

# Interaction of language-specific and cross-linguistic strategies during agreement computation - Evidence from Hindi

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## Abstract

Errors during sentence production have revealed crucial insights about the cognitive underpinnings of language processing. One such widely studied error is the agreement attraction error. Such errors occur when the subject-verb agreement, a crucial linguistic dependency, falters such that the verb shows the features of a ‘distractor’ noun rather than that of the target subject. Previous work on agreement attraction has established similar cross-linguistic patterns, such as the number mismatch asymmetry effect. Such research suggests that the underlying mechanism for agreement computation might be universal. Recent studies, however, indicate that Hindi employs a language-specific strategy during agreement processing that is not reported in other languages. This raises an important question: do the cross-linguistic patterns observed in agreement processing also manifest in Hindi? Our experiment investigates this question by using a preamble repetition task. Based on the nature of mismatch asymmetry and the structure of Hindi nouns, we hypothesize that if number mismatch asymmetry occurs, it should be limited to feminine nouns in Hindi. Our findings confirm the presence of mismatch asymmetry in Hindi, but exclusively for feminine nouns. This suggests that while agreement mechanisms can indeed be influenced by language-specific configurations, certain universal processing strategies are active cross-linguistically. We explain these findings within a cue-based retrieval framework.

**Keywords:** language production, agreement, errors, agreement attraction; Hindi; mismatch asymmetry; markedness; cross-linguistics; SOV; cue-based retrieval; representational; feature percolation

## Introduction

We establish long-distance relationships among words when we construct sentences. Understanding these relationships provides insight into the cognitive foundations of language. A commonly observed long-distance relationship in languages is subject-verb agreement, where the form of the verb changes depending on the subject<sup>1</sup> (see Fig. 1(a)).

Eliciting errors and understanding their patterns have proven to be a vital method of inquiry for the field of psycholinguistics (Traxler, 2011). Likewise, errors of agreement provide crucial insights about the cognitive processes underlying subject-verb agreement. Agreement attraction errors are errors where a ‘distractor’ noun (Fig.1 (b)) influences the verb form instead of the subject. Agreement attraction was first studied in production (e.g., Bock & Miller, 1991; Franck,

<sup>1</sup>Subject-verb agreement is just one kind of agreement; there can also be object-verb agreement. A better term for the noun with which the verb agrees would be ‘controller.’ Given the scope of this paper, we stick to using the term ‘subject.’

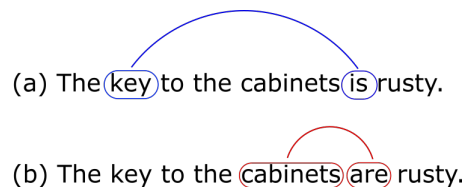


Figure 1: In (a) the verb shows agreement with its subject ('key'), while in (b) it shows agreement with a distractor noun ('cabinets'). (b) is a case of agreement attraction.

Lassi, Frauenfelder, & Rizzi, 2006; Badecker & Kuminiak, 2007; K. M. Eberhard, 1997; Franck, Ve, Vigliocco, & Nicol, 2002; Nicol, Forster, & Veres, 1997; Bock & Eberhard, 1993), then in comprehension (e.g., Wagers, Lau, & Phillips, 2009; Lago, Shalom, Sigman, Lau, & Phillips, 2015; Jäger, Merten, Van Dyke, & Vasishth, 2020; Laurinavichyute & von der Malsburg, 2022).

Broadly, two sets of theoretical accounts explain agreement attraction during sentence production. In the representational accounts (e.g., Bock & Miller, 1991; Franck et al., 2002; K. Eberhard, Cutting, & Bock, 2005; Hammerly, Staub, & Dillon, 2019) a linguistic feature (e.g., number) from the distractor moves up to the subject phrase, changing the linguistic representation of the subject in the process. This movement is called feature percolation and is the primary cause of agreement attraction.

The other account is called the retrieval account (e.g., Lewis & Vasishth, 2005; Wagers et al., 2009; Jäger et al., 2020; Yadav, Smith, Reich, & Vasishth, 2023; Badecker & Kuminiak, 2007). According to this account, the subject is retrieved during production at the agreement site. Sometimes, this retrieval mechanism falters, giving rise to agreement attraction. While the current work is not intended to adjudicate between these accounts, we discuss the results in the light of these accounts.

