The interaction of working memory and expectation-based processes in sentence comprehension

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Background

Vasishth & Lewis 2006 found speed-ups at the verb when material intervenes between the argument and verb (Hindi SPR):

\[(1)\] vo laRkaa \([RC jisne us kaagaz-ko mez ke piiche\]
that boy who that paper-ACC behind table
gire hue dekhaa] bahut jigyaasu thaa
fallen saw very inquisitive was

‘That boy who saw that (piece of) paper was very inquisitive.

Various explanations have been proposed for this speedup. One prominent account is expectation (surprisal), by Levy 2008: *Increasing distance sharpens the expectation for the upcoming verb phrase.*
Background

Vasishth & Lewis 2006 had proposed a reactivation account for anti-locality effects:

1. interposed material that attaches to an argument NP could boost its activation
2. interposed material that attaches to a predicted VP could boost its activation

Both types of reactivation could result in faster retrieval at the critical verb.
Background

In recent work, Husain et al 2014 have shown that expectation strength matters: when the exact lexical item is predicted (strong expectation), anti-locality effects are seen; when only a VP is predicted (weak expectation), locality effects emerge.

**Research question:**
Does strength of activation modulate reactivation effects?
Experiment 1 Design

Our goal was to determine whether reactivation of an argument NP and a VP interacts with expectation (predictability).

1. Subject NP reactivation ±
2. Main VP reactivation ±
3. Predictability of Main VP ±
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Experiment 1

Expt 1 Design

NP reactivation inside an embedded clause

(2)  **raam** [mamaji **ko** kuch buDbuDaate]

_Ram to uncle something while muttering_

saaraa samaan dheere-dheere **uThaa rahaa thaa**

_entire luggage slowly was lifting_

‘Ram was slowly lifting the entire luggage while muttering something to (his) uncle.’

The case marker **ko** ensures that _Raam_ is the subject of _buDbuDaate_, ‘muttering’. That is, _Raam_ is reactivated inside the embedded clause.
No NP reactivation

(3) raam [mamaji ke kuch buDbuDaate]
Ram uncle gen something while muttering
saaraa samaan dheere-dheere uThaa raha thaa
entire luggage slowly was lifting
‘Ram was slowly lifting the entire luggage while (his) uncle
was muttering something.’

Replacing ko with ke makes uncle the subject of muttering. Raam is no longer the subject of muttering.
Experiment 1: NP reactivation

(a) NP-reactivation: NP-subject acts as the subject of both non-finite verb and the main verb.
(b) No NP-reactivation: NP-subject is only the subject of the main verb.
Experiment 1: No VP reactivation

(4) **raam** [mamaji ko kuch buDbuDaate]
    Ram to uncle something while muttering
    saaraa samaan dheere-dheere **uThaa raha thaa**
    entire load slowly was lifting
    ‘Ram was slowly lifting the entire luggage while muttering
    something to (his) uncle.’

Here, the main VP is modified by the embedded clause and one
adverb: *dheere-dheere*, ‘slowly’.
Experiment 1: VP reactivation

(5) raam [mamaji ko kuch buDbuDaate] Ram to uncle something while muttering
saaraa samaan [sadak par] [badi gaadi par se] entire luggage on the road from the big vehicle
dheere-dheere uThaa rahaa thaa slowly was lifting

‘Ram was slowly lifting the entire luggage on the road from the big vehicle while muttering something to uncle.’

Here, the main VP is modified by the embedded clause and three adverbs:

1. sadak par, ‘on the street’.
2. from the big vehicle, ‘from the big vehicle’.
3. dheere-dheere, ‘slowly’.
Experiment 1: VP reactivation

(a) NP-subject [... non-finite verb] adverbial1 **main verb** ...

(b) NP-subject [... non-finite verb] adverbial3 adverbial2 adverbial1 **main verb** ...

(a) No VP reactivation/Short condition: Only one adverbial modifies the main verb.
(b) VP reactivation/Long condition: Three adverbials modify the main verb.
The use of context to manipulate predictability

Context condition:

(6) kyaa raam samaan uThaa rahaa thaa?
   *Was Ram luggage was picking up*
   ‘Was Ram picking up the luggage?’

This context sentence renders the subject NP *Raam* and the main VP predictable.

No context condition:

(7) kyaa hua?
   *What happened*
   ‘What happened?’

Neither the subject NP nor the main VP is predictable.
No VP-reactivation (=Short), NP-reactivation, Context

(8) kyaa raam samaan uThaa rahaa thaa?
Was Ram luggage was picking up
‘Was Ram picking up the luggage?’

haan, raam [mamaji ko kuch buDbuDaate]
yes, Ram to uncle something while muttering
saaraa samaan dheere-dheere uThaa rahaa thaa, . . .
enhite luggage slowly was lifting, . . .

