RICE UNIVERSITY

The Role of Inhibitory Control in Garden-Path Recovery

by

Loan Cam Vuong

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE

Master of Arts

THESIS COMMITTEE:

Randi C. Martin, Elma Schneider Professor,
Chair, Psychology

Katherine Crosswhite, Assistant Professor,
Linguistics

David M. Lane, Associate Professor,
Psychology, Statistics, and Management

Jessica Logan, Assistant Professor,
Psychology

HOUSTON, TEXAS

APRIL 2008

UMI Number: 1455293

INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

UMI[®]

UMI Microform 1455293

Copyright 2008 by ProQuest LLC.

All rights reserved. This microform edition is protected against unauthorized copying under Title 17, United States Code.

ProQuest LLC
789 E. Eisenhower Parkway
PO Box 1346
Ann Arbor, MI 48106-1346

ABSTRACT

The Role of Inhibitory Control in Garden-Path Recovery

by

Loan Cam Vuong

The role of inhibitory control in garden-path recovery was examined in two self-paced reading experiments. Participants read sentence primes that were either garden-path or non-garden-path and that included an equi-biased or a transitive-biased verb. They then read target sentences. The primes resolved against the preferred transitive analysis while the targets resolved towards that analysis. In Experiment 1, younger comprehenders showed an inhibitory effect of garden-path primes on target processing when the verbs were equi-biased and a facilitatory effect when the verbs were transitive-biased. In Experiment 2, a patient with an inhibition deficit and LIFG damage showed a normal prime processing pattern with equi-biased verbs but an abnormal prime processing pattern with transitive-biased verbs. Taken together, the results argue for an involvement of inhibitory control in garden-path recovery. The results further argue that inhibitory control efficiency is modulated by the strength of the bias towards the incorrect analysis.

Acknowledgements

I would like to thank my graduate advisor, Randi Martin, for her support and advice. I am particularly grateful for her patience during the experimentation process of this project. I thank Jessica Logan for her helpful comments and her lively discussion on age-related issues. I appreciate David Lane's discussion and especially his care for preciseness in idea expression. I have benefited from Katherine Crosswhite's questioning of some of the assumptions about sentence processing that I have followed. I thank Olivia Krakower for her help with the experimental materials.

Table of Contents

Introduction.....	1
Experiment 1.....	9
Experiment 2.....	15
General Discussion.....	21
References.....	24

List of Figures

<i>Figure 1.</i> Residual reading times in young comprehenders.....	12
<i>Figure 2.</i> An example of prime reading in a patient with phonological STM deficits...	16
<i>Figure 3.</i> Trimmed reading times in older comprehenders.....	17
<i>Figure 4.</i> Patient ML compared to controls in priming processing at the Subordinate Verb (V1) and the Main Verb (V2) regions.....	19

Introduction

The human language comprehension system is not foolproof. A family of so-called garden-path sentences proves the case. Garden-paths are locally ambiguous sentences that trick the comprehension system into adopting a characterization of the input that is often appropriate but which turns out wrong in the end. Take the sentence “*When the man hunted the deer paced in the zoo*” as an example. In this direct object/subject ambiguity, the subordinate verb *hunted* could be analyzed transitively with the noun phrase (NP) *the deer* serving as its direct object (DO) or intransitively with *the deer* being the subject of the main clause. The transitive analysis is preferred in this case (Christianson, Hollingworth, Halliwell, & Ferreira, 2001). This preference is problematic because the ultimate correct analysis is intransitive.

The present research examined the mechanisms through which the correct but dispreferred alternative is attained after the comprehension system has been garden-pathed (i.e., has committed to the preferred analysis that turns out to be wrong). Following Novick, Trueswell, and Thompson-Schill (2005), I would like to argue that cognitive control processes play a nontrivial role in the recovery process. These mechanisms have been largely ignored in the literature, which primarily concerns the influence of linguistic factors on recovery (e.g., Fodor & Ferreira, 1998; Fodor & Inoue, 1994; Grodner, Gibson, Argaman, & Babynyshev, 2003; Sturt, Pickering, & Crocker, 1999). Some authors (e.g., Lewis, 1998) have made the assumption that garden-path recovery begins with automatic reanalysis processes. Only after those have failed are deliberate processes triggered. This assumption implies that the more difficult the garden-path, the more likely that controlled mechanisms are involved. As my interest lies in

these latter mechanisms, the direct object/subject ambiguity, which has been shown difficult even for college students (Christianson et al., 2001), was used in the study.

