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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 47(0)

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Publication Date

2025

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Peer reviewed

Leveraging Prediction to Investigate the Mental Lexicon: Evidence from an Agglutinating Language

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Abstract

While prediction has previously been considered a strong primitive in Subject-Object-Verb (SOV) languages, it is relatively unknown how prediction might manifest in morphologically complex languages with verbs that potentially undergo morphological decomposition into their constituent verb stems and affixes during online sentence comprehension. In this reading study, we looked at how such top-down (prediction) and bottom-up processes (decomposition) interact in an agglutinating language like Malayalam. We investigate two questions simultaneously (i) whether predicting a suffix actually confers any processing advantage during lexical access in real-time, similar to predicting a verb stem, and (ii) whether this can reveal something about the representations of verb stems and suffixes of words within the mental lexicon. We find that when predicted correctly, suffixes pattern similarly to verb stems, which seems to suggest that suffixes can have independent representations alongside verb stems, thereby aiding visual word recognition by acting as access points to activate lexical entries.

Keywords: language comprehension; word recognition; prediction; morphological complexity; morphological processing; understudied languages

Introduction

Irrespective of the degree of robustness we may be willing to attribute to the prediction mechanism, there is a general consensus on its role in cognition (Bar, 2007; Clark, 2013). Predictive processing has also been touted as instrumental in language processing (Kuperberg & Jaeger, 2016; Marslen-Wilson, 1975). The notion that linguistic units can be predicted well in advance of the actual input is thought to facilitate language comprehension in the presence of other processing demands and resource constraints (Haeuser & Kray, 2023; Kuperberg & Jaeger, 2016). Despite valid concerns about the actual extent of prediction that takes place (Apurva & Husain, 2021; Huettig & Mani, 2016; Luke & Christianson, 2016), an indisputable fact over years of psycholinguistic research has been that successful prediction does seem to ease certain processing demands by lending a facilitatory effect in processing, if not an outright advantage.

While previous work has delineated the limits to prediction in terms of preverbal complexity (Apurva & Husain, 2021), we would like to examine another potential source of complexity: morphological complexity at the verb itself. One way this could be operationalized is through studying the processing of morphologically complex verbs. A good testing ground for this purpose would be to look at agglutinating

languages which are characterised by rich inflectional systems. In this regard, Hankamer (1989) makes the case for agglutinating languages like Turkish, where morphologically complex verbs are possibly the norm rather than the exception, to underscore the importance of morphological parsing in such languages. Such a language in the Indian subcontinent that also possesses dense verbs comparable to traditionally studied agglutinating languages like Turkish and Finnish is Malayalam. The language boasts of highly productive affixation processes resulting in verbs that are phonologically and morphologically transparent (Krishnan, 2020).

Malayalam is also an SOV language. In these languages, we would expect predictive processing to be especially significant, since comprehenders can predict the upcoming clause-final verb even before encountering it in the sentence (Husain, Vasishth, & Srinivasan, 2014; Kamide, Altmann, & Haywood, 2003; Konieczny & Döring, 2003; Yamashita, 1997). The logic behind verb-final languages possibly developing robust prediction mechanisms follows from such languages having cues like preverbal nouns with rich information – case markers, for example – that help make reasonable estimations about the upcoming verb by narrowing down the possibilities that the verb can be or, at the very least, the form that the verb can take (Apurva & Husain, 2021). Malayalam could therefore be an effective candidate language to triangulate this question of how complexity at the verb manifests during processing when its components have been successfully predicted.

In our effort to situate the workings of predictive processing in a morphologically complex language, we contrast two models of morphological processing from the vast theoretical landscape based on their commitments to (a) discrete morphological representations in the lexicon, and (b) compositional processes that operate on complex words during word recognition.

One line of compositional models that have currency in the morphological processing literature is the Taft and Forster (1975) model and its heirs (Taft, 1979; Stockall & Marantz, 2006), which claim that following an affix-stripping procedure, lexical access is driven via the verb stem (or root), which makes contact with a central lexical entry in the mental lexicon. While some of these models differ on how the affixes are then attended to, older models proposed that within the lexical entry of the verb stem a local search is conducted

to find the corresponding affix from the input. Here, the representation of the verb stem is prized and therefore acts as an ‘access point’ (Cho, Pires, & Brennan, 2024). Prediction could pan out in such shared-entry frameworks in two different ways: If the verb stem is predicted correctly in advance, but the affixes are not, then a local search for the correct affix corresponding to the input could be carried out, and a complete overhaul might not be required. However, if the affix has been predicted correctly but the verb stem predicted incorrectly, then one would have to abandon the lexical entry for the verb stem that had been predicted earlier and start over the search for the correct stem’s entry. Affix representations are therefore subordinate to the verb stem in such models.

