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RESEARCH REPORT

Activation of shape and semantic information during ambiguous homophone processing: eye tracking evidence from Hindi

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Abstract In two visual world eye tracking studies, we examined the activation of subordinate meanings of ambiguous homophones in Hindi and particularly when the sentence context is biased towards the dominant meaning. Participants listened to sentences that were either neutral or biased towards the dominant meaning of the homophone and saw a display containing four pictures. In experiment 1, the display had a shape competitor of the subordinate meaning of the homophone in both neutral and biased conditions along with three unrelated distractors. Experiment 2 had semantic competitors of the subordinate meaning of the homophones along with three distractors. Proportion of fixations to different objects overtime suggested that participants activated the subordinate meanings and oriented their attention to the shape and semantic competitors even when the prior context was biased towards the dominant meaning. Overall, these data from Hindi provide further support to those models of lexical access that assume exhaustive access of both the meanings of an ambiguous homophone. These data suggest even a dominant bias does not eliminate the activation of perceptual and conceptual features of the subordinate meaning.

Keywords Lexical ambiguity resolution · Eye movements · Hindi language · Saccades

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Introduction

Language comprehenders often have to deal with lexical ambiguity that may arise because of ambiguous words. Homophones, homonyms and homographs pose a problem since they conceptually refer to two different objects but have similar lexical representation. These ambiguous words generally have a dominant and a subordinate meaning. The dominant meaning has a higher frequency of use and hence is accessed faster compared to the non-dominant (subordinate) meaning. For example, the English word 'pen' has a dominant meaning of a 'writing instrument' and a less dominant (subordinate) meaning of an 'enclosure'. Psycholinguistic theories of lexical access have made conflicting predictions over the issue of priority of access of these two meanings and the role of prior context selecting one meaning over the other. In this study, we examined whether subordinate meaning of an ambiguous homophone word is completely eliminated given a prior bias towards the dominant meaning of the homophone. Unlike most previous studies, we biased the sentence further towards the dominant meaning and examined whether still one sees subordinate meaning activation, something which the context-sensitive models will not predict (Vu et al. 1998). We used the visual world eye tracking paradigm to examine this issue with Hindi native speakers. Below, we review two important models that make conflicting claims about the effect of contextual bias on lexical ambiguity resolution.

One line of studies suggests that both the dominant and subordinate meanings can be active at the same time and contextual bias towards one meaning does not influence the activation of the other meaning (Binder and Morris 1995; Rayner and Duffy 1986; Duffy et al. 1988; Charles et al. 1999; Pacht and Rayner 1993; Clifton and Staub 2008;

MacDonald et al. 1994; Simpson and Burgess 1985; Simpson and Krueger 1991). The reordered access model (Duffy et al. 1988) proposes that if a homonym is balanced, then context can select the most appropriate meaning. On the other hand, if the homonym is not balanced, then the dominant meaning is activated faster compared to the subordinate meaning. Available evidence suggests that in normal circumstances, the dominant meaning activation does not eliminate the activation of the subordinate meanings (Tanenhaus et al. 1979; Tanenhaus and Lucas 1987; Swinney 1979; Duffy et al. 1992; Kambe et al. 2001; Pacht and Rayner 1993; Rayner et al. 2006; Sereno et al. 2006). When there is prior contextual bias towards the dominant meaning, it is accessed even faster, but the activation of the subordinate meaning is not eliminated (Leinenger and Rayner 2013).

Other data suggest that when there is prior bias towards the subordinate meaning, then processing of the dominant meaning takes longer time (Duffy et al. 2001). That is because with a subordinate bias, the subordinate meaning is accessed faster causing delay in the access of the dominant meaning. However, even in this situation, the access of the dominant meaning is not completely eliminated. Rayner et al. (1994) observed longer fixation durations on ambiguous homographs when the prior sentential context was biased towards the subordinate meaning. Thus, for ambiguous words with a highly dominant meaning, a subordinate bias effect is observed irrespective of the contextual bias. The subordinate meaning is activated because of the bias, and the dominant meaning is activated since it enjoys a high frequency (Pacht and Rayner 1993). It is important to note here that the subordinate bias does not eliminate the activation of the dominant meaning but constraints its access (Duffy et al. 1988; 2001). The exhaustive access models argue that biasing information can boost the activation of a particular meaning but it cannot eliminate the activation of the non-contextual meaning completely (Duffy et al. 1988). This model assumes bottom-up activation of both context appropriate and inappropriate meanings in parallel. In sum, the reorder access model claims that frequency and context interact influencing the time course of activation of meanings of ambiguous words.

In contrast to this, context-dependent models (Simpson 1981; Simpson and Krueger 1991) claim that stronger sentential context can be used as a guide to select the appropriate meaning without the need of activating the non-contextual meanings. Prior sentential context can selectively activate lexical access of one meaning exclusively over the other meaning while completely eliminating the access to the non-contextual meaning (Vu et al. 1998; Tabossi 1993). Vu et al. (1998) observed that given a strong dominant bias context, only the dominant meaning was activated. Vu et al. (1998) manipulated verbs or subject nouns to strongly bias the sentences towards one meaning of the ambiguous homonyms. The data showed that stronger context facilitated the recognition of the context appropriate meaning. Vu et al. (1998) did not observe any activation of the dominant meaning of the homonym given a strong subordinate bias. Thus, they argued that if the context is very strongly biased towards one meaning, then one does not see activation of context inappropriate meanings during lexical access (Shillcock and Bard 1993). In sum, the issue has been whether any bias either towards the dominant meaning or the subordinate meaning just constrains the activation of the non-contextual meaning or completely eliminates the context inappropriate meaning. The studies reviewed above have either used the priming methodology that involved lexical access tasks or reading studies with measurement of eye movements. Below, we review some studies with the eye tracking visual world paradigm that have examined these competing claims.