Of interest was a set of central control mechanisms involving inhibition, which refers to the suppression of prepotent responses and of irrelevant or no-longer-relevant information. In garden-path recovery, controlled inhibition might serve to inhibit the preferred but incorrect analysis from blocking the recovery of the dispreferred alternative (Novick et al., 2005). This view gives inhibitory control a critical role in garden-path resolution. Failure to inhibit entails failure to reanalyze at all levels of analysis (e.g., syntactic, thematic). Alternatively, garden-path recovery needs not involve inhibition of any type (e.g., Kaschak & Glenberg, 2004; Van Gompel, Pickering, Pearson, & Gunbar, 2006) or it may involve only automatic inhibition (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994; Vosse & Kempen, 2000). According to the episodic-processing account proposed by Kaschak and Glenberg, for example, the adoption of the incorrect analysis in a garden-path situation would leave behind an episodic trace of that processing in the system. Regardless of whether reanalysis succeeds or fails, later processing involving the same analysis should be facilitated due to the presence of the trace. In contrast, models postulating automatic inhibition (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994; Vosse & Kempen, 2000) claim that the incorrect analysis is inhibited. However, this type of inhibition takes place in a passive manner whenever an ambiguity is present (and successfully resolved). Thus, automatic inhibition applies *regardless* of garden-pathing, that is, regardless of whether the system has committed to the incorrect analysis or not.

Several recent studies have examined the role of inhibition in garden-path recovery. Most of them failed to demonstrate such a role (e.g., Christianson, Williams, Zacks, & Ferreira, 2006; Kaschak & Glenberg, 2004, Van Gompel, Pickering, Pearson, & Gunbar, 2006). These studies found that the incorrect analysis lingered and facilitated later processing (e.g., Kaschak & Glenberg, 2004; Van Gompel et al., 2006). This finding is inconsistent with both the automatic and the controlled inhibition accounts. However, Vuong and Martin (2008) showed that inhibitory effects could obtain when verb-bias is taken into account. Verb-bias is the probability with which a verb occurs in a particular syntactic structure. For example, a verb is said to have a transitivity bias when it is often used with a direct object. When a verb is used about equally often with different structures (e.g., transitive versus intransitive), it is said to be “equi-biased” between those structures. This verb-specific information has been shown to modulate garden-path effects (e.g., Garnsey, Pearlmutter, Myers, & Lotocky, 1997). This factor was further shown to modulate inhibitory effects in Vuong and Martin’s study. Specifically, when the ambiguous verbs were equi-biased, participants were less likely to use the transitive structure in subsequent production (producing a sentence from a sentence fragment) if they just read a garden-path sentence that resolved against the transitive analysis. This suggests that the incorrect analysis had been inhibited (e.g., through a reduction in connection weight involving the inappropriate subcategorization frame, the inappropriate argument structure, or both). In contrast, when the ambiguous verbs were transitive-biased, participants were more likely to use the transitive structure in their subsequent production, suggesting that the incorrect transitive analysis lingered (i.e., was not inhibited). This latter result replicated Van Gompel et al. (2006). Vuong

and Martin (2008) interpreted the results as showing that (i) inhibition has a role in garden-path recovery and (ii) inhibitory control efficiency varies depending on the bias strength towards the incorrect analysis. They argued that inhibition is efficient when the bias is not strong and is compromised when the bias is strong.

The present work sought to further examine the role of inhibitory control in garden-path recovery. Experiment 1 sought to replicate Vuong and Martin's (2008) findings in a task that involved only comprehension. Young healthy comprehenders were tested in this experiment. Experiment 2 aimed to test the claim that the hypothesized inhibitory function is localized to the left inferior frontal gyrus (LIFG) region of the brain (Novick et al., 2005). A patient with an inhibition deficit and LIFG damage, patient ML, was tested along with eight age-matched controls (older comprehenders) and two patients without an inhibition deficit and LIFG damage. The comprehension-to-comprehension priming paradigm was used in both experiments. Participants read sentence primes that immediately preceded target sentences (see examples). Primes were either garden-path or non-garden-path and included either equi- or transitive-biased verbs in the subordinate clause. All prime sentences resolved against the transitive reading (the correct analysis was intransitive). All target sentences, in contrast, resolved towards the transitive reading.

Equi-biased:

Garden-path prime: When the boy/ swung/ the girl/ was/ on the seesaw by herself.

Non-garden-path prime: When the boy/ swung,/ the girl/ was/ on the seesaw by herself.

Target: Before the pupils/ swung/ the teacher/ the class/ was/ already chaotic.

Transitive-biased:

Garden-path prime: When the boys/ pushed/ the tutor/ was/ not in the classroom.

Non-garden-path prime: When the boys/ pushed,/ the tutor/ was/ not in the classroom.

Target: After the man/ pushed/ the waiter/ the hostess/ was/ hostile to him.