Many early production studies utilized a preamble repetition task (e.g., Bock & Miller, 1991; K. M. Eberhard, 1997; Thornton & MacDonald, 2003; Vigliocco & Nicol, 1998; Franck et al., 2002) where the participants listened to or saw an incomplete sentence and repeated the preamble while completing it. Two conditions were mainly compared for such tasks. The first condition is called the match condition, where the subject and the distractor match in features (similar

number features as in Example 1a). Errors in a match condition cannot be attributed to agreement attraction. The other condition is called the mismatch condition, where the subject and the distractor differ by a feature (such as in Example 1b).

- (1) Agreement attraction is the difference between the accuracies in a match and a mismatch condition.
  - a. Match: The key to the cabinet ...
  - b. Mismatch: The key to the cabinets ...

Agreement attraction has been found during production in English (e.g., Bock & Miller, 1991; K. M. Eberhard, 1997; Thornton & MacDonald, 2003; Staub, 2009, 2010), Spanish (e.g., Anton-Mendez, Nicol, & Garrett, 2002; Lorimor, Jackson, & Foote, 2015), Russian (Lorimor, Bock, Zakkind, Sheyman, & Beard, 2008; Slioussar & Malko, 2016), French (Franck et al., 2006, 2002), Slovak (Badecker & Kuminiak, 2007), Hindi (Bhatia & Dillon, 2022), Dutch (Veenstra, Acheson, Bock, & Meyer, 2014) and many other languages. One well-attested phenomenon across languages is the number mismatch asymmetry effect (e.g., Bock & Miller, 1991; K. M. Eberhard, 1997; Staub, 2009; Kandel, Wyatt, & Phillips, 2022).

In the number mismatch asymmetry effect, one kind of distractor (i.e., plural distractors) shows more agreement attraction than its counterpart (i.e., singular distractors). A widely agreed upon explanation for such an effect is that plural nouns have a number feature, while singular nouns do not (e.g., Bock & Miller, 1991; Franck et al., 2002; K. Eberhard et al., 2005; Staub, 2009). For example, in English, ‘cats’ has an ‘s’ marking the plural, and its absence in ‘cat’ makes it singular. This criterion has been used to judge the presence or absence of a feature. For our convenience, we will call it the ‘number mismatch criterion.’

In this work, we inquire into the universality of ‘mismatch asymmetry.’ If a language is known to use a distinct strategy for noun-verb agreement, will it still show mismatch asymmetry? Furthermore, is the aforementioned ‘number mismatch criterion’ also applicable universally? Broadly, this helps us to understand the interplay between language-specific processing strategies vs. strategies that can be deemed universal.

### Agreement Attraction in Hindi

Hindi is an SOV language whose agreement is argued to employ a unique mechanism not reported in previously studied languages such as English, Spanish etc. (Bhatia & Dillon, 2022). According to Bhatia and Dillon, nouns in Hindi are encoded for an abstract controller feature which guides agreement. A distractor can only cause agreement attraction if it is coded as a ‘controller.’ The subject is always encoded with this feature. One way to ensure that the distractor has a controller feature is to check if it participates in agreement elsewhere (Figure 2 (a)).

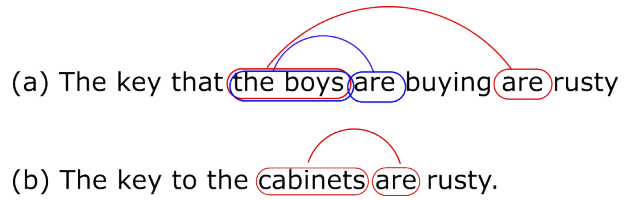


Figure 2: In (a), the distractor (‘the boys’) controls the agreement within its own clause; while in (b) the distractor (‘cabinets’) doesn’t.

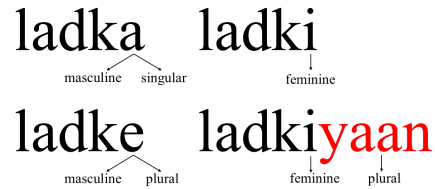


Figure 3: Gender and number morphemes in masculine are presented together as one morpheme (a fusal morpheme). On the other hand, number morpheme is missing in feminine singular but present in feminine plural as a separate morpheme.