Huettig and Altmann (2007) presented participants (experiment 2) with a display containing the shape competitor of an ambiguous homophonous word ‘pen’ preceded by a subordinate biased context along with unrelated distractors. This prior context, ‘ “the *welder locked up carefully, but then he checked the pen*…” ’ boosted the activation of the subordinate meaning of ‘pen’. The display contained an object similar in shape to the dominant meaning of *pen,* i.e. writing instrument, a ‘needle’ and also the picture of a cage representing the subordinate meaning of ‘pen’. Eye movement data showed higher fixations on the ‘needle’ compared to distractors even when the sentence was biased towards the subordinate meaning and the display contained a referent of the subordinate meaning. Huettig and Altmann (2007) argued that contextual boost towards the subordinate meaning did not eliminate the activation the perceptual features of the dominant meaning. Relevant to our study, this study showed that perceptual features of spoken words are activated regardless of prior context. Thus, Huettig and Altmann’s account should predict activation of shape competitors for spoken words if the display contains such matching objects regardless of prior bias. Interestingly, Huettig and Altmann (2007) also observed that in the subordinate bias conditions, looks towards the subordinate competitors were higher as a result of the context effect but this was the case till the speech signal from the critical word arrived. With the onset of the spoken word ‘pen’, looks towards the contextually inappropriate dominant meaning started to rise, indicating the fact that phonological information from the spoken word led to activation of conceptual knowledge which in turn triggered looks towards the dominant meaning referent. Thus, Huettig and Altmann may predict that biasing

information may led to higher activation of one meaning in the beginning, but as soon as there is the critical word, which has some matching visual entity in the display, phonological, perceptual and semantic information from this word will lead to fixations towards referents that are not contextually appropriate.

Chen and Boland (2008) in their experiment 1 presented an actual referent of the dominant meaning of an ambiguous homophone along with a shape competitor of its subordinate meaning and distractors in neutral context. Fixation proportions showed activation of the subordinate meanings even in the presence of the dominant referent. However, looks towards the dominant meaning referent were higher as a result of the context bias. In experiment 2 when the context was biased towards the subordinate meaning, the shape competitors of the dominant meanings still attracted attention. However, this bias towards the subordinate meaning decreased the looks towards the dominant meaning shape competitors. Thus, contextual information influenced the activation of the dominant meaning. Unlike Huettig and Altmann (2007), Chen and Boland (2008) found an influence of context on the activation of shape competitors, which is not what reordered access theory predicts. Rather, this influence of context is consistent with the predictions of the selective access accounts, which suggest an influence of context on context inappropriate activation. Therefore, these two studies do not provide an unambiguous account of the effect of context on activation of perceptual features in a visual world context. Further, these two studies biased the sentence towards the subordinate meaning of the homophone, and it is yet to be known whether there will be any activation of shape competitors of the subordinate meanings when the sentence is biased towards the dominant meaning.

In contrast to the above two studies, Tsang and Chen (2010) biased the prior context of the sentence towards the dominant meaning of an ambiguous morpheme. In the neutral condition, listeners looked more often at the picture depicting the dominant meaning compared to the distractors. Interestingly, in the subordinate biased condition, looks to the dominant meaning were inhibited. When prior context was manipulated to favour the dominant meaning, still there was activation of the subordinate meaning. The authors suggested that in both the neutral and dominant bias conditions, the subordinate meanings are active. Please note that this was not the case with the findings of Huettig and Altmann (2007) who had found dominant meaning activation even in the subordinate bias condition. It may indicate that probably perceptual features like shape or colour or size may get activated in spite of biased sentence contexts but this may not be the case with more grammatical elements, i.e. morphemic knowledge. The ambiguous morphemes used by Tsang & Chen are unique to Chinese, and therefore, it is not known whether such effects are to be found in other languages. From Tsang and Chen (2010), it is not clear how previous sentential context if biased towards the dominant meaning can eliminate the activation of the subordinate meaning in a language like Hindi, which does not have ambiguous morphemes. The studies by Chen and Boland (2008) and Huettig and Altmann (2007) used perceptual shape competitors while Chen and Boland used pictures in a visual search task.

Thus, it is still not clear from these studies if subordinate meanings and perceptual features of their competitors are activated when the prior context is biased towards the dominant meaning. This is a strong test for the context-sensitive models that claim selection for the appropriate meaning. Since dominant meanings are always accessed faster and by further biasing the sentence towards the dominant meaning, the chances of subordinate meaning activation remain very weak. If one finds activation of the subordinate meaning in this situation that would provide robust evidence for the pervasive nature of simultaneous activation of both the meanings. Therefore, we presented both the shape and semantic competitors of the subordinate meanings in two different experiments while biasing the context towards the dominant meaning. Obtaining an effect with both shape and semantic competitors would provide clear evidence for the activation of the subordinate meaning even when the dominant meaning is given an additional prior bias. This would also reveal whether there is any time course difference between the activation of the perceptual and conceptual features when the subordinate meaning is activated.

Following Tsang and Chen (2010), one would expect the inhibition of the dominant meaning when the bias is towards the subordinate meaning. But still it is not known whether the subordinate meaning activation is completely eliminated when the context is biased towards the dominant meaning. It is important to note that Tsang and Chen (2010) did not use ambiguous homophones but morphemes though they had biased the sentence towards the dominant meaning similar to us. The biasing information in our sentences always occurred before the target homophones. We used a visual world paradigm similar to these studies with some important changes. Our design differed from Huettig and Altmann (2007) as well as Chen and Boland (2008) studies, since we did not put any competitors of the dominant meanings in the display nor did we use any actual referents of either of these meanings. We reasoned that it is important to find robust evidence for activation of any perceptual features such as shape and colour during lexical processing in the absence of the actual referents. We included the semantic competitors in place of shape competitors in experiment 2 to

see whether there is any difference between perceptual (shapes) versus conceptual (meaning) knowledge. The exhaustive access model will predict that in spite of the bias, the subordinate meanings will still remain active. On the other hand, the context-sensitive models will predict complete elimination of the subordinate meanings in the biased conditions.

Experiment 1

Experiment 1 examined whether language comprehenders still activate the shape competitor of the subordinate meaning of a homophonous word when the sentence is biased towards the dominant meaning. There was a neutral control condition where the prior context did not indicate any bias towards any particular meaning.

Methods

Participants

Thirty-six student volunteers (Mean age 23 years) from University of Allahabad participated in the main eye tracking experiment. Participants were randomly assigned to the two experimental conditions. All were native Hindi speakers with normal and corrected-to-normal vision. Informed consent was obtained from each participant prior to the experiment. Participants were naive to the purpose of the experiment.

