

ORIGINAL ARTICLE

Predictors of reading comprehension in deaf and hearing bilinguals

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Abstract

This study investigates reading comprehension in adult deaf and hearing readers. Using correlational analysis and stepwise regression, we assess the contribution of English language variables (e.g., vocabulary comprehension, reading volume, and phonological awareness), cognitive variables (e.g., working memory (WM), nonverbal intelligence, and executive function), and language experience (e.g., language acquisition and orthographic experience) in predicting reading comprehension in deaf and hearing adult bilinguals (native American Sign Language (ASL) signers, non-native ASL signers, and Chinese–English bilinguals (CEB)), and monolingual (ML) controls. For all four groups, vocabulary knowledge was a strong contributor to reading comprehension. Monolingual English speakers and non-native deaf signers also showed contributions from WM and spoken language phonological awareness. In contrast, CEB showed contributions of lexical strategies in English reading comprehension. These cross-group comparisons demonstrate how the inclusion of multiple participant groups helps us to further refine our understanding of how language and sensory experiences influence reading comprehension.

Keywords: deaf; bilingual; reading; phonological awareness

Individuals with congenital deafness are often at risk for developmental language delays that can have lifelong consequences for learning and educational achievement. Severe hearing loss can impede the normative development of spoken language acquisition, and delays in exposure to an accessible language, such as American Sign Language (ASL), may result in atypical linguistic competencies, including difficulties with reading. According to the National Center for Educational Statistics (2005), the national average high school reading level for all teenagers was between “basic” and “proficient” at the 12th-grade level where “proficient” is equated with an 8th-grade reading level. In contrast, the mean reading

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level of deaf high school seniors is the 4th grade (Holt, 1993; Traxler, 2000). This long-standing discrepancy of reading achievement between hearing and deaf students has been attributed to a host of causal factors (see Andrews & Wang, 2015, and Lederberg *et al.*, 2013 for overviews). Given the phenotypic variability evidenced in individuals with congenital deafness, it is unlikely that a unitary factor is the cause of observed difficulties. We contend that a more accurate accounting of reading abilities in deaf people with severe to profound congenital hearing loss (hereafter “deaf readers”) will require not only broadening our consideration of the multiple individual variables that might be relevant for a deaf reader, but also to broaden our understanding of what it means to read successfully.

To date, most research comparing hearing and deaf readers hold a rather narrow view of the normally-hearing reader. Reading characteristics of English speakers, who for the most part have uniform educational and linguistic experiences, typically serve as the target profile and sole point of comparison for studies of deaf readers. However, there are many individuals who become successful readers of English but begin the process with very different linguistic and educational experiences. Investigation of the ways in which second-language English readers acquire proficiency in reading English provides a rich opportunity to further our understanding of reading competency (see, e.g., Melby-Lervag & Lervag, 2014). We should not assume that all successful readers actually read in a similar fashion to English-speaking monolingual (ML) hearing readers. As we demonstrate in this paper, we believe there is benefit from taking a broader view of what constitutes “reading ability” across typologically diverse populations when considering English reading abilities in deaf readers.

Proficient reading in typically hearing individuals is built upon multiple linguistic skills and processes, including vocabulary development, phonologic sensitivity, and alphabetic skills (National Institute of Child Health and Human Development, 2000; Snow *et al.*, 1998). Cognitive executive functions such as working memory (WM) further contribute to reading success (Peng *et al.*, 2018), as does generalized knowledge of the world that allows readers to relate to the ideas in text to understand what they are reading (Pressley, 2002; Luckner & Handley, 2008). As reading is a skill typically acquired in childhood with explicit instruction, there is agreement that the precedence and weighting of the multiple component skills is dynamic and changes as a child transitions from a beginning reader to a fluent one (Seidenberg, 2017; Castles *et al.*, 2018).

The Simple View of Reading (Gough & Tunmer, 1986; Hoover & Gough, 1990) posits that reading comprehension is the product of two sets of skills, “decoding” and “linguistic comprehension”. More comprehensive treatments of reading have sought to understand the causal impact of the multiple linguistic and cognitive skills required for reading and reading comprehension (Castles *et al.*, 2018), and have begun to clarify the direct and indirect impact of these skills on reading comprehension (Kim, 2017). However, it is important to note that these theoretical models assume readers with typical hearing and speech perception, and they assume the reader comes to the task with English as their native language. That is, children learn to read an orthography that codes a language they already know.

The applicability of the component processes entailed in these models of typical reading to deaf and hard-of-hearing populations remains an active area of debate. For example, Fariña *et al.* (2017) provide evidence that skilled deaf readers of Spanish do not rely on phonological mediation while maintaining the same level

of orthographic sensitivity as hearing readers, despite the orthographic transparency afforded by written Spanish. Moreover, the utility of these traditional models is further complicated by the fact that deaf readers may exhibit adaptive effects of auditory deprivation that result in abilities that are not evidenced in hearing readers (Corina & Lawyer, 2018). For example, using eye tracking, Bélanger and colleagues have reported differences in gaze strategies and the utility of parafoveal vision in online studies comparing deaf and hearing readers (Bélanger et al., 2012; Bélanger et al., 2013; Bélanger & Rayner, 2015; see also Piñar et al., 2017). These capacities are not reflected in traditional models of reading.¹

There is an extensive literature that explores reading and literacy development in deaf children. One prominent line of explanation suggests that deaf childrens' lack of spoken language phonological awareness restricts reading achievement (Geers, 2003; Johnson & Goswami, 2010; Perfetti & Sandak, 2000; Spencer & Oleson, 2008; Venezky, 1970), while others point to much a wider range of factors including conceptual deficits, undeveloped vocabulary, and faulty educational practices (Chamberlain, 2002; Griswold & Comings, 1974; Harris & Beech, 1995; Izzo, 2002; Marschark, 1993; Mayberry et al., 2011; Miller, 1997; Padden & Ramsey, 2000). Andrews and Wang (2015) offer an evaluative review and ascertain the degree to which properties of reading development in this population mirror or are qualitatively different from problems of typically hearing readers. As noted, given the variability in the biological and sociological experience of deaf children, it is likely that multiple factors conspire to inhibit reading achievement.

Reading in deaf ASL-English bilinguals

Many deaf individuals will ultimately develop competencies in both a signed language and accessible forms of other language(s) during the course of their education. The recognition of deaf signers as bilinguals has led to new characterizations of language processing in signers, particularly in expanding our understanding of how deaf individuals process written forms of spoken language (see Corina & Lawyer, 2018). The expression of bilingualism in deaf individuals is a complex situation that does not map neatly onto common characterizations of spoken language bilingualism (see Corina, 2015 for a discussion). While it is uncontroversial to consider deaf individuals as having a signed first language (L1) if they were exposed to a signed language from birth, the status of what constitutes a second language (L2) for deaf native signers (NS) is more complicated. Their L2 could take the form of a second signed language, spoken English, or even written English (Hoffmeister & Harris, 2014).

The case of non-native deaf signers adds further complexity. For some, their L1 may be a signed language, but one that has been acquired relatively late, with exposure ranging from early childhood to adulthood. These late learners may also have varying degrees of English competency based upon inherently reduced access to spoken English, and individual experiences with explicit oral English training. For these individuals, it may be appropriate to consider each language as an L1 (or perhaps L1a, L1b) with the understanding that the timing of language exposure and degree of language accessibility play different roles in the establishment of

linguistic competencies for each language (Corina, 2015). As with NS, written English may serve as an L2 (Hoffmeister & Harris, 2014).

There is growing evidence that when bilingual deaf signers are asked to process English words, the properties of sign language representations are activated. The majority of these findings are reported in the context of semantic decisions of word pairs in English. A common finding across these studies is that there is a response time interference effect for semantically unrelated trials with phonologically related ASL translations when compared to those with a phonologically unrelated ASL translation (see Emmorey *et al.*, 2016, and Ormel & Giezen, 2014 for reviews). These effects may be modulated by English reading ability, language proficiency (Morford *et al.*, 2014; Morford *et al.*, 2011), and conscious awareness of task constraints (Meade *et al.*, 2017). These interference effects may be quite general and have been documented for nonalphabetic orthographies as well. An eye tracking study of deaf Chinese readers that probed for evidence of sign-based influences during sentence reading in Chinese observed interference effects (parafoveal costs) for preview words that were phonologically related in Chinese Sign Language (Thierfelder *et al.*, 2020).

Comparing deaf readers with hearing bilinguals

In an effort to further understand how bilingualism may impact reading ability, in the present study, we expand our scope of inquiry to include a population of Chinese readers who learned to read English as a second language.² In principle, the inclusion of typically hearing second-language readers of English may allow one to identify the reading processes that are necessary for all readers of English as separate from those processes that may reflect strategic practices that occur as a result of prior language, sensory, or instructional experience.

The college-aged Chinese–English bilinguals (CEB) we include learned either Mandarin or Cantonese as a native language and English as a second language in a formal school setting. They have experience with different orthographic systems. In accordance with educational practices in the People’s Republic of China (PRC), these individuals develop the recognition and writing of approximately 3,000 Chinese characters³ by the time students complete the 6 grades of primary school. Chinese students commonly begin to learn English in kindergarten (5–6 years old⁴) (Wenting, 2019). Phonic-based approaches to reading English are valued as a way to improve reading ability (see, *e.g.*, Chien & Chen, 2002; Leou & Huang, 2006; Liaw, 2003; Wang Lu, 2003; Wang *et al.*, 2006).

Linguistic and cognitive predictors of reading comprehension

Several linguistic and cognitive constructs have been assessed to predict reading performance in hearing, ML adult readers (Long *et al.*, 2008, Long *et al.*, 2006). The extent to which these constructs have been used with deaf and bilingual populations varies, and their relative contributions to reading comprehension have not all been examined in the same study with deaf and bilingual populations. These constructs include phonological awareness, vocabulary knowledge, word fluency, reading volume, executive function, and WM. The current study uses these constructs to

contrast and predict reading performance in deaf ASL–English bilinguals, hearing CEB, and hearing English-speaking ML.

