A proposed experimental study for investigation of reactivation patterns in successive cyclic wh–movement

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1 Introduction

Much of contemporary generative linguistic analysis postulates that wh–sentences such as (1-a) and relative clauses (1-b) are derived by moving a constituent to a clause– or sentence–initial position. This movement supposedly leaves behind a *gap*, also called a *trace*, and it is indicated in the following sentences by t_i. The fronted constituent is called the *filler* of the gap, or the *antecedent* of the trace, and it is marked by the same subscript i as the trace.

(1) a. [Which boy]$_i$ did the crowd at the party accuse t_i of the crime?
b. The policeman saw the boy$_i$ [that]$_i$ the crowd at the party accused t_i of the crime.

This analysis has much theoretic appeal. It reconciles English with languages in which the question phrase is not fronted, i.e. wh–in–situ, such as Japanese. Another obvious advantage of the movement analysis is that verbs now always assign their theta–roles to the same local structural positions.

But is this dependency between the filler and the gap a mere theoretic construct or do the gaps play a measurable role in the way sentences are processed in real time? The late eighties and early nineties saw a remarkable series of experimental studies suggesting the latter option, which will be discussed in some detail here. The crucial element of their experimental

paradigm is that when a listener is presented with a phrase such as (1-b), the antecedent is somehow *reactivated* at the temporal position of its trace[1]. The semantic component of this lexical reactivation is then measured in a lexical priming task.

2 Measuring reactivation using cross–modal lexical priming

The relevant task is called *lexical decision*. A string of letters that either forms a word (e.g. GIRL) or not a word (e.g. LIGR) is presented visually. The task is to respond as quickly and accurately as possible whether it is a word or not by pressing an appropriate button. Interestingly, it has been established independently that subjects detect that a letter string forms a word faster when they have been previously exposed to a semantically related word than when they have not. For example, if a so–called "prime" word BOY is flashed just before the "target" GIRL appears, then subjects respond faster that the latter is a word than when the preceding word is BODY. This phenomenon is called *semantic priming*(Meyer & Schvaneveldt, 1971).

In the paradigm of *cross–modal lexical priming* (henceforth CMLP) the subject is presented a sentence auditorily and at some point during this presentation is asked to perform a lexical decision task. The experimenters then vary the temporal position in the sentence at which the lexical decision task is inserted(Swinney *et al.* , 1988).

The principal finding common to many such studies is that when the lexical decision task is performed at a moment in time corresponding to a trace position in the auditory sentence, the response to a target word that is related to the antecedent is faster than that to an unrelated target. Take the following example. $\boxed{\text{A}}$, $\boxed{\text{B}}$ and $\boxed{\text{C}}$ mark moments in time where the lexical decision task was presented. Subjects responded faster to target words semantically or associatively related to "boy", such as GIRL, than to those that are unrelated, such as perhaps BODY[2], at probe point $\boxed{\text{B}}$.

[1]Note that technically speaking in sentence (1-b) the antecedent of the trace is "that" and not "the boy". It, however, seems reasonable to assume that "that" is identified at an early stage to be coreferent with "the boy" and hence activation of the semantics of the former implies activation of the latter.

[2]Nicol & Swinney (1989) do not report their actual materials.

(2) The policeman saw the boy$_i$ that the crowd at the party $\boxed{\text{A}}$ accused t$_i$ $\boxed{\text{B}}$ of the $\boxed{\text{C}}$ crime.

Their interpretation is that the occurrence of the trace at that position causes a reactivation of the antecedent which in turn semantically primes the response to related targets in the lexical decision task.

We will now investigate in more detail what makes them conclude this.

2.1 Lexical decision materials

It is first of all important to note that we have not measured the activation of the antecedent directly but rather the naming facilitation of semantically related words. For example, if the antecedent in the auditorily presented sentence is "boy" then the semantically related word could be GIRL and a semantically unrelated word BODY. But how can we be sure that there is no inherent difference in responding that GIRL or BODY are words?

There are two ways to control for this(Nicol *et al.* , 1994). In a less ideal case the related and unrelated target words are chosen such that they are matched for frequency of occurrence and length, which are known to be principal factors governing response latency in lexical decision. In a more ideal case the words will be submitted to another group of subjects who are asked to perform the lexical decision task in isolation, that is, without concurrently listening to a sentence. One then looks for pairs of related and unrelated words that most closely match in response latency and uses these in the cross–modal priming task. If they subsequently show a reaction time difference in the main experiment then it can be deduced that this difference must be due to the auditorily presented sentence.

