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Neural correlates of single word reading in bilingual children and adults

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ABSTRACT

The present study compared the neural correlates of language processing in children and adult Spanish–English bilinguals. Participants were asked to perform a visual lexical processing task in both Spanish and English while being scanned with fMRI. Both children and adults recruited a similar network of left hemisphere "language" areas and showed similar proficiency profiles in Spanish. In terms of behavior, adults showed better language proficiency in English relative to children. Furthermore, neural activity in adults was observed in the bilateral MTG. Age-related differences were observed in Spanish in the right MTG. The current results confirm the presence of neural activity in a set of left hemisphere areas in both adult and child bilinguals when reading words in each language. They also reveal that differences in neural activity are not entirely driven by changes in language proficiency during visual word processing. This indicates that both skill development and age can play a role in brain activity seen across development.

1. Introduction

The processing of lexical items in monolinguals has been thought to rely on a left-lateralized network that involves visual association areas such as the fusiform gyrus (FG) for orthographic processing, auditory association areas such as the superior temporal gyrus (STG) for phonological processing, amodal association areas such as the middle temporal gyrus (MTG) for semantic processing, and heteromodal areas in inferior parietal lobule (IPL) for mapping between these different representational systems. Posterior language-processing areas are also thought to be highly connected with anterior systems such as the inferior frontal gyrus (IFG), responsible for more detailed semantic and phonological processing (Bitan et al., 2007; Bolger, Hornickel, Cone, Burman, & Booth, 2008; Booth, 2007; Booth et al., 2006; Price 2000; Pugh et al., 2000; Turkeltaub, Eden, Jones, & Zeffiro, 2002). However, to date, studies of language development have not examined the nature of lexical processing in early second language learners. The current study is designed to fill this gap by investigating the neural correlates of visual word processing in bilingual children and adults who acquired their second language early in childhood.

1.1. Neural development of lexical processing in monolinguals

Neuroimaging studies of language acquisition in monolingual populations have revealed increases in activation in most of the aforementioned regions including the MTG (Chou et al., 2006; Turkeltaub et al., 2002), IPL (Booth, Mehdiratta, Burman, & Bitan, 2008; Chou et al., 2006) and IFG (Booth et al., 2004; Cone, Burman, Bitan, & Booth, 2008; Gaillard et al., 2003; Holland et al., 2001; Shaywitz et al., 2002; Turkeltaub et al., 2002), as a function of increased skill and development. The opposite comparison, which looks at increased activity in children relative to adults has been observed in the right hemisphere. Relative to adults, children tended to activate to a greater extent right IFG in spelling and reading tasks (Booth et al., 2004; Turkeltaub et al., 2002), as well as right STG for semantic judgment of visual words. In addition, decreased activation in right MTG has been associated with decreased skill on semantic judgment of visual words. These results suggest increasing specialization and left lateralization across language development (Holland et al., 2001; Johnson, 2011).

1.2. Neural correlates of second language processing

Although models of lexical processing in monolinguals as outlined above are relatively well-established, additional questions have been raised about language processing and neural organization in those who speak more than one language. The current consensus is that both first (L1) and second language (L2) processing rely on common cortical areas with slight variability occurring due to several factors, including age of acquisition (AOA), proficiency, and

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amount of exposure (Hernandez & Li, 2007; Perani & Abutalebi, 2005; Tatsuno & Sakai, 2005). However, functional magnetic resonance imaging (fMRI) studies regarding lexical processing in bilinguals have primarily considered cross-language differences in adults (Chee, Tan, & Thiel, 1999; Das, Padakannaya, Pugh, & Singh, 2011; Jamal, Piche, Napoliello, Perfetti, & Eden, 2012; Meschyan & Hernandez, 2006; Nakamura et al., 2010) with relatively few studies of bilingual children (Tan et al., 2011; Xue, Dong, Jin, Zhang, & Wang, 2004).

To our knowledge the only study that has investigated the brain activity associated with both child and adult bilinguals was conducted by Archila-Suerte, Zevin, Ramos, and Hernandez (2012). In that study, a group of child and adult sequential Spanish–English bilinguals were asked to listen to pairs of sounds that differed by a single vowel. A group of children between the ages of 6–7, 8–10, and a group of adults ages 18–24 were asked to listen to a series of single syllables consisting of two consonants and a vowel. A control group of monolinguals was also tested across all the age ranges. Bilingual children between the ages of 6–7 showed strong activity in bilateral STG, a pattern present in both monolingual adults and children. Unlike monolinguals, however, bilinguals' pattern of brain activity differed in the older group of children. There was significantly more activity in children aged 8–10, in areas that are involved in cognitive control, including bilateral activity in the inferior parietal lobe and the middle frontal gyrus. These differences diminished in bilingual adults, resulting in activity mostly in bilateral STG. These results suggest that bilinguals' processing of nonsense syllables in English shows a developmental trend that differs significantly from monolinguals. The current study seeks to expand on this by looking at the nature of word reading in both languages in a very similar population.