‘Yes, Ram was slowly lifting the entire luggage while muttering something to (his) uncle, . . .’
VP-reactivation (Long), NP-reactivation, Context

(9) kyaa raam samaan uThaa rahaa thaa?
Was Ram luggage was picking up
‘Was Ram picking up the luggage?’

haan, raam [mamaji ko kuch buDbuDaate]
yes, Ram to uncle something while muttering
saaraa samaan [sadak par] [badi gaadi par se]
entire luggage on the road from the big vehicle
dheere-dheere uThaa rahaa thaa, . . .
slowly was lifting, . . .

‘Yes, Ram was slowly lifting the entire luggage on the road from the big vehicle while muttering something to uncle, . . .’
No VP-reactivation (Short), No NP-reactivation, Context

(10) kyaa raam samaan uThaa rahaa thaa?
   *Was Ram luggage was picking up*
   ‘Was Ram picking up the load?’

haan, **raam** [mamaji ke kuch buDbuDaate]
   *yes, Ram uncle gen something while muttering*
saaraa samaan dheere-dheere **uThaa rahaa thaa**, . . .
   *entire luggage slowly was lifting*, . . .

‘Yes, Ram was slowly lifting the entire luggage while uncle was muttering something, . . .’
VP-reactivation (Long), No NP-reactivation, Context

(11) kyaa raam samaan uThaa rahaa thaa?  
Was Ram load was picking up  
‘Was Ram picking up the load?’

haan, raam [mamaji ke kuch buDbuDaate]  
yes, Ram uncle gen something while muttering  
saaraa samaan sadak par badi gaadi par se  
entire load on the road from the big vehicle  
dheere-dheere uThaa rahaa thaa, . . .

slowly was lifting, . . .

‘Yes, Ram was slowly lifting the entire load on the road from the big vehicle while uncle was muttering something, . . .’
Expt 1: Pretest (sentence completion)

1. Participants were asked to complete the incomplete versions of the items (cut off before the non-finite verb, at ‘slowly’).

2. Twenty-four sets of items, each with eight versions were presented using the centered self-paced reading method in the standard Latin square design.

3. Items were presented using Douglas Rohde’s Linger software, version 2.94 (http://tedlab.mit.edu/~dr/Linger/).

4. The critical items were presented with 122 filler items unrelated to this study.

5. Twenty-one subjects participated for payment. Their mean age was 22.7 years, SD 3.1 years.
Expt 1: Pre-test (sentence completion) results

1. The sentence completion study confirms that there are more exact predictions in the context conditions (84%) compared to just 40% in the no-context condition.

2. Note that in both the context and no-context conditions, a finite verb was almost always produced (98% of the cases in the context conditions, and 94% in the no-context conditions). This shows that the conditional probability of a verb given the left context is close to 1.0.
Experiment 1 Results

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### Experiment 1 Results

The diagram illustrates the reading time in milliseconds (ms) for different conditions: Context and No-Context. The conditions are categorized under No-VP-react and VP-react. The X-axis represents the VP-react condition, while the Y-axis shows the reading time in milliseconds.
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### Experiment 1 Results

<table>
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<th>Effect</th>
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**Table:** The main effect of distance, of NP-reactivation, of context and their interaction on log reading times at the critical region (main verb) in Experiment 1.
Expt 1 Discussion

Experiment 1 found two significant effects,

1 A main effect of context:
The effect of context shows that when the exact identity of the main verb is expected, participants tend to read it faster compared to when its exact identity is not expected.

2 An interaction between the three factors:
this interaction is driven by the NP-reactivation condition, such that the long (VP-reactivation) condition is faster compared to short (no VP-reactivation) condition; by contrast, in the No NP-reactivation condition, no effect of distance is seen.

⇒ You have to activate the NP and the VP to get a facilitation at the main verb.
1. The facilitation at the main verb due to reactivation disappears in the context condition. The cue-based retrieval theory (Lewis and Vasishth, 2005) does not predict any effect of context.

2. The cue-based retrieval theory would have to make an additional assumption to explain it: In the context condition, the strong expectation of the head and dependent would have to lead to higher activation of the head/dependent, i.e. both subject and main verb would need to have a higher base-level activation.

3. Under such conditions, there will be no effect of NP or VP reactivation as the activations of both subject and main verb are already quite high.

So, strength of expectation can in principle modulate reactivation effects.
Experiment 2 Design: Attachment $\times$ Distance $\times$ Context

The goal here was to determine whether reactivating an *embedded* verb leads to facilitation.

