactions. Random effects were accounted for by including by-subject, by-item and by-trial random intercepts and random slopes for subject and item.[4] The prior for the intercept was a normal distribution with mean 2 and standard deviation 2.5 for reading times and with mean 0 and standard deviation 2.5 for comprehension accuracy rates. The prior for the fixed effects was a normal distribution with mean 0 and standard deviation 3.5. The priors for standard deviations of the random effects and the standard deviation of the residuals were a normal distribution with mean 0 and standard deviation 2.5. Priors were also specified for the correlation of the random effects, using a so-called LKJ prior with parameter 2 (see Sorensen et al., 2016). Four sampling chains were run for each model at 4000 iterations, of which the first 2000 iterations were discarded as warm-up samples. Convergence was checked based on R-hat and visual inspection of the chains. Data and analysis code for all experiments reported in the present study is available at https://osf.io/aw8t3. Below, I report the estimated parameters with 95% credible intervals (CrI). When an interaction appeared, a follow-up analysis examined nested simple effects (Schad et al., 2020).

Results

Average comprehension accuracy rates to filler sentences were 90% (range 75–100). Raw reading times for the four regions, comprehension accuracy rates and a summary of the statistical analysis are provided in Tables 1–4. Figure 1 illustrates raw reading times for all regions.

Reflexive and post-reflexive regions

The estimate of the three-way interaction between region, ambiguity and gender was 0.121 CrI [0.001, 0.241]. A follow-up analysis which investigated gender

Table 1. Mean raw reading times in milliseconds and standard errors (SE) at four regions in Experiments 1.

	Reflexive region		Post-reflexive region		Disambiguating region		Post-disambiguating region	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Experiment 1								
Ambiguous, Gender match	652	18	729	24	676	26	622	16
Ambiguous, Gender mismatch	674	25	687	20	731	34	675	27
Unambiguous, Gender match	683	21	682	17	623	29	615	18
Unambiguous, Gender mismatch	745	30	736	22	610	14	642	22

Table 2. Mean comprehension accuracy rates and standard errors (SE) in Experiments 1.

	Comprehension accuracy	
	Mean	SE
Experiment 1		
Ambiguous, Gender match	0.33	0.022
Ambiguous, Gender mismatch	0.18	0.017
Unambiguous, Gender match	0.49	0.023
Unambiguous, Gender mismatch	0.27	0.020

mismatch effects across region and ambiguity showed that in the unambiguous conditions, reading times were longer at the post-reflexive region in gender mismatch than gender match sentences (reflexive region: Estimate = −0.005 CrI [−0.088, 0.078]; post-reflexive region: Estimate = −0.088 CrI [−0.167, −0.011]). This effect indicates gender mismatch effects. In contrast, there was no evidence of gender mismatch effects in the ambiguous conditions (reflexive region: Estimate = −0.019 CrI [−0.091, 0.054]; post-reflexive region: Estimate = 0.020 CrI [−0.065, 0.106]).[5]

Disambiguating and post-disambiguating regions

The main effect of ambiguity was −0.055 CrI [−0.098, −0.011], which shows longer reading times at the (post-)disambiguating regions in the ambiguous than unambiguous conditions. This effect indicates garden-path effects. There was also some evidence of the main effect of gender (Estimate = −0.045 CrI [−0.092, 0.002]), which shows longer reading times at the (post-)disambiguating regions in the gender mismatch than gender match conditions. This effect indicates gender mismatch effects.

Comprehension accuracy

The estimate of the main effect of ambiguity was −0.761 CrI [−1.000, −0.520], which shows lower comprehension accuracy rates in the ambiguous than unambiguous conditions. This effect indicates lingering misinterpretation. The main effect of gender was −0.983 CrI [−1.319, −0.640], which shows lower comprehension accuracy rates in the gender mismatch than gender match conditions.

Discussion

Experiment 1 observed gender mismatch effects at the post-reflexive region in the unambiguous conditions. This finding demonstrates that the subordinate clause subject binds the PRO subject of the adjunct control, a finding consistent with previous studies on the processing of temporal adjunct control constructions (Kwon & Sturt, 2014; Parker

Table 4. Summary of statistical analyses for comprehension accuracy rates in Experiment 1.

