Neuropsychologia 53 (2014) 1–11

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Selective transfer of visual working memory training on Chinese character learning

Bertram Opitz [a,b,*], Julia A. Schneiders [b], Christoph M. Krick [c], Axel Mecklinger [b]

[a] School of Psychology, University of Surrey, Guildford, GU2 7XH, United Kingdom
[b] Department of Psychology, Saarland University, Saarbrücken, Germany
[c] Department of Neuroradiology, Saarland University Hospital, Homburg, Germany

ARTICLE INFO

Article history:
Received 13 February 2013
Received in revised form
12 September 2013
Accepted 24 October 2013
Available online 31 October 2013

Keywords:
Second language
Chinese
Vocabulary learning
Working memory
Training

ABSTRACT

Previous research has shown a systematic relationship between phonological working memory capacity and second language proficiency for alphabetic languages. However, little is known about the impact of working memory processes on second language learning in a non-alphabetic language such as Mandarin Chinese. Due to the greater complexity of the Chinese writing system we expect that visual working memory rather than phonological working memory exerts a unique influence on learning Chinese characters. This issue was explored in the present experiment by comparing visual working memory training with an active (auditory working memory training) control condition and a passive, no training control condition. Training induced modulations in language-related brain networks were additionally examined using functional magnetic resonance imaging in a pretest-training-posttest design. As revealed by pre- to posttest comparisons and analyses of individual differences in working memory training gains, visual working memory training led to positive transfer effects on visual Chinese vocabulary learning compared to both control conditions. In addition, we found sustained activation after visual working memory training in the (predominantly visual) left infero-temporal cortex that was associated with behavioral transfer. In the control conditions, activation either increased (active control condition) or decreased (passive control condition) without reliable behavioral transfer effects. This suggests that visual working memory training leads to more efficient processing and more refined responses in brain regions involved in visual processing. Furthermore, visual working memory training boosted additional activation in the precuneus, presumably reflecting mental image generation of the learned characters. We, therefore, suggest that the conjoint activity of the mid-fusiform gyrus and the precuneus after visual working memory training reflects an interaction of working memory and imagery processes with complex visual stimuli that fosters the coherent synthesis of a percept from a complex visual input in service of enhanced Chinese character learning.

1. Introduction

Communicating with people around the globe is becoming more and more important in an increasingly globalized world. Thereby the ability to speak different languages is a condition precedent. Chinese is one of the languages, which are most frequently spoken all over the world. Thus, learning Chinese as a second language is vitally important for many Westerners. One of the most crucial aspects of second language learning is vocabulary acquisition. As words are the basic building blocks of language, the amount of vocabulary knowledge restricts the learner's production of written and spoken language as well as the comprehension of spoken and written language produced by others (Baddeley, Gathercole, & Papagno, 1998). In contrast to alphabetic languages, little is known about how second language vocabulary acquisition can be improved in the most frequent and most prominent logographic language: Mandarin Chinese. Since the Chinese writing system decidedly differs in the design principles and the characteristics of visual appearance of the words compared to alphabetic languages (Perfetti, Nelson, Liu, Fiez, & Tan, 2010), it provokes the question which processes underlie visual word i.e. character learning in Chinese and whether this process can be trained to result in improved performance in Chinese vocabulary acquisition. In this regard brain imaging methods reveal precious insights in relevant neural networks of second language vocabulary acquisition as they might disclose specific affordances of processing words in a new language system that should provide an indication of underlying processes.

* Corresponding author at: University of Surrey, School of Psychology, Stag Hill, Guildford, GU2 7XH, United Kingdom. Tel.: +44 1483 689449.
E-mail address: b.opitz@surrey.ac.uk (B. Opitz).

0028-3932/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neuropsychologia.2013.10.017

1.1. The Chinese writing system

Chinese is referred to as a logographic writing system. Hence, the basic unit of the script is the character that comprises a number of strokes packed into a square configuration. Unlike alphabetic scripts, visually complex stroke patterns in Chinese characters follow a left–right horizontal, top-bottom vertical or inside–outside orientation. The most striking difference in contrast to alphabetic languages is that characters map onto phonology at the syllable level, such that the usage of grapheme–phoneme correspondence rules as in alphabetic languages is not possible (Perfetti, Liu, & Tan, 2005; Tan, Hoosain, & Siok, 1996). Due to the differences in design principles and visual word forms between Chinese and alphabetic script the neural circuitry involved when alphabetic native speakers learn Chinese characters is not readily inferred from the brain structures involved in learning alphabetic languages. The few available brain imaging studies investigating Chinese character learning in English native speakers consistently found a network that mimics the pattern for Chinese native character processing (Deng, Booth, Chou, Ding, & Peng, 2008; Liu, Dunlap, Fiez, & Perfetti, 2007; Nelson, Liu, Fiez, & Perfetti, 2009) but contrasts with the one for alphabetic word reading (e.g. Tan, Laird, Li, & Fox, 2005a). In more detail, Nelson et al. (2009) demonstrated that native English speakers who were learning Chinese for one year activated bilateral fusiform gyri as well as the left middle frontal gyrus when reading Chinese characters. Those activations are usually not found when processing words in an alphabetic language. Similar activations were found in laboratory training studies of Chinese characters (Deng et al., 2008; Liu et al., 2007). For example, Liu et al. (2007) report comparable regions in bilateral fusiform gyri and the left middle frontal gyrus after native English speakers learned a set of 60 Chinese characters during a 3-day learning period. As the fusiform gyri are involved in the visual analysis of words and objects (e.g. Cohen et al., 2000, 2002; McCandliss, 2003; Riesenhuber & Poggio, 1999), these data suggest that alphabetic native speakers need to adopt additional visual procedures that process the detailed and complex stroke pattern of Chinese characters. Since the simpler left–right-oriented procedures during alphabetic reading are not sufficient for reading Chinese characters, neural resources for enhanced analysis of perceptual details seem to be accessorily recruited.

