

# Influence of phonological relevance on top-down and bottom-up processing: a systematic dichotic listening study

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**Abstract:** Dichotic listening (DL) is a test where auditory stimuli are presented simultaneously to each ear. It is sensitive to hemisphere differences and has been used to study language lateralisation. Recently, dichotic tests have been widely used to study the influence of attention on speech laterality in various disordered populations. The study aims to examine the effect of phonemic relevance on dichotic perception in Kannada. This study was carried out in two phases. Phase 1 aimed to develop and validate a Dichotic word list in Kannada, and Phase 2 involved data collection. Two lists of dichotic pairs were developed and tested with 25 adults across three conditions (free recall, forced right, and forced left). Results showed significant differences in ear responses during the free recall condition, indicating a right-ear advantage. Further, the results showed reduced dichotic performance for phonemically relevant pairs compared to the irrelevant pairs. The findings demonstrated that the right ear advantage can be precisely obtained by increasing the linguistic complexity of dichotic pairs. The addition of phonemic relevance would enhance the clinical utility of dichotic testing for assessing linguistic deficits across various disordered populations.

**Keywords:** Dichotic listening; Free recall; Forced attention; Phonemic relevancy; Right ear advantage

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## 1.0 INTRODUCTION

Dichotic listening refers to the simultaneous presentation of two distinct stimuli, one in each ear ([Hugdahl et al., 1999](#)). Dichotic listening is a technique for studying laterality effects in the auditory modality, in which two different stimuli are presented simultaneously ([Hugdahl et al., 2000](#)). Three attention conditions are typically employed: non-forced (NF),

forced-right (FR), and forced-left (FL). The goal in the FR and FL situations is to block stimuli presented to the opposite ear while concentrating attention on the right ear rather than the left. No attention instruction is provided in the NF condition, which is equivalent to ordinary dichotic listening. The aim is to report the stimuli (syllables) heard regardless of which ear the stimuli are presented to. Dichotic listening has been

used to study interhemispheric transfer ([Westerhausen & Hugdahl, 2008](#)), executive functions and cognitive control ([Hugdahl et al., 2009](#)), and attention ([Hickock, 2009](#); [Shinn et al., 2005](#); [Voyer & Ingram, 2005](#)).

When linguistic stimuli are used, subjects reported right ear advantage (REA). For instance, when two distinct words are simultaneously delivered to each ear, the right ear reports the words more precisely than the left ear does. The dominant contralateral auditory pathways carry information to each ear more effectively in the opposite hemisphere. As a result, the right-ear linguistic input is more strongly connected to the linguistic processes in the left hemisphere, so that during dichotic stimulation, the information transmitted in the ipsilateral auditory pathways is suppressed ([Kimura, 1967](#)). Although both hemispheres receive speech signals and auditory components equally, the dominant left hemisphere extracts linguistic features from the stimulus better ([Josse & Tzourio-Mazoyer, 2004](#)).

It is possible to systematically modify REA by changing the stimulus attributes (bottom-up) or the instruction (top-down). Top-down manipulation is typically carried out by instructing participants to focus on and report from just one ear ([Trejo-Martínez et al., 2018](#)). Comparing this to a free report condition where no attention directive is given (NF), forcing participants to focus on their right ear (FR) usually results in a higher relative attention advantage than when they are instructed to focus on their left ear (FL), which may even reverse the ear advantage ([Hugdahl et al., 2003](#)).

Kannada is a Dravidian language primarily spoken in southern India, with around 60 million speakers, predominantly in Karnataka. Kannada is characterised by an alphasyllabary writing system, written horizontally from left to right, and comprises about twenty dialects ([Ahmed et al., 2022](#)). The English language holds a significant place in Karnataka, functioning alongside Kannada, the official state language ([Brown & Ogilvie, 2010](#)).

