NeuroImage: Clinical 14 (2017) 277–285

Contents lists available at ScienceDirect

NeuroImage: Clinical

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

An fMRI study of implicit language learning in developmental language impairment

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ARTICLE INFO

Article history:
Received 19 August 2016
Received in revised form 20 January 2017
Accepted 24 January 2017
Available online 25 January 2017

Keywords:
Statistical learning
Language
Learning
Specific language impairment
fMRI
Brain

ABSTRACT

Individuals with developmental language impairment can show deficits into adulthood. This suggests that neural networks related to their language do not normalize with time. We examined the ability of 16 adults with and without impaired language to learn individual words in an unfamiliar language. Adults with impaired language were able to segment individual words from running speech, but needed more time to do so than their normal-language peers. ICA analysis of fMRI data indicated that adults with language impairment activate a neural network that is comparable to that of adults with normal language. However, a regional analysis indicated relative hyperactivation of a collection of regions associated with language processing. These results are discussed with reference to the Statistical Learning Framework and the sub-skills thought to relate to word segmentation.

1. Introduction

Developmental language impairment has traditionally been considered a childhood disorder. Indeed, the disorder is typically diagnosed in early childhood, often on the basis of morphosyntactic errors and/or limited vocabulary skills. However longitudinal studies have consistently shown that poor language skills, originally diagnosed during childhood, persist into the adolescent and adult years (Aram et al., 1984; Conti-Ramsden et al., 2008; Elbro et al., 2011; Johnson et al., 2010; Stothard et al., 1998). Persistent impairments can have a significant functional impact into adulthood. Adults with a history of language impairment tend to lag behind their age-peers in terms of educational achievement (Conti-Ramsden and Durkin, 2012; Conti-Ramsden et al., 2009; Elbro et al., 2011). These individuals are also more likely to pursue vocational rather than academic education after the compulsory school years (Conti-Ramsden et al., 2009; Elbro et al., 2011). If working, these adults are more likely than peers to hold jobs that correspond to lower socio-economic outcomes (Conti-Ramsden and Durkin, 2012; Elbro et al., 2011; Johnson et al., 2010).

Despite these outcomes, relatively little is known about the nature of language impairment during the adult years. In this paper, we consider the adult presentation of this disorder from a neurological perspective. Specifically, we are interested in whether and how the neural resources recruited during new learning by young adults with language impairment differ from those of their normal language peers. We employed a task that requires implicit learning of syllable sequences that represent word forms in an unfamiliar language.

The language network of normal adults is well described as involving left-lateralized activation of an inferior frontal and superior temporal network with additional activation typically seen in dorsolateral prefrontal cortex, the lateral precentral gyrus, and the temporoparietal junction (see Hickok, 2012; Price, 2010; Price, 2012; Vigneau et al., 2006 for reviews). Individuals with language impairment also activate this network during language processing, although task related regional differences in activation can occur, when compared with their normal language peers (Ellis Weismer et al., 2005; Plante et al., 2006). These same regions also engage during periods of active language learning by adults with normal language (e.g., Bahlmann et al., 2008; Cunillera et al., 2009; McNealy et al., 2006; Plante et al., 2015a; Plante et al., 2014). However, no information is yet available concerning whether those with developmental language impairment recruit the same neural resources as they attempt to learn from language input. In the present study, we examine the learning of word forms embedded into running speech in a novel language.

1.1. The statistical learning framework

The *Statistical Learning Framework* is a theory that posits that individuals acquire information about the distributional characteristics of

Abbreviations: LI, Language impaired; NL, Normal language.

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http://dx.doi.org/10.1016/j.nicl.2017.01.027

the sensory input they receive and extract information about structure from the input (see Erickson and Theissen, 2015; Gerken and Aslin, 2005; Karmiloff-Smith et al., 1998; Saffran, 2003 for overviews). Learning under the Statistical Learning Framework is unguided, in that learners do not require feedback to learn. Statistical learning relies on general cognitive processes that serve learning in multiple domains. Recent thinking holds that the cognitive skills needed may differ depending on the nature of the statistical learning task. Erickson and Theissen (2015) have proposed that extracting elements from input and linking them may be more important for some types of statistical learning and integration of information across stored units may be more important for others. This perspective implies that encoding of informational units into memory is also critical to the learning process, and Erickson and Theissen (2015) acknowledge a role for both attention to input and working memory as processes basic to statistical learning.

There is evidence implicating poor statistical learning by children and adults with language impairment. Children with SLI are slower to recognize co-occurring syllables as word units compared with their age-mates in an artificial language paradigm (Evans et al., 2009). Likewise, adults and children with impaired language have difficulty recognizing legal combinations of words in an artificial grammar (Plante et al., 2002; Plante et al., 2013). Multiple studies of adolescents and adults show poor learning of dependencies between non-adjacent elements in the input (Hsu et al., 2014; Grunow et al., 2006) and recognizing relations among classes of elements (Torkildsen et al., 2013; Richardson et al., 2006). However, there is evidence that learning can improve if those with language impairment are given more time to learn (Evans et al., 2009) or if input is optimized in ways known to facilitate statistical learning (Torkildsen et al., 2013; Grunow et al., 2006). Therefore, the proposed deficit in statistical learning appears to be one of degree rather than an all-or-nothing phenomenon.

