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Frequency trajectory effects in Chinese character recognition: Evidence for the arbitrary mapping hypothesis

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ABSTRACT

Frequency trajectory is a better measure to investigate age-limited learning effects than age of acquisition (AoA) ratings (Zevin, J. D., & Seidenberg, M. S. (2002). Age of acquisition effects in word reading and other tasks. *Journal of Memory and Language, 47*(1), 1-29). The current study uses frequency trajectory as a variable to investigate age-limited learning effects in Chinese character recognition, and tests predictions of the arbitrary mapping hypothesis as applied in a non-alphabetic writing system. In Experiment 1, regression analyses showed that, compared to rated AoA, frequency trajectory of characters was less affected by other lexical properties, and could explain a significant proportion of variance of AoA. In Experiment 2, the frequency trajectory and predictability from orthography to pronunciation of characters were orthogonally manipulated in a character naming task. The frequency trajectory effect appeared only for the arbitrary mapping condition. In Experiment 3, frequency trajectory and predictability from orthography to meaning of characters were manipulated in a semantic category judgment task. The frequency trajectory effects were found only when the mapping from orthography to semantic is less consistent. In summary, the study confirmed that AoA is a genuine factor affecting word processing, and the AoA effects were limited to those situations in which mapping between input and output representation was arbitrary. These results provide strong cross-linguistic evidence in support of the arbitrary mapping hypothesis.

1. Introduction

For adults, words acquired early in life are typically processed quickly and more accurately than words acquired later in life. This age-of-acquisition (AoA) effect on word processing has been found in a variety of tasks, including: (1) word naming (e.g., Gerhand & Barry, 1998; Ghyselinck, Lewis, & Brysbaert, 2004); (2) visual word decision (e.g., Chen, Wang, Wang, & Peng, 2004; Ghyselinck et al., 2004; Morrison & Ellis, 1995; Morrison & Ellis, 2000); (3) word category decision (e.g., Brysbaert, Van Wijnendaele, & De Deyne, 2000; Chen, Zhou, Dunlap, & Perfetti, 2007; Johnston & Barry, 2005; Van Loon-Vervoorn, 1989); (4) picture naming (e.g., Bonin, Chalard, Meot, & Fayol, 2002; Ellis & Morrison, 1998; Holmes & Ellis, 2006; Morrison, 2003), and (5) object recognition and category exemplar generation (see reviews by Johnston & Barry, 2006; Juhasz, 2005). It has also been found that AoA has an effect on word processing over and above frequency effects (Brysbaert & Ghyselinck, 2006; Fiebach, Friederici, Muller, von Cramon, & Hernandez, 2003; Morrison & Ellis, 1995).

Although AoA effects have been reported in a large number of studies, Zevin and Seidenberg (2002) reviewed the previous AoA literature and found that early-acquired words were significantly more frequent than late-acquired ones. These previous studies (e.g., Gerhand & Barry, 1998; Morrison & Ellis, 1995; Turner, Valentine, & Ellis, 1998) did not control for cumulative frequency, that is, how many

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times a word has been encountered during a person's entire lifetime, including childhood. Zevin and Seidenberg (2002) also pointed out that it is difficult to manipulate the rated AoA while matching other dimensions of the stimuli, because AoA is highly correlated with other variables—such as imageability, length, and familiarity—that also have an influence on lexical processing. Thus, it is very difficult to dissociate the AoA effects from these other factors.

Zevin and Seidenberg (2002) suggested that a better measure of age-dependent learning effects in word processing is the frequency trajectory (FT). Frequency trajectory refers to the distribution of frequency occurrence over a lifetime. For example, some words have a high frequency of occurrence early in childhood, but a low frequency of occurrence in adulthood (i.e., high-to-low frequency trajectory); whereas other words may show the reverse pattern (i.e., low-to-high frequency trajectory). As pointed out by Zevin and Seidenberg (2002), the concepts of frequency trajectory and cumulative frequency circumvented the circularity problem which arises when using a performance measure, such as rated AoA, to predict performance on another task. Therefore, they suggested using frequency trajectory to assess age-dependent learning effects, because it provides a parsimonious explanation as to why some words were acquired before others.