Phonetic characteristics, including voicing and place of articulation, are major factors influencing the precision of dichotic listening, since they determine the degree of interference between competing speech signals. The phenomenon known as "feature sharing effect" refers to a discernible enhancement in the identification of dichotic pairs of competing consonants that share phonetic features ([Pisoni & McNabb, 2014](#)). This phenomenon improves the identification of shared

voicing pairs (e.g., /ba-/da/) over non-shared pairs such as /ba-/pa/, and voice onset time (VOT) contrasts yield robust REA. These findings are predominantly from consonant vowel (CV) syllables. Liquids, fricatives, and vowels (ba, da, ga, pa, ta, ka) are the commonly used stimuli in DL ([Arciuli et al., 2010](#); [Westerhausen & Hugdahl, 2008](#)). A much less explored concept in dichotic processing is phonemic relevance, in which the initial phoneme can be kept the same or changed. Phonemically relevant words are those with the same initial phoneme (eg, Bell, Bet), and phonemically irrelevant are those with different initial phonemes (eg, Back, Car), showing REA in dichotic tasks. Kannada is characterised by a relatively transparent orthographic system, with a consistent correspondence between graphemes and phonemes, unlike English, which exhibits an opaque orthography. This transparency facilitates a more direct and systematic organisation of the phonemic inventory, with clearly defined contrasts in voicing and place of articulation, providing an advantageous framework for studying phonemic similarity in Kannada. Moreover, there is no direct comparison of phonemically relevant vs irrelevant word pairs across conditions of dichotic listening.

This gap is notable given the association of dichotic listening with phonological awareness and language skills, in which deficits predict learning disabilities. However, phonemic manipulations at the word level could yield novel insights into pre-lexical processing and hemispheric interaction. Hence, the present study explores the effect of phonemic relevancy on dichotic perception.

## 2.0 METHODOLOGY

This study was conducted in the Audiology and Speech-Language Pathology Department at Kasturba Medical College, Mangalore. It was conducted prospectively using a cross-sectional design. This research project was reviewed and approved by the Ethics Committee of Kasturba Medical College, Mangalore [IEC KMC MLR 03/2023/112]. The investigation was conducted in two stages. Phase 1 involved developing the Kannada dichotic word list, which was implemented as described in Dsouza et al. ([2024](#)). Phase 2 included data collection from 25 middle-aged adults for two distinct lists (relevant vs irrelevant).

### 2.1 Phase 1: Development and validation of the dichotic double word list in Kannada

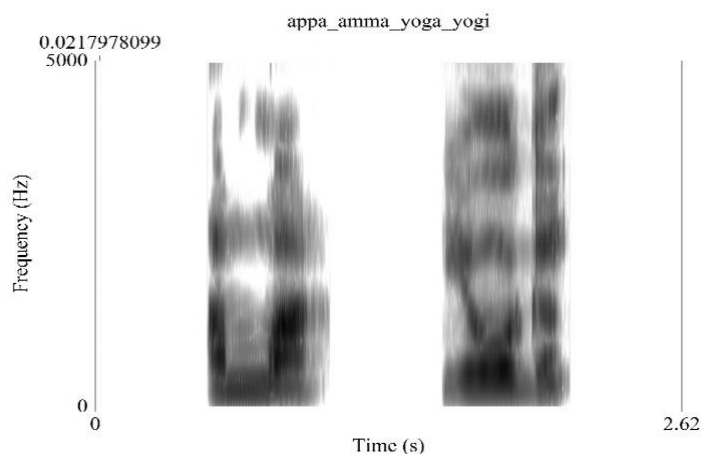
#### 2.1.1 Selection of stimulus and familiarity rating

The Kannada words were taken from the Standard Kannada repository named Kittel dictionary. Kittel's

