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Research report

Bimodal bilingualism as multisensory training?: Evidence for improved audiovisual speech perception after sign language exposure

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ABSTRACT

The aim of the present study was to characterize effects of learning a sign language on the processing of a spoken language. Specifically, audiovisual phoneme comprehension was assessed before and after 13 weeks of sign language exposure. L2 ASL learners performed this task in the fMRI scanner. Results indicated that L2 American Sign Language (ASL) learners' behavioral classification of the speech sounds improved with time compared to hearing nonsigners. Results indicated increased activation in the supramarginal gyrus (SMG) after sign language exposure, which suggests concomitant increased phonological processing of speech. A multiple regression analysis indicated that learner's rating on co-sign speech use and lipreading ability was correlated with SMG activation. This pattern of results indicates that the increased use of mouthing and possibly lipreading during sign language acquisition may concurrently improve audiovisual speech processing in budding hearing bimodal bilinguals.

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1. Introduction

To understand language is to integrate multimodal information (Vigliocco et al., 2014). Audiovisual information is key to understanding speech, especially with hard-to-perceive contrasts (Navarra and Soto-Faraco, 2007) or ambiguity (Lidestam and Beskow, 2006). Even sign language users require integration of facial and corporal cues for successful language processing (Bickford and Fraychineaud, 2006). The unique separation of the articulators during the production of sign (e.g., hands) and speech (e.g., mouth) allow for simultaneous code-blending in hearing signers (Emmorey et al., 2008). That is, often hearing signers will communicate using both spoken and sign language simultaneously. With such an importance on multimodal integration for language processing and the concomitant ability to sign and speak in parallel, sign

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language learners may have increased audiovisual processing abilities as a consequence. In the present study, we examined how exposure to sign language facilitates opportunities for increased audiovisual processing, which in turn affects spoken language processing.

Speech processing is inherently a multimodal experience (Summerfield, 1987). Forty years of work investigating the McGurk Effect has indeed demonstrated that speech processing is not only reliant on the auditory stream, but also the visual stream (McGurk and MacDonald, 1976; Massaro, 1984). Visual information is needed most when communication occurs in noisy environments (Girin et al., 2001; Sumby and Pollack, 1954). Thus, typically hearing speakers use both auditory and visual information during face-to-face communication. The ability to process language audiovisually varies from speaker to speaker; however, many studies have shown enhancements in audiovisual processing (e.g., detection, discrimination and localization) after multisensory training (Lehmann and Murray, 2005; Lovelace et al., 2003; Strelnikov et al., 2011). With evidence of training-induced improvements in audiovisual processing, the current study explored the effect of "linguistic training" from a visual language on audiovisual processing in individuals who are learning a sign language.

Spoken and sign languages differ in terms of their input–output systems with which they are perceived and produced, despite showing similar patterns of neural activation and language network recruitment for native signers and speakers alike (Leonard et al., 2012; MacSweeney et al., 2002, 2006, 2008; Petitto et al., 2000). Spoken languages lend themselves to audiovisual integration because they require the use of oral articulators to aid in auditory processing. Sign languages, on the other hand, use the manual-visual modality in order to process language. Despite modality differences, sign languages exploit the mouth in a number of ways. For instance, sign languages use the mouth for independent morphemes that inflect verbs or noun phrases (Bickford and Fraychineaud, 2006). Beyond grammatical uses of the mouth, the mouth plays an important role in lexical processing such that signers often borrow mouthings from spoken languages (Bickford and Fraychineaud, 2006; Boyes-Braem et al., 2001). A commonly used example of borrowed mouthings in American Sign Language (ASL) is the simultaneous production of [f ʃ] on the mouth during the manual sign FINISH (Bickford and Fraychineaud, 2006; Boyes-Braem et al., 2001; Emmorey et al., 2005). Similarly, mouthings can be used to disambiguate homophonous manual signs such as signs that share the same phonological features like handshape, location and movement (e.g., CANCEL[1] and CRITICIZE), where the full English word is articulated during sign production. Often hearing bimodal bilinguals (e.g., ASL/English bilinguals) will mouth English translations of the signs they are producing (Capek et al., 2008; Davis, 1990; Emmorey et al., 2008). The ability to code-blend, or sign and speak simultaneously, is afforded by the separation of the two articulatory systems. Unlike during audiovisual processing where visual information facilitates greater auditory comprehension (Summerfield, 1987), novice learners of a sign language may need borrowed mouthings in order to comprehend newly-acquired lexical items in sign language. Attunement to the mouth for lexical sign processing and the general immersive experience relying on the visual system to process language may impact spoken language audiovisual processing.

It has been well documented that the brain undergoes neuroplastic changes due to new experiences and training (Draganski et al., 2004; Schlaug et al., 2009). One manner in which neuroplasticity can be induced is through experience with a new language (Mechelli et al., 2004). Several recent studies have shown that the neural network that underlies the first language is changed during the acquisition of a second (Kovelman et al., 2008; Mei et al., 2014; Jones et al., 2012). For instance, the left inferior frontal gyrus is more involved in native language processing for bilinguals than monolinguals (Kovelman et al., 2008; Jones et al., 2012) and the activation of the native reading network is altered after semantic training in a novel language (Mei et al., 2014). If learning a new language, specifically one within one's native language modality, can alter the neural network that underlies native language processing, it would be assumed that learning a language within a new language modality can also alter underlying cognitive structures. Because bimodal bilinguals attune to the mouth during sign language processing, those areas involved in audiovisual processing may also undergo neuroplatic changes.

Audiovisual processing has been shown to activate the superior temporal sulcus (STS; Campbell, 2008; Hocking and Price, 2008; Noesselt et al., 2007). The STS is also involved in biological motion processing, face perception, and is especially attuned to mouth movements that mirror speech and its auditory spatiotemporal dynamics (Campbell, 2008; McCarthy et al., 1999; Pelphrey et al., 2003). Furthermore, the STS is super-additively activated by audiovisual speech sounds when compared to visual mouth movement or audition alone (Wright et al., 2003). It is assumed that greater audiovisual processing should also lead to greater phonological processing. That is, greater audiovisual processing would entail better identification of visual phonemes. Enhanced phonemic processing is likely to also engage the supramarginal gyrus (SMG), an area implicated in phonological processing (Hartwigsen et al., 2010; Sliwinska et al., 2012; Stoeckel et al., 2009). Ruytjens et al. (2006) demonstrated greater activation of the SMG during lipreading when compared to static images of a face. Taken together, one could predict that L2 ASL learners might show greater activation in the STS and SMG during audiovisual processing after sign language exposure.

In the present study, we tested the hypothesis that exposure to a novel sign language would change monolingual audiovisual processing. In a two-time point longitudinal study, we scanned the brains of hearing second language (L2) ASL learners before significant exposure to ASL. We tested their ability to categorize words in the scanner based on whether the word started with a sound produced on the lips or not. After approximately 13 weeks, or one semester, of sign language exposure, we scanned their brains again while they performed the same task. Self-rating measures of the use of co-sign speech (i.e., mouthings) and lipreading were

[1]Sign language lexical glosses are denoted in small capital letters

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