Material

Norming studies

1. Word association rating for meanings of homophones

Fourteen picturable Hindi homophones were selected that had distinct dominant and subordinate meanings "Appendix 1". Thirty other Hindi speakers who did not participate in the main eye tracking study were asked to report all the meanings of the homophones in a pen and paper task. They were not explicitly told about the words' homophonous status. There was no time constraint for the response. This was done in order to confirm the dominant and subordinate meanings of the homophones. The meaning which was rated 80 % of the time as the first response was considered as dominant, and the remaining one was considered as subordinate.

2. Shape similarity rating

Fifteen other Hindi speakers who did not participate in the main experiment or in the homophone rating task did the shape similarity task. Subjects were required to rate the shape similarity of all the pictures with the shape of the subordinate meaning of the homophones on a scale ranging from 1 to 10. Subjects were shown the pictures on a computer monitor and were asked to give any number between 1 and 10 "Appendix 2" to all the pictures. The aim was to establish how similar the competitor was in shape with the subordinate homophone referent's actual shape and to rule out that distractors did not share any shape similarity with the competitors. Each display contained the subordinate shape competitor along with three other distractors. Participants assigned a significantly higher number for the intended shape competitors out of 10 ($M = 7.88$, SD = .36) compared to the distractors ($M = 1.04$, SD = .34), $t(14) = 15.20$, $p < .001$.

3. Rating for strength of sentence context

Two types of simple declarative Hindi sentences were constructed for each homophonous word. Sentences were of similar length (Mean length 4.56 s). The neutral sentences did not contain any word prior to the target word that indicated any bias towards any of the meanings. For neutrality judgment of sentence context, fifteen Hindi native speakers who did not participate in any other previous rating tasks or in the eye tracking studies were asked to rate the sentences on a five point scale (1 = extremely biased towards dominant meaning; 2 = less biased towards dominant meaning; 3 = No particular bias; 4 = less biased towards subordinate meanings; 5 = extreme bias towards subordinate meaning, respectively). The mean rating for neutral sentences was 2.70 with SD (.032), which shows that sentences were considered reasonably neutral.

In the dominant bias sentences, the critical word appeared after sufficient contextual information. Fifteen other subjects were asked to judge whether sentences considered as biased towards the dominant meaning were actually so. The results show that the sentences had a strong dominant biasing context ($M = 1.43$, SD = .021).

A female native speaker of Hindi recorded all the sentences using the commercially available sound editing software Gold Wave while maintaining a neutral intonation throughout. The recordings were saved as .wav files sampled at rate of 4.41 kHz mono channels. An additional fourteen filler sentences were similarly recorded for filler pictures.

Example of sentences used:

1. Neutral sentence

'Bato bato me choti ki charcha hone lagi.'
Talk in mountain peak/hair lock about discussion began

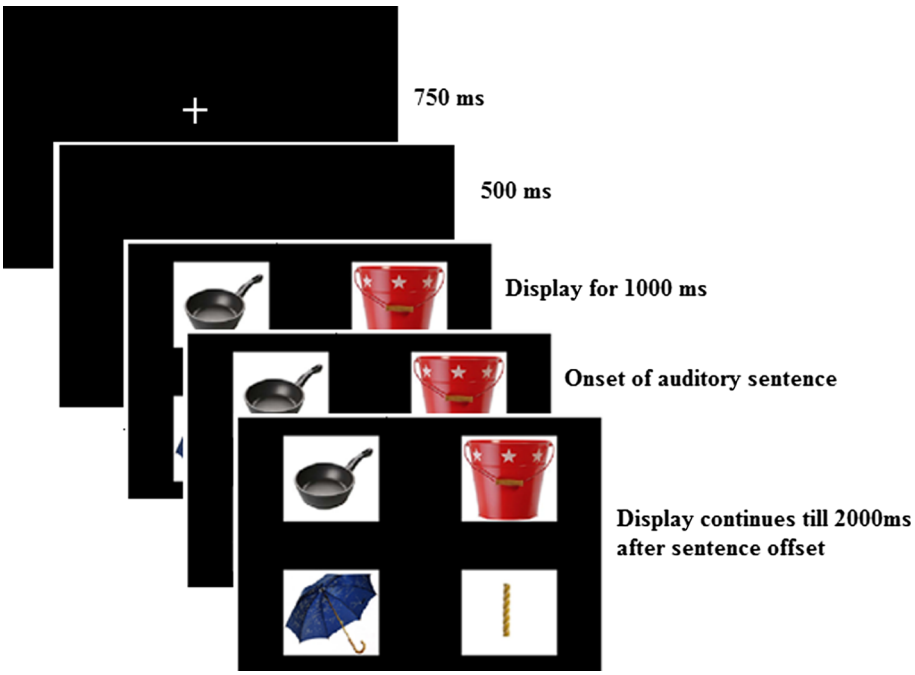


Fig. 1 Sample display showing four objects and trial sequence. After a central fixation, participants see four pictures on the computer screen. After a delay of 1,000 ms, a spoken sentence containing an ambiguous homophone is presented

While talking the discussion on ***choti*** (mountain peak/ hair lock) began.

2. Biased sentence

Himalaya parbat ki choti aath hajar meeter uuchi hai
'Himalaya mountain's peak eight thousand meter high is'

The ***choti*** (peak) of Himalaya is at the height of 8000 metres. (Biased sentence with dominant meaning 'mountain peak').

Care was taken to see that the critical word in both the conditions never appeared as the first word or the last word in the sentence. The critical word was preceded by four words on an average in each sentence. Its position in the neutral conditions ($M = 4.35$, SD = .63) was not significantly different from the biased conditions ($M = 4.21$, SD = .81). In dominant biasing condition, there was sufficient bias towards the dominant meaning of the homophones before the appearance of target word.

Visual displays

Full colour and realistic pictures were used for all the objects in the display. Each display contained a shape competitor of the subordinate meaning along with three completely unrelated distractors. Distractors did not share phonological, semantic or shape similarity with the shape competitors. All images were of the size 269 × 256 in pixels. The pictures were collected from Google images and other freely available databases on the internet. Each picture occupied one quadrant in the display (Fig. 1). The display had a black background.