The stimuli were divided into different presentation regions (indicated by the slashes). The primes had five regions: (1) The “initial” region that contained the conjunctive adverb plus the subordinate subject NP (e.g., *When the boy*), (2) the “V1” region that contained the ambiguous subordinate verb in the garden-path version (e.g., *swung*) and the ambiguous subordinate verb plus the disambiguating comma in the non-garden-path version (e.g., *swung,*), (3) the “subject” of the main clause (e.g., *the girl*) that was temporarily ambiguous between the direct object versus the subject reading, (4) the “V2” region that contained the main verb (e.g., *was*), which served as the error signal in the garden-path version, and (5) the “final” region of the sentence (e.g., *on the seesaw by herself*).

The targets had six regions: (1) The “initial” region that contained the conjunctive adverb plus the subordinate subject NP (e.g., *Before the pupils*), (2) the “V1” subordinate verb region (e.g., *swung*), (3) the “DO” (direct object) region (e.g., *the teacher*), (4) the “subject” of the main clause region (e.g., *the class*), (5) the “V2” main verb region (e.g., *was*), and (6) the “final” region of the sentence (e.g., *already chaotic*).

Predictions for prime processing

Standard effects were expected to obtain for the young comprehenders in Experiment 1. In particular, they were expected to show garden-path versus non-garden-path differences at three critical regions: V1, V2, and the final region. First, at V1, the young comprehenders were expected to make use of the disambiguating comma cue to

immediately block the transitive analysis in the non-garden-path condition. They should lean towards the intransitive reading, hence attempting to close off the subordinate clause at this point. With the lack of benefit of the comma cue in the garden-path condition, the clause should not be closed and the preferred transitive analysis should be pursued. As the end of clauses (and of sentences) is associated with increased processing time (e.g., Mitchell & Green, 1978), an increase in reading times in the *non-garden-path* condition was expected at V1. Second, as already mentioned, at V2 the main verb serves as an error signal in the garden-path condition that the transitive analysis is incorrect. The standard garden-path effect, operationalized as an increase in reading times in the garden-path vs. non-garden-path condition, should be observed in this region. Third, at the final, integrative region of the primes, an increase in reading times was expected for the more difficult garden-path sentences. Finally, commitment to the transitive analysis should be greater with transitive- than with equi-biased verbs. Thus, there should be a bigger garden-path effect for transitive- than for equi-biased verbs. This garden-path by verb-bias interaction could occur at both V2 and the final region of the primes.

In Experiment 2, the older controls, age-matched to the patient, were expected to show the same pattern of effects as the younger comprehenders. Patients without an inhibition deficit and LIFG damage should show a pattern of processing that is similar to that of the controls. As for the patient with LIFG damage (ML), it was expected that he would perform similarly to the controls on sentences with equi-biased verbs, as inhibitory control demand is presumably only moderate in these sentences. However, inhibitory control demand should intensify in sentences with transitive-biased verbs; thus, the patient was expected to show an abnormal pattern in the processing of those sentences.

It was unclear which direction of abnormality, an exaggerated or a minimized garden-path effect, should be predicted. Given the patient's inhibition deficit, one might predict that it would take him an extended amount of time to inhibit the incorrect transitive analysis when the verb has a strong transitive bias (hence an exaggerated garden-path effect should obtain). Alternatively, one could imagine that a strong pre-existing bias towards a particular analysis might lead to "cue blindness" in the patient, that is, the patient might become insensitive to cues that help to disambiguate against that strongly preferred analysis (hence a much reduced garden-path effect should obtain).

Predictions for target processing

If inhibition is involved in garden-path recovery and if inhibitory control demand is only moderate when bias towards the incorrect analysis is not strong, then comprehenders with intact inhibitory abilities should be able to successfully inhibit the incorrect analysis. However, if inhibitory demand is more intense when the bias is strong, then comprehenders should be more likely to fail to inhibit. Thus, inhibitory effects on target processing should be observed for equi-biased verbs and, based on Martin and Vuong (2008), facilitatory effects should be observed for transitive-biased verbs. Inhibition would be shown by increases in target reading times and facilitation by decreases.

The subject region was where the target sentence effects were expected to appear. The reasoning was as follows: If the incorrect transitive analysis is successfully inhibited after garden-path processing (the equi-biased verb condition), participants should be less likely to adopt the transitive analysis, or conversely more likely to pursue the intransitive analysis, when reading the targets. Thus, they should close off the subordinate clause at

the subordinate verb and take the NP following the verb as the subject of the main clause. Processing difficulty should occur at the next region where, instead of the expected main verb, the real main clause subject comes along. Thus, an increase in target reading times in the garden-path vs. the non-garden-path condition was predicted for equi-biased verbs. In the transitive-biased verb condition, inhibition was predicted to fail and the transitive analysis should linger as a result. This should facilitate target reading. A decrease in reading times in the garden-path condition was therefore expected, perhaps at the subject as well as the final, integrative region of the targets.

