

THE ROLE OF PREDICTION AND WORKING-MEMORY  
CONSTRAINTS IN HINDI SENTENCE COMPREHENSION

APURVA



DEPARTMENT OF HUMANITIES AND SOCIAL SCIENCES  
INDIAN INSTITUTE OF TECHNOLOGY DELHI

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THE ROLE OF PREDICTION AND WORKING-MEMORY  
CONSTRAINTS IN HINDI SENTENCE COMPREHENSION

by

Apurva

Department Of Humanities and Social Sciences

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*to the*



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# CERTIFICATE

This is to certify that the thesis titled **The Role of Prediction and Working-memory Constraints in Hindi Sentence Comprehension**, submitted by **Apurva**, to the Indian Institute of Technology, Delhi, for the award of the degree of **Doctor of Philosophy**, is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

**Prof. Samar Husain**

Associate Professor

Dept. of Humanities and Social

Sciences

IIT-Delhi,

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# ABSTRACT

A large body of sentence processing literature assumes *the prediction of upcoming linguistic items* to play a critical role during human sentence processing. Moreover, Subject-Object-Verb (SOV) languages are considered to be particularly good at predicting the upcoming linguistic item (e.g., clause-final verbs) when compared to Subject-Verb-Object (SVO) languages. This assumption is fairly used in sentence processing literature, particularly dealing with the SOV languages. However, this assumption has not been validated empirically.

Using a series of sentence completion tasks, the first part of this thesis investigates the assumption of robust verbal prediction in Hindi (a canonical SOV language) to bridge this gap in the literature. Results from the completion studies show only partial support for the robust verbal prediction. Surprisingly, results also showed that the robustness of prediction is constrained by certain linguistic configurations. In such configurations, a preponderance of grammatically illicit predictions was observed. In particular, participants are more likely to make prediction errors when trying to complete sentences containing three consecutive animate nouns than when completing sentences with fewer nouns. In addition to the completion studies, I also report a series of rating tasks to show that these erroneous parses generated in conditions with three consecutive noun phrases can lead to grammatical illusion in Hindi.

Traditionally, it has been assumed that this robust processing might facilitate the processing of the clause-final verb when the appearance between the verb and the dependent is further delayed in the SOV language. In contrast, a lack of robust prediction in SVO languages results in forgetting the head when the distance between the head and the dependent increases. In other words, the assumption of robust verbal prediction and its maintenance is at the core of the explanation for anti-locality effects and no-structural forgetting in SOV languages.

In the light of these results, i.e., the fallibility of verbal prediction observed in the completion studies, it is required that we do a closer scrutiny of the existing explanations for

anti-locality and lack of structural forgetting in the SOV languages. A two-step investigation is done in the remaining part of the thesis. Since effects such as anti-locality are ‘online’ effects, while completion studies are ‘offline’, in the first step, it was investigated if the results of the completion studies have any bearing during online processing. This step successfully established this relationship between the offline results and online processing patterns. Finally, the second step of this investigation tries to find out the cause behind anti-locality effects and no-forgetting effects in the light of these findings. Preliminary results from this thesis suggest that forgetting can be observed for specific constructions in an SOV language like Hindi, and the anti-locality effect can arise due to a shallow parsing strategy rather than robust predictive processing.

This thesis systematically investigates the prediction process in an SOV language like Hindi and shows that the prediction system may break down while parsing a complex construction. These results highlight the critical effect of working-memory constraints on the prediction system in the SOV languages. The work highlights the nature of prediction errors that arise due to such constraints. Overall, this work reports the fallibility of the prediction system and its effect during online processing. It calls for a re-evaluation of some assumptions behind the existing explanations of anti-locality and no-forgetting effects in SOV languages.

KEYWORDS: Working-memory ; Expectation; Sentence Processing; Head-final Languages.

## सारांश

बहुत सारे शोध अध्ययन के मुताबिक वाक्य-विश्लेषण (सेंटेंस प्रोसेसिंग) के दौरान, मानव मस्तिष्क वाक्यों में प्रस्तुत शब्दों के आधार पर, वाक्य में आगे आने वाले शब्दों का अनुमान पहले से ही लगा लेता है। यह अनुमान लगाने की कार्यविधि की भूमिका वाक्य-विश्लेषण में काफी अहम मानी जाती है। यह अनुमान लगाने की प्रक्रिया खासकर उन भाषाओं में और आसान हो जाती है जिसमें वाक्यों की संरचना कर्ता-क्रिया-कर्म (सब्जेक्ट-वर्ब-ऑब्जेक्ट) के बजाय कर्ता-कर्म-क्रिया (सब्जेक्ट-ऑब्जेक्ट-वर्ब) के रूप में व्यवस्थित होती है। कर्ता-कर्म-क्रिया (सब्जेक्ट-ऑब्जेक्ट-वर्ब) पालन करने वाली भाषाओं से जुड़े सेंटेंस प्रोसेसिंग शोध में इस तथ्य का इस्तेमाल बखूबी किया गया है। हालाँकि यह भी ज्ञात है की इस तथ्य के प्रयोगात्मक प्रमाण (एक्सपेरिमेंटल एविडेंस) सम्बंधित शोध साहित्य में मौजूद नहीं हैं।