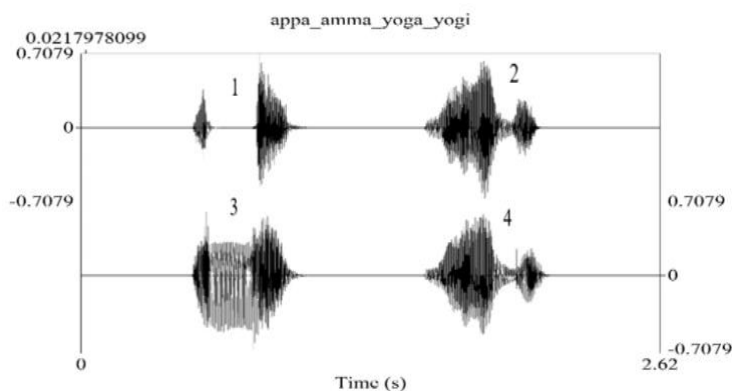
Kannada dictionary categorises the words based on frequency of occurrence from 1 to 10, where 1 is the least frequent and 10 is the most frequent. A total of 518-word terms with a frequency of occurrence greater than five times in the repository were chosen. Familiarity ratings for the selected words were obtained from the general population. They were tasked with rating their familiarity with these words on a 5-point Likert scale, where 1 indicates no familiarity and 5 indicates greater familiarity. 450 words were selected for the stimulus based on familiarity. A standard microphone placed 6 cm from the mouth was used to record these Kannada words. The sounds were produced with adequate intonation and intensity by a male native Kannada speaker. The background noise in the recorded stimuli was eliminated, and the resulting files were saved as .wav files.

Adobe Audition version 3 was used to create dichotic stimuli, with two stimuli saved on the left and two on the right. Each stimulus had a four-second duration (0.5-

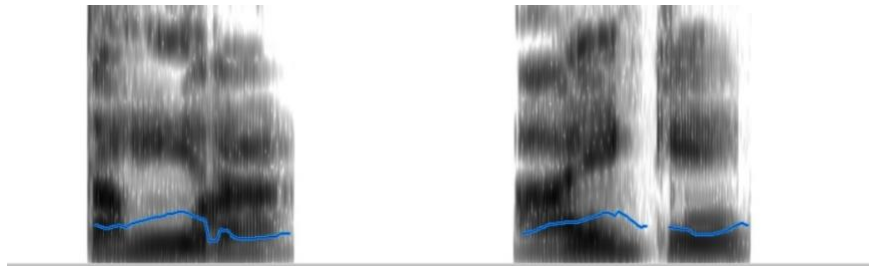
second stimulus, 1-second gap, 0.5-second stimulus, and 2-second gap). A total of 90 dichotic stimuli were prepared and divided among three conditions, with 30 stimuli per condition. Each stimulus consisted of 4 words, with two presented simultaneously to each ear. Each list consisted of two types of dichotic tokens. Phonemically relevant pairs consisted of dichotic combinations that begin from the same Kannada letters (**Fig. 1 and 2**), and regular pairs consisted of dichotic combinations of random words that are phonologically irrelevant. (**Fig. 3 and 4**). An Asus laptop (Windows 11) running on an Intel Core i5 with Realtek High-Definition Audio (Default) was used for testing, along with AKGK72 circum-aural headphones. A calibrated Sound level meter (SLM), Bruel & Kjaer, type 2250 (class I), coupled with an artificial ear, was used to calibrate the sound pressure levels (SPLs) of all the stimuli. Root mean square (RMS) SPL was measured using level A-weighted exposure (LAE), and the overall stimulus intensity was manually adjusted in Adobe Audition 3 to 50-60 dB SPL across all stimuli.



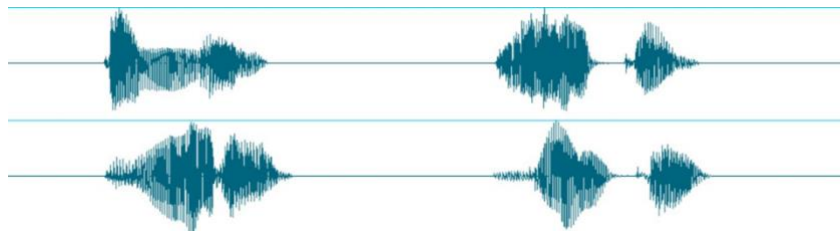
**Figure 1:** Spectrogram of phonemically relevant pairs – appa-amma, yoga-yogi.