Linguistic constructs

Phonological awareness

Research shows that reading an alphabetic orthography hones phonological awareness skills by making the phoneme a salient feature in print, such that there is a reciprocal relationship between phonological awareness and learning to read an alphabetic orthography (Perfetti et al., 1987; Mann, 1986; Stahl & Murray, 1994). Studies of deaf readers show that they can develop phonological awareness, but its relationship to reading comprehension is a matter of debate (see, e.g., Chamberlain, 2002; Izzo, 2002; Miller, 1997, contrasted with Geers, 2003; Johnson & Goswami, 2010; Spencer & Oleson, 2008). Xu (2002) explored the development of Chinese and English phonological awareness for Chinese Mandarin-speaking children and found that there was a strong correlation between children's development of Chinese and their English phonological awareness. However, other studies have suggested limitations of cross-language phonological awareness. For example, some studies of reading development in CEBs show that, while phonological awareness in Chinese predicts skill in reading Chinese and English, phonological awareness of English does not predict their skill in reading English (Gottardo et al., 2001; Li et al., 2012; McBride-Chang & Suk-Han Ho, 2005). In addition, it is worth noting that more universal aspects of acquiring orthographic systems may yield cross-script learning transfer (Wang et al., 2006; Perfetti et al., 2013).

Vocabulary knowledge

Vocabulary knowledge in English has been shown to be a significant predictor of English reading comprehension for first and second-language learners of English (Choi, 2013; Espin & Foegen, 1996; Yovanoff et al., 2005; Melby-Lervag & Lervag (2014), and a source of difficulty in reading for many deaf people (Garrison et al., 1997).

Word fluency

Word fluency is a composite skill that engages lexical and executive function, but is included under language measures in this study. The reported role of word fluency measures in predicting reading comprehension is mixed, with some studies showing predictive effects (Silverman et al., 2013) while others do not (Adlof et al., 2006). The contribution of fluency measures in studies of deaf reader's comprehension is limited (but see Easterbrooks & Lederberg, 2021 for a developmental perspective).

Reading volume

The amount of time spent reading (aka reading volume) naturally reinforces one's proficiency in reading, and can be measured with author recognition tasks (Stanovich & West, 1989). Author recognition tasks have also been shown to predict differences in reading comprehension in deaf people (Marschark et al., 2012) and in bilinguals with English as a foreign language (Kim & Krashen, 1998).

Cognitive constructs

Executive function

Executive function is an umbrella term that covers a wide range of higher-order cognitive processes related to an individual's ability to experience, adapt to, and function in their environment (Hughes, 2011). There is evidence that attentional and some executive processes may be altered in the deaf population, though the cause of these alterations is a matter of debate. Two primary causes have been cited in literature – the auditory deprivation caused by congenital deafness (Kral *et al.*, 2016; Kronenberger & Pisoni, 2018), and the language deprivation caused by the lack of an accessible language in many deaf children's environments (Hall *et al.*, 2018; Hauser *et al.*, 2008). The inclusion of measures of executive function with populations of native and non-native deaf adult signers is a means to help disentangle effects of deafness from language experience.

One component of executive function that has been shown to correlate with the complex task of reading is inhibition control. Inhibition control is the ability to suppress information competing for an individual's attention (Posner, 1980). One function of inhibition control in reading includes the ability to suppress incorrect meanings of ambiguous words and homophones (Gernsbacher, 1990; Gernsbacher & Faust, 1991; Hasher *et al.*, 1999). Inhibitory control in CEB has been studied (Yang *et al.*, 2018), and differences in inhibitory control in deaf people have been explored in several studies (Hall *et al.*, 2017; Hall *et al.*, 2018; Blank *et al.*, 2020); however, the contribution of attentional inhibition in the context of reading in this population is understudied.

Working memory

Working memory has both processing and storage functions (Daneman & Carpenter, 1980; Just & Carpenter, 1992). Sentential reading taxes these functions with lexical retrieval, theme tracking, context-building, proposition storing, and sentence modeling (Just & Carpenter, 1992). It has been argued that the overall efficiency of WM may affect reading comprehension because readers with more efficient processing will effectively have more capacity for storage (Daneman & Carpenter, 1980; Just & Carpenter, 1992; Engle *et al.*, 1999). In a recent meta-analysis, Peng *et al.* (2018) provide an evaluation of the role of domain-general WM and verbal WM in reading. Their findings indicate that, in typically hearing readers, domain-general central executive of WM is implicated in early reading acquisition, and verbal WM is more strongly implicated in later reading performance as readers gain more experience with reading. Complex WM span tasks have been used to study deaf readers and have been shown to predict reading comprehension skills in deaf readers (MacSweeney *et al.*, 1996; Pisoni & Geers, 2000; Garrison *et al.*, 1997; Marschark *et al.*, 2016), and in Cantonese–English bilingual children (Tse & Altarriba, 2014).

Aims of the current study

The current study evaluates the contribution of a broad range of language and cognitive measures in predicting reading comprehension in adult deaf and hearing

Table 1. Group patterns of interest

Test performance	Interpretation
ML, CEB > NNS, NS	Effect of audiological status
ML > CEB, NNS, NS	Effect of native English language experience
ML, NS, CEBs > NNS	Effect of early language experience

readers, and assesses whether these predictive measures differ as a function of bilingual language experience. This research approach encourages us to consider English “reading ability” more broadly and permits new insights into the reading competencies of deaf readers.

To achieve these goals, we collected data from four groups: deaf NS, deaf non-native signers (NNS), hearing CEB who learned English in the PRC (CEB), and English ML. Reading comprehension is the dependent variable and the linguistic, cognitive, and trait measures described below are the independent variables.

The inclusion of four distinct groups of participants permits us to make further inferences. We posit that specific patterns of performance across these groups could highlight how test performance may be impacted by factors of audiological status and language experience. Three broad patterns of interest are shown in Table 1.

Test performance in which ML controls and CEB outperform NS and NNS would suggest that audiological status (i.e., hearing vs. deaf) is affecting test performance. Test performance in which ML outperforms CEB, NS, and NNS would indicate that native English experience is affecting test performance. A pattern in which ML, CEB, and NS outperform NNS would suggest that early native language experience affects test performance. These (non-exhaustive) broad patterns of group performance provide preliminary heuristics for the interpretation of results across the wide number of tests used in this study.

As described in detail below, the data analysis uses a three-pronged approach. First, using ANOVA, we evaluate the performance on each of the individual measures across groups. Second, within each group, we identify measures that are strongly correlated with reading comprehension. Third, we use stepwise linear regression for each group to identify aggregate models that predict reading comprehension based upon strongly correlated individual measures.

Methods

Participants

All 332 participants for this study are adults recruited from 5 different colleges. See Table 2 for a summary of the participant characteristics.

All 216 hearing ML participants have normal hearing and normal or corrected vision. One-hundred and sixty participants identify as female and 56 identify as male. Participants are all between the ages of 17 and 21 with an average age of 18.5.

Twenty-seven hearing CEB who are native speakers of Mandarin or Cantonese and who learned English in the PRC participated in this study. Participants are all between the ages of 18 and 35 with a mean age of 23. Fifteen participants identify as

Table 2. Participant characteristics

		ML	CEB	NS	NNS
Total <i>N</i>		216	27	31	57
Gender	Male	56	11	11	18
	Female	160	15	20	39
<i>M</i> age		18.5	23	22	24
AoA of English	Before the age of 5	1			
	After the age of 5	25			
AoA of ASL	Before the age of 8				24
	After the age of 8				33
Age of onset of deafness	Before the age of 3			31	55
	After the age of 3			0	2
dB loss in the better ear	26–40			1	2
	41–55			1	1
	56–70			2	6
	71–90			11	18
	91+			12	20

female, 11 identify as male, and 1 declined to state their gender. Participant age of acquisition of English is self-reported. One participant learned English before the age of 5, 25 learned English after the age of 5, and 1 participant declined to state their age of acquisition of English.

Thirty-two deaf NS participated in this study. Participants are all between the ages of 18 and 35 with a mean age of 22. Eleven participants identify as male, 20 identify as female, and 1 declined to state their gender. Participant age of acquisition of ASL, hearing loss, and age of the onset of deafness are self-reported. All NS participants report learning ASL prior to the age of 5, and all learned ASL from their parents. All became deaf before the age of 3. One has mild hearing loss in the better ear (26–40 dB), 1 has moderate hearing loss in the better ear (41–55 dB), 2 have moderately severe hearing loss in the better ear (56–70 dB), 11 have severe hearing loss in the better ear (71–90 dB), 12 have profound hearing loss in the better ear (91+ dB), and 3 did not report their hearing loss.

Fifty-seven deaf NNS participated in this study. Participants are all between the ages of 19 and 43 with a mean age of 24. Eighteen participants identify as male and 39 identify as female. Participant age of acquisition of ASL, hearing loss, and age of the onset of deafness are self-reported. Twenty-four participants learned ASL before the age of 8 and 33 learned ASL after the age of 8. Two declined to report their age of acquisition of ASL. None of the NNS learned ASL from their parents. All of those who learned ASL before the age of 8 learned from teachers. All but two became deaf before the age of 3. Two have mild hearing loss in the better ear (26–40 dB), 1 has moderate hearing loss in the better ear (41–55 dB), 6 have moderately severe hearing

Table 3. Individual test measures

Test	Dependent variable	Method	Task description
Phonological Decision	Accuracy	Computerized, self-paced	Presents participants with two words, neither of which are spelled like English words (i.e., KHAT and KLAT)
Orthographic Decision	Accuracy	Computerized, self-paced	Presents participants with two orthographically different but phonetically similar candidates (i.e., BRAIN and BRANE)
Nelson–Denny	Correct responses	Paper and pencil, timed	Multiple-choice, 80-item standardized test of vocabulary comprehension
Word Fluency	Correct words	Paper and pencil, timed	List words containing given word onsets, final letters, or onset and final letters
Author Recognition ¹	Hits minus misses	Paper and pencil, timed	Select real authors from lists of names and foils (50% real, 50% foils)
Magazine Recognition ¹	Hits minus misses	Paper and pencil, timed	Select real magazine names from lists of real names and foils (50% real, 50% foils)
Go/No-Go Paradigm	Correct Responses	Computerized, self-paced	Respond “no” to every letter and number in a sequence unless it is an “X”
Reading Span	Letters recalled in order	Computerized, self-paced	Read sentences for sensibility followed by a letter; after completing a trial of two to seven sentences, recall letters in the order presented
Alphabet Span	Words recalled in order	Computerized, self-paced	Presents a series of two to six words to memorize and then alphabetize
KBIT ²	Correct responses	Paper and pencil, self-paced	Identify a picture from four given choices that completes an abstract pattern

¹The ML dataset uses the Reading Habits Questionnaire (Scales & Rhee, 2001).²The ML dataset uses Raven’s Matrices (Raven, 1962).

loss in the better ear (56–70 dB), 18 have severe hearing loss in the better ear (71–90 dB), 20 have profound hearing loss in the better ear (91+ dB), and 10 did not report their hearing loss.