Apparatus

Before the actual experiment, participants were informed about the sequence of the experiment. Participants were seated at a distance of 70 cm from a 17″ colour CRT monitor at 1,024 × 768 resolutions running at 75 Hz screen refresh rate. Stimuli were presented with PRESENTATION (Neurobehavioral Systems). Participants' eye movements were recorded by SMI high-speed eye tracking system (Sensomotoric Instruments, Teltow, Germany) with a sampling rate of 1,250 Hz. Viewing was binocular, but data from the right eye were used for analysis. The visual stimuli subtended approximately 15 degrees of visual angle. Participants were instructed to keep head movements and eye blinks to minimum. Participants had to rest their chin on a chin rest attached to the eye tracker throughout the experiment. Spoken sentences were played from two speakers kept equidistant from the monitor.

Procedure

The experiment began with a calibration process that was automatic as participants looked at a cross (+) presented at 13 different locations on the monitor. A minimum steady fixation of 400 ms was required at any location for successful calibration. After successful calibration, the experimental trial began with a fixation cross at the centre of the screen for 750 ms followed by a blank screen for

500 ms (Fig. 1). Then, the display containing four coloured pictures was presented, and eye movements were recorded. The position of competitors and distractors was randomised. After 1,000 ms of the onset of display, a spoken sentence was presented via speakers located equidistant from the monitor as well as from the subject. The display remained on the screen till 3,000 ms after the offset of the spoken sentence. Participants were instructed to look at the displays carefully while listening to the spoken sentences. There was no other task to be performed except they were asked not to move their eyes off the computer screen and pay attention (Huettig and Altmann 2007). Each trial lasted for 5–8 s depending upon the duration of the spoken sentence. There were 28 trials in each condition which included 14 filler items as well. In the filler trials, the object mentioned in the sentence was depicted along with three distractors. This was to create a scenario where participants saw the mentioned object in the sentence with equal chance. The filler sentences had similar constrictions to the experimental sentences. Each experimental session took about 12–15 min to complete. Trial presentation was randomised for each participant.

Data analysis

Each quadrant was considered an AOI (area of interest) for calculating fixational eye movements. Fixations <80 ms and blinks were not considered for analysis. We calculated proportion of fixations to the shape competitors and distractors from the auditory onset of the critical word in each trial till 1,200 ms. We compared proportion of fixations to the shape competitors and distractors for biased and neutral conditions across three time windows, i.e. 0–400, 400–800 and 800–1,200 ms intervals. We used these time windows to see whether looks towards a particular object kept increasing overtime compared to other objects. These time intervals were chosen to see how looks towards the shape competitor evolved overtime compared to the distractors. For fixation proportion analysis, looks towards the distractors were averaged.

Results

Proportion of fixations

Figure 2 shows a time course graph of proportion fixations to subordinate shape competitors and averaged distractors for both neutral and biased conditions. The curves are synchronised to the acoustic onset of the spoken target word. The x-axis shows the time in milliseconds from the acoustic onset of the critical word onset till 1,500 ms.

Our main interest was to see whether there were significant amount of looks towards the shape competitors in both the conditions compared to the distractors and whether this attention bias was sustained overtime. That would indicate activation of the shape competitors in neutral and biased conditions. Further, we wanted to know whether the looks to the shape competitors in the biased condition anyway differed from the neutral condition. The fixations towards the three distractors were averaged for analysis. We performed a two-way repeated-measures ANOVA, with sentence type (biased and neutral), object type (competitor, distractor) time window (0–400, 400–800, 800–1,200 ms), as factors was conducted on proportion of fixations to the subordinate shape competitor and averaged distractors. There were significantly higher number of looks towards the shape competitors (.222, SE = .01) than towards the distractors (.190, SE = .006) overall, $F(1, 17) = 45.5$, $p = .001$ indicating a robust activation of shape competitors. Additionally, looks towards the shape competitors were significantly higher in the neutral condition (0.260, SE = .007) compared to the biased condition (0.218, SE = .011), $F(1, 17) = 8.1$, $p = .01$. This indicates that the dominant bias led to less number of looks towards the shape competitors but could not eliminate them completely compared to distractors. Fixations towards the shape competitors kept rising for each successive time windows for both the biased and the neutral conditions $F(2, 34) = 8.2$, $p = .001$. The object type interacted with the time window, $F(2,34) = 21.7$, $p = .001$, showing gradual rise in the fixations for the shape competitor in the successive time window while for distractors the fixations decreased in the successive time window. The three-way interaction among object type × sentence type × time window was significant, $F(2, 34) = 4.3$, $p = .02$.

Discussion

The experiment examined whether a sufficient prior bias towards the dominant meaning of an ambiguous homophone leads to the complete elimination of the activation of the subordinate meaning. Interestingly, the display did not have direct referents of objects representing the subordinate meaning but a shape competitor. Subjects listened sentences that were either neutral or biased towards the dominant meaning of a homophone while they looked at displays containing line drawings of shape competitors of the subordinate meanings along with unrelated distractors. Looks to shape competitors were significantly higher compared to the averaged distractors for both neutral and biased condition. Importantly, looks to the shape competitors were significantly higher in the neutral condition than the biased condition. While these results support the

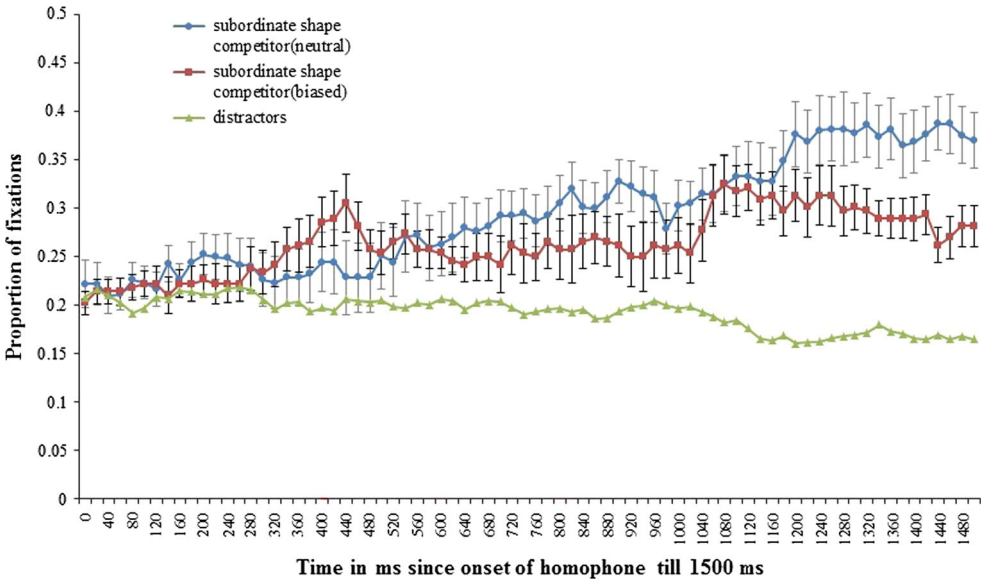


Fig. 2 Plot showing proportion of fixations to subordinate shape competitor and averaged distractors for neutral and dominant-biased contexts

exhaustive access model which proposes that both the dominant and the less dominant meanings are active, they also support the context-sensitive models. That is because, contextual bias led to reduction of fixations to the shape competitors.