Assuming Bhatia and Dillon (2022)’s hypothesis to be true, i.e., distractor needs to necessarily have a controller feature to cause attraction, we ask an important follow-up question: Is agreement in Hindi sensitive ‘only’ to this controller feature? In other words, will having a distractor with a controller feature, the sole condition to elicit attraction? For our convenience, we call it as the ‘controller-only’ hypothesis, i.e. agreement is ‘only’ guided by this controller feature and ‘nothing else.’ Our primary goal is to investigate this hypothesis. This is an important direction of investigation given Bhatia and Dillon (2022) did not manipulate the number of their distractor in their experiments, i.e. it was always plural.

To do so, we only take distractors which have a controller feature and test the presence of mismatch asymmetry in Hindi. If mismatch asymmetry is absent in Hindi, then agreement is ‘only’ guided by the controller feature. This will support the controller-only hypothesis. If mismatch asymmetry is present in Hindi, then we can conclude that agreement is also influenced by other factors. This will reject the controller-only hypothesis.

Additionally, in Hindi, number and gender morphemes are fusal in masculine nouns but not in their feminine counterparts (Figure 3). Applying the ‘mismatch asymmetry criterion’, if mismatch asymmetry arises, it should be restricted to feminine nouns. This is because an overt number marker stays present in the masculine plural as well as the singular. On the other hand, in the feminine singular, there is an absence of an overt marker, unlike in its plural counterpart. So, our secondary goal is to investigate whether ‘mismatch asymmetry criterion’ can be applied beyond cases where the number of morphemes are transparent.

## Experiment

### Task and Procedure

We used a preamble repetition task (e.g., Bock & Miller, 1991; K. M. Eberhard, 1997; Thornton & MacDonald, 2003; Vigliocco & Nicol, 1998; Franck et al., 2002). The participant first saw a fixation cross at the middle of the sentence (Screen 1 in Fig. 4). The participants could take a break anytime they wanted at this screen. When the participant pressed SPACEBAR, ‘\*\*\*’ was shown in the middle of the screen for 600 ms (Screen 2 in Fig. 4) before moving to the next screen. In the next screen, an incomplete sentence like 2a-d was shown for 5000 ms (Screen 3 in Fig. 4) followed by a trigger (Screen 4 in Fig. 4) where the recording started automatically. The participants had to repeat the sentence verbally and complete it as soon as they saw the trigger. There were no restrictions on what they could say to complete the sentence. They pressed ENTER after completing the sentence. The experiment was designed using PCIBex (Zehr & Schwarz, 2018).

(2) a. Match Singular:

wo ladka jise wo kutta dauda  
that boy-M.SG whom that dog-M.SG chase  
raha tha abhi bhi bhag \_\_\_\_  
PROG-M.SG be-PST.SG now still run \_\_\_\_

‘That boy whom that dog was chasing \_\_\_\_ still running.’

b. Match Plural:

wo ladke jise wo kutte dauda  
that boy-M.PL whom that dog-M.PL chase  
rahe the abhi bhi bhag \_\_\_\_  
PROG-M.PL be-PST.PL now still run \_\_\_\_

‘Those boys whom those dogs were chasing \_\_\_\_ still running.’

c. Mismatch Singular:

wo ladka jise wo kutte daude  
that boy-M.SG whom that dog-M.PL chase  
rahe the abhi bhi bhag \_\_\_\_  
PROG-M.PL be-PST.PL now still run \_\_\_\_

‘That boy whom those dogs were chasing \_\_\_\_ still running.’

d. Mismatch Plural:

wo ladke jise wo kutta dauda  
that boy-M.PL whom that dog-M.SG chase  
raha tha abhi bhi bhag \_\_\_\_  
PROG-M.SG be-PST.SG now still run \_\_\_\_

‘Those boys whom that dog was chasing \_\_\_\_ still running.’

### Materials and Design

The experiment had a 2x2 within-subject design. We manipulated two factors: Match and Number. The Match factor was the feature difference between the subject and the distractor. The Match factor had two levels. The first level, match (2a

& 2b), referred to the conditions where the subject and the distractor matched in their number feature. The second level, mismatch, referred to the conditions where the subject and the distractor differed in their number feature. The Number factor was the number of the subject. It had two levels, singular (2a & 2c) and plural (2b & 2d). We used 32 items in total.