The background surveys used to collect self-reported data from the CEB, NS, and NNS groups are included in Appendix A.

Independent measures

The specific tests in this study and their dependent measures are listed in Table 3. The linguistic measures in this study include phonological and orthographic

decision tests to examine participants' use of phonological and lexical mediation in reading (Bell & Perfetti, 1994), the Nelson–Denny test to examine English vocabulary knowledge, a composite measure of word fluency based upon tests from the Educational Testing Service (ETS) (Ekstrom *et al.*, 1976), and author and magazine recognition tests to examine reading volume (Stanovich & West, 1989).

The cognitive measures in this study include a computerized go/no-go paradigm to examine inhibitory control (https://www.sacklerinstitute.org/cornell/assays_and_tools/), an alphabet span task (Craik 1986), and a reading span task (Just & Carpenter, 1980; Unsworth *et al.*, 2005) to examine WM.

We include a standardized measure from the Kaufman Brief Intelligence Test (KBIT) (Kaufman & Kaufman, 1990) for our bilingual groups (*i.e.*, CEB, NS, and NNS).

While the same constructs are measured for all four groups, some of the specific tests in the ML dataset differ from the tests in the CEB, NS, and NNS data collection, as the data for ML controls is provided by the UC Davis Reading Study⁵ courtesy of Dr. Debra Long (see Table 3 notes, see also Freed *et al.*, 2017).

Dependent measure of reading comprehension

The dependent measure in this study is reading comprehension. Participants read up to five natural, professionally written, and edited narrative and expository texts. The five texts are: “The Secret Life of Walter Mitty” by James Thurber, “I am Bigfoot” by Ron Carlson, “Cellphone or Pheromone? New Props for the Mating Game” by Natalie Angier, “The Oval Portrait” by Edgar Allen Poe, and “How a Coffee Shortage Killed the Confederacy” by David A. Norris. Texts were presented using *EPrime* software running on a laptop PC in a moving window paradigm, wherein participants read each story one word at a time by pressing the space bar. With each bar press, the current word disappeared and the next word appeared. This method of reading allows for future analysis of syntactic and semantic parsing in these populations. Following each story, participants answered a series of questions indicating how much they recalled of the story and then answered a set of 10 multiple-choice comprehension questions (Freed *et al.*, 2017). The correct answers were totaled and the scores for each participant were averaged to get one reading comprehension score. That score is the dependent measure in this study. Due to variation in how long participants spent on the self-paced measures, not all participants read all five texts, which is why we use an average reading comprehension score.⁶

Testing procedures

Participants attended two 2.5-hour sessions no more than 1 week apart. Following informed consent and the completion of the background survey, participants took the tests as described above. Testing sessions had as many as four participants at a time, and began with the timed measures and ended with the self-paced measures. Experimenters explained task instructions in English or ASL as appropriate to each participant's communication needs. If more than one language modality was needed at a time, instructions were issued in each modality in turn. During the self-paced

Table 4. Welch's ANOVA and Games–Howell on individual test measures

Measure	<i>M</i>				Welch's test				Games–Howell tests	
	ML	CEB	NS	NNS	<i>F</i> ^a	df1	df2	<i>p</i> ^b	Sig. comparison	<i>p</i> ^b
AvgComp	7.88	7.16	6.96	6.41	14.68	3	62.36	0.000	ML > NNS	0.000
NelsonD	49.96	48.48	46.16	39.98	7.30	3	67.59	0.000	ML > NNS	0.000
PhonAcc	68.80	53.56	51.87	51.12	85.50	3	60.85	0.000	ML > CEB, NS, NNS	0.000
OrthAcc	140.33	138.54	140.10	136.54	2.26	3	56.70	0.092		
GoNoGo	290.75	287.56	286.35	283.48	6.17	3	66.01	0.001	ML > NNS	0.001
Rspan	38.14	41.92	29.70	23.30	20.81	3	58.57	0.000	CEB, ML > NNS	0.000
AlphSpan	73.24	54.78	55.77	48.59	36.59	3	61.50	0.000	ML > NS, NNS	0.000
WordFluency	27.95	19.57	24.26	22.60	17.68	3	70.83	0.000	ML > CEB, NNS	0.000
									ML > NS	0.006

^aAsymptotically *F* distributed.

^bSignificance evaluated with Bonferroni correction at $p < .0083$.

portion of the testing, experimenters were able to address each individual in whichever language modality was required. At least one researcher fluent in ASL was present for the duration of testing with deaf individuals.

Analysis and results

We calculated means for each variable per group. For each variable within each group, scores below three standard deviations from the mean were removed and treated as missing at random because such outliers represent impossible score values for the tests involved and/or errors in the way in which participants responded to computerized tasks. Any participants with two or more missing scores were removed from analysis to control for the possibility that they repeatedly misunderstood tasks or were unable to perform them. One participant was removed from the NS group and no participants from the ML, CEB, or NNS groups. Therefore, the final numbers of participants by group are 31 NS, 57 NNS, 27 CEB, and 216 ML. The complete descriptive statistics for these data are in Appendix B.

Group differences on test measures

Due to the disparate group sizes and heterogeneous variance between group scores, Welch's one-way analysis of variance was calculated to compare groups on those measures for which all groups took the same test. The analysis was significant for all tests except for the orthographic accuracy measure, and the Games–Howell post hoc test revealed differential patterns of scores between groups, summarized in Table 4. The pairwise post hoc tests reported below were evaluated using the conservative Bonferroni correction with a significance threshold of $p < .0083$.

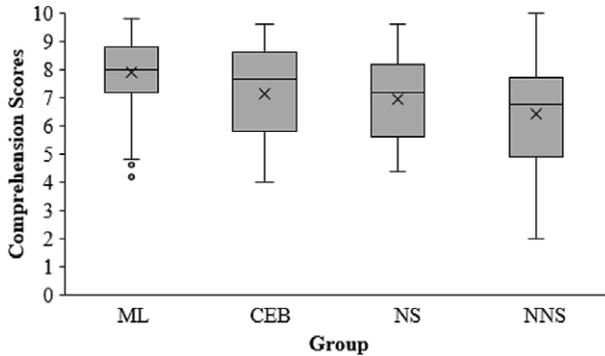


Figure 1. Average Comprehension Scores by Group.

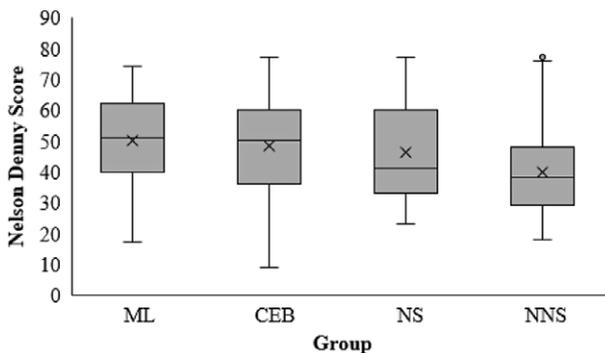


Figure 2. Nelson-Denny Scores by Group.

For expository purposes, we discuss group differences observed for language measures (reading comprehension, vocabulary, phonological and orthographic awareness, and word fluency), cognitive processing tasks (WM span tests and inhibition), and trait variables (i.e., AoA, dB loss, and IQ).

Language measures

There was a main effect of group on reading comprehension ($F(3,62) = 14.681, p < .001$) (see Figure 1 and Table 4). Post hoc testing revealed ML ($M = 7.88$), CEB ($M = 7.16$), and NS ($M = 6.96$) were not significantly different (ML vs. CEB, $p = .136$; ML vs. NS $p < .015$). ML performed significantly better than NNS ($M = 6.41$) (ML vs. NNS $p < .001$) (Table 4). Chinese-English bilinguals, NS, and NNS groups were not statistically significant (all pairwise $p > .224$).

On the Nelson-Denny vocabulary measure ($F(3,67) = .304, p < .001$) (Figure 2, Table 4), scores for the ML ($M = 49.96$), CEB ($M = 48.48$), and NS ($M = 46.16$) were statistically comparable (all pairwise $p > 0.5$). Comparatively, NNS ($M = 39.98$) scored significantly lower than the ML ($p < .001$) (Table 4); however,

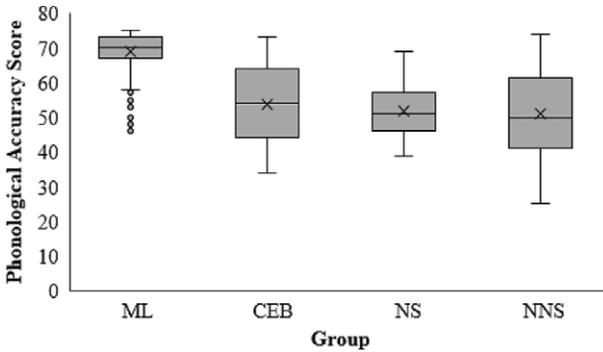


Figure 3. Phonological Accuracy Scores by Group.