**Figure 2:** Waveform of phonemically relevant pairs – (1)appa-(2)amma, (3)yoga-(4)yogi.



**Figure 3:** Spectrogram of phonemically irrelevant pairs – dheera-thamma, gumpu-aayke



**Figure 4:** Waveform of phonemically irrelevant pairs – dheera-thamma, gumpu-aayke

### 2.1.2 Validation

To validate the stimuli, five audiologists were asked to listen to the complete list (90 stimuli), repeat them, and assess their quality by determining whether they could clearly understand what was being said. They were asked to rate the exam on item relevance across intensity, difficulty, duration, distortion, and appropriateness. The participants were required to rate each variable on a five-point Likert scale, with 1 indicating completely inappropriate and 5 indicating completely appropriate.

## 2.2 Phase 2: Data collection

### 2.2.1 Participants

Phase 2 included data collection from 25 middle-aged adults aged 18 to 50 for two different word lists. Participants' written informed consent was obtained before testing.

### 2.2.2 Procedure

The Edinburgh Handedness Inventory was used to assess participants' handedness. Pure-tone audiometry was performed to assess the patient's hearing acuity. Thresholds were obtained using the modified Hugson and Westlake method (ascending and descending method). Subjects with audiometric thresholds below 25 dBHL in both air- and bone-conduction testing were recruited for the study. All subjects were right-handers. A detailed case history of hearing, communication, systemic disease, occupation, and family history was obtained before pure tone audiometry (PTA).

Participants were also examined for middle ear dysfunction using tympanometry on the GSI Tymptstar middle ear analyser, using a 226 Hz probe tone (A type: Normal tympanogram with admittance value of 0.3–1.66 cc and middle ear pressure –100 to +60 dapa). Participants with any history or present middle ear pathology were excluded from the study. The stimuli were played through the calibrated AKG K72 headphones while they were comfortably sitting in a sound-treated room. The participants were told to listen intently to the stimulus in both ears and then respond verbally. The order of presentation was randomised across the subjects. In a few subjects, list 1 (free recall) was presented first, followed by lists 2 and 3; in a few, lists 2 and 3 were presented first, followed by list 1.

### 2.2.3 Conditions

1. Free recall: The subject was asked to concentrate on the stimulus coming from both ears.
2. Forced recall – Right: The subjects were instructed to recall whatever was heard only from the right ear.
3. Forced recall – Left: The subjects were instructed to recall whatever they heard only from the left ear.

### 2.2.4 Scoring

In the free recall condition, each correctly recalled word presented in the right ear was given a score of 1, as was the case in the left ear. Accurate recall of all four stimuli presented to both ears was assigned a double-correct score of 1. Similarly, if the participants correctly recalled both stimuli from the left ear and one stimulus from the

right ear, the left ear was assigned a score of 2, the right ear a score of 1, and *vice versa*. In the forced attention condition, a score of 2 was assigned for correctly recalling both stimuli presented to the attended ear.

### 2.2.5 Statistical analysis

The dichotic test scores were recorded in Excel files and later transferred to SPSS version 25 (SPSS Inc., 2017; SPSS for Windows, Version 25.0, Chicago: SPSS Inc.) for analysis. All data were initially assessed for normality using the Shapiro-Wilk test, which indicated they were not normally distributed. Hence, non-parametric tests like Friedman's test and Wilcoxon signed-rank test were used to assess statistical significance between variables like phonemic relevancy (relevant vs irrelevant) and conditions (Free recall vs Forced Right vs Forced Left).

### 3.0 RESULTS

The study involved 25 participants, including 11 males and 14 females aged between 18 and 50 years, and a mean age of 32.5 years. Two stages of content validation were incorporated to assess the feasibility of the stimulus. Step 1 included a familiarity rating of 518 words, which were selected from a standard Kannada repository. The content validation index (CVI) was calculated for all stimuli using the formula given below,