1.3. Current study

Behavioral studies with early L2 learners have revealed an interesting shift in proficiency across development. Specifically, early L2 acquisition can lead to a shift from L1 dominance in childhood to L2 dominance by adulthood, with the shift occurring as early as age 8–13 years (Kohnert, Bates, & Hernandez, 1999; Meschyan & Hernandez, 2006). The aim of the present study was to examine the neural correlates of lexical processing in early L2 learners during this transition from L1 dominance in childhood to L2 dominance in adulthood, using a single-word reading task in both languages. Although children and adults were expected to recruit a similar network of occipitotemporal, temporoparietal, and frontal cortices, skill and developmental differences were also expected. Specifically, adults were expected to be more proficient and skilled than children at processing L2 (Kohnert et al., 1999). As such, adults were expected to show greater activation than children in brain regions previously reported to increase as a function of skill and development, including the left MTG, IPL, and IFG (Booth et al., 2004; Chou et al., 2006; Cone et al., 2008; Gaillard et al., 2003; Holland et al., 2001; Shaywitz et al., 2002; Turkeltaub et al., 2002). Due to their potentially lower skills, children were expected to recruit similar cortical regions as adults but to a lesser extent, as well as possible additional right hemisphere homologues. Finally, language proficiency should modulate this effect such that age-related differences would be larger in English, the second language, than in Spanish, the first language.

2. Method

2.1. Participants

Participants were forty-one right-handed individuals, 20 adults and 21 children, from the Houston area. Adults were 18–26 years old ($M = 21.55$, $SD = 2.14$), and children were 8–13 years old ($M = 10.52$, $SD = 1.57$), $F(1,39) = 356.65$, $p < .0001$. All participants were native speakers of Spanish who learned English before the age of 9 years. Adults and children did not have a significantly different AOA for English (adults $M = 3.95$, $SD = 2.17$; children $M = 3.67$, $SD = 1.20$), $F(1,39) = .262$, $p = .612$. However, adults and children significantly differed in the percentage of their day that they spoke English (adults $M = 73.50$, $SD = 15.40$; children $M = 54.76$, $SD = 18.34$), $F(1,39) = 12.49$, $p = .001$ and Spanish (adults $M = 28.25$, $SD = 15.41$; children $M = 45.24$, $SD = 18.33$), $F(1,39) = 10.26$, $p = .003$. Demographic information is summarized in Table 1. Experimental procedures were approved by a Human Subjects Committee and written informed consent was obtained from all participants and legal guardians of minors.

2.2. Task and procedures

After giving consent, participants were screened for handedness, claustrophobia, history of neurological, psychiatric, and learning disorders, language history, and presence of metal in the body. Participants' English and Spanish proficiency was also measured using the picture vocabulary (WLPB-PV) and listening comprehension (WLPB-LC) subtests of the Woodcock Language Proficiency Battery Revised (Woodcock, 1991). A composite proficiency score was calculated for each language by adding the scores on the two subtests.

During the fMRI experiment, participants were visually presented with a series of single-words on a rear projection video display via a mirror attached to the scanner head coil. Participants were asked to read each word silently and press a button on a hand-held button box when they read each word. A covert reading task was chosen for several reasons as opposed to a lexical decision task or a picture naming task. Bilingual children are learning two different languages and show a somewhat uneven change in language proficiency relative to monolingual children. Previous work in our laboratory (Kohnert et al., 1999) has found that Spanish–English bilingual children show improvement in picture naming between the ages of 5 and 14. However, children can show up to 50% error rates in Spanish picture naming despite having much higher accuracy rates when having to match a picture to the correct word for the same lexical items. Gollan, Montoya, Fennema-Notestine, and Morris (2005) have also shown interference in bilingual adults naming pictures as well. Thus, picture naming was a task that would likely lead to considerable interference in retrieval.

Additionally, lexical decision tasks involve a meta-linguistic component that could cloud the ability to look at language processing in a group of children learning English as a second language during childhood. Lexical decisions in each language become complicated due to the fact that they rely on different lexical and orthographic patterns that might differ across languages. A child who is learning two sets of different patterns may have considerable difficulty with a word-nonword decision, which would appear in their pattern of brain activity. These differences may not be directly related to their language knowledge but to the difficulty in making decisions about language. Thus, a simple word reading task that taps into lexical processing that children could perform competently in both languages was used. The task was covert to reduce movement artifacts in the scanner.

The experimental stimuli consisted of 60 English nouns and 60 Spanish nouns. The number of syllables, AoA, and frequency of the words were controlled across languages. AoA of the stimuli was determined based on unpublished behavioral norms in which monolingual and early bilingual adults estimated the age at which they had learned each word. This method of objectively obtaining AOA has been used in the literature (Morrison, Chappell, & Ellis, 1997). Word frequency was determined using the MCWord