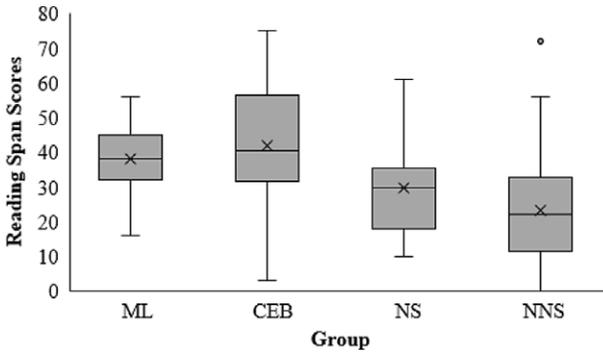


Figure 4. Reading Span Scores by Group.

differences between CEB, NS, and NNS groups were not statistically significant (all pairwise $p > 0.1$).

As with other language measures, for phonological awareness, ML scores ($M = 68.80$) were the highest ($F(3,60) = 85.46, p < .001$), followed by the CEB ($M = 53.56$), NS ($M = 51.87$), and then NNS ($M = 51.12$) (see Figure 3 and Table 4). Pairwise comparisons indicated that MLs scored significantly higher than the three bilingual groups (all pairwise $p < .001$) (Table 4). However, differences between CEB, NS, and NNS groups were not statistically significant (all pairwise $p > .95$).

On the word fluency measure ($F(3,70) = 17.675, p < .001$), pairwise comparisons showed that ML scores ($M = 27.95$) were statistically different from CEB ($M = 19.57$), NS ($M = 24.26$), and NNS ($M = 22.60$) (all pairwise $p < .008$) (Table 4). However, in a now-familiar pattern, the CEB, NS, and NNS scores did not differ from one another (all pairwise $p > 0.03$).

Cognitive measures

Performance on the go–no-go task ($F(3,66) = 6.167, p < .001$) (Table 4) was highly comparable across groups. In pairwise comparisons, only the scores for the ML

Table 5. Significant correlations with reading comprehension by group

Variable	ML	CEB	NS	NNS
NelsonD	.498**	.627**	.791**	.603**
<i>p</i>	0.000	0.000	0.000	0.000
PhonAcc	.461**		.475**	.634**
<i>p</i>	0.000		0.007	0.000
OrthAcc	.151*	.640**		
<i>p</i>	0.027	0.000		
Rspan	.353**			.351**
<i>p</i>	0.000			0.008
AlphSpan	.368**	.415*		.627**
<i>p</i>	0.000	0.031		0.000
WordFluency	.252**	.477*		.399**
<i>p</i>	0.000	0.012		0.002
LiteracyPractice	.221**	N/A	N/A	N/A
<i>p</i>	0.001			
Raven	.209**	N/A	N/A	N/A
<i>p</i>	0.002			
Recognition	N/A	.550**	.650**	.491**
<i>p</i>		0.003	0.000	0.000
KBIT	N/A			.469**
<i>p</i>				0.000

**Correlation is significant at the 0.01 level (two-tailed).

*Correlation is significant at the 0.05 level (two-tailed).

controls ($M = 290.75$) were statistically different from NNS ($M = 283.48$) ($p < .001$) (Table 4).

On the reading span test ($F(3,58) = 20.805$, $p < .001$) (Figure 4 and Table 4), we observed that the CEB group ($M = 41.92$) scored highest, followed by ML ($M = 38.14$), NS ($M = 29.70$), and then NNS groups ($M = 23.30$). The ML, CEB, and NS scores did not differ significantly from one another (all pairwise $p > .01$); however, CEB and ML groups performed significantly better than the NNS (all pairwise $p < .001$) (Table 4), while the NS and NNS did not differ from one another ($p = 0.18$).

On the alphabet span test ($F(3,61) = 36.585$, $p < .001$), the ML ($M = 73.24$) performed the highest, followed by the NS ($M = 55.77$), CEB ($M = 54.78$), and then NNS groups ($M = 48.59$). Monolingual scores were statistically different from NS and NNS ($p < .001$) (Table 4), but did not differ from the CEB ($p > .01$). However, scores of the NS, CEB, and NNS did not differ from one another (all pairwise $p > .34$).

Trait variables

An additional Welch's one-way analysis of variance was calculated to compare the CEB, NS, and NNS groups on the KBIT, with a Bonferroni correction value of $p < .016$. The analysis was significant, ($F(2,65.5) = 9.386$, $p < .000$). The Games–Howell post hoc test revealed that the CEB group ($M = 29.85$) is significantly higher than the NNS ($M = 26.93$) ($p < .001$), but not the NS ($M = 27.74$) with the Bonferroni correction ($p < .05$). An additional Welch's one-way analysis of variance assessed the degree of self-reported hearing loss in the better ear in native and non-native deaf signers. There was no group difference observed ($F(1,55) = .734$, $p = .395$).

Variable correlations with reading comprehension

We took Pearson correlations for each variable with reading comprehension for each group. We sought to retain as many variables that had any strong relationship to reading comprehension as possible for each group without preselected control variables. Variables that had a zero-order correlation ($p < .05$) with reading comprehension for each group were retained for further analysis, as these were the variables with a significant relationship to reading comprehension without controlling for any other variables. In addition to the test score variables, age of acquisition of English was included for the CEB group, and age of acquisition of ASL and dB loss in the better ear were included for the NS and NNS groups.

The tests with significant zero-order correlations with reading comprehension for each group (Table 5, see Appendix C for complete correlation matrices) were then used in stepwise linear regression to explore models for reading comprehension for each group.⁷ We used conservative statistical measures to assess each model because of our small sample sizes. For each group, the predicted residual sum of squares (PRESS) statistic was used to select the most appropriate model, and then the PRESS statistic was used to calculate a predicted R squared (Garson, 2016) to ensure models were not over fit due to the small sample sizes and number of predictor variables. Given the degree of correlation between the predictor variables, the variance inflation factors (VIF) and tolerance statistics were examined for each predictor in the final models for each group to ensure no corrective measures were needed to address multicollinearity, and residual plots for all models were also examined to ensure model adequacy. Variance inflation factors and tolerance statistics are reported with each regression table.

Hearing English monolinguals

The variables with a zero-order correlation with reading comprehension for the ML group included the Nelson–Denny, the measures of phonological and orthographic awareness, the reading span and alphabet span measures, the word fluency measure, the reading habits questionnaire, and the Raven's matrices.

A stepwise multiple regression was conducted to evaluate which of the variables were necessary to predict reading comprehension. The model summary and regression coefficients are shown in Tables 6 and 7. At step three of the analysis, the Nelson–Denny, the reading span task, and the phonological accuracy measure

Table 6. Model summary for ML

Model	R	R ²	R ² _{adj}	Std. error	Change statistics				
					R ² change	F change	df1	df2	p
1	.498 ^a	0.248	0.244	0.935	0.248	66.301	1.000	201.000	0.000
2	.554 ^b	0.307	0.300	0.900	0.059	16.956	1.000	200.000	0.000
3	.594 ^c	0.352	0.343	0.872	0.046	14.004	1.000	199.000	0.000

^aPredictors: (Constant), NelsonD.^bPredictors: (Constant), NelsonD, Rspan.^cPredictors: (Constant), NelsonD, Rspan, PhonAcc.**Table 7.** Regression coefficients for ML

Model		B	Std. error	β	t	p	Tolerance	VIF
1	(Constant)	5.990	0.241		24.817	0.000		
	NelsonD	0.038	0.005	0.498	8.143	0.000	1.000	1.000
2	(Constant)	4.990	0.336		14.847	0.000		
	NelsonD	0.033	0.005	0.439	7.249	0.000	0.944	1.059
	Rspan	0.032	0.008	0.249	4.118	0.000	0.944	1.059
3	(Constant)	2.280	0.794		2.871	0.005		
	NelsonD	0.024	0.005	0.319	4.768	0.000	0.727	1.376
	Rspan	0.029	0.008	0.222	3.748	0.000	0.93	1.076
	PhonAcc	0.048	0.013	0.25	3.742	0.000	0.731	1.368

entered into the regression equation and were significantly related to reading comprehension ($F(3,199) = 36.093$, $p < .001$). The PRESS statistic for this model was 158.97, compared to 170.29 and 182.31 of the other models, which indicated that this was the best-fit model. The predicted R squared for the model was .319, which indicated that this model explained 32% of the variance in reading comprehension scores for this group.

Hearing Chinese–English bilinguals

The variables with a zero-order correlation with reading comprehension for the CEB group included the Nelson–Denny, the measure of orthographic awareness, the alphabet span task, and the measures of word fluency and reading volume.

A stepwise multiple regression was conducted to evaluate which of the variables were necessary to predict reading comprehension. The model summary and regression coefficients are shown in Tables 8 and 9. At step two of the analysis, orthographic accuracy and Nelson–Denny entered into the regression equation and were significantly related to reading comprehension ($F(2,23) = 12.514$, $p < .001$). The PRESS statistic for this model was 40.25, compared to 49.14 of the other model, which indicated that this was the best-fit model. The predicted R squared for the

Table 8. Model summary for CEB

Model	<i>R</i>	<i>R</i> ²	<i>R</i> ² _{adj}	Std. error	Change statistics				
					<i>R</i> ² change	<i>F</i> change	df1	df2	<i>p</i>
1 ^c	.640 ^a	0.409	0.384	1.2845	0.409	16.61	1	24	0.000
2 ^c	.722 ^b	0.521	0.479	1.1811	0.112	5.384	1	23	0.030

^aPredictors: (Constant), OrthAcc.^bPredictors: (Constant), OrthAcc, NelsonD.^cDependent Variable: AvgComp.**Table 9.** Regression coefficients for CEB

Model		B	Std. error	β	<i>t</i>	<i>p</i>	Tolerance	VIF
1 ^a	(Constant)	-26.424	8.243		-3.205	0.004		
	OrthAcc	0.242	0.059	0.640	4.076	0.000	1.000	1.000
2 ^a	(Constant)	-17.107	8.578		-1.994	0.058		
	OrthAcc	0.161	0.065	0.425	2.482	0.021	0.709	1.410
	NelsonD	0.040	0.017	0.398	2.32	0.030	0.709	1.410

^aDependent Variable: AvgComp.

model was .399, which indicated that this model explained 40% of the variance in reading comprehension scores for this group.