Experiment 2

Previous studies have observed the activation of semantic competitors of spoken words in neutral contexts (Huettig and Altmann 2005, Yee and Sedivy 2006).

Experiment two was similar to experiment one in every aspect except that we substituted line drawings of semantic competitors of subordinate meanings of the homophones in place of the shape competitors. Experiment two was designed to explore this with a similar design as experiment one.

Methods

Participants

Thirty-six participants (mean age 23 years) from the University of Allahabad students community participated in this eye tracking experiment. All were native Hindi speakers with normal or corrected-to-normal vision. We would like to note that these were the same participants who took part in experiment 1. However, these experiments were held on different days. It is unlikely that using the same participants would have affected the results. That is, it is unlikely that participants were conscious of the shape relationships with the spoken words in the first experiment. Secondly, in the absence of any explicit task, we assume that participants did not bring in additional resources to improve their performance. Informed consent was obtained from each participant prior to the experiment.

Material

The material was the same except that semantic competitors "Appendix 2" of the subordinate meaning were used in place of shape competitors. The distractor pictures as well the fillers were the same as in experiment 1.

Norming study for semantic competitors

Fifteen subjects who did not participate in the main experiment or in any of the rating studies were asked to rates the semantic similarity of all the pictures in the display with the subordinate meaning of homophones by assigning number between 1 and 10. They were instructed to rate each image in the display according to the associative or categorical similarity with the subordinate referent of the homophonous words. The overall mean for the subordinate semantic competitors ($M = 7.30$, SD $= .36$) differed significantly from the distractors, ($M = .92$, SD $= .34$), $t(14) = 16.18$, $p < .001$. The result of the ratings confirmed significant difference between semantic relatedness of the semantic competitors from the distractors. For every display, the phonological similarity between the competitors and distractors was controlled.

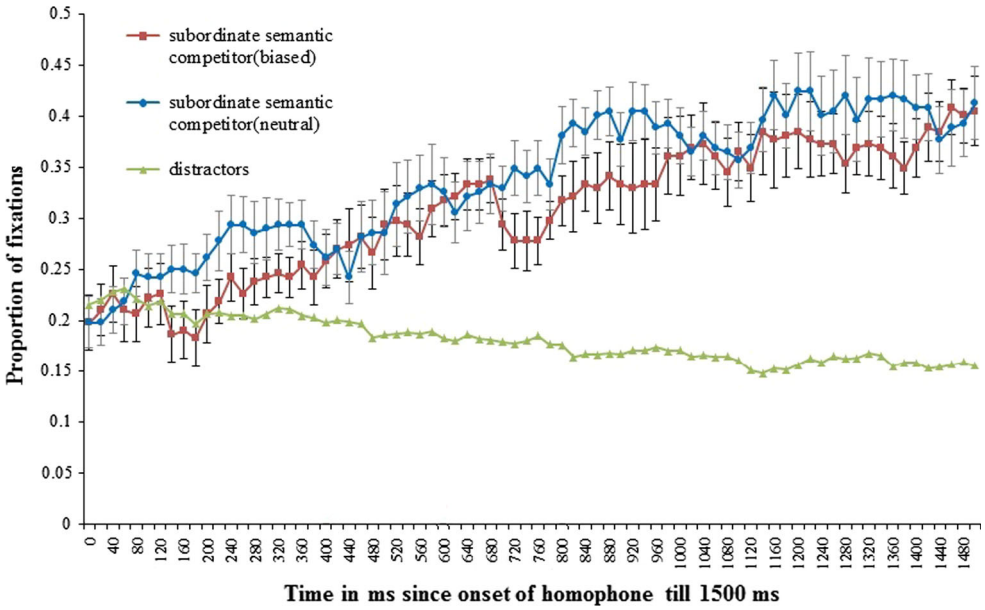


Fig. 3 Plot showing proportion of fixations subordinate semantic competitor and averaged distractors for neutral and dominant-biased context

Design and procedure

The eye movement recording procedure was similar to the first experiment. Subjects were instructed to listen to the sentences carefully and look at the display without taking their eyes off from the computer monitor. The experiment lasted for fifteen minutes.

Results

Figure 3 shows fixation proportions on subordinate semantic competitors in neutral and biased conditions along with the averaged distractors, from the onset of critical word till 1,500 ms. Similar to the analysis of experiment one, we compared fixation proportions to the subordinate semantic competitors with to the averaged distractors both by participants and by items at different time points.

A two-way repeated-measures ANOVA, with sentence type (biased and neutral), object type (competitor, distractor) time window (0–400, 400–800, 800–1,200 ms), as factors was conducted on proportion of fixations to the subordinate semantic competitor and distractors. There were significantly higher number of looks towards the semantic competitors (0.306, SE = .01) than to the distractors (0.187, SE = .006), $F(1, 17) = 78.5$, $p = .001$. Fixations towards the semantic competitor kept rising in the successive time windows, $F(2, 34) = 10.2$, $p = .001$, while for distracters looks decreased. However, looks towards the semantic competitor for neutral and biased conditions did not differ significantly, $F(1, 17) = 3.9$, $p = .06$. The interaction between object type and sentence type, $F(1, 17) = .42$, $p = .52$ as well as the interaction between sentence type and time window $(2, 34) = .21$, $p = .80$, did not reach the level of significance. The three-way interaction between object type x sentence type x time window, $F(2, 34) = .150$, $p = .86$, was also not found to be significant.

