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Brain-based individual difference measures of reading skill in deaf and hearing adults

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ABSTRACT

Most deaf children and adults struggle to read, but some deaf individuals do become highly proficient readers. There is disagreement about the specific causes of reading difficulty in the deaf population, and consequently, disagreement about the effectiveness of different strategies for teaching reading to deaf children. Much of the disagreement surrounds the question of whether deaf children read in similar or different ways as hearing children. In this study, we begin to answer this question by using real-time measures of neural language processing to assess if deaf and hearing adults read proficiently in similar or different ways. Hearing and deaf adults read English sentences with semantic, grammatical, and simultaneous semantic/grammatical errors while event-related potentials (ERPs) were recorded. The magnitude of individuals' ERP responses was compared to their standardized reading comprehension test scores, and potentially confounding variables like years of education, speechreading skill, and language background of deaf participants were controlled for. The best deaf readers had the largest N400 responses to semantic errors in sentences, while the best hearing readers had the largest P600 responses to grammatical errors in sentences. These results indicate that equally proficient hearing and deaf adults process written language in different ways, suggesting there is little reason to assume that literacy education should necessarily be the same for hearing and deaf children. The results also show that the most successful deaf readers focus on semantic information while reading, which suggests aspects of education that may promote improved literacy in the deaf population.

1. Introduction

Reading can be difficult for many people who are deaf. Reading outcomes are generally poor for deaf individuals, but some deaf people do nonetheless achieve high levels of reading proficiency (Allen, 1986; Goldin-Meadow and Mayberry, 2001; Qi and Mitchell, 2012; Traxler, 2000). To improve the potential for all deaf individuals to read well, we must determine what allows some to become proficient readers, while many others struggle (Mayberry et al., 2011). Though there have been decades of research on the causes of reading difficulty in deaf individuals, conflicting results prevent a clear consensus (Allen et al., 2009; Mayberry et al., 2011; Mayer and Trezek, 2014; Paul et al., 2009).

The overarching question in this debate has been, do deaf children read in the same ways as hearing children, albeit with reduced access to sound, or do they read in qualitatively different ways (Hanson, 1989; Mayer and Trezek, 2014; Perfetti and Sandak, 2000; Wang et al., 2008; Wang and Williams, 2014)? The answer has profound implications for education; if deaf children read proficiently in different ways from hearing children, they may learn best in different ways as well. One potential answer to this question is that proficient reading in deaf and hearing individuals is dependent on the same types of (neuro)cognitive capacities and skills. For example, proficient reading is often claimed to be fundamentally grounded in an individual's ability to compute, in real time, syntactic representations of sentence structure (Russell et al., 1976; Trybus and Buchanan, 1973). However, it is known that deaf children have considerable difficulty understanding syntactically non-canonical or complex structures, such as passive constructions (Power and Quigley, 1973) and relative clauses (Quigley et al., 1974). Faced with these realities, one pedagogical strategy has been to withhold syntactically complex sentences from pedagogical materials for the deaf (Shulman and Decker, 1980) and to gradually introduce a theory-motivated progression of grammatical structures. Even when this pedagogical approach is employed, however, literacy levels in deaf

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students remain low.

An alternative approach is predicated on the possibility that deaf individuals might be able to achieve significant gains in literacy through different means. Specifically, this approach is motivated by evidence that deaf readers can make significant gains in literacy by focusing on semantic cues, even while remaining insensitive to key grammatical aspects of sentences (Cohen, 1967; Sarachan-Deily, 1980; Yurkowski and Ewoldt, 1986). The notion that deaf individuals rely more on meaning and less on syntax has previously been proposed (e.g. Ewoldt, 1981). The general claim is that relatively proficient deaf readers employ a semantically-driven predictive comprehension strategy that works most effectively when they are familiar with the semantic domain of the text (cf. Boudewyn et al., 2015; Pickering and Garrod, 2007). A deaf individual's reading proficiency would then be a function of her or his ability to extract the intended meanings from sentences and larger units of text, rather than the ability to construct precise syntactic representations of sentences that the individual reads.