The results of simulations in connectionist models further showed the frequency trajectory effects on word processing were observed only when there was an arbitrary mapping between input and output representation. Zevin and Seidenberg (2002) argued that late-learned patterns could make use of network structures formed by the early learning patterns if the mapping between input and output was consistent. However, if the mapping was less consistent or arbitrary, the network had to memorize individual patterns, and then the AoA effects would be produced. This idea was further supported by the behavioral study of Zevin and Seidenberg (2004) which found no frequency trajectory effects in an English word naming task. They indicated that the systematic mapping between spelling and sound in English may explain the absence of a frequency trajectory effect. So, the age-limited learning effect is minimal in an English word naming task. Bonin, Barry, Meot, and Chalard (2004) found that frequency trajectory of words is a reliable predictor of order of word acquisition in French. They used multiple regressions to reanalyze some previously published data, showing that frequency trajectory had a reliable influence on spoken and written object naming latencies and lexical decision times, but not on spelling-to-dictation or on word naming latencies. They thought that the mapping relationships between input and output representations were arbitrary in the task of spoken and written object naming and lexical decision, but not in the task of spelling-to-dictation and word naming. Therefore, frequency trajectory effects seem to emerge in the former tasks but not in the latter ones.

In summary, the effects of frequency trajectory during word identification were only found when there was an arbitrary mapping between input and output representation. This idea is supported by the arbitrary mapping hypothesis, which assumes that AoA effects reflect the arbitrary nature of the mapping between input and output representations formed during the development of the lexical network. When the mapping between input and output is arbitrary or inconsistent, AoA effects will be increased (Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Monaghan & Ellis, 2002).

In addition, one interesting study by Monaghan and Ellis (2002) showed a strong AoA effect for English words with inconsistent pronunciations but not for words with consistent pronunciations. The connectionist simulations of Lambon Ralph and Ehsan (2006) found the greatest AoA effects emerged for the arbitrary mapping, intermediate effects for quasi-systematic and systematic mappings, and small AoA effects for the quasi-consistent mapping between input and output representation. The results were further supported in their empirical study: A substantial AoA effect was observed in the picture naming task (which involves an arbitrary mapping between semantics and phonology), but no AoA effect was found in a word naming task (which involved a quasi-consistent mapping between orthography and phonology). Chen et al. (2007) also found strong AoA effects in Chinese when the input and output relationship was arbitrary (see also Liu, Hao, Shu, Tan, & Weekes, 2008). These studies support the arbitrary mapping hypothesis for the explanation of AoA effects; however, the AoA measure of these studies was not based on frequency trajectory. In addition, Raman (2006) found AoA effects of word naming task even for the highly transparent orthography of Turkish, thus failing to support the arbitrary mapping hypothesis. Therefore, the arbitrary mapping hypothesis still warrants further examination.

Chinese offers an ideal way to test (1) whether effects of frequency trajectory will be found, and (2) whether these effects will be limited to those situations in which there is an arbitrary mapping between input and output.

It is well known that Chinese is quite different from alphabetic writing systems (Perfetti & Zhang, 1995; Yan, Tian, Bai, & Rayner, 2006). The basic writing units of Chinese are characters, which map onto a single syllable morpheme rather than onto phonemes. There are no grapheme–phoneme correspondence rules as in alphabetic languages. Therefore, compared to written words in most alphabetic languages, Chinese is relatively less predictable in the mapping between orthography and phonology (Monaghan & Ellis, 2002; Zevin & Seidenberg, 2002). Thus Chinese provides an interesting tool to test the arbitrary mapping hypothesis. Next we give a detailed introduction for Chinese characters and their mapping relations from orthography to phonology and from orthography to meaning.

More than 80% of Chinese characters are phonograms which consist of at least two subcomponents: a phonetic radical and a semantic radical (Tan & Perfetti, 1997). Usually, the phonetic radical is on the right side of a phonogram and may provide information about the pronunciation of the character (Shu, Zhou, & Wu, 2000); the semantic radical is usually on the left side of a phonogram and may provide information about the meaning of the character. When the exact meaning cannot be guessed from the semantic radical, it sometimes still provides more general categorical meaning of the character. For instance, the phonogram '湖'