Discussion

Similar to experiment one, there participants activated the semantic competitors of the subordinate meaning for both the biased and neutral conditions. However, in this case, the dominant bias did not lead to a noticeable decrease in the number of looks towards the semantic competitors. Thus, context had no effect on the activation of the inappropriate meanings. This result suggests the exhaustive access of both dominant and subordinate meanings of ambiguous homophone.

In the biased condition, the contextual manipulation towards the dominant meaning did not block the activation of the semantic competitors. These results support an account of lexical activation that is parallel and non-selective.

Both these experiments suggest that a bias towards the dominant meaning of an ambiguous homophone does not prevent listeners activating the shape and semantic competitors of the subordinate meaning. However, it is important to directly compare data from both the experiments to examine whether there was any difference between activation of shape and semantic information as such (we thank an external reviewer for suggesting this).

Comparison of both shape and semantic effects

We compared data from both the experiments to examine whether fixations to shape and semantic competitors in neutral and biased sentence types differed significantly from one another. An ANOVA was conducted with sentence type (neutral, biased), time windows (0–400, 400–800, and 800–1,200 ms) and competitor type (competitor, distractor) as within-subject factor and competitor type (shape, semantics) as a between subject factor. The main effect of competitor was found significant, $F(1, 34) = 120.4$, $p = .001$, showing significantly higher fixations to the competitor items (0.29, SE = .007) as compared to the distractors (0.18, SE = .004) for all sentence types. The two-way interaction between competitor type and time windows was found significant, $F(2, 68) = 36.9$, $p = .001$. The post hoc analysis revealed that the fixations to the competitor items (shape/semantics) showed significant rise in the fixations from 0 to 400 ms (0.243, SE = .009) through 400–800 ms (0.298, SE = .011), and also in 800–1,200 ms time windows (.350, SE = .012). This indicates an early activation of competitors and persistence of looks over a longer time window compared to distractors. Fixations to shape competitors did not differ significantly from fixations to semantic competitors as a function of sentence type across the experiments.

General discussion

Eye movement patterns in both the experiments indicated activation of the shape and semantic competitors of the subordinate meanings of the ambiguous homophones for both neutral and dominant meaning-biased contexts. In experiment one, we presented displays which contained the shape competitor of the subordinate meaning of an ambiguous homophone among distractors. These displays were presented along with neutral and dominant meaning-biased contexts. There was significantly higher number of looks towards the shape competitors in both biased and neutral conditions compared to distractors with critical word onset. However, when compared across the sentence types, there was significantly less number of looks towards the shape competitors in the biased condition than the neutral condition. This indicates when the sentence was biased towards the dominant meaning of the homophone, there was less activation of the shape competitor, but there was no complete elimination of the effect. The overall observation that in spite of bias there was activation of shape competitors supports the reordered access model of lexical access (Duffy et al. 1988) and other theories (Rayner et al. 1994) that propose exhaustive access of both the dominant and subordinate meanings. However, we also observed an effect of context on the level of activation of the shape competitor if not complete elimination. The biased context decreased the activation of the shape competitor, and this is consistent with the predictions of the context selective models (Martin et al. 1999). Chen and Boland (2008) had found that a subordinate bias context had decreased the activation of the dominant meaning and they had interpreted this effect supporting the context selective models. However, Huettig and Altmann (2007) did not observe any effect on the activation of the dominant meaning shape competitor when the context was biased towards the subordinate meaning.

In our second experiment, we presented semantic competitors of the subordinate meaning in both neutral and dominant-biased contexts. There was significantly higher number of looks towards the semantic competitors compared to the distractors. However, unlike the shape competitors, a dominant bias context did not significantly decrease the activation of the semantic competitors. Thus, these set of findings are consistent with the predictions of the exhaustive access models. Therefore, these results do not support the context-sensitive models (Vu et al. 1998) that claim selection of only one meaning given sufficient contextual bias and a complete elimination of the context inappropriate meaning. The difference between the activations of the two types of competitors as a function of sentence type is likely due to the difference between a perceptual attribute (shape) and a conceptual (semantic) attribute during lexical access. Huettig and Altmann (2007) had shown that shape competitors are activated early compared to semantic competitors. However, when we compared both the experiments, we did observe any difference between shape and semantic competitors with regard to their time course of activation or in magnitude.

Results of this study complement findings from previous visual world studies in this area in important ways but there are also important differences. Huettig and Altmann (2007) found dominant meaning activation even in a subordinate bias context. In this study, the shape competitors of the dominant meanings attracted looks even when the sentence had a prior bias towards the subordinate meaning. In our study, we did not map activation of the dominant meaning in any way. Our display did not have any direct or indirect reference of the dominant meaning. However, we biased the sentence towards the dominant meaning anticipating this would eliminate activation of the subordinate meaning. Therefore, while Huettig and Altmann (2007) observed that contextual manipulation had no effect on the activation of the dominant meaning, we observed that context had some effect on the shape competitors but not on semantic competitors. Chen and Boland (2008) had observed that given a prior bias towards the subordinate meaning of the homophone, looks towards the shape competitors of the

dominant meanings decreased, suggesting a context effect. Nevertheless, this did not completely eliminate the activation of the dominant meanings. Chen and Boland (2008) suggested that this context effect cannot easily be accommodated into a strict version of the reordered access model. Since we did not bias the sentence towards the subordinate meanings, it is difficult to directly compare our results with Chen and Boland (2008) or Huettig and Altmann (2007). However, since we found an influence of context on the shape competitors in the first experiment, these data also cannot be easily explained by the reordered access model. More importantly, our results suggest that it is not only the dominant or high frequent meaning that is activated in the neutral condition as some accounts would hold (Vu et al. 1998) but also the subordinate meanings.

The similarity between our study and that of Tsang and Chen (2010) was that they both biased the sentence towards the dominant meaning. However, Tsang and Chen (2010) had examined ambiguous morphemes, and their study did not map activations to shape or semantic competitors. Tsang and Chen (2010) found activation of the subordinate meaning in morpheme ambiguity resolution when the sentence was biased towards the dominant meaning. A dominant meaning context favoured the access of the dominant meaning, but did not eliminate the activation of the subordinate meaning. Interestingly, Tsang and Chen (2010) found a significant inhibitory effect on the activation of the dominant meaning when the context was biased towards the subordinate meaning. Neither Huettig and Altmann (2007), nor Chen and Boland (2008) observed such complete inhibition of the context inappropriate meaning as a result of contextual influence. We observed some effect of context on shape competitors but not on semantic competitors, but still looks towards both these competitors were significantly higher compared to unrelated distractors for both sentence types. Therefore, it is likely that contextual bias affects the activations of different types of features in qualitatively different manner.