इस पीएचडी शोध लेख के प्रथम भाग में मैं वाक्य-पूर्णता प्रयोगों (सेंटेंस-कम्प्लीशन एक्सपेरिमेंट्स) का इस्तेमाल करके, शोध साहित्य में ऊपर वर्णित तथ्य के प्रयोगात्मक प्रमाण न होने के इस अंतर को पाटने की कोशिश करूँगा। इस कार्य के लिए मैं हिंदी भाषा का इस्तेमाल करूँगा जो की एक कर्ता-कर्म-क्रिया (सब्जेक्ट-ऑब्जेक्ट-वर्ब) भाषा है। हमारी इस जांच प्रक्रिया के परिणाम काफी आश्चर्यजनक हैं। वाक्य-पूर्णता प्रयोगों के मुताबिक यह तथ्य केवल आंशिक तौर पर सत्य है। इन प्रयोगों से ये भी पता चला है की यह शत प्रतिशत सम्भावित नहीं है की हिंदी भाषा के हर वाक्य में आगामी क्रिया का सही अनुमान लगाया जा सके। हमारे प्रयोगों में ऐसा भी देखा गया है की ऐसे कुछ ही वाक्य संरचना है जिसमें की ये सम्भव है। जिन वाक्यांशों में तीन सजीव संज्ञाओं (एनिमेट नाउज़) का इस्तेमाल किया गया, वहाँ पर प्रतिभागियों ने ज़्यादा गलतियाँ की है और सही तरह से वाक्य पूरा नहीं कर पाए हैं बजाए उन वाक्यांशों के जहाँ पर तीन से काम सजीव संज्ञाओं का प्रयोग किया गया था।

इन वाक्य-पूर्णता प्रयोगों के अलावा मैंने सेंटेंस रेटिंग प्रयोगों के ज़रिए ये भी दिखाने की कोशिश की है की किस वजह से तीन संज्ञाओं वाले वाक्यांशों को प्रतिभागियों ने ग़लत वक्याखंड से पूर्ण किया है और ये ग़लत वक्याखंड हिंदी भाषा में व्याकरणिक भ्रम (ग्रामैटिकल इलूज़न) पैदा कर सकते हैं।

पारम्परिक रूप से ये देखा गया है की कर्ता-कर्म-क्रिया भाषाओं में जब क्रिया का स्थान उसपर आधारित कर्म और कर्ता से थोड़ी दूरी पर हो तो, अनुमान लगा पाने की वजह से आखिरी क्रिया पर वाक्य-विश्लेषण की प्रक्रिया आसान हो जाती है। इस प्रभाव को ऐंटाई-लोकैलिटी प्रभाव के नाम से जाना जाता है। इसके विपरीत कर्ता-क्रिया-कर्म भाषाओं मूल (हेड) और आश्रित (डिपेंडेंट) की दूरी बढ़ जाने से, या तो मूल का विश्लेषण कठिन हो जाता है या कई बार मूल को आंशिक तौर पे भुलाया भी जा सकता है। दूसरे शब्दों में

ये कहा जा सकता है की क्रिया का अनुमान लगाने की क्रियविधि के द्वारा ही कर्ता-कर्म-क्रिया भाषाओं में ऐंटाई-लोकैलिटी प्रभाव या नो-स्ट्रक्चरल फ़र्गेटिंग प्रभाव का स्पष्टीकरण दिया जा सकता है।

इन प्रमाणों के आलोक में, खासकर वाक्य-पूर्णता प्रयोगों से प्राप्त नतीजों से यह पता चलता है की कर्ता-कर्म-क्रिया भाषाओं में ऐंटाई-लोकैलिटी प्रभाव या नो-स्ट्रक्चरल फ़र्गेटिंग प्रभाव का स्पष्टीकरण संदेहास्पद है और ये बेहद आवश्यक है की इन प्रभावों के व्यखाओं की करीबी जाँच की जाए।