Older adults have been shown to have a certain degree of inhibition deficit (see Hasher, Lustig & Zacks, 2007 for a recent review). If so, in comparison to the younger comprehenders who presumably have intact inhibitory abilities, the older comprehenders in Experiment 2 should show a smaller inhibitory effect for equi-biased verbs and a bigger facilitatory effect for transitive-biased verbs. Patients without an inhibition deficit (and no LIFG damage) should show a similar magnitude of effects as the older controls. In contrast, patient ML should show no inhibition or even facilitation for equi-biased verbs and exaggerated facilitation for transitive-biased verbs.

Alternative predictions

According to the episodic-processing account proposed by Kaschak and Glenberg (2004), the processing trace associated with the incorrect transitive analysis should be left in the system after garden-pathing has been induced. This trace should facilitate later processing that involves the transitive construction. The account would therefore predict facilitatory effects of the primes on target processing for both equi-biased and transitive-

biased verbs. This should also be true for all participant groups across the two experiments.

According to automatic inhibition accounts like MacDonald et al. (1994), inappropriate alternatives associated with an ambiguous verb should be automatically inhibited following successful ambiguity resolution. This should be true whether garden-pathing has been induced or not. This means that the incorrect analysis should be inhibited to the same level in the garden-path as in the non-garden-path condition. The accounts would therefore predict no difference in prime effects on target processing. To the extent that automatic inhibition mechanisms in older comprehenders and patient ML remain intact, no differences in the effects of primes on target processing should be found in the controls vs. the patient.

Experiment 1

This experiment used a self-paced reading task involving only comprehension to examine the role of inhibitory control in garden-path recovery in younger comprehenders.

Methods

Participants

Thirty-four Rice undergraduates who were native speakers of English participated in the study for credit toward experiment participation requirements for psychology classes. Data from three participants were removed because post-experimental questionnaires indicated that they were aware of the prime-target manipulation and had developed strategies in reading the experimental sentences.

Materials

Verbs were selected from corpus data reported in Gahl, Jurafsky, and Roland

(2004). A verb was classified as equi-biased when it was used about equally frequently in the transitive vs. intransitive form and as transitive-biased when it was used at least twice as often in the transitive than in the intransitive form. Based on those criteria, 12 equi-biased and 12 transitive-biased verbs were selected for the study. Twenty-four experimental pairs were constructed. Each pair consisted of a prime and a target sentence (see examples in Introduction). For each prime item, two sentence versions were created. In the garden-path version, the NP following the subordinate verb could temporarily be analyzed as the verb's direct object or as the subject of the main clause. In the non-garden-path version, a comma was inserted right after the subordinate verb to immediately disambiguate against the transitive reading. Both prime versions shared the same target sentence. Both the prime and the target shared the same subordinate verb. The conjunctive adverbs differed in the prime vs. target.

Two stimulus lists were created. Both verb types were included in each list. Each verb type was presented in both the garden-path and non-garden-path conditions but no specific verbs were repeated within a list. Across the two lists, each of the 24 critical verbs was presented once in each prime condition. Difficult sentence fillers of various two-clause structures such as object and subject relatives were also included. Six filler pairs were constructed so that a garden-path "prime" was followed by a garden-path "target" (i.e., both the "prime" and "target" of a pair were garden-path). Six other filler pairs had a non-garden-path prime – non-garden-path target pairing. Twenty-four additional fillers that had same structure as the targets were also included. The lists were pseudorandomized such that the different experimental conditions alternated throughout the lists. To encourage careful reading of the sentences, about 1/3rd of all sentences were

followed by comprehension questions. (All of the questioned sentences were fillers.) Half of the questions had “yes” as correct responses, half “no.”

Procedure

Participants read sentences at their own pace. A trial started with a row of asterisks that lasted for 1000 ms. Regions of a sentence appeared serially, each staying on the screen until participants pressed a key to advance. The reading time for a region was recorded as the duration of time between region onset and key press. In some trials comprehension questions followed the end of the sentence. Otherwise, a row of asterisks appeared on the screen for 1000 ms before the first region of the next sentence appeared. In experimental trials, the prime appeared immediately before its target. At the end of the session, participants were asked whether they noticed anything about the sentences and whether they had adopted any particular strategies in reading them.

Results

Reading times that were below 300 ms and above 3 s were removed. To adjust for differences in region length across conditions, a regression equation that predicted reading time from region length was derived for each participant using all experimental and filler items (Ferreira & Clifton, 1986). Residual reading times beyond 2.5 *SD* from the mean for a particular region and condition were excluded from analysis. This method affected 7.5% of the data. The remaining data were submitted to analyses of variance that treated participants and items as random effects. A summary of the prime and target reading results is provided in Figure 1.

Figure 1. Residual reading times in young comprehenders.