Differences in results among these three studies can arise given the fact that all of them including ours had several differences in design and stimuli. Huettig and Altmann (2007) did not have direct referents of the dominant meaning in the display, whereas Chen and Boland (2008) as well as Tsang and Chen (2010) presented the direct visual referents along with competitors. Both Huettig and Altmann (2007) and Chen and Boland (2008) did not use semantic competitors thus it is not known whether given a subordinate bias there is activation of semantic competitors of the dominant meanings. We obtained robust results particularly in the absence of direct visual referents of both the dominant and the subordinate meanings for both shape and semantic competitors. Thus, while our results do indicate simultaneous activation of subordinate meanings, it also shows some effect of context at least for the activation of certain features like shape.

The reordered access model postulates that the subordinate meaning will still be active when there is a dominant bias, suggesting simultaneous activation of both the meanings. However, this model does not explicitly suggest that when context is biased towards the dominant meaning, there will be no activation of the subordinate meaning. Given the fact that subordinate meanings are used less often, context-sensitive models would propose a complete absence of any activation of subordinate meanings particularly when the dominant meaning is given further boost. As such, the dominant meanings of polarised homophones are accessed first because of their higher frequency. However, both of our experiments showed that subordinate meanings are active in a dominant bias condition as they are in the neutral condition. We further show that there is a possibility that sentential bias may selectively constrain the activation of particular features, i.e. perceptual versus conceptual. Activation of the semantic competitors in such a manner is also consistent with previous visual world studies where such effects have been found with unambiguous words (Mirman and Magnuson 2009; Yee et al. 2009; Huettig et al. 2006; Yee and Sedivy 2001).

A direct comparison between activations of shape and semantic competitors for dominant-biased and neutral sentences suggested that there was no statistical difference. We cannot claim that shape competitors were activated faster or more robustly compared to the semantic competitors. Further, looks towards the shape and semantic competitors did not differ as a function of sentence type. For both the studies, the respective competitors attracted significantly higher number of fixations compared to distractors for both sentence types. Further experimental work is necessary to confirm this issue between time course of activation of perceptual and conceptual features during ambiguous homophone processing. What we have shown here is that along with frequency and context, one has to also consider the type of information that is activated in the discussion of context influence on ambiguity resolution. Activation of shape (perceptual) and semantic (conceptual) information of the subordinate meaning of an ambiguous homophone when prior context supports a dominant bias supports those theories of meaning and knowledge representations that consider a sensorimotor basis of feature representation (Barsalou 1999; Warrington and McCarthy 1987). Though, we did not find any difference in the time course of activation of semantic and shape information as such. Our results thus provide very robust evidence of activation of both surface-based perceptual information and deep conceptual information during ambiguous homophone processing.

The design of the study does not allow us to quantify how much attention the dominant meaning received, since none of the pictures were related to it like they were in Huettig and Altmann (2007) study. However, we found strong activations for the less common meaning of the ambiguous homophone affecting shifts in visual attention. In the experimental trials, where targets were absent, there is a possibility that participants came to know one of the objects resembling to the spoken word and started to search for it cooperatively. In a target absent situation, participants just searched the object which was somehow related to the spoken word on some features. Previous studies have found evidence for activation of semantic (Yee and Sedivy 2006) and shape competitors when targets were present (Dahan and Tanenhaus 2005). It is important to note that Huettig and Altmann (2007) claimed that given any prior context, when the critical word arrives, any object in the display matching the conceptual content of the spoken word will attract attention immediately.

Our findings are consistent with earlier observations where different experimental paradigms were used. For example, Binder (2003) reported higher fixation times for ambiguous words even when the context was biased towards the dominant meaning (experiment 2). The results suggest that activation of the less dominant meaning is still possible in spite of a dominant bias. Similar results were obtained by Kambe et al. (2001) in a study where discourse context was biased towards the dominant meaning of the lexically ambiguous words which led to an increase in reading times.

Thus, we can conjecture that sentential contexts do not eliminate activation of meanings that are not supported by the bias, at least when the visual context supports those meanings (Pollatsek et al. 2010). Therefore, lexical processing appears to be fairly autonomous in most cases (Swinney 1979). Our results do suggest that all meanings of a lexically ambiguous word are activated temporarily in spite of any biasing contexts (Onifer and Swinney 1981). The results do not support the conclusions drawn by Tabossi et al. (1987) who claimed that given sufficient contextual bias towards the dominant meaning, the subordinate meaning may not be activated at all. If this would have been the case, then overt visual attention to shape and semantic competitors would not have differed from distractors in biased conditions in our experiments. In our study, apart from the bias in the sentence, the visual context played a crucial role. The availability of an object in the display which represented the shape and semantic competitor might have facilitated their activations in the dominant bias condition (Huettig and Altmann 2007). Therefore, previous results obtained with the priming techniques, and these results from visual world studies should be compared carefully as they may constrain or facilitate such activations differently.

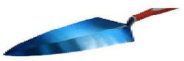
We did this study with Hindi spoken words where as previous studies have been mostly with English. It is important to extend such findings into other languages than English, since that would add more cross linguistic perspective to our understandings of these mechanisms (Jaeger and Norcliffe 2009). Another potentially interesting attribute of Hindi which may affect homophone processing is its spelling to sound consistency. English homophones could have different spellings (e.g. *flower*/*flour*), whereas Hindi homophones are always orthographically written the same way. Interestingly, very few studies have actually examined how orthographic factors could affect processing of ambiguous homophones (see Kreuz 1987 for similar observations). Orthographic factors could be important, since it is now known that listeners activate orthographic information during spoken word processing (Tanenhaus et al. 1980; Pattamadilok et al. 2009a, b). Thus, it is possible that the distinct spellings of English homophonous words might facilitate the selective retrieval of one of the meanings, whereas for Hindi this may not be the case. For example, in the case of Hindi listeners, retrieving one meaning of the homophone given similar spellings for both the meanings may be a little difficult. Thus, one cannot rule out this orthographic consistency aspect to spoken homophone processing which therefore makes exploring this issue in a language like Hindi more relevant.