	Comprehension accuracy			
	Estimate	95% credible intervals		Rhat
Experiment 1				
Intercept	−0.990	−1.270	−0.719	1.00
Ambiguity	−0.761	−1.000	−0.520	1.00
Gender	−0.983	−1.319	−0.640	1.00
Ambiguity:Gender	0.276	−0.202	0.750	1.00

Table 3. Summary of statistical analyses for reading times in Experiment 1.

	(Post-)reflexive regions				(Post-)disambiguating regions			
	Estimate	95% credible intervals		Rhat	Estimate	95% credible intervals		Rhat
Experiment 1								
Intercept	1.794	1.687	1.904	1.01	1.935	1.820	2.051	1.01
Region	−0.023	−0.074	0.025	1.00	0.024	−0.059	0.107	1.00
Ambiguity	0.033	−0.012	0.076	1.00	−0.055	−0.098	−0.011	1.00
Gender	−0.024	−0.076	0.026	1.00	−0.045	−0.092	0.002	1.00
Region:Ambiguity	−0.004	−0.064	0.057	1.00	0.043	−0.043	0.126	1.00
Region:Gender	−0.022	−0.084	0.041	1.00	0.045	−0.019	0.107	1.00
Ambiguity:Gender	0.046	−0.055	0.145	1.00	0.000	−0.092	0.090	1.00
Region:Ambiguity:Gender	0.121	0.001	0.241	1.00	−0.012	−0.137	0.113	1.00

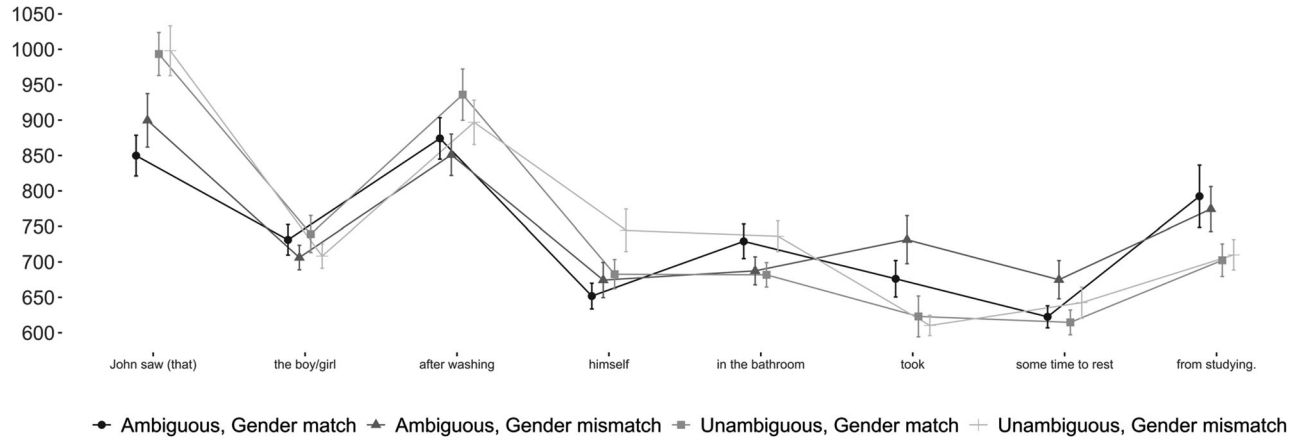

Figure 1. Raw reading times in Experiment 1. Error bars indicate standard errors.

et al., 2015). In contrast, gender mismatch effects were absent in the ambiguous conditions. The absence of gender mismatch effects indicates that participants misanalysed the temporarily ambiguous phrase as the complement of the main clause verb and consequently referred the PRO subject to the main clause subject. Experiment 1 also observed garden-path effects at the disambiguating region and lingering misinterpretation. These findings are consistent with previous studies (Christianson et al., 2001; Frazier & Rayner, 1982; Sturt, 2007) and demonstrate that garden-path effects and lingering misinterpretation result from initial misanalysis.

Interestingly, gender mismatch effects were present at the disambiguating region not only in the unambiguous conditions, which may have merely resulted from spillover effects from the post-reflexive region, but also in the ambiguous conditions. This issue is discussed in detail in the General discussion.