Recall that we are interested in investigating the effect of fusional morphology during agreement attraction. In order to investigate this, out of the 32 items, 16 had masculine nouns and the other 16 had feminine nouns.

Similar to Experiment 1 in Bhatia and Dillon (2022), we used sentences with a subject modified by an object-relative clause and a verb. We included ‘abhi bhi’ before the verb, roughly translating to ‘still’, to influence the participants towards producing the progressive aspect. This is because the progressive aspect in Hindi contains both the number and gender features. Unlike, Bhatia and Dillon, the nouns only differed by one feature similar to previous studies investigating number mismatch asymmetry (e.g., Bock & Miller, 1991; K. M. Eberhard, 1997; Staub, 2009; Kandel et al., 2022).

### Participants

We collected data from 65 participants (preregistered on OSF).<sup>2</sup> Data elicited from one participant got corrupted so we ran our analysis on the data from 64 participants. The pre-registered participant number was decided through a power analysis based on a norming study with 30 participants. The power analysis showed a requirement of 55 participants to reach 80% power for the main effect of Match (getting a main effect of match indicates the presence of agreement attraction); we decided to collect data from 65 participants in anticipation of data loss during data collection. The average age of our participants was 23 (25 females and 40 males). Like Bhatia and Dillon, data was collected only from Western Hindi speakers, who show gender agreement and ergativity in their grammar. The participants were selected based on a pretest. Participants were given remuneration following the recommendations from the institute’s ethics committee.

### Analysis procedure

All the recordings were manually coded for gender and number of the controller, attractor and auxiliary verb produced by the participants. There were many cases where the gender value was not recoverable from the agreement due to use of certain forms of ending or muffled audio. A total of 173 (0.084%) such observations were coded as NA. Hence, we focused only on the correct number agreement at the verb and marked it as 1, otherwise 0. To emphasize, in our analysis, non-agreement errors were NAs, and only agreement attraction errors were considered errors (as 0s). We only accepted instances where the participants repeated the subject and the distractor with gender and number as intended in the stimuli.<sup>3</sup>

<sup>2</sup><https://osf.io/8tznj>

<sup>3</sup>We also accepted such cases where the participants produced a different noun, as long as their gender and number features were

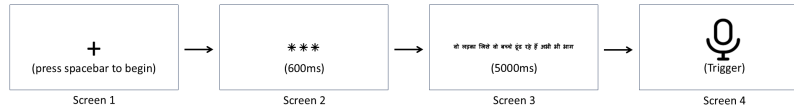


Figure 4: Trial sequence for the preamble repetition task.

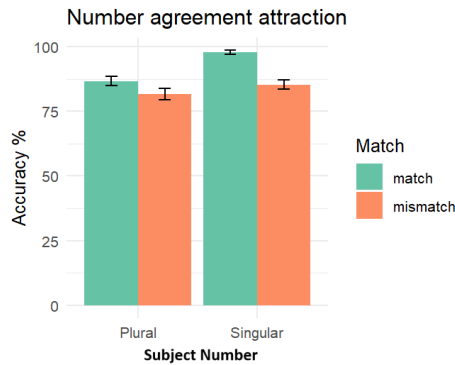


Figure 5: Overall accuracy percentages across four conditions in Experiment 1.

All the analysis was done using R programming language (version 4.3.1) (R Core Team, 2022). We analyzed the agreement accuracy in the experimental conditions with a Bayesian logistic regression model using the brms package (Bürkner, 2017). The dependent variable was the response type (coded as 0 or 1), modelled as a binary outcome with a Bernoulli distribution. In the model all the factors were sum-coded. For the Match factor, mismatch was coded as 1 while match was coded as -1. For the Number factor, conditions with singular subjects were coded as 1 and plurals as -1. For the additional analysis to investigate the effect of fusional morphology, i.e., the effect of Gender, items with feminine nouns were coded as 1 and masculine as -1. Our priors were as follows:

- Intercept: Normal ( $\mu = 2.65$ ,  $\sigma = 1$ ). In terms of percentage, the central 95% ranged from  $\approx 66.5\%$  to  $\approx 99\%$  accuracy centred at 93.4%. The point estimate is taken from Bhatia and Dillon (2022)'s experiment 1, while the spread assumes that agreement accuracy is high among speakers.
- Main effects and interactions: Normal ( $\mu = 0$ ,  $\sigma = 1.5$ ). In terms of percentage, if we assume the effect size to be around 93.4%, then this prior means that there can be a change in the accuracy with the central 95% ranging from  $\approx -17\%$  to  $\approx 5\%$  centred at 0.
- Standard deviation: Normal ( $\mu = 0$  and  $\sigma = 0.5$ )
- Correlation matrices: LKJ distribution (Lewandowski, Kurowicka, & Joe, 2009; Schad, Betancourt, & Vasishth, 2021) with  $\eta = 2$ .

same as the stimulus. This was done to avoid unnecessary data loss.

We present credible intervals<sup>4</sup> to express our confidence in the true effect.

## Predictions

If our data captures agreement attraction, we expect to see an effect of Match such that the mismatch condition leads to less accuracy than match conditions. If number mismatch asymmetry exists in our data, as reported cross-linguistically, we expect to see an interaction effect such that items with a singular subject will show more agreement attraction than those with a plural subject. Finding a mismatch effect also means that we have evidence against the 'Controller only' hypothesis. With regard to the investigation involving the effect of fusional morphology on mismatch asymmetry effect, an interaction effect between Match, Number and Gender such that the interaction between Number and Match is driven by feminine nouns, will mean that the 'number mismatch criterion' applies in Hindi.

## Results

Figure 5 shows a graphical representation of the accuracies across Match and Number. These percentages show that the difference between match and mismatch conditions are much higher in singular condition than in plural condition. The overall accuracy in singular condition is higher than the plural condition.

Our statistical analysis revealed an estimate of -0.75 [95% CrI: -1.18, -0.36] for Match, 0.75 [95% CrI: 0.32, 1.23] for Number, and -0.58 [95% CrI: -1.02, -0.19] for the interaction between Match and Number. A nested analysis showed that the effect of Match in the singular condition (-0.59 [95% CrI: -0.91, -0.25]) was much higher than the effect of Match during the plural condition (-0.17 [90% CrI: -0.54, 0.20]). Hence, we are 95% confident the true effect for Match and the interaction of Match and Number is negative while for Number, it is positive.

Figure 6 and 7 show a graphical representation of the accuracies in percentage across Match and Number for feminine and masculine conditions, respectively. These percentages show that the overall mean accuracy decrease from a match to a mismatch condition in singular is much higher than plural in feminine conditions than for masculine conditions. In addition to that, the difference between match and mismatch in

<sup>4</sup>We do not adopt a hard and fast rule of 95% CrI not containing zero as the only test for having an effect. Instead, look at the posterior spread to make informative judgements regarding the uncertainty (see McElreath (2018); Chromý, Lacina, and Dotlačil (2023) for use of credible intervals less than 95%).

the feminine singular condition is much higher than in masculine conditions. Finally, we see that the accuracy decrease in the feminine plural condition is higher than in the masculine plural condition.

We added Gender as another factor in the analysis to investigate the influence of fusional morphology.<sup>5</sup> For the interaction effect between Match, Number and Gender, we obtained an estimate of -0.35 [90% CrI: -0.67, -0.03]. A nested analysis gives an estimate of -0.79 [95% CrI: -1.28, -0.32] for the interaction of Match and number when considering only the feminine condition and -0.06 [95% CrI: -0.47, 0.35] for the interaction between Match and Number when considering only the masculine condition. This shows that this interaction is majorly isolated to the feminine condition and could even be missing from the masculine condition.

For the Gender effect, we obtained an estimate of -0.4 [90% CrI: -0.75, -0.05]. For the interaction between gender and number, the estimate was 0.08 [90% CrI: -0.25, 0.41]. Finally, for the interaction between match and gender, the estimate was -0.37 [90% CrI: -0.71, -0.06]. A nested analysis revealed that the estimate of match in feminine condition (-0.98 [95% CrI: -1.47, -0.50]) show a much higher and consistent effect than in masculine condition (-0.25 [95% CrI: -0.66, 0.17]) where the effect either non-existent or uncertain. Hence, this effect is atleast higher in feminine condition than the masculine condition.