Other decompositional models privilege both representations of stems and affixes and say that during lexical access, both the stem and the affix can be activated in parallel. One such example of an independent-entry model is described in the Word and Affix Model of Complex Word Reading (Beyersmann & Grainger, 2023), where both the embedded stem and affix are activated simultaneously (using different mechanisms), followed by a matching of the input with the activated representations. In such a framework, both verb stems and affixes have independent representations (also see piece-based models as described in Embick, Creemers, and Goodwin-Davies (2022) and Halle and Marantz (1993)), implying that predicting either would be advantageous in the larger scheme of comprehension. Such models would therefore agree that affixes can also act as access points similar to verb stems.

Previous treatments that tackle this question of representations (Cho et al., 2024) have looked at priming, specifically root and suffix priming effects in English. We would like to use prediction as another potential methodology to probe whether verb stems and suffix representations are on equal footing in a morphologically complex language like Malayalam. In the studies reported below, we examine the processing of a complex word within a sentential context, seeing how sentences could represent a “more ecologically valid testing arena” (Caffarra, Karipidis, Yablonski, & Yeatman, 2022) for studying visual word recognition as opposed to studying the processing of words in isolation.

The Current Study

In order to explore the role of a suffix during lexical access, we present our results from two experiments: a norming study, which was a sentence completion task, and Experiment 1, which was a self-paced reading (SPR) task. To preview our results, we find that suffixes can indeed be predicted in the language using certain adverbials, and that when suffixes are predicted correctly, we do observe shorter reading times (RTs) on average. This would imply that within the lexicon, suffixes do have independent representations on equal footing with verb stems, allowing them to also function as access points during lexical access.

Norming Study: Sentence Completion

We first tested what stems and suffixes are predicted by Malayalam speakers using an online completion task. The intention with this exploratory study was three-fold: Firstly, it allowed us to test the effectiveness of the cues for predicting the suffixes. Secondly, the normed responses could also serve as items for the subsequent experiment. Thirdly, the paradigm could be utilized as a cloze task to assess the predictability of the verb stem for the next experiment.

Participants

30 native speakers of Malayalam were recruited to participate in the experiment. All participants were college students in the age range 18-30, with a mean rating of 6.8 on self-reported reading proficiency in the language on a 7-point Likert scale. Each experiment lasted for 30-45 minutes on average, following which they were remunerated INR 125 for their time.

Materials and design

As the task at hand was sentence completion, and we were looking at the verb stems and the suffixes that were being elicited, this experiment did not follow a factorial design. The suffixes that we were interested in eliciting in this task were the future tense and the negation suffix, such that participants would provide verb constructions that looked like V-FUT or V-FUT-NEG (where V - Verb stem; FUT - future tense suffix; NEG - negation suffix).

We intended on cuing the future tense suffix by way of temporal adverbials like ‘tomorrow’, ‘next year’, etc. (See Dillon, Nevins, Austin, and Phillips (2012) for a similar manipulation in Hindi). Tense is obligatory in Malayalam, and in pilots conducted prior to this study, we found that when given simple sentence preambles in the absence of any predictive cues, a verb stem with the simple past tense suffix is resorted to. Thus, with the past tense suffix being the default, and the simple present tense occurring infrequently, we decided on the future tense being a potential suffix to elicit.

Our reasoning for deciding on the negation suffix was again determined via previous pilots where we found that the adverbial ‘inimeilil’ (‘henceforth’/‘no longer’), functioning as a strong negative polarity item (NPI), could cue the prediction of the negation suffix. We also intuited that this adverbial would cue the prediction of the future tense (alongside the negation suffix as a portmanteau morpheme), since using ‘henceforth’ would have to necessarily situate the event described by the verb in the sentence in the future (similar to ‘Henceforth, I **will not** drink soda’ in English). In our study, 32 critical sentence preambles were designed with the above cues, along with 80 fillers. The preambles either contained 2 or 3 noun phrases (NPs). A pair of sample stimuli is given below:

(a) **To elicit V-FUT**

naale kuttī-je adhyapika _____
tomorrow child-ACC teacher _____
'Tomorrow the teacher _____ the child'

(b) **To elicit V-FUT-NEG**

inimeḷil kuttī-je adhyapika _____
henceforth child-ACC teacher _____
'Henceforth, the teacher _____ the child'

Procedure

Sentence completion paradigms have been used routinely in the comprehension literature to operationalize predictability in the form of cloze scores (Staub, Grant, Astheimer, & Cohen, 2015; Levy, 2008; Taylor, 1953), where the predictability of a word can be computed as the probability with which participants complete sentence preambles with that word.