Below, I report Experiment 2 which investigated whether the processor conducts revision during sentence processing. As discussed in the Introduction and demonstrated by Experiment 1, temporarily ambiguous sentences cause garden-path effects. However, garden-path effects do not indicate that the processor revises temporary ambiguities. Recent studies have addressed this issue by investigating the structure that the processor creates after garden-path effects (Fujita & Cunnings, 2021b; Slattery et al., 2013). However, in the experimental sentences used in these previous studies, the disambiguating region was always adjacent to the temporarily ambiguous phrase (e.g. After the bank manager telephoned David's father/mother$_{[\text{temporarily ambiguous phrase}]}$ grew$_{[\text{disambiguating region}]}$ …). Such sentences do not necessarily provide evidence that the processor conducts revision, given that the processor may merely attempt to attach the disambiguating region to the local nominal (e.g. Fodor & Inoue, 1998). Also, the current evidence for revision is limited to subject-object ambiguities. Experiment 2 addressed these issues by testing a research design similar to the one used in Slattery et al. and complement ambiguities.

Experiment 2

Experiment 2 investigated whether the processor conducts revision, using sentences as in (4a–d).

(4a) *Ambiguous, Gender match*

The nurses noticed the mother of Maria visited the hospital to introduce herself to the doctor during lunch.

(4b) *Ambiguous, Gender mismatch*

The nurses noticed the father of Maria visited the hospital to introduce herself to the doctor during lunch.

(4c) *Unambiguous, Gender match*

The nurses noticed that the mother of Maria visited the hospital to introduce herself to the doctor during lunch.

(4d) *Unambiguous, Gender mismatch*

The nurses noticed that the father of Maria visited the hospital to introduce herself to the doctor during lunch.

Regions: The nurses noticed (that) | the mother/father | of Maria | visited | the hospital | to introduce | herself | to the doctor | during lunch.

(4a/b) are temporarily ambiguous complement sentences while (4c/d) are unambiguous sentences. (4a–b) contain a reflexive "herself" in the subordinate clause.

Table 5. Mean raw reading times in milliseconds and standard errors (SE) at four regions in Experiment 2.

	Disambiguating region		Post-disambiguating region		Reflexive region		Post-reflexive region	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Experiment 2								
Ambiguous, Gender match	588	23	591	20	470	10	502	12
Ambiguous, Gender mismatch	633	29	586	19	480	11	572	17
Unambiguous, Gender match	548	17	582	20	459	9	505	12
Unambiguous, Gender mismatch	579	20	547	15	478	11	593	18

The grammatical antecedent for the reflexive is "the mother/father" because only "the mother/father" c-commands the reflexive in its binding domain (Chomsky, 1981). The reflexive and antecedent match in gender ("the mother … herself") in (4a/c) but mismatch ("the father … herself") in (4b/d). Crucially, unlike Slattery et al., (4a–d) contain a proper noun ("Maria") between the reflexive and antecedent, which matches the reflexive's gender.

Longer reading times are expected at the disambiguating region in the ambiguous (4a/b) than unambiguous (4c/d) conditions due to garden-path effects (Frazier & Rayner, 1982). In the unambiguous conditions, reading times should be longer at the reflexive region in gender mismatch (4d) than gender match (4c) sentences due to gender mismatch effects (Sturt, 2003). In the ambiguous conditions (4a/b), if the processor revises the temporarily ambiguous phrase as the subordinate clause subject (Slattery et al., 2013), similar gender mismatch effects should arise. However, if the temporarily ambiguous phrase remains in the main clause due to a failure to conduct revision, there are two possible consequences. One is that the processor analyses the disambiguating and subsequent regions as a subordinate clause with a null subject (e.g. [$_{TP}$ The nurses [$_{T'}$ T [$_{VP}$ [$_{VP}$ noticed [$_{DP}$ the father/mother of Maria]] [$_{CP}$ [$_{C}$ ~~that~~] [$_{TP}$ ø [$_{T'}$ T [$_{VP}$ visited [$_{DP}$ the hospital …]]]]]]]]; see Slattery et al., 2013 for a similar prediction). In this case, at the reflexive region, gender mismatch effects should be absent, and the ambiguous conditions should elicit longer reading times than the unambiguous conditions due to difficulties in finding the antecedent for the reflexive. The other possible consequence is that the processor analyses the local nominal as the subordinate clause subject ([$_{TP}$ The nurses [$_{T'}$ T [$_{VP}$ [$_{VP}$ noticed [$_{DP}$ the father/mother of ~~Maria~~]] [$_{CP}$ [$_{C}$ ~~that~~] [$_{TP}$ Maria [$_{T'}$ T [$_{VP}$ visited [$_{DP}$ the hospital …]]]]]]]) following its general preference for local attachment (Fodor & Inoue, 1998; Frazier, 1979; Kimball, 1973; Sturt et al., 2002). In this case, both gender mismatch and ambiguity effects should be absent at the reflexive region, given that the local nominal ("Maria") matches the reflexive's gender in (4a–d).

