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## 2pSCb14. Consonant confusability and its relation to phonological dissimilarity


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Consonant similarity can be measured indirectly through a language's phoneme inventory, lexicon (e.g. cooccurrence restrictions), or phonology (e.g. processes that take similarity or dissimilarity into account). It can also be measured more directly as confusability in a perception task. Thus far, consonant similarity in Bengali has only been measured indirectly, through the inventory, lexicon, and phonology. Previous studies (Khan 2006) claim that speakers judge the similarity of consonants in echo reduplication, where the initial consonant of the base is systematically replaced with a phonologically dissimilar consonant in the reduplicant, e.g. kashi 'cough' > kashi-tashi 'cough, etc.' but thonga 'bag' > *thonga-tonga > thonga-fonga 'bags, etc.'). This measurement of similarity assumes a set of features assigned language-specific weights; for example, [voice] is weighted more heavily that [spread glottis], to explain why speakers treat the pair [t, th] as more similar than the pair [t, d]. But does the measurement of similarity inherent in the echo reduplicative construction correspond to the relative perceptibility of different consonant contrasts? The current study examines data collected in a perception experiment, comparing the relative confusability of Bengali consonants produced in different types of noise with the claims of phonological notions of similarity associated with echo reduplication.


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# INTRODUCTION

Consonant similarity can be measured either indirectly or directly. Indirect measures of consonant similarity include feature-based analyses of the phoneme inventory, descriptions of the cooccurrence restrictions within the lexicon, and interpretations of phonological processes that take similarity or dissimilarity into account. More direct measures of consonant similarity typically come in the form of confusability scores collected through a perception task, either consonant discrimination or consonant identification. To get an accurate picture of a language's measurement of consonant similarity, all of these measures should be taken into consideration, but languages such as Bengali have so far only been examined using indirect measures (Khan 2006, 2007). The current study uses data collected in a consonant identification task to build a confusion matrix for Bengali, to better understand how well previous indirect measures reflect the psychological reality of Bengali consonant similarity.

## Background

Thus far, consonant similarity in Bengali has only been measured indirectly, through the inventory, lexical patterns, and reduplicative patterns. Previous studies (Khan 2006) claim that Bengali speakers use measurements of the similarity of consonants in the fixed segmentism patterns of echo reduplication, where the initial consonant of the base is systematically replaced with a phonologically dissimilar consonant in the reduplicant. For example, a /k/-initial word such as /kaʃi/ 'cough' is reduplicated with the initial /k/ replaced with fixed segment /t/ in /kaʃi-taʃi/ 'cough, etc.'; this is the default pattern in Bengali. However, words beginning with /t/ cannot be replaced with fixed segment /t/, e.g. /tene/ 'having pulled' is reduplicated as /tene-fene/ 'having pulled, etc.' rather than with default fixed segment /t/ (*/tene-tene/).

Furthermore, words starting with consonants similar to /t/ avoid replacement with fixed segment /t/, e.g. /t$^{h}$oŋa/ 'bag' is reduplicated as /t$^{h}$oŋa-foŋa/ 'bags, etc.' rather than with default fixed segment /t/ (*/t$^{h}$oŋa-toŋa/), with higher rates of default /t/-use for consonants that are less similar to /t/, e.g. /tɕuʃe/ 'having sucked' can be reduplicated as either /tɕuʃe-fuʃe/ or with the default /tɕuʃe-tuʃe/ 'having sucked, etc.'. It is in this last type of case that it becomes clear that Bengali speakers must use some measurement of consonant similarity to judge whether, and at what relative frequency, a given consonant can be replaced by default fixed segment /t/.