Our paradigm was administered online via the PCIBex platform (Zehr & Schwarz, 2018). Stimuli were pseudorandomized such that at least 3 fillers intervened between critical trials. Sentences were displayed using a centered presentation. This was done to provide continuity with the later SPR experiment while ensuring that participants would have access to the same kind of visual environment when reading in both experiments.

Participants initially underwent a practice session where they familiarized themselves with the keypresses involved. Each trial in the experiment started with a fixation cross, followed by the individual words of a sentence which they navigated using successive presses of the space bar. At the end of the sentence preamble, a textbox appeared in which they would type in their completions using the English letters on their keyboard. Note that, unlike the traditional cloze procedure, here we only elicit the sentence-final verb and not every successive word following the first word.

Participants were instructed to read the sentence at a comfortable pace and complete it meaningfully with the first word/words that came to their mind.

Results

All responses were coded for whether the completion had the tense and negation suffix correctly predicted or not, along with the type of negation suffix. We also noted down the grammaticality of the response, and whether the completion was a complex predicate.

We report here the percentages of correctly predicted future tense (V-FUT) and negation suffixes (V-FUT-NEG): V-FUT was predicted correctly 100% of the time in those sentences with a temporal adverbial cuing the future tense. V-FUT-NEG was predicted correctly 99.4% of the time in those sentences with the NPI adverbial cuing the negation suffix. Of these, the negation suffix that negates verbal sentences '-illa' (Asher & Kumari, 1997) was elicited 95.6% of the time. The others were prohibitive imperatives (such as '-aruth' and '-enḍa').

These results clearly point to successful predictions being made for suffixes in the language and validate the usage of the aforementioned cues to elicit the suffixes that we are interested in for the purpose of the next experiment. Cloze scores were also calculated for different verb stems for each sentence preamble to be used in the following experiment.

Experiment 1 - Self-paced reading

To provide converging evidence from previous work in lexical access with tasks studying words in isolation, we examined the predictability of an upcoming verb stem and its suffixes within a sentential context through a self-paced reading paradigm.

Participants

59 native speakers of Malayalam were recruited to participate in the experiment. All participants were college students in the age range 18-28, with a mean rating of 6.27 on self-reported reading proficiency in the language on a 7-point Likert scale. Each experiment lasted for 30 minutes on average, following which they were remunerated INR 125 for their time.

Design and materials

Our experiment implemented a 2x2 within-subjects design manipulating the variables Verb Stem Predictability (with the levels Predictable stem (V_P) vs Not predictable stem ($!V_P$)) and Suffix Predictability (with the levels Predictable suffix (S_P) or a Not predictable suffix ($!S_P$)).

All critical stimuli comprised 2 or 3 NPs and the verb embedded in a reported speech context ('...ennā aval paraḷu' meaning 'She said that...') to account for spillover effects (Kaiser, 2013). The sentence preambles from the norming study were reused, with the verb stems created using the completions, such that high or low cloze scores from the completions determined whether the stem in a verb was predictable or not. We follow the conventions from Staub (2015) (who cite Rayner and Well (1996)'s study), where they report that RTs for words with low cloze probability (<0.08) differed significantly from words with medium (0.13-0.68) and high predictability (>0.68), with the medium and high cloze words not differing from each other significantly. In the sample stimuli below, the predictable stem 'thall-' and not predictable stem 'kaan-' have cloze scores of 0.45 and 0.04 respectively. Additionally, the presence or absence of the sentence-initial cue (to trigger the prediction of the upcoming suffixes) corresponded to the suffix being predictable or not. The cue here is the adverbial 'inimeḷil' ('henceforth') to elicit a V-FUT-NEG suffix. The critical region has been underlined, and the reported speech represented as [...] in the interest of space.