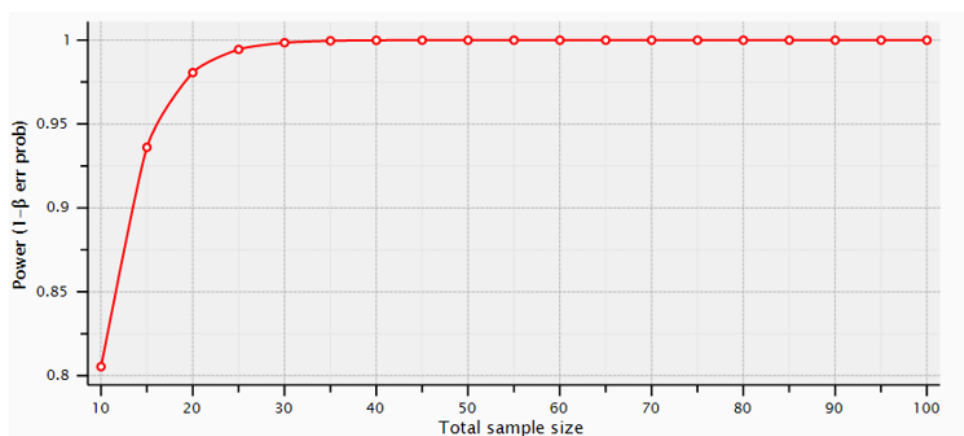
and the results showed a CVI greater than 0.8 for 450 stimuli, which were selected to form the dichotic set. In Step 2 of content validation, which involved validation of dichotic tokens, the CVI was calculated for all 90 stimuli, yielding a CVI of 0.8.

$$CVI = \frac{\text{Number of experts rating the item as relevant}}{\text{Total number of experts}}$$

A pilot test was conducted to evaluate equivalency by assessing each list under free-recall conditions across 10 healthy individuals. The results indicated no significant differences, indicating that each list is equally balanced. All data were initially assessed for normality using the Shapiro-Wilk test, which indicated they were not normally distributed. Hence, nonparametric tests, such as the Friedman test and the post hoc Wilcoxon signed-rank test, were used to assess significance. All subjects were right-handers. Statistics were applied to test for significance at the 5% level. The descriptive statistics are provided in **Table 1**. A post hoc power analysis was conducted to evaluate the adequacy of the sample size, and the results are presented in **Figure 5**. It illustrates the relationship between effect size and statistical power, indicating that the study achieved acceptable power.

**Table 1:** Dichotic scores in all four conditions

Condition	Irrelevant				Relevant			
	Mean	SD	Median	IQR	Mean	SD	Median	IQR
Free recall Right	25.36	4.3	26	23, 28	21.56	5.19	22	19.5, 23.5
Free recall Left	20.48	5.11	20	17.5, 25	16.08	6.52	15	13, 19.5
Double correct	5.04	3.9	4	2, 8	2	2.55	1	0, 3
Forced Right	28.32	3.09	29	28, 30	24.88	3.89	26	21.5, 28.5
Forced Left	28.16	2.85	29	27.5, 30	23.96	8.98	25	21.5, 28.5



**Figure 5:** Power analysis of sample size

Friedman's test was conducted to explore the effect of phonemic relevance (relevant vs irrelevant) under dichotic conditions (Free recall vs Forced Right vs Forced Left). Results indicated statistically significant differences across all conditions for both the relevant and irrelevant lists ( $\chi^2(10)=193.16$ ;  $p=0.0001$ ). Further analysis using post hoc Wilcoxon signed rank test revealed a statistically significant difference between right and left ear scores in both relevant and irrelevant conditions in the free recall condition (Relevant:  $z = -4.046$ ,  $p=0.0001$ ; Irrelevant:  $z = -3.580$ ,  $p=0.0001$ ). Right ear scores were substantially higher than left ear scores in both lists. Regarding the forced recall condition, the results showed no statistically significant differences between ear scores (right vs left) for both the list (Relevant:  $z = -1.014$ ,  $p=0.311$ ; Irrelevant:  $z = -0.550$ ,  $p=0.582$ ). Further analysis revealed a significant difference between free recall and forced attention condition in both the list where forced recall scores were larger when compared to free recall scores (Relevant free vs FR:  $z = -3.373$ ,  $p=0.001$ ; Relevant free vs FL:  $z = -4.111$ ,  $p=0.0001$ ; Irrelevant free vs FR:  $z = -3.765$ ,  $p=0.0001$ ; Irrelevant free vs FL:  $z = -4.261$ ,  $p=0.0001$ ).