इस पीएचडी शोध लेख के दूसरे भाग में हमने जाँच के दो-चरणों और उस से प्राप्त प्रमाणों का ज़िक्र किया है। जैसा की हम जानते हैं की 'ऐंटाई-लोकैलिटी' प्रभाव या 'नो-स्ट्रक्चरल फ़र्गेटिंग' प्रभाव मूलतः ऑनलाइन प्रयोगों में पाया गया है जबकि हमें मिले सारे परिणाम ऑफ़लाइन प्रयोगों से मिले हैं। इसीलिए पहले चरण में हमने ये पता लगाने की कोशिश की है की ऑफ़लाइन पाए गए प्रमाणों का फ़र्क ऑनलाइन प्रयोगों में पड़ता है या नहीं? इस चरण के अन्वेषण में हम ऑनलाइन और ऑफ़लाइन प्रयोगों के बीच सम्बंध स्थापित करने में सफल रहे। अंततः दूसरे चरण में हमने अपने पाए गए नए प्रमाणों के आलोक में ऐंटाई-लोकैलिटी प्रभाव या नो-स्ट्रक्चरल फ़र्गेटिंग प्रभाव के वजह को जानने की कोशिश की। प्रारम्भिक नतीजों के अनुसार हिंदी जैसी भाषाओं में भी स्ट्रक्चरल फ़र्गेटिंग प्रभाव के प्रमाण मिल सकते हैं। इसके साथ ही हमने ये भी पाया की हिंदी जैसी भाषाओं में ऐंटाई-लोकैलिटी प्रभाव भी पाया जाता है, लेकिन शोध साहित्य में उपलब्ध व्याख्यान यथोचित नहीं है। हमने ये पाया की ऐंटाई-लोकैलिटी प्रभाव, सतही पदच्छेद क्रियविधि (शालो पार्सिंग स्ट्रैटेजी) की वजह से हैं।

इस पीएचडी शोध लेख ने पद्धतिबद्ध रूप से कर्ता-कर्म-क्रिया जैसी भाषाओं में आने वाले क्रिया के अनुमान लगाने का अध्ययन किया और पाया की मुश्किल वाक्यों में प्रतिभागी क्रिया का अनुमान लगाने की क्रियविधि त्रुटिपूर्ण हो सकती हैं। ये प्रमाण हिंदी व अन्य कर्ता-कर्म-क्रिया वाली भाषाओं के वाक्य विश्लेषण में वर्किंग मेमोरी के अहम भूमिका को स्थापित करते हैं। इस पीएचडी शोध लेख के प्रमाण ये भी दिखाते हैं की शोध साहित्य के अवधारणा विपरीत वर्किंग मेमोरी की भूमिका क्रिया के अनुमान लगाने में काफ़ी अहम है और किसी भी तरह की अनुमाने लगाने में हुई त्रुटि के लिए वर्किंग मेमोरी ज़िम्मेदार हो सकता है। इस शोध लेख में वर्किंग मेमोरी के प्रतिबंधन से अनुमान लगाने की प्रक्रिया में जो परिवर्तन आता है, उसका भी उल्लेख किया गया है। कुल मिलाकर, इस शोध लेख के ज़रिए हम ये बताते हैं की, क्रिया का अनुमान लगाने के प्रक्रिया त्रुटिपूर्ण हो सकती है और इसका प्रभाव ऑनलाइन सेंटेन्स प्रॉसेसिंग पर भी दिखता है। अंततः हमारा ये मानना है की हिंदी व अन्य कर्ता-कर्म-क्रिया वाली भाषाओं के वाक्य विश्लेषण में पूर्वानुमान की भूमिका के पुनर्मूल्यांकन की सख्त ज़रूरत है। इसके साथ ही ऐंटाई-लोकैलिटी प्रभाव व नो-स्ट्रक्चरल फ़र्गेटिंग प्रभाव के वजहों की पद्धतिबद्ध तरीके से अन्वेषण की ज़रूरत है।

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## ABBREVIATIONS

|             |                                      |
|-------------|--------------------------------------|
| <b>RT</b>   | Reading Time                         |
| <b>SPR</b>  | Self-paced Reading                   |
| <b>SRC</b>  | Subject Relative Clause              |
| <b>ORC</b>  | Object Relative Clause               |
| <b>DLT</b>  | Dependency Locality Theory           |
| <b>SPLT</b> | Syntactic Prediction Locality Theory |
| <b>WM</b>   | Working-memory                       |
| <b>EU</b>   | Energy units                         |
| <b>MU</b>   | Memory units                         |
| <b>SOV</b>  | Subject-Object-Verb                  |
| <b>SVO</b>  | Subject-Verb-Object                  |
| <b>LC</b>   | Local Coherence                      |
| <b>RC</b>   | Relative Clause                      |
| <b>SOV</b>  | Subject-Object-Verb                  |
| <b>SVO</b>  | Subject-Verb-Object                  |
| <b>ERG</b>  | Ergative                             |
| <b>PERF</b> | Perfective                           |
| <b>NOM</b>  | Nominative                           |
| <b>DAT</b>  | Dative                               |
| <b>ABL</b>  | Ablative                             |
| <b>ACC</b>  | Accusative                           |
| <b>LOC</b>  | Locative                             |
| <b>INST</b> | Instrumental                         |
| <b>PST</b>  | Past                                 |
| <b>HAB</b>  | Habitual                             |
| <b>CONT</b> | Continuous                           |
| <b>INF</b>  | Infinitival                          |

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|             |                                       |
|-------------|---------------------------------------|
| <b>fMRI</b> | Functional magnetic resonance imaging |
| <b>DoM</b>  | differential object marking           |
| <b>ADV</b>  | Adverb                                |
| <b>PP</b>   | Prepositional Phrase                  |