Native signers

The variables with a zero-order correlation with reading comprehension for the NS group included the Nelson–Denny, measure of phonological awareness, and the measure of reading volume.

A stepwise multiple regression was conducted to evaluate which variables were necessary to predict reading comprehension. The model summary and regression coefficients are shown in Tables 10 and 11. At step one of the analysis, the Nelson–Denny vocabulary measure entered into the regression equation and was significantly related to reading comprehension ($F(1,26) = 43.545$, $p < .001$). This was the only independent variable included in the regression analysis. The PRESS statistic for this model was 30.76. The predicted *R* squared for the model was .528, which indicated that this model explained 53% of the variance in reading comprehension scores for this group.

Non-native signers

The variables with a zero-order correlation with reading comprehension for the NNS group included the Nelson–Denny, the measure of phonological awareness, the reading span and alphabet span measures, the word fluency measure, the measure of reading volume, and the KBIT.⁸

Table 10. Model summary for NS

Model	<i>R</i>	<i>R</i> ²	<i>R</i> ² _{adj}	Std. error	Change statistics				
					<i>R</i> ² change	<i>F</i> change	df1	df2	<i>p</i>
1	.791 ^a	0.626	0.612	0.9679	0.626	43.545	1	26	0.000

^aPredictors: (Constant), NelsonD.
^bDependent Variable: AvgComp.

Table 11. Regression Coefficients for NS

Model		B	Std. error	β	<i>t</i>	<i>p</i>	Tolerance	VIF
1 ^a	(Constant)	3.249	0.592		5.491	0.000		
	NelsonD	0.080	0.012	0.791	6.599	0.000	1.000	1.000

^aDependent Variable: AvgComp

Table 12. Model summary for NNS

Model	<i>R</i>	<i>R</i> ²	<i>R</i> ² _{adj}	Std. error	Change statistics				
					<i>R</i> ² change	<i>F</i> change	df1	df2	<i>p</i>
1 ^d	.634 ^a	0.402	0.390	1.4164	0.402	34.937	1	52	0.000
2 ^d	.751 ^b	0.564	0.547	1.2214	0.162	18.929	1	51	0.000
3 ^d	.772 ^c	0.597	0.572	1.1863	0.033	4.061	1	50	0.049

^aPredictors: (Constant), PhonAcc.
^bPredictors: (Constant), PhonAcc, AlphSpan.
^cPredictors: (Constant), PhonAcc, AlphSpan, NelsonD.
^dDependent Variable: AvgComp.

A stepwise multiple regression was conducted to evaluate which variables were necessary to predict reading comprehension. The model summary and regression coefficients are shown in Tables 12 and 13. At step three of the analysis, the phonological awareness measure, the alphabet span measure, and the Nelson–Denny entered into the regression equation and were significantly related to reading comprehension ($F(3,50) = 24.643, p < .001$). The PRESS statistic for this model was 91.09, compared to 91.16 and 119.19 of the other models, which indicated that this was the best-fit model, though not by much. The predicted R squared for the model was 0.48, which indicated that this model explained 48% of the variance in reading comprehension scores for this group.

Discussion

In our regression analysis, we identify different predictors of reading comprehension across our four groups of participants, which is not unexpected given that that the individual measures themselves often differentiate the four groups.

Table 13. Regression coefficients for NNS

Model		B	Std. error	β	t	p	Tolerance	VIF
1 ^a	(Constant)	1.689	0.821		2.057	0.045		
	PhonAcc	0.092	0.016	0.634	5.911	0.000	1.000	1.000
2 ^a	(Constant)	0.995	0.726		1.371	0.176		
	PhonAcc	0.066	0.015	0.453	4.470	0.000	0.832	1.202
	AlphSpan	0.042	0.010	0.441	4.351	0.000	0.832	1.202
3 ^a	(Constant)	0.837	0.709		1.180	0.244		
	PhonAcc	0.054	0.016	0.370	3.471	0.001	0.709	1.411
	AlphSpan	0.034	0.010	0.357	3.334	0.002	0.705	1.419
	NelsonD	0.029	0.014	0.229	2.015	0.049	0.625	1.601

^aDependent Variable: AvgComp.

Cognitive and linguistic measures

We observe two major patterns with the measures in our data. First, we observe that ML hearing controls outperform non-native deaf signers across all language and cognitive measures. Second, across many of these measures, we find less differentiation in performance between CEB, NS, and NNS groups, and on specific measures between ML, CEB, and NS groups. Consideration of these patterns provides insight into the contribution of linguistic and auditory factors in test performance.

The finding that ML participants outperform NNS suggests that both normative spoken language acquisition and intact sensory experiences afford advantages across the selected linguistic and cognitive tasks. While it is not surprising that tests of English language ability differ between these groups, it is noteworthy that across all but one language measure (OrthAcc), NNS show poorer performance. This suggests that deafness, in the absence of normative native language experience, may have cascading effects on cognitive abilities such as WM and executive function. This is consistent with evidence that early auditory deprivation and impoverished early language experience may impact downstream, distal, cognitive processes that are not related directly to sensory loss (Kral et al., 2016). Further, we note that, at the group level, the NNS also showed differences in nonverbal IQ.

A comparison across the four groups of participants reveals informative sub-patterns that allow us to make preliminary observations regarding how linguistic and auditory factors affect test performance (see Table 1). We report these patterns to provide some initial heuristics to help characterize this large and complex set of results.

We suggest that instances where ML, CEB, and NS outperform NNS may be indicative of cases where early language experience (regardless of language or language modality) affords performance advantages. On both the reading comprehension measure (our main dependent variable of interest) and the Nelson–Denny vocabulary measure, we observed that Bonferroni-corrected pairwise comparisons between ML, CEB, and NS scores were not statistically different. These data

reinforce the well-established importance of accessible early language experience in academic achievement and in the acquisition of second languages (Scott & Hoffmeister, 2017; Mayberry, 2007). In the present context, early native language experience may provide necessary capacities for rich lexical-semantic associations that may be marshaled for subsequent (not-native) vocabulary learning.

It is of further interest to note that this same pattern (i.e., ML, CEB, NS > NNS) is observed on the cognitive go–no-go test. As discussed, this is an executive function task that requires inhibitory control. There is a large (and controversial) literature suggesting that such processes may be impacted by auditory deprivation (Beer *et al.*, 2014; Kronenberger *et al.*, 2014), or by delayed language acquisition (Dye & Hauser, 2014; Hall *et al.*, 2018). The present data, which shows that deaf NS tend to pattern with other individuals who have benefitted from early language (e.g., English in ML, Mandarin, or Cantonese in CEB) provides support for the latter interpretation, that delayed language acquisition and not auditory deprivation may be a causal factor in deficits in executive function regulation in congenitally deaf individuals.

On another cognitive measure, reading span, we observe patterns whereby ML and CEB outperform deaf participants (NS and NNS) (i.e., ML, CEB > NS, NNS). We suggest this pattern may highlight measures whereby hearing ability provides a task advantage. Reading span taxes both linguistic and WM functions. Some researchers have suggested that a lack of auditory experience impacts retrieval strategies used in verbal learning and memory (Pisoni & Cleary, 2004; Conway *et al.*, 2009; Pisoni *et al.*, 2016). In this view, experience with sound provides a “scaffolding” for human cognition and helps individuals to develop general cognitive abilities related to encoding and processing of temporal or sequential patterns (Conway *et al.*, 2009). However, whether such posited deficits reflect immutable cognitive limitations or merely reveal differences in strategic processes used in the specific verbal–linguistic tasks awaits further study.

Examining across individual measures, we note several tests where ML outperformed CEB, NS, and NNS groups. We observe this pattern for tests of phonological awareness, alphabet span, and word fluency. We interpret this pattern as revealing individual measures which heavily weigh early spoken English language experience. It is interesting to note that two of these measures, alphabet span and word fluency, engage executive control functions (e.g., WM, inhibitory control) in addition to English language skills, and under these combined demands, we observe the potential impact of native English language experience. Under one account, early English experience may ultimately provide readers with more efficient routes for English language understanding, thus freeing additional capacities required under combined tests that tax multiple faculties. We discuss phonological awareness in detail below.

Contribution of language and cognitive measures to reading comprehension

The Nelson–Denny vocabulary test is a significant predictor for all groups. In fact, the NS has no predictors in addition to the Nelson–Denny vocabulary test, which explains 58% of the variance in reading comprehension in that group. This is in line with prior research that shows that high-level vocabulary comprehension is a critical attribute in successful reading, and is a stable predictor across grade levels for hearing English ML (Espin & Deno, 1995; Espin & Foegen, 1996; Yovanoff *et al.*, 2005)

as well as for second-language learners of English and deaf individuals (Choi, 2013; Garrison et al., 1997; Lervag & Aukrust, 2010; Sarchet et al., 2014; Spencer & Marschark, 2010). It is interesting to consider whether the acquisition of English vocabulary across the groups of participants proceeds in a uniform fashion. Whereas the two hearing groups could have acquired the vocabulary through either spoken interactions or through reading, the NS, for example, may have acquired the vocabulary on the Nelson–Denny mainly through reading. As noted above, researchers have entertained the possibility that, for deaf signers, English language proficiencies may be attained primarily through exposure to written English (Hoffmeister & Caldwell-Harris, 2014).

The phonological awareness measure predicts reading comprehension in the ML and NNS groups while the test of orthographic awareness predicts reading comprehension in the CEB group. We offer two interpretations of these findings.

Under one account, the phonological awareness measure used here is tapping into spoken language meta-awareness abilities that have long been associated with learning to read and, in the present study, are reflected in reading comprehension scores. This variable in the regression models for ML and NNS groups reflects a common understanding of the role of speech abilities in reading achievement (Geers, 2003; Johnson & Goswami, 2010; Perfetti & Sandak, 2000; Spencer & Oleson, 2008; Venezky, 1970).