Prime reading. As expected, the younger comprehenders showed increasing reading times in the non-garden-path condition at V1 (the subordinate verb region). This was true for both equi- and transitive-biased verbs, with the main effect of Garden-path being marginal in the participant analysis and significant in the item analysis: $F_1(1, 30) = 3.69, p = .06$; $F_2(1, 22) = 11.32, p = .003$. The participants continued to spend more time in the non-garden-path conditions at the NP following V1 (the subject region) (main effect of Garden-path: $F_1(1, 30) = 7.08, p = .01$; $F_2(1, 22) = 7.75, p = .01$). At V2 (the main verb region, where the error signal in the garden-path structure appeared), the expected garden-path effect was found. The participants showed an increase in reading times in the garden-path conditions (main effect of Garden-path: $F_1(1, 30) = 41.97, p <$

.0001; $F_2(1, 22) = 48.50, p < .0001$). There was a marginal Garden-path by Verb-bias interaction ($F_1(1, 30) = 3.18, p = .09$; $F_2(1, 22) = 3.07, p = .09$), indicating that the garden-path effect was bigger for transitive-biased (effect size = 204 ms) than for equi-biased verbs (effect size = 117 ms) (paired comparisons between the garden-path versus the non-garden-path conditions were significant for each verb type, $ps < .002$). Finally, participants continued to show increased reading times in the difficult garden-path conditions at the final region of the primes (main effect of Garden-path: ($F_1(1, 30) = 3.16, p = .09$; $F_2(1, 22) = 16.85, p < .0001$). They also spent more time in the more difficult transitive-biased than in the equi-biased verb conditions, which was true *regardless* of garden-pathing (main effect of Verb-bias: $F_1(1, 30) = 18.76, p < .0001$; $F_2(1, 22) = 2.73, p = .11$).

Target reading. There was a significant main effect of Garden-path at the subject region ($F_1(1, 30) = 4.64, p = .04$; $F_2(1, 22) = 7.20, p = .01$), which was qualified by a significant Garden-path by Verb-bias interaction ($F_1(1, 30) = 4.21, p = .05$; $F_2(1, 22) = 7.45, p = .01$). As predicted, for equi-biased verbs, participants were slower after garden-path than after non-garden-path primes ($t_1(30) = 3.63, p = .001$; $t_2(11) = 5.08, p = .0004$). The difference was not significant for transitive-biased verbs ($ps > .85$). The predicted facilitatory effect for transitive-biased verbs obtained at the final region of the targets, where there was a significant Garden-path by Verb-bias interaction ($F_1(1, 30) = 8.63, p = .01$; $F_2(1, 22) = 4.50, p = .05$). In contrast to the results at V2, here the participants were faster after garden-path than after non-garden-path primes, but this was true only for transitive-biased verbs ($t_1(30) = 3.58, p = .001$; $t_2(11) = 2.76, p = .02$; equi-biased verbs: $ps > .3$).

Discussion

With a comprehension-to-comprehension priming task, Experiment 1 replicated Vuong and Martin's (2008) findings that had been obtained with production. The prime results confirmed that the garden-path effect was successfully induced during prime trials for both verb types. However, the effects of primes on target processing differed for equi- versus transitive-biased verbs. Whereas the equi-biased garden-path primes led to slower target processing, the transitive-biased garden-path primes led to faster processing. The result for equi-biased verbs is taken to indicate successful inhibition of the incorrect transitive analysis when that analysis is only mildly preferred. The result for transitive-biased verbs is taken to indicate that inhibition fails (and therefore reanalysis fails) when the incorrect transitive analysis is strongly preferred. Taken together, the results provide further support for accounts that postulate inhibitory control in garden-path recovery (Novick et al., 2005). One aspect of the prime results should be pointed out. That is the main effect of Verb-bias at the final region of the primes. A substantial increase in reading times was observed in the transitive-biased compared to the equi-biased verb conditions. The effect was present for both the difficult garden-path *and* the "easy" non-garden-path sentences (see Figure 1), suggesting that more processing effort is needed to make sense of the sentence when the ultimate structure is highly dispreferred. This is true even when the sentence is clearly unambiguous.

The LIFG region of the brain has been proposed to subserve the inhibitory mechanisms of interest (Novick et al., 2005). Experiment 2 was done to examine the hypothesized link between LIFG-based inhibition and garden-path recovery.

Experiment 2

Experiment 1 shows that inhibitory control is involved in garden-path recovery. The current experiment was done to further examine that role in a patient with an inhibition deficit and LIFG damage. Two other patients without an inhibition deficit nor LIFG damage and eight age-matched comprehenders were tested as controls.

Methods

Participants

Patient ML has a lesion that includes the LIFG, frontal areas more superior to the LIFG, and substantial areas of the left parietal lobe. Previous studies have shown that he has inhibition deficits for verbal materials (Hamilton & Martin, 2005, 2007).