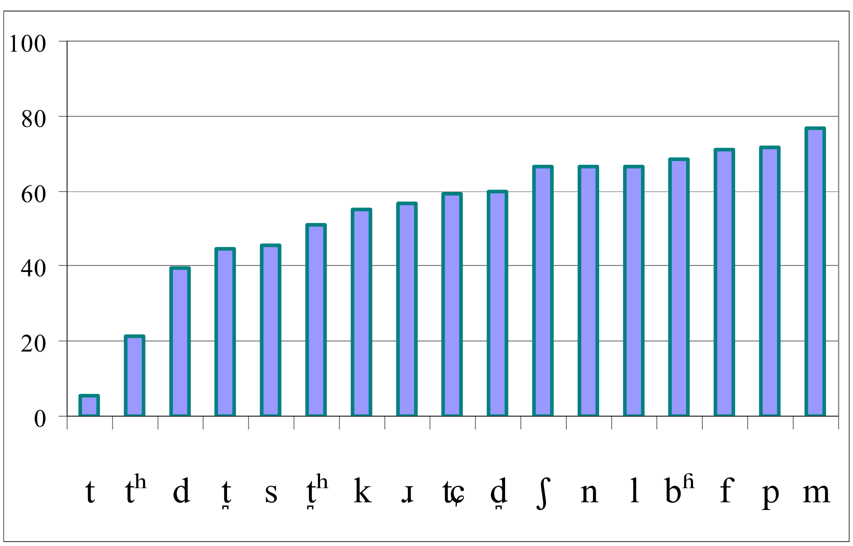


**FIGURE 1.** Percentage of /t/-use by base-initial consonant in Khan's (2006) study of Bengali fixed segment echo reduplication. While /t/-initial bases are hardly reduplicated with a fixed /t/-initial reduplication, consonants dissimilar to /t/ (e.g. /f, p, m/) use fixed /t/ over 70% of the time. /t/-use increases as the base-initial consonant is more dissimilar from /t/.

The reduplication data suggests that the most similar consonants to /t/ are, in order, /t, t$^{h}$, d, t̪, s, t̪$^{h}$/. This order assumes that aspiration is the least contrastive feature, i.e. unaspirated and aspirated sounds sharing all other features will be the most confusable sounds. Voicing would be slightly more contrastive, minor place above that, and major place being the most contrastive.

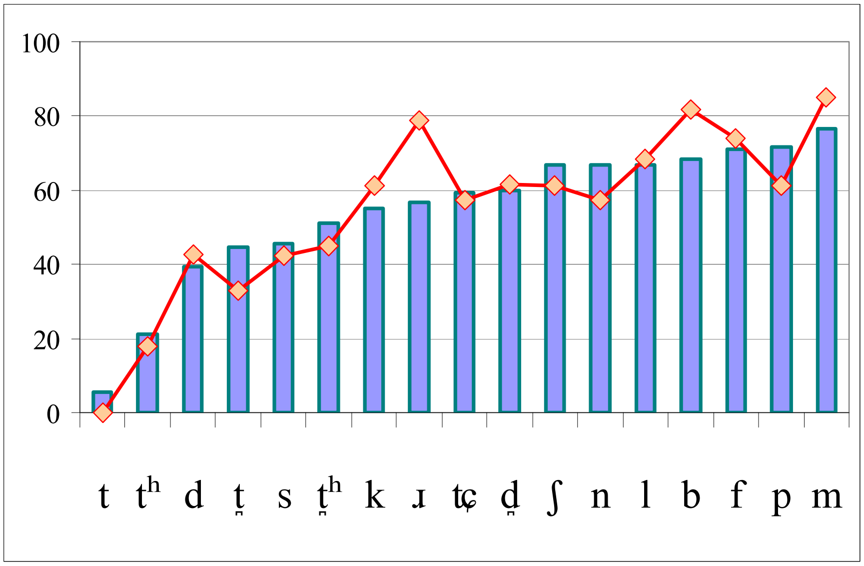


**FIGURE 2.** Percentage of /t/-use by base-initial consonant is shown in blue columns, while the red line indicates the predicted rate of /t/-use given the feature weighting metric introduced in Khan (2006).

## Research questions

Does the measurement of similarity inherent in the echo reduplicative construction correspond directly to the relative perceptibility of different consonant contrasts? The current study examines data collected in a perception experiment, comparing the relative confusability of Bengali consonants produced in noise with the claims of phonological notions of similarity associated with echo reduplication to answer the following questions:

1. Which consonants of Bengali are more easily confusable acoustically?
2. Do confusability scores seem to reflect an intuitive notion of consonant similarity in Bengali?
3. How well do these confusability scores reflect the similarity measurements proposed in previous studies of echo reduplication (Khan 2006, 2007)?

## METHODS

Multiple recordings were made of an adult female native speaker's productions of 27 legal [Ca] syllables (all possible onset consonants followed by [a]) and 27 legal [aC] syllables (all possible coda consonants preceded by [a]), using a portable USB microphone in a quiet room. Following the transcription system presented in Khan (2010), the consonants (in Bengali alphabetical order) included /k, k$^{h}$, g, g$^{ɦ}$, tɕ, tɕ$^{h}$, dʑ, dʑ$^{ɦ}$, t, t$^{h}$, d, d$^{ɦ}$, t̪, t̪$^{h}$, d̪, d̪$^{ɦ}$, n, p, f, b, b$^{ɦ}$, m, ɹ, l, ʃ, s, h, ŋ, ɽ/, with /ŋ, ɽ/ excluded from the onset condition and /d$^{ɦ}$, h/ excluded from the coda condition in accordance with the phonotactic patterns of existing Bengali words. The clearest examples of each of the 54 syllables were then normalized for amplitude. Then, two types background noise were added to copies of these 54 recordings, multi-talker babble and pink noise (both taken from the NOISEX database[1]), giving 54 syllables × 3 background noise conditions (i.e. babble, noise, none) = 162 unique recordings.

