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Short communication

Neural correlates of age of acquisition on visual word recognition in Persian

Mehdi Bakhtiar*, I-Fan Su, Hyun Kyung Lee, Brendan Stuart Weekes

Laboratory for Communication Science, Division of Speech and Hearing Sciences, University of Hong Kong, Hong Kong

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ABSTRACT

The effect of Age of Acquisition (AoA) on visual word recognition is remarkable. However, there is debate about the loci of AoA effects. The Arbitrary Mapping hypothesis assumes AoA reflects mappings between input (e.g. orthography) and output (e.g. phonology) formed during the acquisition of literacy. An alternative view is that AoA reflects the acquisition of concepts. The AM hypothesis predicts reduced AoA effects on the recognition of written words with transparent mappings between orthography and phonological e.g. *chair* compared to written words with more opaque mappings between orthography and phonology e.g. *choir*. In the Persian language, mappings between letters and phonological output are predictable and transparent. However, in skilled reading, many written words become opaque due to the omission of vowels (diacritics) in adult text. Using event-related potential methods (ERP) we tested the prediction that AoA effects on ERP components would be reduced for words with transparent spellings compared to words with opaque spellings for skilled readers. We found an effect of AoA on visual word recognition in the window between 300 and 450 ms with higher N400 negativity for late acquired words and an interaction between transparency and AoA at an unexpected late component (450 −700 ms) with significantly higher positivity for late acquired opaque words only. We conclude that AoA effects on Persian visual word recognition reflect arbitrary mappings between print and sound and offer a neurolinguistic account of AoA effects.

1. Introduction

The age of acquisition (AoA) of a word has an effect on visual word recognition across languages (Izura et al., 2011; Juhasz, 2005) including Persian (Bakhtiar & Weekes, 2015). Written words learnt early in life are recognised faster and generate fewer errors than words acquired later in life. Remarkably, the effect of AoA has a neural correlate in skilled reading that is independent of related variables such as word frequency, imageability and word length. Neural effects are observed in both Indo-European languages that use an alphabet with predictable mappings between print and sound such as English (Hernandez & Fiebach, 2006), German (Fiebach, Friederici, Muller, Von Cramon, & Hernandez, 2003) and Spanish (Cuetos, Barbon, Urrutia, & Dominguez, 2009) as well as Sino-Tibetan languages such as Chinese that use characters that contain relatively few predictable mappings between orthography and phonology (Weekes, Chan, & Tan, 2008). The Persian language by contrast uses a

* Corresponding author. Laboratory for Communication Science, Division of Speech and Hearing Sciences, Meng Wah Building, University of Hong Kong, Pokfulam Road, Hong Kong.
E-mail address: bakhtiar@connect.hku.hk (M. Bakhtiar).

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Semitic (Arabic) script that contains both predictable (transparent) and less predictable (opaque) characters (Bakhtiar & Weekes, 2015). We know that AoA has an effect on skilled word recognition in Persian speakers. However, no study has investigated the neural correlates of AoA effects during word recognition in Persian.

AoA effects on adult written word recognition are controversial (Cortese & Schock, 2013; Izura et al., 2011; Weekes & Chen, 1999). One question is whether AoA is independent of word frequency. Some argue that AoA is simply a proxy measure for word frequency (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Lewis, 1999; Zevin & Seidenberg, 2002) reflecting the cumulative frequency of exposure i.e. words learnt later in life are less frequent as there is less opportunity for exposure. However, studies report independent effects of AoA and cumulative frequency on visual word recognition (Cortese & Khanna, 2007). Other authors suggest that the effects of AoA dissociate into different sources: one frequency related and the other frequency-independent (Brysbaert & Ghyselinck, 2006). According to Brysbaert and Ellis (in press), the magnitude of the AoA effect is larger than the frequency effect in tasks such as picture naming and picture writing, word associate generation, semantic fluency and naming to definition because the real AoA effect results from activation of verbal outputs at the stage of access to semantic knowledge.

