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# Effect of orthography over neural regions in bilinguals: A view from neuroimaging

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## HIGHLIGHTS

- Reading in two distinct orthographies.
- Inferior frontal and middle temporal are key neural regions in reading process.
- Middle and superior frontal neural regions are crucial in orthographic mapping.

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## ABSTRACT

Effects of written script processing on neural regions have been explored using fMRI in a group of bilingual population that has not so far been studied, namely, Urdu–Hindi skilled bilinguals. Hindi and Urdu languages are very similar at the spoken level but differ greatly in scripts; Hindi is a highly transparent script, whereas Urdu is more opaque. The common regions (conjunction analyses) observed for Urdu–Hindi bilingual readers are left inferior frontal gyrus (IFG) (BA 44/45), bilateral middle temporal (BA 22), left fusiform gyrus (BA 37) and bilateral middle occipital regions. The distinct regions for Urdu words were found in left superior frontal and left middle frontal regions whereas; no distinct region was found for Hindi words. Imaging result suggests that middle and superior frontal regions are crucial for the orthography and graphemic complexity of Urdu script.



## 1. Introduction

Research in neuro-bilingualism has emphasized understanding on how two languages are formed in a single brain. Most of the research has concentrated on finding a common as opposed to a segregated language network in bilinguals, with less attention being given to understanding of the effect of orthography over neural regions. Studies have reported that orthographic transparencies have impact on reading acquisition (for details, see [1]). Thus, the objective of the present research was to examine whether the reading of scripts of different orthographic depths (deep Urdu and transparent Hindi orthography) induces distinct brain activity in bilinguals. To this end, a single word reading task design was applied, in which BOLD fMRI responses were recorded from skilled Urdu–Hindi bilinguals.

Hindi and Urdu languages belong to the Indo-Aryan language family. Hindi uses the Devanagari writing system, which is considered to be semi-syllabic (having both syllabic and alphabetic properties), and in which there is a direct correspondence between letters and sounds with very little ambiguity. Hindi consonants are pronounced with an inherent schwa vowel, without having any independent graphemic form [2]. Vowels appear as discrete letters in word-initial, medial, or final positions. In non-initial positions, vowel signs are placed nonlinearly above, below, or to the left or right of consonants [3]. In contrast to Urdu, the mapping of spelling to sound is highly consistent in Hindi and vowel marking is obligatory. Urdu is written in Nasta'liq, a form of Arabic script. It is derived from the Semitic family and contains three phonological layers—the indigenous layer of Indo-Aryan and the borrowed layers of Semitic and Iranian [4]. The Semitic model does not have retroflexion, aspiration, nasalization, or vocalic sound; thus, the Urdu system added a total of seventeen sounds to represent these distinctions [5]. Urdu script has distinct graphemic features specifically for retroflexion and aspiration, which are supposed to increase its complexity, whereas the Devanagari script of Hindi does not treat retroflexion or aspiration as distinctive features [6]. The absence

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of vowel diacritics in Urdu and the mapping of multiple phonemes by a single grapheme also suggest that Urdu is orthographically much deeper than Hindi [7]. Studies have suggested theoretical frameworks to account for the impact of orthographic transparency on reading acquisition [8,9]. These studies suggest that reading in orthographically transparent languages involves higher phonological processing using grapheme-to-phoneme conversion, whereas for an opaque orthography, reading involves more lexical to semantic processing. The psycholinguistic grain size theory (PGST) with respect to the orthographic properties of language also suggests that the size of the units that form the lexical representations are important for grapheme-to-phoneme correspondences (for details, see [10]). In transparent orthographies, phonological processing integrates small orthographic units and follows sub-lexical decoding strategies, whereas opaque orthographies integrate larger orthographic units and support lexical, whole-word reading processing [11]. The grain size theory is considered as a better alternative to the Orthographic Depth Hypothesis, which derives from the classical dual-route models of reading [12].

Assessing the impact of reading over neural regions in Urdu–Hindi bilinguals is relevant because the two scripts are essentially identical to their corresponding spoken level and they share a common syntactic structure, morphology and lexicon. So any differences in the neural regions of bilinguals are directly related to effect of orthographic differences. No reported neuroimaging study has made use of the uniqueness and versatility of these languages for a cross-language comparative study of reading in the bilingual's brain.