Overall, after the second analysis, we are 90% confident that the true effect for gender, the interaction between match and gender, and match, number and gender is negative (see McElreath (2018); Chromý et al. (2023) for use of credible intervals less than 95%).

## Discussion

The current study provides us with four key findings - (1) Hindi exhibits agreement attraction, confirming the effect observed in Bhatia and Dillon (2022), (2) Hindi shows mismatch asymmetry during agreement attraction, (3) mismatch

<sup>5</sup>We do not report the effect of Number, Match, and their interaction in the second analysis because the estimates were similar to the previous analysis.

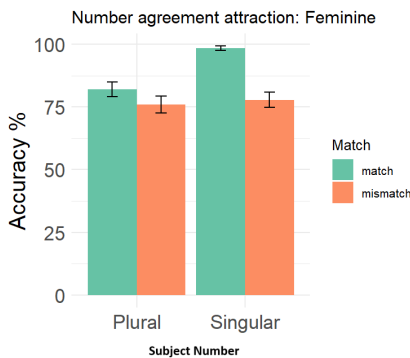


Figure 6: Accuracy percentages across four conditions in Experiment 1 in feminine conditions.

asymmetry is higher and isolated to items with feminine nouns than items with masculine nouns, and finally (4) agreement attraction in Hindi is much higher in items with feminine nouns than in items with masculine nouns. Taken together, we find evidence against a ‘controller-only’ hypothesis. Additionally, we find evidence for the ‘number mismatch criterion.’ Given these findings, we can now examine them through the lens of theoretical frameworks that account for agreement attraction.

The feature percolation account can explain these findings partially. In particular, this account can explain the number mismatch asymmetry. It can also explain the 3-way interaction between Gender, Number and Match, i.e., a higher prevalence of mismatch asymmetry in case of items with feminine noun compared to items with masculine nouns (cf. Figure 10 vs Figure 11). However, it fails to explain the observed Gender×Match interaction, i.e., items with feminine nouns show more agreement attraction than items with masculine nouns. This suggests that the features of the subject noun can also influence agreement attraction (Slioussar & Malko, 2016). The feature percolation account currently lacks a mechanism to incorporate the effect of subject noun on agreement attraction.

Similar to the feature percolation account, the retrieval account can also explain the mismatch asymmetry found in the current work. However, as we discuss below, the other results can only be explained by this account under certain additional assumptions. Previous research (e.g., Badecker & Kuminiak, 2007; Kandel et al., 2022) has suggested that during production the cue at the retrieval site is more sensitive to a plural feature (compared to a singular feature). However, under this assumption a mismatch asymmetry should appear for items with masculine as well as feminine nouns. For the retrieval account to explain the 3-way interaction between Gender, Number and Match, it needs to assume that the retrieval cue is sensitive to the presence of a ‘Number’ marker. Relatedly, it needs to assume that the +number feature will be active whenever the noun has a number morpheme/marker; see Figure 12 vs. Figure 13.

Finally, can the cue-based retrieval account explain the

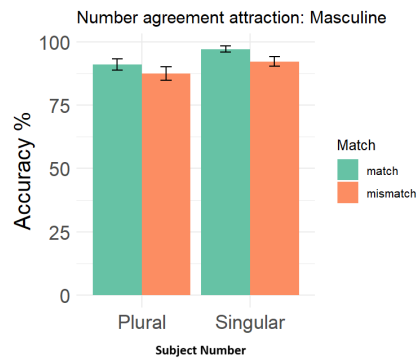


Figure 7: Accuracy percentages across four conditions in Experiment 1 in masculine conditions.

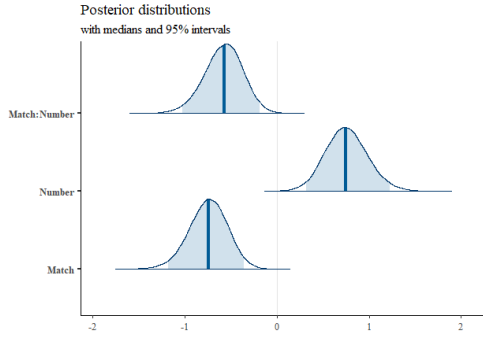


Figure 8: Posterior distribution of match, number and their interaction. The shaded area in the graph shows 95% confidence intervals.