Prior research on deaf literacy has primarily used behavioral tasks, such as reaction time measures and standardized reading tests. While much has been learned from this work, the field lacks detailed information on how the brains of deaf readers process written language in real time. Such data would help identify the neurocognitive mechanisms by which deaf people read successfully, by providing critical information about which aspects of language a deaf reader is sensitive to when processing written text. Event-related potentials (ERPs), recorded while a subject reads, provide a unique way to better understand how deaf readers read. ERPs are especially well-suited for studying reading for two reasons. First, ERPs respond to specific aspects of language. Grammatical errors in sentences typically elicit a positive-going component starting around 500–600 ms in an ERP response (the P600 effect), while semantic errors in sentences elicit a negative-going component peaking around 400 ms (the N400 effect) (Kaan et al., 2000; Kutas and Federmeier, 2000; Kutas and Hillyard, 1984, 1980; Osterhout et al., 1994; Osterhout and Holcomb, 1992). When a word in a sentence is anomalous in both grammar and semantics, both effects are elicited in a nearly additive fashion (Osterhout and Nicol, 1999). Second, mounting evidence links ERP response variability to individual differences in linguistic abilities, and the size of an individual's ERP response can be viewed as an index of their sensitivity to a particular type of information (McLaughlin et al., 2010; Newman et al., 2012; Ojima et al., 2011; Pakulak and Neville, 2010; Rossi et al., 2006; Tanner et al., 2014, 2013; Weber-Fox et al., 2003; Weber-Fox and Neville, 1996). Prior ERP research in deaf readers (Skotara et al., 2012, 2011) has not explored individual differences in participants' responses, nor how ERP responses relate to subjects' reading skill. The answers to these questions have the potential to shed light on how some deaf individuals read more proficiently than others, and whether proficient deaf and hearing individuals read in similar or different ways.

In the present study, we used the systematic differences in individuals' ERP responses to better understand similarities and differences in how deaf and hearing adults read. Participants read sentences with semantic, grammatical, and simultaneous semantic-grammatical errors while ERPs were recorded. We compared the magnitude of participants' N400 and P600 responses to their performance on a standardized reading comprehension test. Because many factors contribute to how well someone reads, we used multiple regression models to control for potentially confounding variables. If deaf and hearing participants read proficiently using similar strategies or mechanisms, we would expect to see similar relationships between reading skill and sensitivity to semantic and grammatical information, as reflected by N400 and P600 size, in both groups. However, if deaf and hearing participants showed different relationships between reading skill and ERP response sizes, it would indicate that the two groups were reading proficiently using different strategies or mechanisms.

2. Materials and methods

2.1. Participants

Participants were 42 deaf (27 female) and 42 hearing (27 female) adults. The number of participants needed was determined via power analysis (see Section 2.6). All deaf participants were severely or profoundly deaf (hearing loss of 71 dB or greater, self-reported), except for one participant with profound (95 dB) hearing loss in the left ear and moderate (65 dB) hearing loss in the right ear. All deaf participants lost their hearing by the age of two. Thirty-three of the 42 deaf participants reported being deaf from birth. Three of the remaining deaf participants reported that it was likely they were deaf from birth but had not been diagnosed until later (still by age two). The final six deaf participants reported clear causes of deafness that occurred after birth but before age two. All deaf participants reported having worn hearing aids in one or both ears at some point in life; 22 participants still wore hearing aids, 5 participants only wore them occasionally or in specific circumstances, and 15 participants no longer wore them. One participant, age 28.5 years, had a unilateral cochlear implant, but it was implanted late in life (at age 25.8 years) and the participant reported rarely using it. Other than that, individuals with cochlear implants did not take part in this study. The average age of deaf participants was 38.6 years (range: 19–62 years) and the average age of hearing participants was also 38.6 years (range: 19–63 years); there was no significant difference in the ages of the two groups ($t = -0.011$, $p = 0.991$). All participants had normal or corrected-to-normal vision, except for one deaf participant with reduced peripheral vision due to Usher syndrome. The deaf participant with Usher syndrome did not have any difficulty in completing any of the study procedures. No participants had any history of significant head injury or epilepsy. While most participants were right-handed, two of the deaf participants and seven of the hearing participants were left-handed, as assessed by an abridged version of the Edinburgh Handedness Inventory (Oldfield, 1971). One deaf participant and one hearing participant reported being ambidextrous.

All participants filled out a detailed life history questionnaire that asked about their language background and education history. Hearing participants had completed an average of 17.3 years of education (standard deviation 2.5 years) and deaf participants an average of 16.5 years (standard deviation 2.1 years); there was not a significant difference in years of education between the two groups ($t = -1.611$, $p = 0.111$). The first language of all hearing participants was English, and English was the only language that had been used in their homes while they were growing up. Deaf participants came from a wide variety of language backgrounds, and were asked in detail about their spoken and manual/signed language exposure and use throughout their life. On a 1–7 scale, where 1 = all oral communication, 7 = all manual/signed communication, and 4 = equal use of both, deaf participants were asked about their method(s) of communication at the following points in their life: a) overall while they were growing up (incorporating language use both in school and in the home), and b) at the current point in time. Importantly, a '7' on this scale did not distinguish between the use of American Sign Language (ASL) and manually coded forms of English (i.e., Signed Exact English, SEE, or Pidgin Sign English, PSE). Participants also wrote descriptions of their language use at each of these points in time, which served two purposes. First, it allowed us to confirm that the participants' ratings on the 1–7 scales generally corresponded to what they described – and if the ratings did not seem to correspond, the participant was asked for clarification. Second, these descriptions allowed us to distinguish between participants who grew up using and being exposed to ASL versus those who grew up using and being exposed to forms of Manually Coded English. The language backgrounds of the deaf participants were extremely diverse. On both

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