Two non-LIFG patients without an inhibition deficit (as determined through the picture-word interference task, e.g., Schriefers, Meyer, & Levelt, 1990) were tested as controls for patient ML. Both presented with some degree of phonological short-term memory (STM) deficits. Unfortunately, the self-paced reading task turned out to be unfit for these patients. Comments during testing sessions suggested that both preferred to quickly pace through the regions of a sentence because they felt they would “lose it” otherwise. Strategies like this invalidate the use of the self-paced reading task, which assumes that readers process each presentation unit more or less fully before advancing to the next unit. Because of that, data from these control patients were omitted from analysis (but see Figure 2 for an example).

Figure 2. An example of prime reading in a patient with phonological STM deficits.

Eight healthy older participants, who were native speakers of English, were tested as age-matched controls to patient ML. They were recruited from the Houston community. They and the patients were paid \$10 per hour for their participation.

Materials

This experiment used the same materials as in Experiment 1, except that another set of filler sentences were created so that fillers would not repeat across the two stimulus lists. Both stimulus lists were tested on each participant. Versions of a prime item differed across the two lists while its corresponding target repeated across lists.

Procedure

This experiment used the same procedure as in Experiment 1, with the exception that the participants could, if they wished, take a break half way through the session. They were tested in two sessions, which were at least several days apart. The order of list presentation was counterbalanced across the healthy controls.

Results

Two sets of analysis were done. The first set was on the controls' data only. As the same target sentence was used across prime conditions, raw reading times were

analyzed. Reading times that were below 300 ms and above 10 s were removed. Those that were beyond 2.5 *SD* from the mean for a particular region and condition were also removed. This method affected 3.12% of the data. The second set of analysis examined data from patient ML and the controls. To adjust for overall long reading times in the patient, log transformation of untrimmed data was done (only unreasonably fast reading times on a phrasal region, less than 150 ms, were omitted. Four data points were affected).

Controls. The prime and target reading results for the controls are presented in Figure 3.

Figure 3. Trimmed reading times in older comprehenders.

Prime reading. The older comprehenders' results were similar to those of the younger comprehenders. They, too, read V1 (the subordinate verb region) more slowly in the non-garden-path conditions (main effect of Garden-path: $F_1(1, 7) = 10.12, p = .02$; $F_2(1, 22) = 17.51, p < .0001$). They also showed the standard garden-path effect at V2 (the

main verb region), such that reading times increased in the garden-path conditions (main effect of Garden-path: $F_1(1, 7) = 15.49, p = .006$; $F_2(1, 22) = 22.70, p < .0001$). At the final region of the primes, unlike the younger comprehenders, the older comprehenders showed no effect of Garden-path ($ps > .45$). They did not show a reliable effect of Verb-bias, either (the effect was marginally significant in the participant analysis: $F_1(1, 7) = 4.99, p = .06$, and far from significance in the item analysis: $F_2(1, 22) = .49, p = .49$).

Target reading. The only effect of primes on target processing was at the subject region, where the interaction between Garden-path and Verb-bias was marginally significant in the participant analysis and significant in the item analysis ($F_1(1, 7) = 3.96, p = .09$; $F_2(1, 22) = 7.20, p = .01$). Interestingly, in contrast to the younger comprehenders, the older participants processed the region faster after garden-path than after non-garden-path primes in the equi-biased verb condition ($t_1(7) = 3.47, p = .01$; $t_2(11) = 2.86, p = .02$). No significant difference was found in the transitive-biased verb condition ($ps > .49$).

Patient ML vs. controls.

Prime reading. Log transformed results obtained for the controls were similar to the untransformed results reported above. There were significant main effects of Garden-path at V1 ($F_1(1, 7) = 11.96, p = .011$; $F_2(1, 22) = 12.29, p < .0001$) and V2 ($F_1(1, 7) = 12.08, p = .01$; $F_2(1, 22) = 22.77, p < .0001$). At the final region of the primes, the main effects of Garden-path ($ps > .21$) and of Verb-bias were not significant ($F_1(1, 7) = 3.38, p = .11$; $F_2(1, 22) = .43, p = .52$).

As is clear from Figure 4, patient ML showed a pattern of prime processing that was different from the controls. At V1, he showed a significant interaction between

Garden-path and Verb-bias ($F(1, 22) = 4.63, p = .04$). Similar to the controls, he slowed down when reading non-garden-path sentences with equi-biased verbs ($t(11) = 1.81, p = .10$). Unlike the controls, he showed a reversed numerical pattern for non-garden-path sentences with transitive-biased verbs ($p = .23$). At V2, ML showed the standard garden-path effect ($F(1, 22) = 3.53, p = .07$). Although the interaction was not significant ($p = .27$), paired comparisons showed that the effect was significant for equi-biased ($t(11) = 2.94, p = .01$) and not for transitive-biased verbs ($p = .67$).

Figure 4. Patient ML compared to controls in priming processing at the Subordinate Verb (V1) and the Main Verb (V2) regions.