Participants

Eighty native English speakers (mean age 20; range 18–43), none of whom took part in Experiment 1, participated in Experiment 2 for course credit. As in Experiment 1, the participants in Experiment 2 were recruited via the SONA system and completed the experiment online.

Materials

Experimental materials comprised 24 sets of sentences as in (4a–d). The proper noun between the reflexive and antecedent always matched the reflexive's gender. Experiment 2 contained the same filler sentences as in Experiment 1. A yes/no comprehension question followed all experimental sentences and two-thirds of the filler sentences. Following Slattery et al., none of the comprehension questions for experimental sentences queried the temporary ambiguity or the reflexive's antecedent.

Procedure and data analysis

The subordinate clause verb ("visited") and following phrase ("the hospital") were analysed as the (post-)disambiguating regions to test for garden-path effects, and the reflexive ("herself") and following phrase ("to the doctor") as the (post-)reflexive regions to test for gender mismatch effects. As comprehension questions did not examine lingering misinterpretation, I did not analyse accuracy rates. The rest of the procedure and data analysis was identical to Experiment 1.

Results

Mean comprehension accuracy rates to filler and experimental sentences were 88% (range 75–99). A summary of reading times and inferential statistics is provided in Tables 5 and 6. Figure 2 illustrates raw reading times for all regions.

Table 6. Summary of statistical analyses for reading times in Experiment 2.

	(Post-)disambiguating regions				(Post-)reflexive regions			
	Estimate	95% credible intervals		Rhat	Estimate	95% credible intervals		Rhat
Experiment 2								
Intercept	2.160	2.040	2.279	1.01	2.343	2.217	2.467	1.01
Region	0.031	−0.047	0.112	1.00	−0.154	−0.251	−0.058	1.00
Ambiguity	−0.045	−0.101	0.014	1.00	0.008	−0.047	0.062	1.00
Gender	0.001	−0.060	0.061	1.00	−0.115	−0.166	−0.064	1.00
Region:Ambiguity	−0.011	−0.090	0.068	1.00	0.049	−0.017	0.114	1.00
Region:Gender	0.062	−0.023	0.147	1.00	−0.134	−0.219	−0.049	1.00
Ambiguity:Gender	−0.017	−0.120	0.087	1.00	0.011	−0.099	0.122	1.00
Region:Ambiguity:Gender	−0.084	−0.231	0.066	1.00	0.028	−0.117	0.176	1.00