**TABLE 1.** Examples of stimulus items illustrating the three conditions manipulated: consonant, syllable position, and background noise.

| Consonant | Syllable position | Background noise |
|---|---|---|
| k | Onset | None |
| k | Onset | Pink noise |
| k | Onset | Multi-talker babble |
| k | Coda | None |
| k | Coda | Pink noise |
| k | Coda | Multi-talker babble |
| $k^h$ | Onset | None |
| $k^h$ | Onset | Pink noise |
| $k^h$ | Onset | Multi-talker babble |
| $k^h$ | Coda | None |
| $k^h$ | Coda | Pink noise |
| $k^h$ | Coda | Multi-talker babble |

Seven adult native speaker subjects (4 female, 3 male) were presented with these 162 recordings in a consonant identification task run as a Multiple Forced Choice (MFC) listening experiment in Praat (Boersma & Weenink 2013). Seated in a quiet room, facing a laptop, and wearing Sony MDR-V200 headphones, subjects heard a syllable, where the consonant choice, syllable position (i.e. onset vs. coda), and added background noise type (i.e. none, pink noise, babble) were manipulated. See Table 1 for example stimuli. Upon hearing the stimulus, subjects were asked to use a mouse to click on the orthographic representation of the consonant they heard in the syllable. See Figure 3 for a screenshot of the experimental interface. Subjects were told that the consonant could occur at the beginning or the end of the syllable. A training session was run with the investigator present, using similar stimuli (with all syllable positions and background noise types included) but with the vowel [i] instead of [a]. All oral and written instructions were given in Bengali.

Each recording was presented three times, giving a total of 162 × 3 = 486 trials. Stimuli were blocked by added background noise type; in order of presentation, these were, (1) multi-talker babble (“babble”), (2) pink noise (“noise”), and (3) no added background noise (“clear”). Stimuli were pseudorandomized within each block, so that repetitions of the same recording would not occur consecutively. Subjects were given the option of a break after every 54 trials; subjects reported that they rarely took advantage of this option.