In sum, it is one thing to claim that stronger contextual bias should completely eliminate the activation of the context inappropriate meaning and another to say that biased context will decrease the activation of the non-contextual meaning. Our study does not provide equivocal support to either the exhaustive access model or the context-sensitive model. We observe activation of the subordinate meaning even when the context was further biased towards the dominant meaning. Thus, along with frequency and bias type, it is important to consider the type of feature that is activated, i.e. perceptual and conceptual. Finally, we would conclude suggesting that activation of multiple meanings of an ambiguous homophone affect attentional shifts to visual objects that share semantic or shape information with any one of the meanings.

Appendix 1

Neutral sentences	Biased sentences
1. *Usne patrika me **bali** ka chitra dekha*	1. *Usne kaan me **bali** pehan rakhi thi*
[He/she magazine in bali of photo saw]	[She ear in bali wearing was]
He/she saw the photo of ***bali***(grain stalk/ear-ring) in the magazine	She was wearing ***bali***(ear-ring) in her ears
2. *Usne kai baar apni **kunji** ke bare me poocha*	2. *Chor ne nakli **kunji** se taala khola*
[He/she several times his/her kunji about asked.]	[Thief duplicate key by lock opened]
He/she asked about his/her kunji(key/guide book) several times	Thief opened the lock using duplicate ***kunji***(key/guide book)
3. kuch der baad ***lava*** thanda ho gaya	3. *jwalamukhi se nikla **lava** patthar ban jata hai*
[Sometime after lava cooled]	[Volcano from coming out lava stone becomes]
After sometime lava (volcanic eruption/fried grain) cooled down	***Lava*** (eruptions) that comes out from volcano takes form of stones
4. *We sab **patri** ke bare me baat kar rahe the*	4. *Sarkaar ne railway **patri** ke navinikaran ki yojana banai*
[They all patri about talking were]	[Government railway patri to renovate planned]
They all were talking about **patri**(scale/railway track)	Government planned to renovate the ***patri*** (railway tracks)
5. *Use aangan me **patra** pada mila*	5. *Use kai mahino purana **patra** aaj mila*
[He/she courtyard at patra lying found]	He/she several months old patra today received]
He/she found **patra**(letter/leaf) lying at the courtyard	He/she received several months old ***patra***(letter) today
6. *Andhere me wah **kundli** nahi dekh paya*	6. *Jyotishi ne **kundli** dekhkar uska bhavishya bataya*
[Dark in he/she kundli not see could]	[Astrologer kundli looking his/her future told]
He could not see ***kundli*** (horoscope/snake's posture) in the dark	The astrologer looked to his/her ***kundli*** and told about his/her future.
7. *Bacche ki kitaab me **bel** ka chitra bana tha*	7. *Doctor ne use **bel** ka ras peene ki salah di*
[Chlld's book in bel of picture drawn was]	[Doctor his/her bel of juice drink to advised]
There was a picture of ***bel*** (fruit/creeper) in child's book	The doctor advised him/her to drink ***bel*** (a fruit) juice
8. *Bato bato me **choti** ki charcha hone lagi*	8. *Himalaya ki **choti** 8000 meter unchi hai*
[Talks in choti about discussion began]	[Himalaya's choti 8000 metre high is]
While talking discussion on ***choti*** (mountain peak/hair lock) began	The ***choti*** (peak) of Himalaya is 8000 metres high
9. *Usne haath me **panna** le rakha tha*	9. *Bacche ne kitaab se **panna** faad dia*
[He/she hand in panna holding was]	[Child book from panna tore]
He/she was holding ***panna*** (paper/emerald) in hand	The child tore a ***panna***(page) from the book
10. *Taak ke upar **batua** rakha tha*	10. *Usne pant ki jeb me batua rakha tha*
[Shelf on batua kept was]	[he/she pant's pocket wallet kept]
Batua(wallet/cooking utensil) was kept on the shelf	he/she kept **batua**(wallet) in his pant's pocket
11. *jab tak wah pakadtaa **stri** gir padi*	11. *Us natak me **stri** ki gambhir bhoomika thi*
[Until he held stri fell]	[That play in stri of serious role was]
Until he/ she held ***stri*** (lady/iron) fell down	In that play the **stri**(lady) was in serious role
12. *Use daraaj me **golian** milin*	12. *Use din me dawa ki kai **golian** khani hai*
[He/she drawer in golian found]	[He/she day in medical of several pills eat has to]
He/she found ***golian*** (pills/bullets)in drawer	He/ she has to take several medical ***golian***(pills) in a day
13. *kaafi dhoondhne par use **mohar** mil gai*	13. *Usne daftar jakar **mohar** lagwa li*
[Lot searching after he/she mohar got]	[He/ she office went ***mohar*** received]
After searching a lot he/she got ***mohar*** (stamp/gold coin)	He/she went to office and got a mohar (stamp)stamped
14. *Wah sham ko **taar** le aaya.*	14. *Aandhi se bijli ka **taar** toot gaya*
[He/she evening in taar (telegram/wire) brought]	[Strong wind of because electric ***taar***(wire) broke]
He/she brought ***taar***(wire/telegram) in the evening	The electric ***taar***(wire) broke down because of strong wind

Appendix 2

Homophones in Hindi	1)dominant meaning 2)subordinate meaning	Subordinate shape competitor	Subordinate semantic competitor
Bali	1)earring 2)grain stalk	 feather	 Rice grains
kunji	1) key 2)guide book	 Hard disk	 Writing pad
lava	1)volcanic eruption 2)friedgrain	 Honey bees	 corn
patri	1)railway track 2)scale	 Mouth organ	 Measuring tape
Patra	1)letter 2)leaf	 masonry tool	 grass
Kundli	1)horoscope 2)snake's posture	 Mosquito-coil	 scorpion
bel	1)fruit 2)creeper	 Electric wire	 bouquet
Choti	1)mountain peak 2)hair lock	 rope	 Hair clips
panna	1)page 2)emerald	 Ice cube	 ring
batua	1)wallet 2)round vessel	 Tennis racket	 girdle
stri	1)lady 2)iron	 jug	 Ironed clothes
golian	1)tablets 2)bullets	 lipstick	 gun
mohar	1)stamp 2)gold coin	 plate	 Rupee note
taar	1)wire 2)telegram	 Photo frame	 Postal stamp

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