1. Attachment: Nested vs crossing dependency.
2. Distance: As in experiment 1.
Experiment 2 Design: Attachment

*According to me* attaches to main verb:

(12)  
\[
\text{Ram gen according to me loudly laughing}
\]
\[
\text{bilkul Theek thaa definitely good was}
\]

‘According to me it was absolutely ok for Ram to laugh loudly.’

*Because of me* attaches to embedded non-finite verb:

(13)  
\[
\text{Ram gen because of me loudly laughing definitely}
\]
\[
\text{bilkul Theek thaa good was}
\]

‘It was absolutely ok for Ram to laugh loudly because of me.’
Experiment 2 Design: Attachment

Attachment:

Distance:

(a) [NP-gen according to me ... non-finite verb] ... main verb ...

(b) [NP-gen because of me ... non-finite verb] ... main verb ...

(a) [NP-gen ... adverbial1 non-finite verb] ... main verb ...

(b) [NP-gen ... adverbial3 adverbial2 adverbial1 non-finite verb] ... main verb ...
Expt 2: Short, AttachMV, Context

(14) kyaa raam ka hasnaa Theek thaa?
was Ram GEN laughing ok was
‘Was it ok for Ram to laugh’ (literally: Was Ram’s laughing ok?)

haan, [raam kaa mere khayaal se zor zor se hasnaa]
yes, Ram GEN according to me loudly laughing
bilkul Theek thaa, . . .
definitely good was, . . .

‘Yes, according to me it was absolutely ok for Ram to laugh loudly, . . .’
Expt 2: Long, AttachMV, Context

(15) kyaa raam ka hasnaa Theek tha?

Was Ram GEN laughing ok was

‘Was it ok for Ram to laugh’ (literally: Was Ram’s laughing ok?)

haan, [raam ka mere khayaal se [do din pehle]

yes, Ram GEN according to me two days ago

[sabke saamne] zor zor se hasnaa] bilkul Theek

in front of everyone loudly laughing definitely good

thaa, . . .

was, . . .

‘Yes, according to me it was absolutely ok for Ram to laugh loudly two days ago in front of every one, . . . .’
Expt 2: Pretest (sentence completion)

1. Participants were asked to complete the incomplete version of the items (cut off before the non-finite verb).

2. Twenty-four sets of items, each with eight versions were presented using the centered self-paced reading method in the standard Latin square design.

3. Items were presented using Douglas Rohde’s Linger software, version 2.94 (http://tedlab.mit.edu/~dr/Linger/).

4. The critical items were presented with 122 filler items unrelated to this study.

5. Twenty-one subjects participated for payment. Their mean age was 22.7 years, SD 3.1 years.
Expt 2: Pretest (sentence completion) results

- The sentence completion confirms that there are more exact predictions of the non-finite verb in the context conditions (71%) compared to just 2% in the no-context condition.

- If one considers prediction of a non-finite verb category (i.e. any non-finite verb) then the percentage prediction in no-context conditions is 86% for the context condition, and 56% for the no-context condition. This shows that in the no-context condition a non-finite verb is being predicted.
Expt 2: Results (Reading times at embedded verb)

![Graph showing reading times at embedded verb]

- **Context**
  - Short
  - Long

- **No-Context**
  - Short
  - Long

Attachments:
- AttachMV
- AttachNFV

Reading time [ms]
- 1000
- 900
- 800
- 700
- 600
- 500
- 400
- 300
- 200
- 100
- 0
### Expt 2: Results (ANOVA contrasts), on log RTs

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## Expt 2: Results (Nested contrasts), on log RTs

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</tr>
</tbody>
</table>
Expt 2: Discussion

1. When the activation of the predicted nonfinite verb is high (i.e., in the context conditions), reactivation of this nonfinite verb does not have any effect.

   *Note: there is a tendency towards a locality effect that we cannot explain yet*

2. But when the activation of the nonfinite verb is low (i.e., in the no-context conditions), reactivation of the nonfinite verb shows a facilitatory effect.
Conclusion

This is, to our knowledge, the first set of studies to show the interaction between activation and expectation strength.

1 Experiment 1 and 2 show that facilitation due to reactivation can disappear when the reactivated phrase is strongly expected (i.e. its exact identity is predictable).

2 In Experiment 1 the NP subject and the VP were strongly expected in the prediction context condition, while in Experiment 2’s prediction context condition the critical nonfinite verb was expected.

3 The results suggest that the effect of strong (respectively, weak) expectation should lead to relatively high (respectively, low) activation of the predicted phrase.
Conclusion

1. Expectation directly affects activation of predicted chunks.

2. Reactivation effects as proposed in Vasishth & Lewis 2006 only emerge in weak expectation configurations.

The Levy 2008 expectation account and the Vasishth and Lewis 2006 reactivation account for antilocality effects are not two alternative accounts but are actually closely related.