The lack of phonological awareness as a significant predictor in the regression model of the CEB group is consistent with previous research that has reported that phonological awareness in English does not predict English reading skills in Mandarin native speakers (Gottardo et al., 2001; Li et al., 2012; McBride-Chang & Suk-Han Ho, 2005; but see also Xu, 2002). Indeed, the importance of the orthographic awareness test as a factor in predicting reading comprehension in the CEB group may be an indication of a greater reliance on visually-based word-level lexical processing over phonological strategies.

That the CEB group does not demonstrate a strong relationship between performance on the phonological awareness test and reading comprehension is an important finding. This suggests that these native Mandarin speakers, in spite of having poor English-based phonological recoding, nevertheless achieved adequate reading comprehension that was not statistically different from the ML group. While many studies have linked limitations of deaf readers' reading ability to a lack of spoken phonological awareness, the present data, with its inclusion of a hearing English–L2 bilingual group, calls into question the strong causal inferences often elicited by this pattern of performance. The lack of phonological awareness as a predictor of reading comprehension for the NS group further questions this inference.

The data also suggest a more nuanced interpretation. Reading researchers have long acknowledged the reciprocal causal relationship between phonological awareness and reading, where by a certain level of phonological awareness is necessary for understanding the rudiments of the alphabetic principle, but as the learning of phoneme–grapheme correspondences progress, this knowledge, in turn, promotes the development and refinement of phonological awareness (Perfetti et al., 1987; Stanovich, 1986; Tunmer & Rohl, 1991). Castles et al. (2003) have explored the relationships between orthographic knowledge and performance on phonological awareness tasks, such as phoneme deletion. They provided evidence that in English-speaking adults, solutions to phonological awareness tests may be aided

by orthographic components of the tests whereby orthographic information is activated in an automatic and involuntary manner. In this sense, phonological awareness performance, in part, reflects the impact of mediating variables such as facility with orthographic processing. This interpretation finds support when one considers the strong positive correlations between the phonological and orthographic tests observed for both the ML and the CEB groups (ML: $R^2 = .320$ $p < .001$; CEB: $R^2 = .516^{**}$ $p < .007$), and the lack of this relationship for deaf participants (NS: $R^2 = 0.124$, $p > .50$; NNS: $R^2 = 0.222$ $p > 0.1$). This suggests that the implicit activation of orthographic information on sound-based phonological awareness tasks is less available for deaf readers. It also suggests that prior orthographic experience may influence the relative weightings of orthographic versus phonological awareness on reading comprehension. In the case of the CEB group, whose first learned script is not alphabetic, orthographic accuracy predicts reading comprehension. For the ML group, whose first learned script is alphabetic, phonological accuracy predicts reading comprehension. Furthermore, the presence of phonological accuracy as a significant predictor of reading comprehension for the NNS group, but not for the NS group, suggests that native ASL experience may influence the relative importance of phonological awareness skills in reading even though deaf native ASL signers do not have prior orthographic experience with a different script. Taken together, this pattern of results highlights the importance of the inclusion of typologically diverse English readers in assessing the contribution of component processes in successful reading. The present data suggest that English phonological awareness may be less deterministic for the development of skilled English reading than has been previously assumed.

Both the ML and NNS groups have complex WM span tasks as significant predictors of reading comprehension (reading and alphabet span respectively). Both the alphabet and reading span tasks require explicit English knowledge to perform the task. The tasks differ in that alphabet span requires participants to memorize lists of words and subsequently recall them in alphabetic order. In contrast, the reading span task requires participants to read sentences and determine whether they make sense or not. Thus, the reading span measure includes processes that are closely related to sentential text comprehension.

Prior research has observed the effects of verbal WM on adult ML and bilingual readers of English (Peng *et al.*, 2018). However, our data reveals a different pattern. It is particularly interesting to note that, in contrast to the NNS group, no WM span tasks predicted reading comprehension scores of the NS group. These data further suggest that NS are approaching reading comprehension in a different manner than the non-native deaf signers. While the NNS regression models appear more similar to the hearing ML, the native bilingual groups (CEB and NS) indicate that alternative strategies may be employed to reach similar reading comprehension outcomes. The inclusion of these multiple groups of participants in this study highlights these differential strategies and motivates the need to consider multiple models of reading in assessing the performance of English language reading competencies.

Effects of deafness on reading comprehension

In the present study, we observed that self-reported dB loss in the better ear did not predict reading comprehension for either of the deaf groups. This lack of

relationship between hearing loss and higher-level reading comprehension, sentence comprehension, and reading achievement in young deaf adults has been previously reported (Jackson et al., 1997; Miller, 2005).

Limitations

As noted, in our post hoc pairwise comparisons, we chose a conservative threshold of $p < .0083$ to assess significance across groups. This conservative threshold masks more subtle sub-patterns and trends that are evident in these data. For example, we observe many cases where ML are significantly different from NNS (as assessed by our statistical threshold), and based on this same criterion, observe a lack of difference between ML, CEB, and NS. We interpret this pattern as being consistent with a profile where by ML, CEB, NS > NNS (see Table 1); however, we acknowledge that, strictly speaking, the CEB and NS seldom differed from the NNS at this same $p < .0083$ threshold. In addition, we note that scores on the nonverbal KBIT were significantly different for NNS from CEB and NS groups. For the sake of transparency, we provide a complete accounting of the descriptive results from each of these measures (Appendix B) and tables reporting the complete pairwise comparisons (Appendix D). This provides the reader with an opportunity to further scrutinize the specific details of these test results and to draw additional inferences.

Second, the reporting of these separate individual measures fails to take into account (nor do we wish to imply) that these are neither pure nor orthogonal assessments of specific linguistic and cognitive skills. Our accounting does not assess the correlations between these measures as they relate to our dependent measure. To address these concerns, we conducted a correlational analysis across these measures followed by stepwise linear regression to further identify significant linguistic, cognitive, and demographic factors that predict reading comprehension across these groups.⁹

Third, a limitation of the current approach is that we are not able to directly evaluate differences between groups in terms of the size of the effects of the predictor variables on comprehension outcomes. That is, our modeling approach does not let us assert that the effects of a given predictor variable are larger or smaller in one group than in others.¹⁰ A focus for further research should be to include larger numbers of native and non-native deaf readers, which would facilitate matching the predictor characteristics, demographics, and other key variables across groups. Evaluating nested models is one technique that allows inferences about differences across groups in terms of predictor-outcome relationships; however, such models require larger sample sizes than are available here. Nonetheless, the current results suggest some intriguing possibilities that warrant further investigation.

Conclusions

This study of adult deaf readers calls attention to the need to assess multiple factors that may underlie reading comprehension in this population, and demonstrates the utility of taking a broader view of reading comprehension in studies of deaf readers which includes examining the performance of hearing English-L2 bilingual readers.

This study highlights three factors that inform our understanding of skilled reading in English by deaf individuals.

First, the data highlight the importance of English vocabulary for reading comprehension. We observe that the Nelson–Denny vocabulary test was a significant predictor for all four groups of participants. This finding suggests that deaf signing children may benefit from targeted English vocabulary instruction, as this knowledge broadly promotes reading comprehension across individuals with varied linguistic and sensory backgrounds.

Second, our data provide a more nuanced view of the role of phonological awareness in reading comprehension. The measure of phonological awareness was a predictive factor of reading comprehension for ML and NNS groups, but did not emerge as a predictor for the NS or CEB groups. This important finding reaffirms the contention that there may be multiple routes to skilled reading, including routes that, for adult readers, down weigh the reliance on phonological factors. However, our data suggest that possible alternative routes (e.g., enhanced reliance on visual orthographic properties as in the case of CEB) may be limited to cases where English–L2 bilingual readers have a native L1.

Third, our data indicate selective effects of cognitive factors in predicting reading comprehension in deaf signers. We observe that WM measures predict reading comprehension in ML and NNS groups. At the same time, across all four groups, we do not find evidence that executive inhibitory control tasks are predictive of reading comprehension abilities. Collectively, these patterns of results are important contributors to the controversy over causal mechanisms of observed executive function and WM difficulties in deaf readers. Our findings provide support for the argument that delayed language acquisition and not auditory deprivation may be a causal factor in deficits in executive function regulation in congenitally deaf individuals, and that these deficits may impact reading processes.

Our results suggest a need to consider the relative weighting of component reading processes in light of the background characteristics of deaf readers, as there may be trade-offs among skills that ultimately promote text comprehension. The comparisons of deaf readers to other bilingual readers who may hold a differing set of skills, but nevertheless are able to achieve the same end goal, provides new opportunities to understand the multiple approaches to successful reading.

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Conflicts of interest. We have no conflicts of interest to disclose.

Notes

1. It is interesting to consider how traditional computational models of reading (e.g., DRC model (Coltheart *et al.*, 2001), the Triangle model (Harm & Seidenberg, 2004; Plaut *et al.*, 1996), and the CDP+ model (Perry *et al.*, 2007 & 2010) would have to be modified to accommodate the differences between hearing and deaf readers. However, this exercise is beyond the scope of the present article.

2. There are a number of shared linguistic characteristics of Chinese and ASL that differ from English including simple syllable structure (Cheng, 1973; Corina, 1996), little tense, and rich aspect marking

(Aronoff et al., 2005; Li et al., 1993), relatively free word order (Li & Thompson, 1976), lack of passive voice (Aronoff et al., 2005, but see Chao, 1968), use of pragmatic inference over syntactic structure (Huang, 1989; Lillo-Martin 1986, 1999; Tai, 2008), lack of articles (Bellugi & Fischer, 1972; Li & Thompson, 1989), and a lack of plural affixation (Li et al., 1993; Sandler & Lillo-Martin, 2006). These similarities make CEB a linguistically compelling comparison group for ASL–English bilinguals.

3. As discussed by Wu et al. (1999), current practice of the learning of characters involves a combination of structure memorization (e.g., concentrated character method), relying on semantic, phonetic, word, and sentence contextual cues (e.g., diversified reading), and since the 1980s, the use of alphabetic cues (pinyin) to aid in the mastery of characters. Pinyin is an alphabetic script that represents the syllables of spoken Chinese. The most frequent 3,500 characters cover 99.48% of the characters in popular books, magazines, and newspapers, while the 2,500 considered by educators as essential for basic reading and writing cover 97.97%.