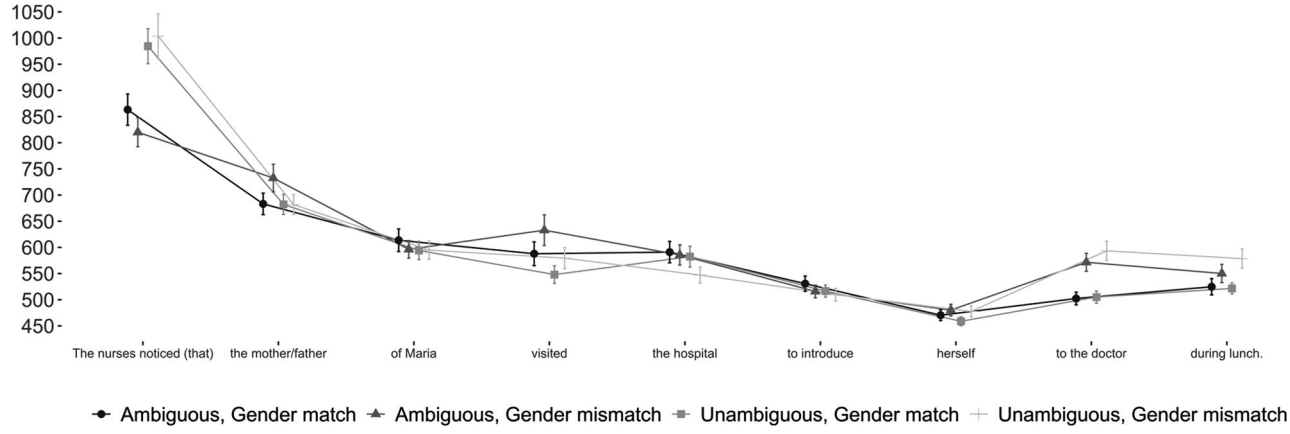

Figure 2. Raw reading times in milliseconds in Experiment 2. Error bars indicate standard errors.

Disambiguating and post-disambiguating regions

The main effect of ambiguity was −0.045 CrI [−0.101, 0.014], which suggests longer reading times at the (post-)disambiguating regions in the ambiguous than unambiguous conditions. This main effect indicates garden-path effects.

Reflexive and post-reflexive regions

The main effect of gender was −0.115 CrI [−0.166, −0.064], which shows longer reading times in the gender mismatch than gender match conditions. This main effect indicates gender mismatch effects in both ambiguous and unambiguous conditions. As the model provided evidence of the region by gender interaction (Estimate = −0.134 CrI [−0.219, −0.049]), a follow-up analysis tested gender mismatch effects for the reflexive and post-reflexive regions separately. This follow-up analysis showed larger gender mismatch effects at the post-reflexive than reflexive regions (reflexive region: Estimate = −0.048 CrI [−0.111, 0.015]; post-reflexive region: Estimate = −0.182 CrI [−0.256, −0.107]).

Discussion

Consistent with Experiment 1, Experiment 2 observed garden-path effects at the disambiguating region, which suggests that participants initially misanalysed the temporarily ambiguous phrase and attempted revision upon disambiguation. Importantly, gender mismatch effects were present at the (post-)reflexive regions in both ambiguous and unambiguous conditions. The presence of gender mismatch effects demonstrates that during revision, participants constructed globally correct structures, a finding compatible with previous studies (Fujita & Cunnings, 2021b; Slattery et al., 2013).

General discussion

The present study reported two self-paced reading experiments that investigated the mechanism underlying garden-path effects. While previous studies have assumed that garden-path effects result from initial misanalysis, none of them has corroborated this assumption. Experiment 1 is the first to provide evidence that garden-path effects occur in consequence of initial misanalysis. Experiment 1 also demonstrated that initial misanalysis is the source of lingering misinterpretations. These findings indicate that in temporarily ambiguous sentences, the processor initially constructs incorrect structures and later attempts revision but persists with initial misinterpretations after disambiguation.