2.2 Reactivation

In order to speak of reactivation, the following crucially need to obtain(Nicol *et al.* , 1994):

First of all the facilitation needs to also occur at the antecedent position. Most studies do not present these measurements as they are considered self–evident.

Secondly, the facilitation is absent or at least significantly less at some point in time between the antecedent and the trace. If this is not the case, it is possible that the priming that is measured is due entirely to that of

the antecedent (i.e. the effect could be *residual* priming of the antecedent). Under normal circumstances the priming dacays with the time that passes since the presentation of the prime(Glaser & Glaser, 1982; Koch & Brown, 1994). Indeed in the previously mentioned study the activation due to the trace at probe point [B] seems to persist to cause significant priming also at [C]. The relevant finding with respect to the antecedent priming decay is that by probe point [A] the effect is no longer significant and thus be able to constrast with the activation at [B].

This means that it is crucial in such an experimental paradigm for there to be sufficient sentential material between the antecedent and the trace and that furthermore none of this material should in turn prime either the related or unrelated targets for the lexical decision task. This second element has not been explicitly remarked in any of these studies. Take example (3). Assume that we are testing the differential activation of the related target GIRL. Then a word such as "woman" may not intervene between the antecedent and trace. For if it would then any activation at [B] could be entirely due to it.

(3) The policeman saw the boy$_i$ that the crowd at the party [A] of the *woman* accused t$_i$ [B] of the [C] crime.

Finally, clearly the facilitation must be present at the trace position, which all of the studies report to be the case.

2.3 Is the target integrated in the sentence?

In reaction to these findings, McKoon & Ratcliff (1994) point at the following possible confound. The subject receives two linguistic materials at the same time: a sentence presented auditorily and a string of letters visually. If his or her reaction is to integrate the target word into the sentence, then perhaps the reaction time difference reflects merely how well it is felt to fit.

Take example (4). Assume that our related target is GIRL and our unrelated target BODY. The authors suggest that GIRL fits better after the verb "accused" than before it. Though they do not provide an argument as to why, presumably they feel that since a subject is already given, another subject could not be inserted before "accused". However, after it there is a slot for an argument and when the lexical decision task is presented the listener has not yet parsed "the boy". This differential fit does not affect the

target BODY, presumably since a body cannot accuse nor be accused.

(4) The crowd at the party [A]{ GIRL, BODY } accused [B]{ GIRL, BODY } the boy.

McKoon & Ratcliff (1994) visually present sentences of this sort to their subjects and insert the lexical decision at probe points [A] or [B]. Since no movement has taken place, they hypothesise that finding a differential priming effect between these two positions cannot be explained by trace reactivation and would hence call into doubt the current interpretation of the results in CMLP studies. And indeed they find this differential priming effect for sentences of the type given.

Though these results are interesting, the authors do not present any explanation as to why Swinney *et al.* (1988) found a priming effect also position [C]. It seems reasonable that neither GIRL nor BODY would be a particularly good fit there, hence McKoon & Ratcliff (1994)'s proposal cannot account for the finding that facilitation also occurred at [C].

But the focus of Nicol *et al.* (2006)'s response is on the mode of presentation of the sentence. An important difference between the Swinney *et al.* (1988) and follow–up McKoon & Ratcliff (1994) study is that the latter presents the sentence visually. This entails that both the sentence and the lexical decision task are visual and this, the former argue, causes the subjects to integrate the lexical decision target into the sentence and modulates their response times by a goodness–of–fit response. Nicol *et al.* (2006) replicate the experiment but vary the mode of presentation of the sentence: it is either visual, normal rate auditory or slow rote auditory. They find the McKoon & Ratcliff (1994)–effect in visual and slow auditory presentation, but crucially not in the normal rate auditory presentation (which they used in their original study).

One then concludes that when a sentence is presented auditorily at a normal rate, the visual lexical decision target is not integrated into the sentence. That is, the two sensory modes are treated to an important extent in parallel, without them being integrated. Thus the most plausible explanation for the differential semantic priming is reactivation of the antecedent.

2.4 The case of A–movement

Similar experiments have investigated the reactivation of traces left by A–movement, such as passivisation(Osterhout & Swinney, 1993) or with nonaccusatives(Friedmann *et al.* , 2008; Charnavel *et al.* , 2009). The results seem empirically plausible but generally less robust than those of A'–movement. Since this paper is mainly concerned with A'–movement, a detailed discussion would be beyond our scope here.