4. Students in less-developed cities may begin later, closer to 8 years old.

5. National Institutes of Health grant to Debra L. Long (R01HD048914).

6. To quantify the number of texts read, we used a one-way ANOVA to examine group differences. The ML group read significantly more texts than the CEB group ($p < .005$), and the NNS group ($p < .014$), but not the NS group ($p < .40$). No other comparisons were significant.

7. In response to a reviewer query about the differences between participants who read some as opposed to all of the texts, we reran our statistical tests using an average reading comprehension score from only the two texts all but very few participants had read. This analysis did not qualitatively change our results on the regression models for each group, with the exception that word fluency was added as a predictor for the NS group. The ML and NNS model fit statistics were slightly worse (ML PRESS 232.68, $R^2_{\text{pred}} = .165$; NNS PRESS 106.3, $R^2_{\text{pred}} = .425$), and those for the NS and CEB groups were slightly better (CEB PRESS 34.20, $R^2_{\text{pred}} = .471$; NS PRESS 26.35, $R^2_{\text{pred}} = .686$).

8. Based upon a reviewer's comment, we separately examined the patterns of correlations for NNS who learned ASL prior to the age of 5 from those who learned after the age of 5. Both subgroups showed the same zero-order correlations except for word fluency and reading volume, which were significant only for the later learners. These differences may reflect greater English-based skills in deaf signers who learned ASL later in life. Further examination of reading profiles within the non-native signing groups appears warranted, but an in-depth accounting is beyond the scope of the current paper.

9. To take one example noted by a reviewer, examining correlations between group performance on the nonverbal intelligence and linguistic individual measures suggests stronger correlations for NS and NNS relative to ML and CEB. Such patterns may indicate that, relative to hearing participants, deaf signers exhibit less differentiated cognitive capacities, or utilize differentiated cognitive capacities more broadly across disparate cognitive domains, or utilize cognitive strategies that engage visual-spatial abilities while engaging putatively linguistic skills. While the reported data permits readers to form such inferences, the current research efforts were not intended to evaluate these possibilities, which would benefit from more targeted inquiries.

10. Cates (2015) makes use of a principal component factor analysis of these data, the results of which are used in a multiple linear regression analysis. The results are largely comparable to the data patterns reported here.

References

- Adlof, S. M., Catts, H. W., & Little, T. D. (2006). Should the simple view of reading include a fluency component?. *Reading and Writing*, 19(9), 933–958. <https://doi.org/10.1007/s11145-006-9024-z>
- Andrews, J. F., & Wang, Y. (2015). The qualitative similarity hypothesis: Research synthesis and future directions. *American Annals of the Deaf*, 159(5), 468–483. <https://doi.org/10.1353/aad.2015.0005>
- Aronoff, M., Meir, I., & Sandler, W. (2005). The paradox of sign language morphology. *Language*, 81(2), 301–344. <https://doi.org/10.1353/lan.2005.0043>
- Beer, J., Kronenberger, W. G., Castellanos, I., Colson, B. G., Henning, S. C., & Pisoni, D. B. (2014). Executive functioning skills in preschool-age children with cochlear implants. *Journal of Speech, Language, and Hearing Research*, 57(4), 1521–1534. https://doi.org/10.1044/2014_jslhr-h-13-0054

- Bélanger, N. N., Mayberry, R. I., & Rayner, K. (2013). Orthographic and phonological preview benefits: Parafoveal processing in skilled and less-skilled deaf readers. *The Quarterly Journal of Experimental Psychology*, *66*(11), 2237–2252. <https://doi.org/10.1080/17470218.2013.780085>
- Bélanger, N. N., & Rayner, K. (2015). What eye movements reveal about deaf readers. *Current Directions in Psychological Science*, *24*(3), 220–226. <https://doi.org/10.1177/0963721414567527>
- Bélanger, N. N., Slatery, T. J., Mayberry, R. I., & Rayner, K. (2012). Skilled deaf readers have an enhanced perceptual span in reading. *Psychological Science*, *23*(7), 816–823. <https://doi.org/10.1177/0956797611435130>
- Bell, L. C., & Perfetti, C. A. (1994). Reading skill: Some adult comparisons. *Journal of Educational Psychology*, *86*(2), 244. <https://doi.org/10.1037/0022-0663.86.2.244>
- Bellugi, U., & Fischer, S. (1972). A comparison of sign language and spoken language. *Cognition*, *1*(2), 173–200. [https://doi.org/10.1016/0010-0277\(72\)90018-2](https://doi.org/10.1016/0010-0277(72)90018-2)
- Blank, A., Frush Holt, R., Pisoni, D. B., & Kronenberger, W. G. (2020). Associations between parenting stress, language comprehension, and inhibitory control in children with hearing loss. *Journal of Speech, Language, and Hearing Research*, *63*(1), 321–333. https://doi.org/10.1044/2019_jslhr-19-00230
- Castles, A., Holmes, V. M., Neath, J., & Kinoshita, S. (2003). How does orthographic knowledge influence performance on phonological awareness tasks? *The Quarterly Journal of Experimental Psychology*, *56*(3), 445–467. <https://doi.org/10.1080/02724980244000486>
- Castles, A., Rastle, K., & Nation, K. (2018). Ending the reading wars: Reading acquisition from novice to expert. *Psychological Science in the Public Interest*, *19*(1), 5–51. <https://doi.org/10.1177/1529100618772271>
- Cates, D. M. (2015). *Predictors of reading comprehension skill in deaf and hearing bilingual readers* (UMI No. 3706567) [Doctoral dissertation, University of California, Davis]. ProQuest Dissertations and Theses Global.
- Chamberlain, C. (2002). *Reading skills of deaf adults who sign: Good and poor readers compared* [Doctoral dissertation, McGill University, Montréal, Québec].
- Chao, Y. R. (1968). *A grammar of spoken Chinese*. Berkeley, CA, US: University of California Press.
- Cheng, C.-C. (1973). *A synchronic phonology of Mandarin Chinese*. Berlin, Boston: De Gruyter Mouton. <https://doi.org/10.1515/9783110886407>
- Chien, L. C., & Chen, S. H. (2002). A developmental study on phonological awareness and spelling in Taiwanese EFL children. *English Teaching & Learning*, *27*, 41–66.
- Choi, S. (2013). Working memory capacity, vocabulary knowledge, and reading comprehension of EFL learners. *English Language Teaching*, *25*(1), 25–42. <https://doi.org/10.17936/pkelt.2013.25.1.002>
- Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, *108*(1), 204. <https://doi.org/10.1037/0032-295x.108.1.204>
- Conway, C. M., Pisoni, D. B., & Kronenberger, W. G. (2009). The importance of sound for cognitive sequencing abilities: The auditory scaffolding hypothesis. *Current Directions in Psychological Science*, *18*(5), 275–279. <https://doi.org/10.1111/j.1467-8721.2009.01651.x>
- Corina, D. P. (1996). ASL syllables and prosodic constraints. *Lingua*, *98*(1–3), 73–102. [https://doi.org/10.1016/0024-3841\(95\)00033-x](https://doi.org/10.1016/0024-3841(95)00033-x)
- Corina, D. P. (2015). Neurolinguistic studies of sign language bilingualism. In M. Marschark & P. E. Spencer (Eds.), *The Oxford handbook of deaf studies in language* (p. 276). Oxford, England: Oxford University Press. <https://doi.org/10.1093/oxfordhb/9780190241414.013.18>
- Corina, D. P., & Lawyer, L. A. (2018). Language in deaf populations. In S.-A. Rueschemeyer & M. Gareth Gaskell (Eds.), *The Oxford handbook of psycholinguistics* (p. 259). Oxford, England: Oxford University Press. <https://doi.org/10.1093/oxfordhb/9780198786825.013.12>
- Craik, F. I. M. (1986). A functional account of age differences in memory. In F. I. M. Craik (Ed.), *Memory, attention, and aging: Selected works of Fergus I. M. Craik* (pp. 409–422). New York, New York, US: Routledge. <https://doi.org/10.4324/9781315440446>
- Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19*(4), 450–466. [https://doi.org/10.1016/s0022-5371\(80\)90312-6](https://doi.org/10.1016/s0022-5371(80)90312-6)
- Dye, M. W., & Hauser, P. C. (2014). Sustained attention, selective attention and cognitive control in deaf and hearing children. *Hearing Research*, *309*, 94–102. <https://doi.org/10.1016/j.heares.2013.12.001>
- Easterbrooks, S. R., & Lederberg, A. R. (2021). Reading fluency in young elementary school age deaf and hard-of-hearing children. *The Journal of Deaf Studies and Deaf Education*, *26*(1), 99–111. <https://doi.org/10.1093/deafed/ena024>