(a) **$V_P S_P$:**

inimeḷil kuttī-je adhyapika thal-illa [...] [$\dots$]
henceforth child-ACC teacher hit.FUT-NEG
'Henceforth, the teacher will not hit the child'

- (b) **V_P!S_P:**
kuṭṭi-je adhyapika thal-illa [...]
 child-ACC teacher hit.FUT-NEG
 ‘The teacher will not hit the child’
- (c) **!V_PS_P:**
inimeṭilil kuṭṭi-je adhyapika kaan-illa [...]
 henceforth child-ACC teacher see.FUT-NEG
 ‘Henceforth, the teacher will not see the child’
- (d) **!V_P!S_P:**
kuṭṭi-je adhyapika kaan-illa [...]
 child-ACC teacher see.FUT-NEG
 ‘The teacher will not see the child’

A total of 10 critical stimuli were derived based on the sentences from the norming study. Creating the stimuli was a non-trivial task, as verbs across conditions had to be matched for length to the extent possible. Additionally, some sentences from the norming study could not be reused, since they had completions containing repeated verbs or complex predicates. 48 fillers were interspersed between the critical stimuli, comprising sentences with intransitive constructions and other suffixes. Comprehension questions targeting the subject or direct/indirect object were also created for 50% of the critical items and fillers.

Procedure

We employed an SPR paradigm (Just, Carpenter, & Woolley, 1982), assuming that RTs (measured in milliseconds) index relative momentary processing difficulty. Our experiment was designed and hosted on the PCIBex platform (Zehr & Schwarz, 2018). Sample stimuli were randomized and displayed using a centered presentation and followed a Latin square design. Each session began with a practice run. At the beginning of each trial, participants saw a fixation cross on their monitors, followed by the individual words in a sentence which they navigated through using successive presses of the space bar. 50% of all trials were followed by a comprehension question targeting different parts of the sentence. Participants were instructed to read at a comfortable pace and answer the question that appeared at the end of some of the sentences.

Predictions

Under the assumption that RTs can act as a proxy for relative processing difficulty contingent on successful predictions, we hypothesize the following: Models that claim independent representations for both verb stem and suffix would predict a main effect of stem predictability and/or a main effect of suffix predictability - crucially without any interaction effects - such that RTs of verbs with predictable stems are on average read faster than RTs of verbs with not predicted stems (in the sample stimuli, corresponding to conditions (a) + (b) «

(c) + (d)), and/or RTs of verbs with predictable suffixes are read faster than verbs with not predicted suffixes ((a) + (c) « (b) + (d)), implying that predicting the suffix has an advantage whether or not the stem is predicted, and that suffixes have an independent status of their own. Alternatively in the shared-entry world, if we find an interaction effect such that the difference in verb stem predictability differs for different levels of suffix predictability ((b) - (a) « (d) - (c)), this would show that due to partial revision of the stem, predicting the suffix is immaterial unless you have correctly predicted the stem, resulting in a kind of bottom-up reading of the entire verb.

Data analysis

No participant answered more than 20% of all comprehension questions incorrectly. RTs above 3000 ms were filtered, which resulted in 2.3% of our data being unused. We believe this to be a fair criterion based on the following aspects of our design: Computing z-values and discarding values greater than 3 is fairly typical in SPR experiments (see Ratcliff (1993) and Wagers, Lau, and Phillips (2009) for precedents). We also computed an upper bound of 2376ms using the interquartile range, against which we believe our criterion is a more conservative estimate. Additionally, in a separate lexical decision task, we found subjects taking not more than 1500ms on average to attend to complex words, which included these two suffixes, when such words were presented in isolation. Lastly, sparse RT values such as 3000ms can reasonably be attributed to participants waiting too long on a keypress.

For our analysis, linear mixed-effects models over log RTs at the critical region (the verb) and the post-critical region (the quotative particle ‘ennə’ in the reported speech clause) were fit, with Verb Stem Predictability, Suffix Predictability and an interaction term as fixed effect predictors. Both predictor variables were sum-coded. Maximal random effects were added to the extent supported by the model, following the recommendations of Barr, Levy, Scheepers, and Tily (2013).

Results

Figure 1 shows RTs at the critical and post-critical regions for the four conditions. In the critical region, we find a significant effect for Suffix Predictability ($t = 2.35$, $p = 0.01$), implying that verbs with predicted suffixes were indeed read faster, even if the verb stem was not predicted (as in condition (c)). We also found a main effect of Verb Stem Predictability ($t = 2.04$, $p = 0.04$).¹ In the postcritical region, we find a significant effect for Suffix Predictability only ($t = 2.44$, $p = 0.01$). There were no significant interactions in either model.