2.5 What is the mechanism of reactivation?

Now what is it that happens at the point in time roughly corresponding to a trace position in the auditorily presented sentence? What kind of cognitive processing takes place then that can causes the antecedent of the trace to be activated? This is an intimidating question that many of the authors that have presented CMLP studies have only peripherally addressed. The reason is that the way sentences are parsed is still fairly poorly understood, though much more recent work has proposed detailed models for these processes(Van Gompel & Pickering, 2006) that hopefully in the future will be applied to understanding these findings.

Several observations, however, can be made.

2.5.1 Antecedents are selected syntactically

Nicol & Swinney (1989) show that only syntactically possible antecedents are reactivated. In their sentence (5) lexical targets semantically related to "the boy" are facilitated at B. But this is not true for targets related to the "the crowd", suggesting that it is not reactivated. This means that the gap–filling procedure detected that "the boy" is a possible antecedent but "the crowd" is not. That is, it is aware to some extent of the syntactic structure of the sentence and the constraints on possible antecedents of wh–movement.

(5) The policeman saw the boy$_i$ that the crowd at the party A accused t$_i$ B of the C crime.

2.5.2 Gap–filler is greedy

Frazier & Clifton (1989) compared the reading times of the same direct object DP either at a location where there could have been a trace ("the guests"

in example (6-a)) or where there could not (example (6-b)), the context otherwise being as similar as possible. They found that reading times in the former are significantly longer than in the latter.

(6) a. Who did the housekeeper from Germany urge [the guests] to consider?
b. The housekeeper from Germany urged [the guests] to consider the new chef.

They conclude the parser is greedy in that it recognises there *might* be a trace and continues to make inferences on the basis of that, i.e. without waiting for conclusive evidence that there must indeed be a trace there.

This is consistent with recent developments in the empirical investigation of parsing, which suggest that our brains are capable of performing syntactic computation rapidly (E.Stabler, personal communication).

The results of this study in isolation remain questionable. The example sentences (6) differ in many respects and therefore the difference in reading time of the direct objects may be due to many factors that are difficult to tease apart. However, neural imagery studies report findings reinforcing this "active filler" hypothesis(Zurif *et al.* , 1993).

2.5.3 Gap–filling is independent of semantics

Hickok *et al.* (1992) argue that the process of gap–filling is not influenced by semantics. Take for example (7-a). When a listener has heard the sentence up to probe point B, it is certainly a possibility that "which doctor" is the antecedent to a trace argument of "remind". Since by assumption the listener has not yet heard how the sentence continues this trace–account cannot be ruled out yet. However, in example (7-b) it is implausible that "remind" is followed by a trace since the antecedent "which movie" is not something that can be reminded.

(7) a. Which doctor did John A remind B Mary to see t_i ?
b. Which movie did John A remind B Mary to see t_i ?

Surprisingly, the authors find priming of antecedent–related targets at probe point B of *both* sentences. They conclude that the possible antecedents the listener identifies and reactivates are not restricted by semantic plausibility.

This is supported by Garnsey *et al.* (1989), who show in their EEG–study

that wh–gaps are filled even by implausible antecedents, causing the semantic mismatch N400–potential, and similarly by Tanenhaus *et al.* (1989).

3 Successive cyclicity

The theory of movement in syntax has subsequently been extended by postulating that moving constituents have to stop at the specifiers of certain phrase types when they move out of them before doing so. The phrase types in question are at least CP and DP and potentially VP and they are called *phases*. This pattern of movement is called *successive cyclicity*. It means that there is one more trace in the sentences that we have been discussing so far, as exemplified in (8).

(8) The policeman saw the boy$_i$ that$_i$ the crowd at the party [$_{\text{VP}}$ t$_i$ $\boxed{\text{A}}$ accused t$_i$ of the crime].

From a theoretic point of view this analysis is generally felt to be satisfying, as it offers an explanation for a number of phenomena such as why wh–phrases seem not to be able to move out of wh–islands.

In the light of the previous discussion this is quite interesting. Successive cyclicity postulates that, in addition to the dependency between the antecedent to its base position, there exist similar dependencies between the antecedent and each of its intermediate traces. Further, if the reactivation reported so far has indeed been a measure of such dependencies then it would be expected that such reactivation also appears at intermediate trace positions, e.g. $\boxed{\text{A}}$ in example (8). Our endeavour here is to design an experiment that tests this prediction.