Although the Statistical Learning Framework does not make specific neurological predictions, there have been multiple studies that have examined the neural basis of statistical learning in the verbal domain. The statistical learning network for verbal material overlaps substantially with the network used to process language form (e.g., Bahlmann et al., 2008; Cunillera et al., 2009; Karuza et al., 2013; McNealy et al., 2006; McNealy et al., 2010; Plante et al., 2015a, 2015b; Plante et al., 2014; Newman-Norlund et al., 2006; Optiz and Kotz, 2012). Most relevant to the present study are studies that have used artificial languages in which spoken syllable triplets co-occur as word units. These have consistently reported left-lateralized activation in the superior temporal gyrus (Cunillera et al., 2009; Karuza et al., 2013; McNealy et al., 2006, 2010). Activation in inferior parietal (Karuza et al., 2013; McNealy et al., 2010) and ventral premotor regions (Cunillera et al., 2009) has also been reported. Activation levels in other regions, including the inferior frontal gyrus and basal ganglia have been reported to correlate with post-scan test performance (Karuza et al., 2013; McNealy et al., 2010), but this region is not significantly activated during the learning period itself.

Natural language studies of word segmentation are less common. In the one available study (Plante et al., 2015b), two groups of listeners were scanned while listening to Norwegian sentences that either provided or did not provide statistical cues to embedded words. Input that permitted statistical learning of the embedded words not only prompted rapid learning, but recruited a much more widely-distributed neural network than did input that lacked distributional cues. In addition to the superior temporal gyrus activation consistently reported in artificial language studies, activation included the inferior and middle frontal gyrus, superior and inferior parietal lobule, and posterior temporal-occipital junction, as well as regions in the thalamus and basal ganglia.

Given that the Statistical Learning Framework is intended to account for how language is acquired, it is not surprising that imaging studies most consistently report activation in areas classically associated with language processing. Considered within the context of the Statistical Learning Framework, the overall pattern of activation during learning should reflect the key cognitive processes involved. At least two processes are required to segment words from an unfamiliar language. First, information about syllable order must be extracted from the input. In studies involving encoding the serial position of individual words within word lists, stronger activation in the left superior temporal gyrus, left inferior frontal gyrus (BA44), and left supramarginal gyrus have been documented (Clark and Wagner, 2003; Cassanto et al., 2002; Kalm and Norris, 2014; Optiz and Kotz, 2012). This suggests that the basic language network may be directly involved in tracking order dependencies. Second, syllables showing strong order dependencies must be encoded as individual words in memory. Activation in the left superior temporal gyrus, left inferior frontal gyrus, left dorsolateral prefrontal cortex, and bilateral superior parietal lobule has been associated with successful encoding of words into memory (Blumfeld and Ranganath, 2006; Clark and Wagner, 2003; Cassanto et al., 2002; Davachi et al., 2001; Kalm and Norris, 2014). These findings suggest that a broad network reported in statistical word learning studies to date may actually relate to at least two distinct processes predicted by the Statistical Learning Framework.

1.2. The present study

For the present study, we have adopted the natural language learning task from Plante et al. (2015b) in which adults were able to identify words in an unfamiliar language (Norwegian) rapidly when statistical cues to word units were present. In that study, adults with typical language skills were asked to segment real bi-syllabic words from spoken Norwegian sentences. This task shares conceptual similarities with artificial language tasks in which syllable-level dependencies allow learning of word units. In the present study, the natural language task provides a learning context that has ecological validity for the central issue of natural language processing.

There are three logical possibilities for how adults with impaired language may compare to their normal-language counterparts. The first is that adults with language impairment fail to recognize distributional cues in the input, preventing them from using these cues to segment words. If this is the case, adults with language impairment should perform very poorly and consequently activate a very restricted network. This outcome would be similar to typical adults who were provided with input that lacked distributional cues to word boundaries (cf. Plante et al., 2015b). A second possibility is that performance is strong and the neural networks will be fundamentally similar for both groups. However, the participants with language impairment may have to expend more effort than the typical language group to obtain performance parity. A third outcome represents an intermediate and more likely outcome. Adults with impaired language will learn from distributional information, but it will take them longer than their normal langue peers to achieve above-chance performance (cf. Evans et al., 2009). Under this scenario, it is likely that their neural response will differ most from their peers when learning is weakest, although activation may normalize as learning strengthens. We will focus exploration on regions predicted to relate to unguided language learning likely to be activated by the specific demands for this task (order information: superior temporal gyrus, inferior frontal gyrus, supramarginal gyrus; memory encoding: superior temporal gyrus, inferior frontal gyrus, middle frontal gyrus, superior parietal lobule).

2. Materials and methods

2.1. Participants

The participants were 32 college-enrolled adults. Half were identified as having impaired language skills (the LI group) and were receiving academic support services for their disability. This group included 7 males and 9 females whose average age was 20 years (SD = 2.2 years).