Target reading. Similar to the trimmed results, the log transformed results of the controls showed prime effects on target processing at the subject region (Garden-path by Verb-bias interaction: $F_1(1, 7) = 3.63, p = .10$; $F_2(1, 22) = 4.37, p = .05$). The controls were faster after garden-path than after non-garden-path primes in the equi-biased verb condition ($t_1(7) = 3.47, p = .01$; $t_2(11) = 2.21, p = .05$; the difference was not significant in the transitive-biased verb condition: $ps > .49$). Patient ML showed a marginal trend toward a Garden-path by Verb-bias interaction at the DO region of the targets ($F(1, 22) = 2.40, p = .14$). He spent more time after garden-path than after non-garden-path primes

that contained equi-biased verbs ($t(11) = 1.68, p = .13$). The garden-path vs. non-garden-path difference was far from significance for those containing transitive-biased verbs ($p > .9$).

Discussion

As expected, patient ML was similar to the controls in the processing of prime sentences that contained equi-biased verbs but different from the controls in the processing of prime sentences that contained transitive-biased verbs. For the transitive-biased primes, he differed from controls in showing no effects of the comma cue at the subordinate verb (in the non-garden-path structure) nor of the error signal at the main verb (in the garden-path structure). Thus, in the face of a strong pre-existing bias towards a particular analysis, the patient appeared insensitive to cues that point to the weaker alternative.

There were no marked differences between patient ML and the controls in the influence of primes on target processing. First, the controls showed facilitation for the transitive structure at the subject region in the equi-biased verb condition. Although the patient showed some evidence of slowing at the DO region instead, this seeming difference might most plausibly be due to the same underlying parsing operation. Specifically, the patient's early slowing at the DO region could be due to an adoption of the transitive analysis, so that the increase in reading times reflected efforts to close off the subordinate clause. One could entertain the alternative interpretation that the increase in reading times reflects efforts to initiate a clause (i.e., the intransitive analysis was pursued and the DO NP was mistaken as the subject of the main clause). If so, the patient should have shown processing difficulty when the real subject of the main clause arrived,

but he did not. In short, both the patient and the controls appeared to pursue the transitive analysis more readily after having read equi-biased garden-path primes. It is unclear why the patient did not show a stronger facilitatory effect than the controls. Perhaps the inhibitory demand required in the equi-biased verb condition was within the patient's residual inhibitory ability. In addition, as mentioned previously, older adults are not without inhibition deficits (e.g., Hasher et al., 2007). Those conditions might be responsible for the similarity in the facilitatory effect in the patient vs. the controls.

The lack of facilitation for transitive-biased verbs in both the patient and the controls is very surprising. Both were expected to show strong transitivity priming for these verbs. An inspection of the older and the younger comprehenders' results at the final region of the primes offers an explanation. Of relevance is the verb-bias effect for the *non-garden-path* sentences in the younger comprehenders (see Discussion in Experiment 1). No reliable effect was present in the older controls (see Results), or the patient ($p = .73$). This difference suggests that the older controls and the patient might not have spent enough processing effort on the difficult transitive-biased sentences. It thus appears that these participants failed to adequately overcome the strong transitive bias even when the sentences were unambiguous (i.e., non-garden-path). The lack of the predicted facilitatory effects could therefore be due to a comprehension failure in *both* the garden-path *and* the non-garden-path conditions.

General Discussion

This research provides further converging evidence for an Inhibitory Control account of garden-path processing. Experiment 1 with the younger comprehenders replicated Vuong and Martin (2008). Inhibitory effects on target processing were found

when bias towards the incorrect analysis was not very strong and facilitatory effects were found when bias was strong. Importantly, Experiment 2 revealed an abnormal pattern of garden-path insensitivity in prime processing in a patient with an inhibition deficit and LIFG damage when bias was strong. Interestingly, Experiment 2 also revealed a failure to inhibit in the healthy older comprehenders when inhibitory demand was only moderate (as shown by the facilitation in target processing in the equi-biased verb condition). And finally, in the face of a strong bias towards an inappropriate alternative, even the “easy” non-garden-path sentences were difficult for the older comprehenders and the patient. Taken together, the study suggests that, as inhibitory deficits increase in severity (younger comprehenders versus older comprehenders versus patients), there is a corresponding increase in difficulty with sentences that resolve against the highly preferred analysis.

The present research has two major limitations. First, the study did not collect data on the final interpretation of the sentence. Differences in reading times among different experimental conditions reflect processing dynamics that could be interpreted in different ways. For example, more time spent at a particular region in a particular experimental condition could be used to argue that processing is more complete in that condition. However, one cannot rule out the possibility that the extra time was spent in vain. Thus, claims about successful or unsuccessful processing should be accompanied by data that probe the end results of the processing. Second, the current study was unable to examine garden-path processing in patients without LIFG-based inhibition deficits (due to the patients’ pacing strategies). It remains to be established that the abnormal

processing pattern found in patient ML is indeed specific to deficits in LIFG-based inhibition.