3.1 Review of previous results on successive cyclicity

A careful review of the previously published studies revealed that some have, unintentionally, been measuring priming at precisely such intermediate trace positions. Nicol & Swinney (1989)'s probe point $\boxed{\text{A}}$ in sentences such as (8) corresponds to a successive cyclic trace if we assume that VPs are phases. For the authors it merely constituted a control point to verify that the activation of the antecedent had sufficiently decayed. Indeed they find no priming of the antecedent "boy", whereas if there were a successive cyclic trace there

one would expect there to be reactivation priming there similar to that found at the antecedent base position.

Does this, then, *avant la lettre* falsify the claim of successive cyclicity? Such a conclusion seems too strong for the following reasons. First of all the probe point might simply be too close to "the crowd", which the authors find *is* significantly primed at that moment. It is unclear why this priming would interfere with the priming of "the boy," especially since it is not a possible antecedent.

Also, it is possible that the measurement technique is not sufficiently precise to pick up the reactivation of the trace. Indeed Nicol *et al.* (1994) suggest that a negative result of McKoon & Ratcliff (1994) may be due to an unlucky choice of probe point. They report that much depends on exact temporal position at which the lexical decision task is inserted since the decision moment in the lexical decision task must coincide with the moment that syntactic processing has revealed there to be a trace.[3]

Building on this point, I suggest the following explanation. Imagine that the listener has heard the sentence up to the probe point $\boxed{\text{A}}$ in example (9), then he or she has no way of inferring that a VP boundary just occurred. The sentence could just as well have continued with "at the mayer's house".

(9) The policeman saw the boy$_i$ that$_i$ the crowd at the party t$_i$ $\boxed{\text{A}}$ at the mayer's house ...

One could object that it the parser is shown to be greedy in assigning potential traces. But in all such studies a verb was presented before the probe point. It is reasonable that the subject deduces the existence of an argument position and then tries to fill it with previously encountered wh–phrases. Now at point $\boxed{\text{A}}$ above there is no such argument position yet and therefore it seems far–fetched for even a greedy parser to consider the possibility a verb phrase might appear.

Thirdly, it might simply be incorrect to count VPs as phases. Indeed, many authors consider only CPs and DPs to be phases. Therefore, in what follows I will concentrate on probing for intermediate traces at CP and DP boundaries.

[3]In order to make our experiment more robust in this sense, I will argue to investigate response trajectories rather than mere reaction time in the lexical decision task. The former measurement technique has been shown to give a more reliable and robust picture of the time–course of priming phenomena.

3.2 An experimental proposal to investigate cyclity

To the best of my knowledge, no previous study has probed for antecedent reactivation at the locations of intermediate traces. Therefore I will propose an experiment that aims to do just that.

The following sentences will constitute the core of experiment. The control sentence is identical to the material of Nicol & Swinney (1989) and is aimed at verifying that we correctly replicate their findings. If we find a similar effect in this sentence as they do and we fail to find an effect in the other sentences then we can exclude the possibility that this is due to a problem in our experimental setup. Each sentence contains a number of probe points which are labeled [ANTEC], [LAG], [CYC] and [BASE] and they mark the temporal locations at which we will insert the lexical decision during the presentation of the sentence.

(10) a. **Control**
The policeman arrested the boy that$_i$ [ANTEC] the crowd at the party [LAG] accused [BASE] of the crime.

b. **CP–Intermediate**
The policeman arrested the boy that$_i$ [ANTEC] the crowd at the party [LAG] said [$_{\text{CP}}$ t$_i$ [CYC] that the prosecutor accused t$_i$ [BASE] of the crime].

c. **DP–Intermediate**
The policeman arrested the boy that$_i$ [ANTEC] the crowd at the party [LAG] showed [$_{\text{DP}}$ t$_i$ [CYC] a surprisingly revealing picture of t$_i$ [BASE] to the officer].

During the actual experiment sentences of this type will be interleaved with distractor sentences that have a completely different structure. Furthermore the subject will be asked a comprehension question after a number of these sentences to ensure that he or she attends to it.

3.3 Measurement technique

I will further propose to refine the temporal resolution of our response measurement. Since previous experiments and particularly the failures to replicate them have shown that much depends on a lucky choice of probe moments(Nicol *et al.* , 1994) I propose the use of a measurement technique that is more robust.

