



Clinical neuroanatomy

Hidden word learning capacity through orthography in aphasia

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ARTICLE INFO

Article history:

Received 28 February 2013

Reviewed 30 April 2013

Revised 14 June 2013

Accepted 14 October 2013

Action editor Marco Catani

Published online 24 October 2013

Keywords:

Aphasia

Learning

Vocabulary

Anomia

Aphasia treatment

ABSTRACT

The ability to learn to use new words is thought to depend on the integrity of the left dorsal temporo-frontal speech processing pathway. We tested this assumption in a chronic aphasic individual (AA) with an extensive left temporal lesion using a new-word learning paradigm. She exhibited severe phonological problems and Magnetic Resonance Imaging (MRI) suggested a complete disconnection of this left-sided white-matter pathway comprising the arcuate fasciculus (AF). Diffusion imaging tractography confirmed the disconnection of the direct segment and the posterior indirect segment of her left AF, essential components of the left dorsal speech processing pathway. Despite her left-hemispheric damage and moderate aphasia, AA learned to name and maintain the novel words in her active vocabulary on par with healthy controls up to 6 months after learning. This exceeds previous demonstrations of word learning ability in aphasia. Interestingly, AA's preserved word learning ability was modality-specific as it was observed exclusively for written words. Functional magnetic resonance imaging (fMRI) revealed that in contrast to normals, AA showed a significantly right-lateralized activation pattern in the temporal and parietal regions when engaged in reading. Moreover, learning of visually presented novel word–picture pairs also activated the right temporal lobe in AA. Both AA and the controls showed increased activation during learning of novel versus familiar word–picture pairs in the hippocampus, an area critical for associative learning. AA's structural and functional imaging results suggest that in a literate person, a right-hemispheric network can provide an effective alternative route

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<http://dx.doi.org/10.1016/j.cortex.2013.10.003>

for learning of novel active vocabulary. Importantly, AA's previously undetected word learning ability translated directly into therapy, as she could use written input also to successfully re-learn and maintain familiar words that she had lost due to her left hemisphere lesion.

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1. Introduction

Previous studies on the neural substrates of learning have delineated a general framework of complementary hippocampal and cortical systems in binding and consolidating memories for novel contents (McClelland, McNaughton, & O'Reilly, 1995) such as new word–referent pairs (Davis & Gaskell, 2009), respectively. Moreover, functional neuroimaging evidence indicates that the left dorsal temporo-frontal pathway involved in word production is also crucial for learning new active vocabulary (Hickok & Poeppel, 2007; Rodríguez-Fornells, Cunillera, Mestres-Missé, & de Diego-Balaguer, 2009). The available evidence from aphasia is in line with these views. Meinzer et al. (2010) showed that the extent of damage to the left hippocampus and surrounding tissue predicts language therapy outcomes in aphasia. Moreover, the few studies on acquisition of new active vocabulary in aphasia indicate that chronic lesions in the left cortical language areas, even in mild aphasia, can severely hamper acquisition and maintenance of novel words (Grossman & Carey, 1987; Gupta, Martin, Abbs, Schwartz, & Lipinski, 2006; McGrane, 2006; Tuomiranta et al., 2011; Tuomiranta, Rautakoski, Rinne, Martin, & Laine, 2012).

In the present paper, we extend this current knowledge on the neurocognition of word learning by presenting behavioral and structural–functional neuroimaging data from a case of aphasia (AA) with a disconnected left dorsal temporo-frontal pathway who nevertheless learned and maintained new active vocabulary on par with healthy controls. The imaging data were expected to shed light on the alternative neural pathways that our patient is using to enable her remarkable learning and maintenance of novel words. We employed a well-studied new-word learning paradigm that involves learning of the names of ancient farming equipment (Laine & Salmelin, 2010). Learning was evaluated with spontaneous naming of the novel objects, a measure that is particularly demanding for individuals with aphasia who almost always suffer from anomia (Laine & Martin, 2006). We employed novel word learning rather than the more traditional approach of re-teaching premorbidly mastered words that have become inaccessible in aphasia, because we wanted to specifically target the word learning mechanisms that encode and store new word–referent associations. Re-teaching of familiar but inaccessible words for an aphasic individual is clinically of utmost importance but, in terms of basic research, makes it difficult to separate the involvement of word learning mechanisms from memory retrieval where access to lost words is re-gained through phonological or semantic cues given by the therapist.

Over the last four decades, different aspects of verbal learning in aphasia have been probed in experimental studies.

Early studies quantified aphasic individuals' ability to re-learn to produce familiar words (e.g., Sarno, Silverman, & Sands, 1970) or compared the learning rate and capacity of aphasic versus healthy participants with word list learning tasks (e.g., Tikofsky, 1971). More recently, the effects of short-term memory on verbal learning in aphasia have been a focus of inquiry (e.g., Freedman & Martin, 2001; Martin & Saffran, 1999). Several investigations have also added challenge to the verbal learning tasks through introducing partly novel materials (e.g., Breitenstein, Kamping, Jansen, Schomacher, & Knecht, 2004; Freed, Marshall, & Nippold, 1995; Marshall, Freed, Karow, 2001; Marshall, Neuburger, & Phillips, 1992). Of particular interest for the present paper are studies that have utilized a design where genuinely novel referents have been paired with genuinely novel names (Grossman & Carey, 1987; Gupta et al., 2006; Laganaro, Di Pietro, & Schnider, 2006; McGrane, 2006; Morrow, 2006; Tuomiranta et al., 2011, 2012). Looking at active vocabulary acquisition as measured by spoken naming, of these investigations one showed practically no learning (Gupta et al., 2006), one probed only passive vocabulary (Morrow, 2006), and one did not measure naming accuracy (Laganaro et al., 2006). Three investigations reported statistically significant short-term novel word learning that varied between aphasic participants (McGrane, 2006; Tuomiranta et al., 2011, 2012). Not surprisingly, in the latter two studies that included also healthy controls, the performance levels of the individuals with aphasia were impaired. Only two studies (Grossman & Carey, 1987; Tuomiranta et al., 2012) reported some long-term maintenance of novel referent-word pairs in aphasic participants, and in the latter study that included healthy controls, the long-term maintenance of the aphasic individuals was significantly impaired. In summary, the previous literature indicates that some individuals with aphasia are able to acquire at least some novel active vocabulary, even though their learning outcomes are impaired in relation to normal performance both in the short-term and long-term. Nevertheless, these findings inspired us to look further into the word learning abilities of individuals with aphasia and led to the discovery of the present case which, to our surprise, showed learning and maintenance of novel active vocabulary on par with healthy controls.

Current views on the neural substrates of language differentiate two major left-sided pathways: a dorsal stream (linking perisylvian language areas and inferior frontal regions) for sound-motor connections and a ventral stream (connecting temporal and prefrontal regions via the extreme capsule) for auditory comprehension (Hickok & Poeppel, 2007; Kümmerer et al., 2013; Parker et al., 2005; Saur et al., 2008, 2010; Ueno, Saito, Rogers, & Lambon Ralph, 2011). The lesion in our patient affected especially a major component of the dorsal pathway, namely the arcuate fasciculus (AF), a large

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