Neuroimaging research using brain imaging technology has suggested that a network of left-lateralized regions in the occipitotemporal, temporoparietal, and frontal cortices participates in aloud and silent reading [13,14]. Previous research has consistently reported that there are overlapping neural regions underlying the processing of the two languages in the brains of early bilinguals [15,16]. Based on previous studies, it is predicted that reading by proficient early Urdu–Hindi bilinguals in either language would produce a similar cortical network. At the same time, it is hypothesized that there would be involvement of some additional brain regions, reflecting the substantial differences in the orthographies of Urdu and Hindi.

## 2. Materials and methods

### 2.1. Participants

Eighteen right-handed fluent male bilinguals (mean age = 28.3 years, SD = 3.2) participated in the study. All of the bilingual participants received their language exposure when they were below the age of five years and each learned to read both languages at home. The bilingual participants lived and had studied in India at the time of testing, considered themselves equally fluent in Hindi and Urdu, and had only nominal exposure to other languages. A bilingual language background questionnaire (developed in-house) was used to quantify language use in and outside of the home (Table 1). All participants had normal vision acuity with no history of neurological disease. Informed consent was obtained from each participant following the protocol approved by the Institutional Human Ethics Committee of the Institute.

### 2.2. Behavior test

#### 2.2.1. Passage reading time

To measure reading fluency in line with some earlier studies (e.g., [17]), a written passage of 250 words was presented to each participant individually. The time taken to read the passage was measured by the participant pressing a button upon beginning and again on completing the reading.

**Table 1**
Language background and self-assessment of subjects.

| Language background | Urdu (*M*, SD) | Hindi (*M*, SD) |
|---|---|---|
| *Urdu–Hindi bilingual* | | |
| Age of first exposure (years) | 00 (00) | 00 (00) |
| Formal study (years) | 13.91 (2.62) | 14.62 (2.72) |
| *Language self assessment (scale; 1–4, 4 = excellent)* | | |
| Listening comprehension | 3.72 (0.46) | 3.6 1(0.50) |
| Reading comprehension | 3.72 (0.46) | 3.52 (0.51) |
| Speaking comprehension | 3.61 (0.50) | 3.61 (0.50) |
| Writing comprehension | 3.77 (0.42) | 3.5 (0.51) |

| Parameter | Urdu | Hindi | *P* value |
|---|---|---|---|
| *Performance inside the scanner during reading task* | | | |
| Overall accuracy (% correct) | 90.44 (3.66) | 89.22 (2.93) | ns |
| Overall response time (ms) | 72.22 (1.86) | 72.44 (2.43) | ns |

#### 2.2.2. Materials

Stimuli were one hundred eighty concrete nouns (90 Hindi and 90 Urdu words) and 90 false-font stings, i.e., unfamiliar characters in Hindi and Urdu matched to word length. False-font strings are associated with neither phonological nor semantic representations, and are primarily used to control non-linguistic computations (e.g., motor execution and response selection). The average number of phonemes for both Hindi and Urdu words was 4.11 (SD 1.01). Due to the unavailability of standard norms to ascertain the rating of the frequency of Hindi and Urdu words, an independent group of 30 native readers rated the frequency of the words on a seven-point scale. There were no significant differences in Hindi and Urdu word frequency ($t\,(29) = 1.52$, $p \leq 0.14$). An illustration of word stimuli is given below:

Word in Hindi; कमल (*Kamal*) (*Hindi*) (*Lotus*)
Word in Urdu: کمل (*Kamal*) (*Urdu*) (*Lotus*)

#### 2.2.3. Task procedure

Based on previous neuroimaging studies on reading single words [18,19], the experimental design involved a reading task in which each participant was instructed to silently read a word and then press one of the two buttons to indicate the presence (right thumb button) or absence (left thumb button) of an italicized letter in the word (e.g., कलम (pen), नमक (salt) in Hindi; نمک (salt), قلم کے (pen) in Urdu). Participants also performed the same task on false-font strings or 'pseudofonts'. Before being scanned, participants were trained to the task. Trials were presented in a block design in which each block consisted of 6 words (3 words with italic letters and 3 words without italic letters in an 18-s block). The experiment included three scanning sessions. Each session lasted for 470 s and consisted of five task blocks for each condition (Hindi, Urdu, and non-word) interspersed with a fixation crosshair (12 s). The words were randomly presented within a block, and task blocks within a session were counterbalanced across the subjects. The stimuli and a fixation crosshair were presented in black on a white background. For all conditions, each trial was presented for 2000 ms, with an inter-trial interval (ITI) of 1000 ms (a crosshair). The task and stimuli were programmed with E-prime software and presented with an OLED visual display attached to the head coil.