Despite the limitations, the present research argues strongly for a role of inhibitory control in garden-path recovery. Future work should address whether the representation that gets inhibited is lexically specific (applies to a particular verb) or lexically independent (applies to a particular structure in general, e.g., the transitive structure). With regard to brain localization, the evidence is promising for a localization of the inhibitory mechanisms to the left inferior frontal gyrus of the human brain. Future studies should further examine this possibility. Future studies should also begin to work out the details of the language – cognitive control system interaction demonstrated in this study.

References

- Christianson, K., Hollingworth, A., Halliwell, J. F., & Ferreira, F. (2001). Thematic roles assigned along the garden path linger. *Cognitive Psychology*, 42, 368–407.
- Christianson, K., Williams, C., Zacks, R., & Ferreira, F. (2006). Younger and older adults' good enough interpretations of garden-path sentences. *Discourse Processes*, 42, 205-238.
- Ferreira, F. and Clifton, C.J. (1986). The independence of syntactic processing, *Journal of Memory and Language*, 25, 248–368.
- Fodor, J.D., & Ferreira, F. (1998). *Reanalysis in sentence processing*. Dordrecht, The Netherlands: Kluwer. 39, 633–651.
- Fodor, J. D., & Inoue, A. (1994). The diagnosis and cure of garden path. *Journal of Psycholinguistic Research*, 23, 407 –434.
- Gahl, S., Jurafsky, D., & Roland, D. (2004). Verb subcategorization frequencies: American English corpus data, methodological studies, and cross-corpus comparisons. *Behavior Research Methods, Instruments, & Computers*, 36, 432-443.
- Garnsey, S. M., Pearlmutter, N. P., Myers, E., & Lotocky, M. (1997). The contribution of verb bias and plausibility to the comprehension of temporarily ambiguous sentences. *Journal of Memory and Language*, 37 (1), 58-93.
- Grodner, D., Gibson, E., Argaman, V. & Babyonyshev, M. (2003). Against repair-based reanalysis in sentence comprehension. *Journal of Psycholinguistic Research*, 32,141-166.
- Hamilton, A.C., & Martin, R.C. (2005). Dissociations among tasks involving inhibition:

- a single-case study. *Cognitive, Affective and Behavioral Neuroscience*, 5 (1), 1–13.
- Hamilton, A.C., & Martin, R.C. (2007). Proactive interference in a semantic short-term memory deficit: role of semantic and phonological relatedness. *Cortex*, 43, 112–123.
- Hasher, L., Lustig, C., & Zacks, R. T. (2007). Inhibitory mechanisms and the control of attention. In A. Conway, C. Jarrold, M. Kane, A. Miyake, A., & J. Towse (Eds.), *Variation in working memory*. Pp. 227–249. New York: Oxford University Press.
- Kaschak, M.P., & Glenberg, A.M. (2004). This Construction Needs Learned. *Journal of Experimental Psychology: General*, 133(3), 450–467.
- Lewis, R.L. (1998). Leaping off the garden path: Reanalysis and limited repair parsing. In Fodor, J.D. and Ferreira, F. (eds), *Reanalysis in Sentence Processing*. Boston: Kluwer Academic.
- MacDonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review*, 101, 676–703.
- Mitchell, D.C., & Green, D.W. (1978). The effects of context and content on immediate processing in reading. *Quarterly Journal of Experimental Psychology*, 30, 609–636.
- Novick, J.M., Trueswell, J.C., & Thompson-Schill, S.L. (2005). Cognitive control and parsing: Re-examining the role of Broca's area in sentence comprehension. *Journal of Cognitive, Affective, and Behavioral Neuroscience*, 5(3), 263–281.
- Schriefers, H., Meyer, A. S., & Levelt, W. J. M. (1990). Exploring the time course of lexical access in language-production: Picture-word interference studies. *Journal of*

Memory and Language, 29, 86-102.

Sturt, P., Pickering, M. J., & Crocker, M. W. (1999). Structural change and reanalysis difficulty in language comprehension. *Journal of Memory and Language*, 40, 136–150.

Van Gompel, R.P.G., Pickering, M.J., Pearson, J., & Jacob, G. (2006). The activation of inappropriate analyses in garden-path sentences: Evidence from structural priming. *Journal of Memory and Language*, 55, 335-362.

Vosse, T. & Kempen, G. (2000). Syntactic structure assembly in human parsing: A computational model based on competitive inhibition and a lexicalist grammar. *Cognition*, 75, pp. 105–143.

Vuong, L.C., & Martin, R. C. (2008). The role of inhibitory control in garden-path recovery. Poster presented at the annual *Conference on Human Sentence Processing*, Chapel Hill, NC.