Further analysis was conducted to compare dichotic performance across the list (relevant vs irrelevant) conditions. The results showed a statistically significant difference between the lists in all three conditions, where the dichotic scores for irrelevant lists were larger when compared to the relevant list (Free recall right:  $z = -3.736$ ,  $p=0.0001$ ; Free recall left:  $z = -3.456$ ,  $p=0.001$ ; FR:  $z = -3.865$ ,  $p=0.0001$ ; FL:  $z = -3.816$ ,  $p=0.0001$ ). This suggests that phonological relevance increases task difficulty, thereby leading to poorer scores across all three conditions.

#### 4.0 DISCUSSION

The results showed a significant difference in dichotic scores between the right and left ears in healthy controls, with higher scores in the right ear compared to the left, indicating a right-ear advantage in the free recall condition. The phenomenon was seen in both phonemically relevant and irrelevant stimulus lists. The REA has been proposed as a reliable indicator of cerebral language asymmetry, as language and linguistic abilities are lateralized to the left hemisphere ([Westerhausen et al., 2023](#)). Not only behavioural studies but also several neurophysiological studies have shown greater activation in the left hemisphere compared with the right during dichotic presentation ([Hugdahl et al., 1999](#)). The most widely recognised explanation for REA is the structural model first

proposed by Kimura ([1961](#); [1967](#)). According to this idea, the REA results from the interaction between the left hemisphere's linguistic specialisation and the auditory pathway's contralateral dominance. The left hemisphere is known to be involved in language function. Furthermore, asymmetry is frequently observed in the projections made from each ear to the bilateral auditory cortices. Compared to the ipsilateral route, the contralateral pathway is more powerful.

A few recent studies have failed to replicate this effect, particularly in adults ([Fuente et al., 2007](#)). One possible reason could be the stimulus used to test the dichotic processing. Several studies have used CV syllables, which may not be appropriate stimuli to assess hemispheric differences. According to recent findings, consonant-vowel stimuli are thought to be processed bilaterally in the brain, as they are associated with the first phases of phonological processing ([Hickock, 2009](#)). This means there is a lower chance of one ear detecting a distinct advantage over the other. This is a crucial finding, as it may make it more difficult to assess auditory advantage when a linguistically simpler input is represented in both hemispheres.

According to some experts, there would be a greater likelihood of a right-ear advantage if language complexity increased ([Strouse & Wilson, 1999](#)). Studies using word pairs have shown significant differences between the right and left ears, suggesting that differences in stimulus selection can greatly influence the presence of an auditory advantage ([Bhat et al., 2021](#)). This concept is also evident in the current study. As linguistic complexity increased from simple word pairs to more complex phonemically relevant pairs, dichotic scores decreased while maintaining the right-ear advantage. Using such complex linguistic pairs would prevent saturation of dichotic performance in adults, thereby enabling precise estimation of ear advantage.

In the forced recall condition, the results showed no significant differences between the forced-right and forced-left conditions. This indicates that when the subject was asked to focus on the right ear, right-ear performance was enhanced, leading to the right-ear advantage. Similarly, when the subject was asked to pay attention to the left ear, the left ear performance was enhanced, leading to the left ear advantage. These results are consistent with a prior review of attention and cognitive control using the dichotic forced attention paradigm ([Hugdahl et al., 2009](#)). The modulation of the ear advantage with attention was attributed to the

strong influence of top-down cognitive control over the perceptual asymmetry.

## 5.0 LIMITATIONS AND FUTURE DIRECTIONS

The present study is limited to a small sample size and restricted to the healthy adult population. The absence of a clinical population further limits the applicability of findings to individuals with auditory or neurological disorders.

Further studies should aim to incorporate a larger sample size and a broader focus to include pediatric and

clinical populations. In addition, neurophysiological measures could be incorporated alongside behavioural assessments to better understand the neural mechanisms.

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**Conflict of Interest:** The author declares no conflict of interest.

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