Note that our model estimates in Table 1 are in the log scale.

¹We note that the main effect of verb stem predictability was less stable when we did not remove some outliers from the data.

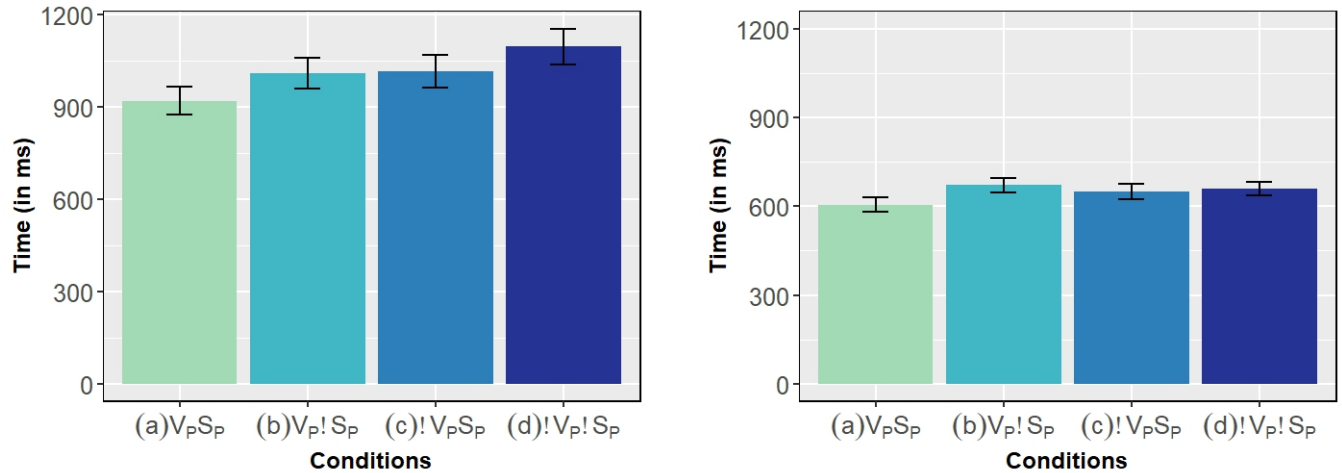


Figure 1: Reading times (RTs) in ms at the critical (left bar plot) and post-critical (right) regions across the four conditions

	Critical Region				Postcritical Region			
	Coefficient	SE	<i>t</i> -value	<i>p</i> -value	Coefficient	SE	<i>t</i> -value	<i>p</i> -value
Intercept	6.79	0.06	109.78	<0.001	6.4	0.02	223.73	<0.001
Verb Stem Predictability	0.03	0.01	2.04	0.04	0.01	0.01	0.90	0.37
Suffix Predictability	0.04	0.01	2.35	0.01	0.03	0.01	2.44	0.01
Verb Stem:Suffix Predictability	0.006	0.01	0.35	0.71	-0.02	0.01	1.67	0.09

Table 1: lmer model output at the critical and post-critical regions with predictors Verb Stem predictability and Suffix predictability for Experiment 1.

Discussion

In a self-paced reading experiment, we probed whether the predictability of a suffix may be comparable to the predictability of a verb stem during lexical access in comprehension.

Reconciling these results with previous literature, we find that the independent entry line of models is able to explain this set of data, which claim that predicting a suffix is akin to predicting a verb stem in relation to the parallel activation routes they employ, and that the outcome associated with the predictability of a suffix is not wholly contingent on the predictability of the verb stem.

The central question that we wanted to arrive at with this experiment was – What could prediction imply representationally? The picture of the mental lexicon that emerges from our data is thus: During the processing of a sentence, available cues trigger the predictions of stems and suffixes through pre-activation. These could be semantic, syntactic, phonological or even contextual. At this stage, while we cannot commit to a singular model of morphological processing and can only speculate, our data (following from the specifications of the independent entry models) seems to lean towards an architecture with network-like connections with multiple layers of representation for orthography, phonology, morphol-

ogy, semantics and so on. Therefore, a semantic cue could predictively preactivate a morphological node/unit. Once the parser actually arrives at the verb, a process of morphological decomposition takes place, segmenting it into its constituent verb stem and affixes. This is followed by the activation of the embedded stem and a parallel activation of the affix representations. Since our suffix has already received a certain amount of activation, a facilitatory effect is observed in the form of shorter RTs at the verb on average.