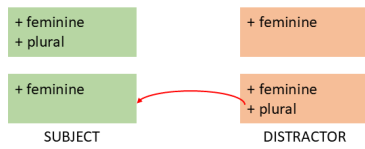


Figure 10: A number feature can only percolate up from a feminine plural distractor. Hence, there should be a mismatch asymmetry effect.

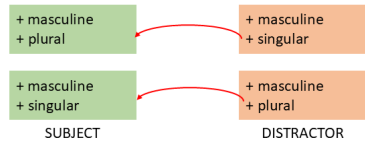


Figure 11: A number feature can always percolate to the subject for masculine nouns. Hence, there should not be a mismatch asymmetry effect.

Gender×Match interaction? Recall that items with feminine nouns show more agreement attraction than items with masculine nouns. This effect can also be explained by the cue-based retrieval account. In masculine items the distractor gets a partial activation boost from the +number feature. On the other hand, in feminine nouns, the distractor gets a relatively higher boost from the +number feature (i.e., in items with feminine nouns); see Figure 12 vs. Figure 13. This asymmetry explains the Gender×Match interaction. Overall, this suggests that a cue-based retrieval account can explain the key findings better.

Together, our findings confirm the presence of mismatch asymmetry in Hindi but exclusively for feminine nouns. This suggests that while agreement mechanisms can indeed be influenced by language-specific configurations, certain universal processing strategies are active cross-linguistically.

## Conclusion

We conducted a sentence production experiment which aimed to test whether cross-linguistic patterns can emerge in a language like Hindi, which uses a language-specific agreement strategy. To do so, we checked if Hindi shows number mis-

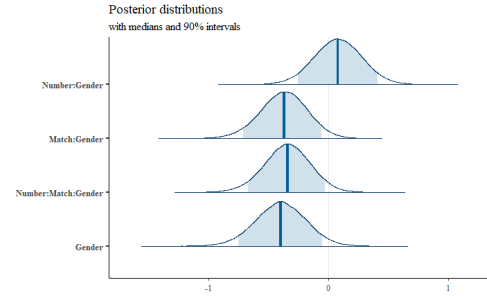


Figure 9: Posterior distribution of gender, the interaction between number and the three way interaction. The shaded area in the graph shows 90% confidence intervals.

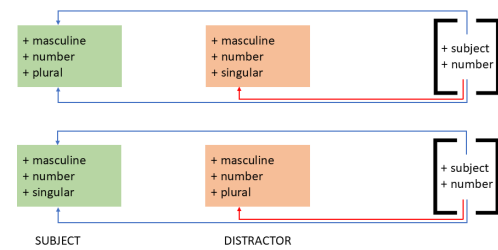


Figure 12: Cues that can pick out a subject are generated at the agreement site during production. +subject is an abstract cue representing all those cues. The +number feature is always shared amongst the subject and the distractor for the masculine nouns. Hence, there should not be a mismatch asymmetry effect.

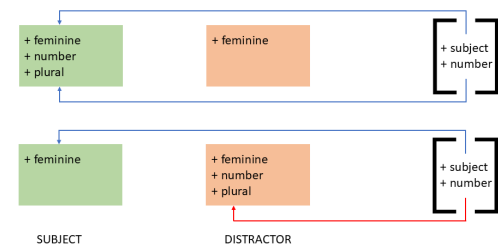


Figure 13: Cues that can pick out a subject are generated at the agreement site during production. +subject is an abstract cue representing all those cues. The +number feature only matches the distractor when it is plural in feminine nouns and not when it is singular. Hence, there should be a mismatch asymmetry effect.

match asymmetry, a pattern attested cross-linguistically. Additionally, Hindi also provided us with a unique opportunity to test the influence of fusional morphology on number mismatch asymmetry. Results show that mismatch asymmetry is indeed observed in Hindi. Interestingly, this effect was only active for items with feminine nouns suggesting that the presence of a number marker correlates with the presence of number feature. We argued that a cue-based retrieval account can explain these findings better. Together, our results highlight the interplay of language-specific processing mechanisms with cross-linguistic universal principles.

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