Interestingly, in ambiguous sentences (e.g. "John saw the boy/girl after washing himself in the bathroom took some time to rest from studying"), although gender mismatch effects were absent at the (post-)reflexive regions ("himself in the bathroom"), they were present at the (post-)disambiguating regions ("took some time to rest"). One possible interpretation of this finding is that when the processor encounters the disambiguating region, it revises not only the temporarily ambiguous phrase ("the boy/girl") but also the attachment site of the adjunct control and syntactic relationships between the reflexive/PRO subject and their antecedent. In the following, I will illustrate this interpretation in detail. At the temporarily ambiguous region, the processor constructs the incorrect structure ("John saw the boy/girl … "). As a result, the processor analyses the temporal adjunct control as modifying the main clause and refers the PRO subject to the main clause subject ("John$_i$ saw the boy/girl$_j$ after PRO$_i$ washing … "). When encountering the reflexive, the processor co-refers it with the PRO subject. Thus, the main clause subject controls both the PRO subject and the reflexive at this point ("John$_i$ saw the boy/girl$_j$ after PRO$_i$ washing himself$_i$ … "). At the disambiguating region, if the processor conducts revision, it analyses the temporarily ambiguous phrase as the subordinate clause subject ("John$_i$ saw ~~that~~ the boy/girl$_j$ after PRO$_i$ washing himself$_i$ in the bathroom took … "). If at this point, the processor recognises that the adjunct control must modify the predicate of the subordinate clause, it attaches the adjunct control to the subordinate clause. Because the antecedent of the PRO subject depends on the clause that the adjunct control modifies, the processor also needs to revise the PRO subject as co-referential with the subordinate clause subject ("John$_i$ saw ~~that~~ the boy/girl$_j$ after PRO$_j$ washing himself$_i$ in the bathroom took … "). Now, the subordinate clause subject controls the PRO subject. Thus, the processor needs to revise the reflexive as referring to the PRO subject bound by the subordinate clause subject ("John$_i$ saw ~~that~~ the boy/girl$_j$ after PRO$_j$ washing himself$_j$ in the bathroom took … "). However, the reflexive does not match the gender of the subordinate clause subject in gender mismatch sentences ("John$_i$ saw ~~that~~ **the boy/girl$_j$** after PRO$_j$ washing **himself$_j$** in the bathroom took … "), which results in gender mismatch effects at the disambiguating region. Thus, gender mismatch effects observed at the disambiguating region potentially indicate that the processor revises the temporarily ambiguous phrase, the attachment site of the adjunct control and the reflexive-/PRO subject-antecedent relationships.

Such a revision mechanism may shed light on how the processor conducts revision. In psycholinguistics, there are broadly two accounts for how revision proceeds during sentence processing. One is that the processor conducts revision by repairing incorrect structures (e.g. Fodor & Inoue, 1994, 1998; Sturt & Crocker, 1996). The other is that revision proceeds by reprocessing (some portion of) the input (Grodner et al., 2003). According to the repaired-based account, revision involves a complicated structure-manipulating operation. For example, Fodor and Inoue (1998) argued that during revision, the processor eliminates all grammatical conflicts caused by misanalysis or repair processes. In complement sentences such as "Mary saw the girl drank some water", their account assumes the following. When the processor encounters the disambiguating region ([$_{TP}$ Mary [$_{T'}$ T [$_{VP}$ saw [$_{DP}$ the girl]]]] <- input: drank), it initially incorporates the input word into the current structure by inserting phrase structures for the subject position, its predicate, the null complementiser and its projection ([$_{TP}$ Mary [$_{T'}$ T [$_{VP}$ saw [$_{DP}$ the girl [$_{CP}$ [$_{C}$] [$_{TP}$ [$_{DP}$] [$_{T'}$ T [$_{VP}$ drank]]]]]]]). The processor then checks whether "the girl" is an appropriate constituent as the specifier of the TP (SpecTP) based on whether its phi-features match the input word and whether the main clause verb "saw" can accept a complement clause. Since these are all permitted by grammar, the processor incorporates "the girl" into SpecTP ([$_{TP}$ Mary [$_{T'}$ T [$_{VP}$ saw [$_{CP}$ [$_{C}$ ~~that~~] [$_{TP}$ [$_{DP}$ the girl] [$_{T'}$ T [$_{VP}$ drank]]]]]]). On the other hand, the reprocessing account predicts a computationally simple revision process. According to this account, when garden-path effects occur, all the processor does is locate the temporarily ambiguous region and reparse it without engaging in a structure-manipulating operation as predicted by the repair-based account. As described above, Experiment 1 suggested that the processor revises the attachment site of the adjunct control and the reflexive-/PRO subject-antecedent relationships. Given such a revision process is difficult to complete without engaging in structure-manipulating operations and not computationally economical, the result of Experiment 1 is more compatible with the repair-based account.

Experiment 2 also demonstrated that the processor conducts revision during the processing of temporarily ambiguous complement sentences.[6] This finding is consistent with previous studies which have reported that during revision of subject-object ambiguities, the processor constructs structures compatible with the correct interpretation of the sentence (Fujita & Cunnings, 2021b; Slattery et al., 2013). Crucially, in addition to extending the previous finding to complement ambiguities, the present study provided evidence that the processor does not analyse a

nominal that is locally available but grammatically inappropriate as the correct attachment site for the disambiguating region.