Recently psychophysical studies have investigated trajectories of subject's pointing to answer options rather than having them pressing a button to respond. In a typical task subjects were presented two answer options on a screen and either required to point to them with their hands(Schmidt & Seydell, 2008; Song & Nakayama, 2008) or even a computer mouse(Spivey *et al.* , 2005). The advantage of such measurement techniques is that quantities such as the direction of movement reveal precisely *when* priming happens during the response phase(van Vugt & Cavanagh, 2009). In particular, it has been shown that small priming effects can be revealed in response trajectories for which the overall response time is not sufficiently sensitive(Finkbeiner *et al.* , 2008).

Thus, it is possible that such finer measurements can reveal priming of intermediate traces, e.g. at point [A] in example (8), where previous studies could not.

In our lexical decision task I therefore propose that the participant will be shown the target string of letters in the center of the screen, e.g. GIRL. He or she is then asked to point the mouse cursor at either one of two options shown in the top corners of the screen: NONWORD or WORD, the correct answer in the example would thus be WORD.

3.4 Hypothesis

I hypothesize to find the same priming pattern in the control sentence. I further expect to find similar effects in the extended CP–Intermediate and DP–Intermediate sentences, as shown in table 1. The additional probe point [CYC] in these sentences will be the crucial factor in determining reactivation at intermediate trace positions. What would be the importance of either possible finding? The two possible outcomes will now be discussed in further detail.

3.4.1 Finding intermediate reactivation

Finding a reactivation at the intermediate trace positions would be quite spectacular. This would prove a direct support for the successive cyclic account of movement. It could also provide an example case in which experimental results and syntactic theory formation mutually inform one another(Schutze, 1996).

Table 1: Hypothesised priming findings

	ANTEC	LAG	CYC	BASE
Control	full priming	none	—	reactivation priming
CP–Intermediate	full priming	none	TEST	reactivation priming (possibly reduced)
DP–Intermediate	full priming	none	TEST	reactivation priming (possibly reduced)

What is more, it would constitute a direct support for the syntactic theory of movement in a way that the studies so far have not been able to. One could argue that the reactivation results we have seen so far are a mere reflection of the listener's becoming aware of the semantic link between the antecedent and the verb of which we construe it as an argument. That is to say, nothing so far has forced us to conclude that the subject is aware of the moved phrase originating at the trace position.

However, if we find reactivation of the antecedent at intermediate trace positions, this would provide an interesting puzzle for those who deny a movement account of relative clause formation. The reason is that there seems to be no semantic connection between the specifier of a CP or DP and the antecedent of a trace it contains. Thus we would find a valuable piece of evidence in favour of syntactic movement in general.

3.4.2 Not finding intermediate reactivation

Finding a negative result is always difficult to interpret.

One plausible interpretation is that the reactivation studies have not pointed us to where traces are located, but rather the points where integration of syntactic structures happens. Therefore the absence of reactivation at phase boundaries would not falsify the claim that there are traces there. Consider example (11-a). At point [A] the listener is aware that a verb is introduced and the subject is missing. Thus we are likely to find reactivation at [A] even though there is no trace at that very position. Under this account the CP–boundary at [B] in (11-c) is not likely to cause reactivation: though there may be a trace there, the subject will realise that only later in the sentence.

(11) a. Which doctor do you think t_i loved [A] Mary?

b. Which doctor do you think Mary loved [A] t_i?
c. Which doctor do you think [B] Mary loved [A] t_i?

For this reason, it is possible that one still finds a reactivation at intermediate traces, but only once the subject has realised that the CP–boundary has occurred. One could therefore test at one further probe point, marked by [CYC'], which corresponds to the moment when the subject arguibly knows a CP–boundary is crossed and hence, if successive cyclicity holds, reactivates the antecedent.[4]

(12) **CP–Intermediate–bis**
The policeman arrested the boy that$_i$ [ANTEC] the crowd at the party [LAG] said [$_{CP}$ t_i that [CYC'] the prosecutor accused t_i [BASE] of the crime].

4 Conclusion

This paper presents a brief review of empirical evidence for semantic reactivation of a wh–moved antecedent at the position of the trace. With the technique of cross–modal lexical priming a series of studies have found robust priming effect at these positions.

An experimental paradigm is proposed in which this technique is applied to investigate potential reactivation of the antecedent at positions where the theory of successive cyclic movement predicts the occurrence of traces. Hopefully in the future these experimental studies will be further elaborated through recently proposed models of parsing so as to yield a better understanding of the nature of movement in syntax as well as the nature of the reactivation findings.

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[4]This, then, constitutes another important motivation for the use of response trajectory measurements, as these will be able to reveal when in time the trace reactivation might happen and be probably much less sensitive to precise temporal alignment of parsing and lexical decision.

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