We do not make any claims at this point about the nature of the representations of the verb stems and suffixes themselves, as this isn't explicitly tested for in the experiments. We speculate that the representations themselves could look very different – for example, assuming a feature-based representation, the verb stem's internal representation could be specified for features like valency, whereas affixes could be specified for the word class of the resulting word when affixed to a stem (as in the case of derivational affixes). This set of experiments concerns itself only with whether the mechanisms recruited by these representations are similar, and about the outcomes of these mechanisms in terms of a reduction in processing demands (as reflected by shorter RTs).

Claims about predictions must additionally be complemented by a note on the maintenance of said predictions.

Storage costs (in the sense of Gibson (1998)) associated with maintaining predictions before the predicted unit is encountered could accumulate, or the strength of predictions could decay given the complexity of the intervening material. In our study, simple NPs intervened between the cue and the verb, where the first NP was marked for either the accusative/dative case, and the second NP was always (zero) marked for the nominative. A case marker would always appear only on the first NP, across all items. We therefore do not expect maintenance to be a confound for this set of data.

We would also like to comment on the nature of the cues used to elicit the prediction of suffixes here. Dillon et al. (2012) showed in an acceptability judgement task with electrophysiological measures that the parser reacts differently to incorrectly made morphological predictions when preceded by a semantic cue (a past temporal adverbial like ‘yesterday’ to elicit past tense forms) versus a morphosyntactic cue (the ergative case marker to elicit perfective forms). In our study, we made use of a syntactic cue (the NPI adverbial) to elicit the future+negation suffix (and also a semantic cue to elicit tense in the first completion study). The nature of the dependencies formed between the cue and the predicted suffix is therefore different for each of these manipulations, potentially leading to a qualitative difference in the kinds of suffixes that can be predicted. In order to tackle the previous question of maintenance costs in the face of complexity, and the current question of the cues themselves, we intend on capitalizing on the rich system of inflectional affixes in the language to study if and how our findings may change when successively more complex verb constructions, and consequently multiple cues to elicit their prediction, are introduced in the sentence.

Finally, it is important to note that we have not set up our hypothesis space to include hybrid models of lexical access that propose multiple routes during lexical access – where certain words are accessed as whole words while others undergo decomposition – subject to factors like regularity (Marslen-Wilson & Tyler, 1998), frequency (Caramazza, Laudanna, & Romani, 1988; Giraudo & Grainger, 2003), etc. We hypothesize that given its agglutinative nature, Malayalam speakers are much less prone to encountering irregular words (Krishnan, 2020), and thus the distinction observed between regular and irregular words in studies with languages like English might not neatly translate as such in languages like Malayalam. As for those models that propose a differential effect based on frequencies of the units involved, we do allow for the possibility that such factors would play a significant role across all languages, and in fact we concede that frequency measures like stem frequency and suffix frequency (and also possibly surface frequency) will have to be incorporated into future replications to present a clearer picture of the predictive mechanisms at work.

Despite these caveats, we reiterate that our results still provide evidence in support of suffixes having a cognitive reality in the mental lexicon that is separate from verb stems. Aside from being relatively understudied in the wider psycholin-

guistic literature, our study in Malayalam also addresses limitations of previous work in the lexical processing literature by situating the verb within a sentential context instead of studying it in isolation.

Conclusion

Previous work in the prediction literature has demonstrated that correctly predicting, say, a verb (or a verb stem in a morphologically complex language) in advance would lead to an easing of processing demands once the verb is actually encountered. Our objective with the reported experiments was to test whether this kind of advantage is extended to the other morphemes within the verb as well, namely the suffixes in Malayalam.

In a sentence completion experiment, we were first able to confirm that given the right cues, suffixes like tense and negation could be predicted consistently. In a self-paced reading experiment, we examined the status of the predictability of the suffix with respect to the predictability of its verb stem, and found that predicting a suffix correctly lent itself to faster reading times at the verb independent of correctly predicting the verb stem. These results are in accordance with the independent entry line of models, which claim a separate representation for suffixes in which they are not subordinate to the verb stem. In such an architecture, suffixes could also act as access points during lexical access. In studying morphological processing in a predictive framework, our work has implications for existing processing accounts of both prediction and morphology in regard to how top-down and bottom-up processes interface during online processing.

Acknowledgments

We would like to thank Dr. Kishore Selva Babu and the students of Christ University (Bangalore) for their help with the data collection; Gicy George for helping with stimuli preparation; and the anonymous reviewers of CogSci 2025 for their suggestions.

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