Experiment 2 demonstrated that the processor conducts revision in complement sentences. However, this finding does not necessarily mean that an analogous revision mechanism operates in other types of temporarily ambiguous sentences. For example, as discussed in the Introduction, Fodor and Inoue (1998) argued that in subject-object ambiguities, the processor fails to conduct revision and consequently analyses a local nominal as the main clause subject. However, this account does not apply to complement ambiguities. Such an argument is conceivable, given that subject-object ambiguities are potentially more difficult to revise than complement ambiguities (e.g. Sturt et al., 1999). The present study tentatively concludes that the processor constructs globally correct structures during revision. Examining the potential effect of revision difficulty on the revision mechanism will be a fruitful avenue of future research.

Another issue regarding revision that requires further exploration is why initial misinterpretations linger. As reported in the present study, Experiments 1 and 2 indicated that the processor conducts revision but persists with initial interpretations after disambiguation. Slattery et al. (2013) argued that upon disambiguation, the processor constructs a structure compatible with the correct interpretation of the sentence, but "before a legal and complete structure [the globally correct structure] is created (Christianson et al., 2001), a revised structure [the constructed structure compatible with the correct interpretation of the sentence] may be overlaid on the existing, initial, ultimately incorrect tree" (p. 115–116). The initial structure decays gradually over time but affects subsequent language comprehension until it disappears from memory. In complement ambiguities, their account means that upon disambiguation, the processor analyses the temporarily ambiguous phrase as the subordinate clause subject but preserves its original analysis as the complement of the main clause verb ([$_{TP}$ Mary [$_{T'}$ T [$_{VP}$ [$_{VP}$ saw [$_{DP}$ the girl]] [$_{CP}$ [$_{C}$ ~~that~~] [$_{TP}$ the girl [$_{T'}$ T [$_{VP}$ drank]]]]]]]). While such a revision account can explain why misinterpretations linger, it is not clear why initially assigned structures decay over time under this account. If an initial structure is not revised as proposed by Slattery et al., it should not decay but remain as part of the sentence structure as a whole, given that the processor needs it to analyse the sentence. Another account of lingering misinterpretation is that during revision, the processor constructs globally correct structures but fails to discard the semantic component of initial structures (see also Sturt, 2007). As the present study posits that the processor constructs grammatical structures during revision, it is against the former account but consistent with the latter one. Addressing this issue will be key to elucidating the mechanism underlying lingering misinterpretation.

Conclusion

The present study reported two self-paced reading experiments that investigated the mechanism underlying garden-path effects. Experiment 1 demonstrated that the processor misanalyses temporarily ambiguous sentences, which subsequently causes garden-path effects and lingering misinterpretation. Experiment 2 indicated that during revision, the processor constructs globally correct structures. These findings provide evidence for how the processor processes temporarily ambiguous garden-path sentences.

Notes

1. The present study defines revision as a process where, after recognising a signal indicating that the current structure is incorrect (e.g., a disambiguating word), the processor constructs a grammatical structure compatible with the signal.
2. Although the previous paragraph discussed the possibility that garden-path effects do not result from initial misanalysis, for readability, the rest of the Introduction is written based on the assumption that the processor initially misanalyses temporarily ambiguous sentences.
3. Note that Slattery et al. (2013) concluded that during revision, the processor constructs a structure where the temporarily ambiguous phrase is analysed as both the direct object and the subject.
4. I did not include a by-trial random slope for region, as such a model hardly converges.
5. As a reviewer pointed out, to quantify whether the data support a null model or an alternative one, it is necessary to compute Bayes factors.
6. As a reviewer pointed out, a serial processing account and a ranked parallel processing account predict how the processor conducts revision in different ways (see Gibson & Pearlmutter, 2000; Grodner et al., 2003; Lewis, 2000). The serial processing account posits that the processor constructs globally correct structures and discards initially assigned ones during revision. In the ranked parallel account, the processor conducts revision by reranking analyses. Both of these accounts are compatible with the present study in that the processor constructs globally correct structures during revision. As this issue is beyond the scope of the present study, I do not discuss it in detail here.

Disclosure statement

No potential conflict of interest was reported by the author.

Data availability statement

Data, analysis code and experimental materials are provided at https://osf.io/aw8t3/.

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