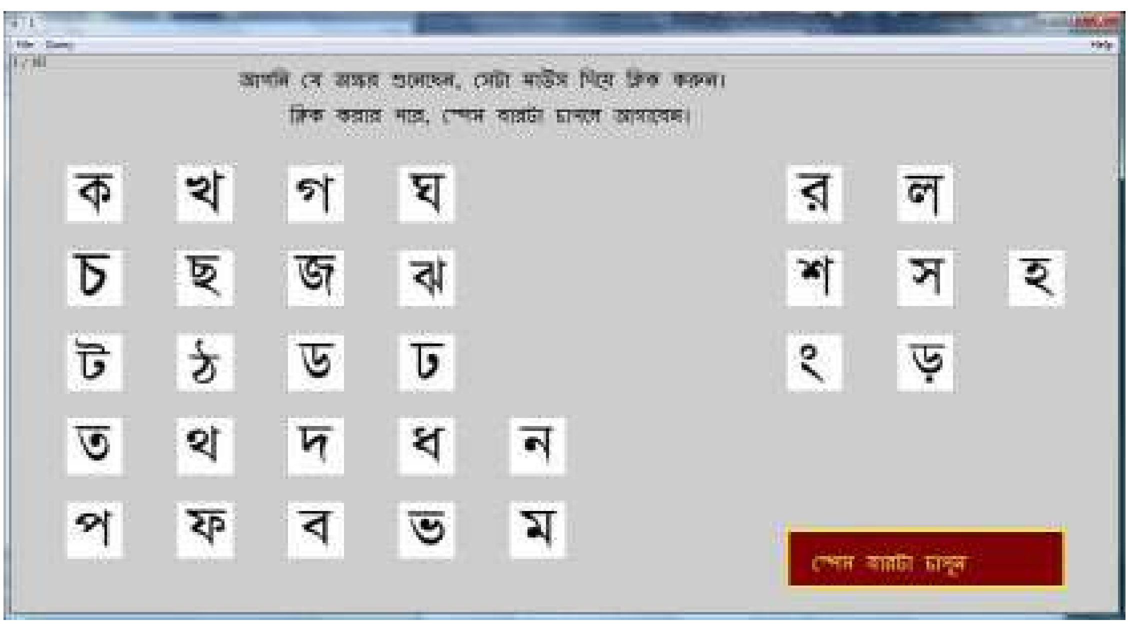

**FIGURE 3.** Screenshot of the MFC experiment run in Praat. The instructions at the top read <আপনি যে অক্ষর শুনেছেন, সেটা মাউস দিয়ে ক্লিক করুন। ক্লিক করার পরে, স্পেস বারটা চাপলে আগাবেন।> /apni dʑe ɔkʰːoɹ ʃunetɕʰen, ʃeta maws d̪ie klik koɹun. klik kɔɹaɹ pɔɹe, spes baɹta tɕaple agaben/ '(Please) use the mouse to click the letter you have heard. After clicking, you will continue if you press the space bar'. Below the instructions, all possible responses given as consonants in orthographic representation are provided in alphabetical order, and a button at the bottom right reads <স্পেস বারটা চাপুন> /spes baɹta tɕapun/ '(Please) press the space bar'.

## RESULTS AND DISCUSSION

Responses were compiled across speaker but kept separate for the background noise and syllable position conditions. The data were arranged in a series of confusion matrices, with the stimulus consonant on the left column and the response consonants arranged in the remaining columns. Tables 1–3 below are the confusion matrices for consonants in onset position, illustrating the no-noise condition, the pink noise condition, and the babble condition, respectively. In the interest of space, sonorants and fricatives, which showed the least confusion, are excluded from the tables. Coda consonant confusion matrices are not shown here.

**TABLE 1.** Confusion matrix for stop and affricate consonants in onset position with no background noise.

| | k | kʰ | g | gʱ | tɕ | tɕʰ | dʑ | dʑʱ | t | tʰ | d | dʱ | t̪ | t̪ʰ | d̪ | d̪ʱ | p | b | bʱ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| k | 12 | | 8 | 1 | | | | | | | | | | | | | | | |
| kʰ | | 21 | | | | | | | | | | | | | | | | | |
| g | | | 18 | 3 | | | | | | | | | | | | | | | |
| gʱ | | | | 21 | | | | | | | | | | | | | | | |
| tɕ | | | | | 21 | | | | | | | | | | | | | | |
| tɕʰ | | | | | | 17 | | 4 | | | | | | | | | | | |
| dʑ | | | | | | | 20 | 1 | | | | | | | | | | | |
| dʑʱ | | | | | | | | 21 | | | | | | | | | | | |
| t | | | | | | | | | 8 | 2 | 8 | 3 | | | | | | | |
| tʰ | | | | | | | | | | 18 | 1 | 2 | | | | | | | |
| d | | | | | | | | | | | 19 | 2 | | | | | | | |
| dʱ | | | | | | | | | | | 2 | 18 | | | | 1 | | | |
| t̪ | | | | | | | | | | | 1 | | 13 | 2 | 4 | 1 | | | |
| t̪ʰ | | | | | | | | | | | | | | 21 | | | | | |
| d̪ | | | | | | | | | | | | | | | 19 | 2 | | | |
| d̪ʱ | | | | | | | | | | | | | | | | 21 | | | |
| p | | | | | | | | | | | | | | | | | 10 | | |
| b | | | | | | | | | | | | | | | | | | 18 | 3 |
| bʱ | | | | | | | | | | | | | | | | | | | 21 |

**TABLE 2.** Confusion matrix for stop and affricate consonants in onset position with pink noise.

| | k | kʰ | g | gʱ | tɕ | tɕʰ | dʑ | dʑʱ | t | tʰ | d | dʱ | t̪ | t̪ʰ | d̪ | d̪ʱ | p | b | bʱ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| k | 6 | | 6 | | | | | | | | 1 | | 1 | | 4 | 2 | | | |
| kʰ | | 21 | | | | | | | | | | | | | | | | | |
| g | | | 19 | 1 | | | | | | | | | | | 1 | | | | |
| gʱ | | | | 16 | | | | | | | | 1 | | | | 4 | | | |
| tɕ | | | | | 16 | | 4 | 1 | | | | | | | | | | | |
| tɕʰ | | | | | | 19 | | 2 | | | | | | | | | | | |
| dʑ | | | | | 2 | | 18 | 1 | | | | | | | | | | | |
| dʑʱ | | | | | | | | 21 | | | | | | | | | | | |
| t | | | | | | | 1 | | 3 | 1 | 15 | 1 | | | | | | | |
| tʰ | | | | | | | | | 1 | 17 | 1 | 2 | | | | | | | |
| d | | | | | | | 1 | | | | 17 | 3 | | | | | | | |
| dʱ | | | | | | | | | | | 2 | 14 | | | | 5 | | | |
| t̪ | | | | | 1 | | | | 3 | 1 | 3 | | 7 | | 5 | 1 | | | |
| t̪ʰ | | 1 | | | | | | | | 10 | | | | 10 | | | | | |
| d̪ | | | | | | | | | | | 8 | | | | 11 | 2 | | | |
| d̪ʱ | | | | 4 | | | | | | | | 2 | | | | 15 | | | |
| | | | | | | | | | | | | | | | | | | | |
| p | | | | | | | | | | | | | | | | | 13 | 1 | |
| b | | | | | | | | | | | | | | | | | | 19 | 2 |
| bʱ | | | | | | | | | | | 1 | 6 | | | | 14 | | | |