1.2. The role of working memory in vocabulary acquisition

Evidence that working memory processes underlie vocabulary acquisition comes from various studies demonstrating that vocabulary knowledge in alphabetic second languages correlates with phonological working memory capacity as measured by digit span and non-word repetition (e.g. Baddeley et al., 1998; Cheung, 1996; Kormos & Sáfár, 2008; Slevc & Miyake, 2006; Speciale, Ellis, & Bywater, 2004). The implication is that second language learners in an alphabetic language have to rely on the phonological loop that provides short-term storage of novel unfamiliar sound patterns and enables the formation of more stable long-term phonological representations in the mental lexicon (Baddeley, 2003; Baddeley et al., 1998). As written words are automatically transformed into a phonological code using grapheme–phoneme conversion rules, retention depends crucially on the acoustic and phonological characteristics for both visually and auditorily presented words (Baddeley, 2003).

Again, not much is known about the relationship between vocabulary acquisition and working memory in the case of logographic Chinese. Critically, a simple adoption of the auditory working memory mechanisms required for alphabetic languages seems unlikely due to decidedly different design principles of the Chinese language system. In the case of learning Chinese vocabulary as a second language, one would assume that for learning new characters short-term retention of visual written segments is more strongly required. Crucially, as those segments are visually more complex and cannot be converted into phonemes, additional visual-orthographic analysis and visual short-term storage are mandatory. While studies investigating visual working memory as a predictor for language learning, are scarce, a couple of developmental studies have examined determinants of reading ability in Chinese children focusing primarily on visual processing skills and phonological awareness (Ho & Bryant, 1997a; Huang & Hanley, 1995; McBride-Chang & Ho, 2005; Siok & Fletcher, 2001; Siok, Spinks, Jin, & Tan, 2009; Tong & McBride-Chang, 2010). Huang and Hanley (1995) reported that visual skills such as visual form discrimination and visual paired-associate learning predicted reading in native Chinese but not in native English children. Subsequent investigations found that visual processing skills, such as the ability to visually memorize abstract figures over a short period of time (Siok & Fletcher, 2001), or detecting and memorizing stroke patterns and recognizing abstract shapes among alternatives (Ho & Bryant, 1997b), predicted reading Chinese characters at early stages of learning to read. Contrarily, phonological skills correlated with reading abilities predominantly at higher grades. The strongest evidence for the assumption that visual-orthographic processes are mandatory for Chinese character reading comes from Tan, Spinks, Eden, Perfetti, and Siok (2005b) who showed that the ability to read Chinese is predominantly related to a child's writing (and drawing) skills while phonological awareness plays a minor role. Taken together, these findings, though heterogeneous, suggest that visual orthographic processing skills as measured by working memory-like tasks are crucial especially in early stages of learning to read in Chinese due to the demanding visual complexity of the characters system.

Following these lines of arguments, we assume that the language system's design principles impose constraints on the role working memory processes play for the acquisition of words in a second language. We argue that working memory skills in general predict vocabulary acquisition in a second language – also in Chinese. More specifically, we predict that – contrary to alphabetic languages – there is a unique contribution of visual working memory to Chinese character acquisition.

1.3. Working memory training and its transfer

Capitalizing on the reasoning outlined above, an appropriate means to enhance Chinese second language learning could be the specific training of visual working memory processes. Working memory training has recently attracted a great deal of attention as a method to improve cognitive functioning in general (Melby-Lervag & Hulme, 2013). Although there is a large variation in methodology regarding sample characteristics, length and intensity of training and the use of transfer tasks, there is consensus that working memory can be trained. Despite rather mixed evidence it has been claimed that working memory training can – under specific conditions – transfer to various tasks that were not trained directly (for recent reviews see Klingberg, 2010; Boot, Blakely, & Simons, 2011; Diamond & Lee, 2011). Two of the conditions assumed to be met for such transfer to occur are that the criterion task and the transfer task (a) engage similar processing components and (b) recruit overlapping brain regions (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Jonides, 2004; Lövdén, Lindenberger, Bäckman, Schaefer, & Schmiedek, 2010). Following this account, in the present study we aim at investigating whether visual working memory training can generally improve second language character acquisition in Chinese due to shared processing components