Competing accounts of the AoA effect on visual word recognition are quite relevant to the neurobiology of language. The Arbitrary Mapping (AM) hypothesis assumes AoA effects on written recognition are limited to words with unpredictable mappings between orthography and phonology. For example the irregularly spelt words *yacht* and *choir*. Contrary to this assumption however, AoA has an effect on written word recognition in languages with nearly complete transparency between orthography and phonology (e.g. German and Spanish) at both the behavioural and neural levels (Ellis, Burani, Izura, Bromiley, & Venneri, 2006; Fiebach et al., 2003; Weekes et al., 2008). This shows that type of script matters when explaining AoA effects. An alternative view is that the effect of AoA reflects the acquisition of concepts during the learning of vocabulary (Vervoorn, 1989). Effects of AoA on semantic tasks such as word associate generation and categorization (Brysbaert, Van Wijnendaele, & De Deyne, 2000) support this account. The corollary is that AoA effects emerge in adult lexical decision during obligatory semantic processing that is a necessary outcome of written word recognition (Raman, 2008).

Evidence for the arbitrary mapping and semantic hypotheses can be found in behavioural and computational modelling studies. Similarly, neurological evidence is equivocal with regard to the arbitrary mapping and semantic hypotheses. On the one hand, evidence of AoA effects on word recognition at the neural level (found with fMRI) in German mitigates the arbitrary mapping hypothesis. However, cross-linguistic evidence is not directly supportive of the semantic hypothesis given that no unique brain regions associated with semantic processing only were identified in studies of Chinese, English or German. This is not surprising given that fMRI is a relatively blunt instrument for distinguishing the time course of the stages in written word recognition compared to fine grained techniques such as ERP and MEG (see for example Wydell, Vuorinen, Helenius, & Salmelin, 2003).

Cuetos et al. (2009) used ERP methods to compare the effects of frequency, AoA and rated imageability on silent word reading in Spanish. They reported that, high frequency words elicited higher positivity than low frequency words in the time window between 175 and 360 ms post-stimulus onset over posterior electrodes. However, an independent effect of AoA was observed in the time window between 400 and 610 ms post stimulus onset with greater N400 negativity for late acquired than early acquired words. Cuetos et al. proposed the early frequency related component is related to orthographic recognition whereas the later AoA related component reflects either semantic processing or semantic to phonological retrieval. Critically, Cuetos et al. argued that their results are problematic for the AM hypothesis because Spanish is a transparent script and therefore AoA is not expected to show any effect at all at the neural level. It is not clear from the Cuetos results if the AM hypothesis can be rejected since words with unpredictable mappings between orthography and phonology were not manipulated in the study. Weekes (2011) reported a significant effect of AoA on Chinese character recognition using a visual lexical decision task in the time windows between 300–500 ms and 500–700 ms. However, contrary to prediction, there was no interaction between AoA and character transparency in Chinese (an opaque script).

Here we examine the neural correlates of AoA on word recognition using Persian an Indo-European language that uses Arabic script with clearly defined differences between words with predictable and unpredictable mappings between orthography and phonology. Persian orthography is an ideal testing of the AM hypothesis because, although print to sound mappings are consistent and predictable during the acquisition of literacy, skilled readers typically encounter written words with unpredictable pronunciations when read out of context (Baluch, 2005). This is because as in other Semitic scripts most text encountered in daily life omits all short vowels (a, e, o) making mappings between orthography and phonology less predictable for the majority of words (we will call these opaque words). Take as an example the word *srd*/cold/which can be read aloud in at least three ways/sard, serd, sord/, even though only one production has a lexical representation i.e./sard/and other pronunciations are nonwords. Transparent words retain long vowels (â, i, u), written in a letter format with consistent mappings between graphemes and phonemes e.g. *tâb*/swing/that can be read in one way/tâb/only. Behavioural studies of oral reading in Persian report (1) orthographic transparency effects on reading in Persian i.e. transparent words read aloud faster and more accurately than opaque words by adults and children (Bakhtiar & Weekes, 2015; Baluch, 2005; Baluch & Shahidi, 1991; Rahbari & Senechal, 2009; Rahbari, Senechal, & Arab-Moghaddam, 2007) and (2) larger effects of AoA for opaque than transparent words (Bakhtiar & Weekes, 2015).

No study has examined the neural correlates of AoA effects on recognition of words in Persian. Timmer, Vahid-Gharavi, and Schiller (2012) reported ERP correlates of orthographic transparency effects in Persian using a masked onset priming paradigm. The key finding was a priming effect on oral reading from phonologically matched onset primes (tâs → tup) compared with a mismatch prime condition (qâb → tup) for transparent words only. In addition, ERP results showed an early