**TABLE 3.** Confusion matrix for stop and affricate consonants in onset position with multi-talker babble.

| | k | kʰ | g | gʱ | tɕ | tɕʰ | dʑ | dʑʱ | t | tʰ | d | dʱ | t̪ | t̪ʰ | d̪ | d̪ʱ | p | b | bʱ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| k | 10 | | 4 | 1 | 1 | | | | 1 | | 2 | | 1 | | 1 | | | | |
| kʰ | | 14 | | 3 | | | | | | | | | | 2 | | 2 | | | |
| g | | | 21 | | | | | | | | | | | | | | | | |
| gʱ | | | | 21 | | | | | | | | | | | | | | | |
| tɕ | | | | | 14 | 1 | 6 | | | | | | | | | | | | |
| tɕʰ | | | | | 1 | 11 | | 8 | 1 | | | | | | | | | | |
| dʑ | | | | | | | 21 | | | | | | | | | | | | |
| dʑʱ | | | | | | 1 | | 20 | | | | | | | | | | | |
| t | | | | | | | | | 4 | | 13 | 4 | | | | | | | |
| tʰ | | | | | | | | | 2 | 11 | | 8 | | | | | | | |
| d | | | | | | | | | | | 16 | 4 | | | | | | | |
| dʱ | | | | 1 | | | | | | 1 | 1 | 13 | | | | 2 | | | 2 |
| t̪ | | | | | 3 | | | | 1 | | | | 11 | | 4 | 2 | | | |
| t̪ʰ | | | | 1 | | | | | | | | 2 | | 2 | | 16 | | | |
| d̪ | | | | | | | | | | | 5 | | | | 13 | 1 | 1 | | |
| d̪ʱ | | 1 | 1 | 1 | | | | | | | | 2 | | 1 | | 15 | | | |
| p | 2 | | 3 | | | | | | | | | | | | | 1 | 7 | 1 | |
| b | | | 8 | 1 | | | | 1 | | | | | | 1 | | | 1 | 5 | 3 |
| bʱ | | | 2 | 1 | | | | | 1 | 1 | 1 | | 1 | | | 6 | 1 | | 4 |

## Discussion

The most typical confusions in Bengali onset consonants across all three background noise conditions are in voicing and aspiration, primarily in the former. Confusions in minor place are almost nonexistent in the clear condition, with only a handful seen in the noise condition. Confusions in major place are only seen in the babble condition, where all types of confusions are common. These results are similar to the predictions of Khan (2006), except that voicing was found to be more confusable than aspiration.

## FUTURE DIRECTIONS

The current study should only be seen as the initial part of a larger investigation of the connections between similarity as measured by confusability and similarity as revealed through phonological alternation. More subjects will no doubt need to be run to reach the statistical power needed for confident claims about this connection. However, even with the current findings, it is clear that similarity as measured by confusability shows notable resemblances to the predictions proposed by Khan's (2006) phonological study of consonant similarity Bengali.

## ACKNOWLEDGMENTS

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## REFERENCES

Boersma, P. and Weenink, D. **(2013)**. Praat: doing phonetics by computer, version 5.3.39, http://www.praat.org/. (Retrieved 18 Jan. 2013.)

Khan, S. D. **(2006)**. "Similarity avoidance in Bengali fixed-segment reduplication," Unpublished master's thesis, UCLA.

Khan, S. D. **(2007)**. "Similarity avoidance in East Bengali fixed-segment reduplication," Proc. WECOL 34, edited by E. Bainbridge and B. Agbayani (Fresno: California State University), pp. 257–271.

Khan, S. D. **(2010)**. "Bengali (Bangladeshi Standard)," J. IPA **40**(2), pp. 221–225.

[1] Rice University Digital Signal Processing group **(1995)**. Noise data, http://spib.rice.edu/spib/select_noise.html/. (Retrieved 19 Jan. 2013.)