- Ekstrom, R. B., Dermen, D., & Harman, H. H. (1976). *Manual for kit of factor-referenced cognitive tests* (Vol. 102). Princeton, NJ: Educational Testing Service.
- Emmorey, K., Giezen, M., & Gollan, T. (2016). Psycholinguistic, cognitive, and neural implications of bimodal bilingualism. *Bilingualism: Language and Cognition*, *19*(2), 223–242. <https://doi.org/10.1017/S1366728915000085>
- Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: a latent-variable approach. *Journal of Experimental Psychology: General*, *128*(3), 309. <https://doi.org/10.1037/0096-3445.128.3.309>
- Espin, C. A., & Deno, S. L. (1995). Curriculum-based measures for secondary students: Utility and task specificity of text based reading and vocabulary measures for predicting performance on content-area tasks. *Diagnostique*, *20*, 121–142.
- Espin, C. A., & Foegen, A. (1996). Curriculum based measures at the secondary level: Validity of three general outcome measures for predicting performance on content area tasks. *Exceptional Children*, *62*, 497–514.
- Fariña, N., Duñabeitia, J. A., & Carreiras, M. (2017). Phonological and orthographic coding in deaf skilled readers. *Cognition*, *168*, 27–33. <https://doi.org/10.1016/j.cognition.2017.06.015>
- Freed, E. M., Hamilton, S. T., & Long, D. L. (2017). Comprehension in proficient readers: The nature of individual variation. *Journal of Memory and Language*, *97*, 135–153. <https://doi.org/10.1016/j.jml.2017.07.008>
- Garrison, W., Long, G., & Dowaliby, F. (1997). Working memory capacity and comprehension processes in deaf readers. *The Journal of Deaf Studies and Deaf Education*, *2*(2), 78–94. <https://doi.org/10.1093/oxfordjournals.deafed.a014315>
- Garson, G. D. (2016). *Partial least squares: Regression and structural equation models*. Asheboro, NC: Statistical Associates Publishers.
- Geers, A. E. (2003). Predictors of reading skill development in children with early cochlear implantation. *Ear and Hearing*, *24*(1), 59S–68S. <https://doi.org/10.1097/01.aud.0000051690.43989.5d>
- Gernsbacher, M. A. (1990). *Language comprehension as structure building*. Hillsdale, NJ, US: Erlbaum. <https://doi.org/10.21236/ada221854>
- Gernsbacher, M. A., & Faust, M. E. (1991). The mechanism of suppression: a component of general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(2), 245. <https://doi.org/10.1037/0278-7393.17.2.245>
- Gottardo, A., Yan, B., Siegel, L. S., & Wade-Woolley, L. (2001). Factors related to English reading performance in children with Chinese as a first language: More evidence of cross-language transfer of phonological processing. *Journal of Educational Psychology*, *93*(3), 530. <https://doi.org/10.1037/0022-0663.93.3.530>
- Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading, and reading disability. *Remedial and Special Education*, *7*(1), 6–10. <https://doi.org/10.1177/074193258600700104>
- Griswold, L. E., & Commings, J. (1974). The expressive vocabulary of preschool deaf children. *American Annals of the Deaf*, 16–28.
- Hall, M. L., Eigsti, I. M., Bortfeld, H., & Lillo-Martin, D. (2017). Auditory deprivation does not impair executive function, but language deprivation might: Evidence from a parent-report measure in deaf native signing children. *The Journal of Deaf Studies and Deaf Education*, *22*(1), 9–21. <https://doi.org/10.1093/deafed/enw054>
- Hall, M. L., Eigsti, I. M., Bortfeld, H., & Lillo-Martin, D. (2018). Executive function in deaf children: Auditory access and language access. *Journal of Speech, Language, and Hearing Research*, *61*(8), 1970–1988. https://doi.org/10.1044/2018_JSLHR-L-17-0281
- Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: cooperative division of labor between visual and phonological processes. *Psychological Review*, *111*(3), 662. <https://doi.org/10.1037/0033-295x.111.3.662>
- Harris, M., & Beech, J. (1995). Reading development in prelingually deaf children. *Children's Language*, *8*, 181–202. <https://doi.org/10.4324/9781315789224-9>
- Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In Gopher, D. & Koriat, A. (Eds). *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application* (pp. 653–675). Cambridge, MA, US: The MIT Press. <https://doi.org/10.7551/mitpress/1480.003.0032>

- Hauser, P. C., Lukomski, J., & Hillman, T.** (2008). Development of deaf and hard-of-hearing students' executive function. In M. Marschark & P. C. Hauser (Eds.), *Deaf cognition: Foundations and outcomes* (pp. 286–308). New York, New York, US: Oxford University Press. <https://doi.org/10.1093/acprof:oso/9780195368673.003.0011>
- Hoffmeister, R.K. & Caldwell-Harris, C.L.** (2014). Acquiring English as a second language via print: The task for deaf children. *Cognition*, *132*(2), 229–242. <https://doi.org/10.1016/j.cognition.2014.03.014>
- Holt, J. A.** (1993). Stanford Achievement Test—8th edition: reading comprehension subgroup results. *American Annals of the Deaf*, *138*(2), 172–175. <https://doi.org/10.1353/aad.2012.0684>
- Hoover, W. A., & Gough, P. B.** (1990). The simple view of reading. *Reading and Writing*, *2*(2), 127–160. <https://doi.org/10.1007/bf00401799>
- Huang, C.T.J.** (1989) Pro-drop in Chinese: A generalized control theory. In O.A. Jaeggli & K. J. Safir (Eds.), *The null subject parameter. Studies in natural language and linguistic theory*, 15. Springer, Dordrecht. https://doi.org/10.1007/978-94-009-2540-3_6
- Hughes, C.** (2011). Changes and challenges in 20 years of research into the development of executive functions. *Infant and Child Development*, *20*(3), 251–271. <https://doi.org/10.1002/icd.736>
- Izzo, A.** (2002). Phonemic awareness and reading ability: An investigation with young readers who are deaf. *American Annals of the Deaf*, *147*(4), 18–28. <https://doi.org/10.1353/aad.2012.0242>
- Jackson, D. W., Paul, P. V., & Smith, J. C.** (1997). Prior knowledge and reading comprehension ability of deaf adolescents. *Journal of Deaf Studies and Deaf Education*, *2*(3), 172–184. <https://doi.org/10.1093/oxfordjournals.deafed.a014323>
- Johnson, C., & Goswami, U.** (2010). Phonological awareness, vocabulary, and reading in deaf children with cochlear implants. *Journal of Speech, Language, and Hearing Research*, *53*(2), 237–261. [https://doi.org/10.1044/1092-4388\(2009/08-0139\)](https://doi.org/10.1044/1092-4388(2009/08-0139))
- Just, M. A., & Carpenter, P. A.** (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review*, *87*(4), 329. <https://doi.org/10.1037/0033-295x.87.4.329>
- Just, M. A., & Carpenter, P. A.** (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, *99*, 122–149. <https://doi.org/10.1037/0033-295x.99.1.122>
- Kaufman, A. S., & Kaufman, N. L.** (1990). *Kaufman brief intelligence test*. John Wiley & Sons, Inc. https://doi.org/10.1007/springerreference_183806
- Kim, H., & Krashen, S.** (1998). The author recognition and magazine recognition tests, and free voluntary reading as predictors of vocabulary development in English as a foreign language for Korean high school students. *System*, *26*(4), 515–523. [https://doi.org/10.1016/s0346-251x\(98\)00035-9](https://doi.org/10.1016/s0346-251x(98)00035-9)
- Kim, Y. S. G.** (2017). Why the simple view of reading is not simplistic: Unpacking component skills of reading using a direct and indirect effect model of reading (DIER). *Scientific Studies of Reading*, *21*(4), 310–333. <https://doi.org/10.1080/10888438.2017.1291643>
- Kral, A., Kronenberger, W. G., Pisoni, D. B., & O'Donoghue, G. M.** (2016). Neurocognitive factors in sensory restoration of early deafness: a connectome model. *The Lancet Neurology*, *15*(6), 610–621. [https://doi.org/10.1016/s1474-4422\(16\)00034-x](https://doi.org/10.1016/s1474-4422(16)00034-x)
- Kronenberger, W. G., Beer, J., Castellanos, I., Pisoni, D. B., & Miyamoto, R. T.** (2014). Neurocognitive risk in children with cochlear implants. *JAMA Otolaryngology–Head & Neck Surgery*, *140*(7), 608–615. <https://doi.org/10.1001/jamaoto.2014.757>
- Kronenberger, W. G., & Pisoni, D. B.** (2018). Neurocognitive functioning in deaf children with cochlear implants. In H. Knoors & M. Marschark (Eds.), *Evidence-based practices in deaf education* (pp. 363–396). New York, New York, US: Oxford University Press. <https://doi.org/10.1093/oso/9780190880545.003.0016>
- Lederberg, A. R., Schick, B., & Spencer, P. E.** (2013). Language and literacy development of deaf and hard-of-hearing children: successes and challenges. *Developmental Psychology*, *49*(1), 15. <https://doi.org/10.1037/a0029558>
- Leou, Y. M., & Huang, S. H.** (2006). The implementation of a balanced reading instruction in Taiwan. *CELEA Journal*, *29*(5), 11–17, 32.
- Lervåg, A., & Aukrust, V. G.** (2010). Vocabulary knowledge is a critical determinant of the difference in reading comprehension growth between first and second language learners. *Journal of Child Psychology and Psychiatry*, *51*(5), 612–620. <https://doi.org/10.1111/j.1469-7610.2009.02185.x>
- Li, C. N., & Thompson, S. A.** (1976). On the issue of word order in a synchronic grammar: A case against 'movement transformations'. *Lingua*, *39*(3), 169–181. [https://doi.org/10.1016/0024-3841\(76\)90001-2](https://doi.org/10.1016/0024-3841(76)90001-2)

- Li, C. N., & Thompson, S. A. (1989). *Mandarin Chinese: A functional reference grammar*. Berkeley, CA, US: University of California Press. <https://doi.org/10.2307/2055534>
- Li, M., Cheng, L., & Kirby, J. R. (2012). Phonological awareness and listening comprehension among Chinese English-immersion students. *International Education*, 41(2), 4.
- Li, P., Bates, E., & MacWhinney, B. (1993). Processing a language without inflections: A reaction time study of sentence interpretation in Chinese. *Journal of Memory and Language*, 32(2), 169–192. <https://doi.org/10.1006/jmla.1993.1010>
- Liaw, M. L. (2003). Integrating phonics instruction and whole language principles in an elementary school EFL classroom. *English Teaching & Learning*, 27(3), 15–34.
- Lillo-Martin, D. (1986). Two kinds of null arguments in American Sign Language. *Natural Language & Linguistic Theory*, 4(4), 415–444. <https://doi.org/10.1007/bf00134469>
- Lillo-Martin, D. (1999). Modality effects and modularity in language acquisition: The acquisition of American Sign Language. In W. Ritchie & T. Bhatia (Eds.), *Handbook of child language acquisition* (pp. 531–567). Academic Press.
- Long, D. L., Johns, C. L., & Morris, P. E. (2006). Comprehension ability in mature readers. In M. Traxler & M. Gernsbacher (Eds.), *Handbook of psycholinguistics 2nd Edition* (pp. 801–833). Academic Press. <https://doi.org/10.1016/b978-012369374-7/50021-3>
- Long, D. L., Prat, C., Johns, C., Morris, P., & Jonathan, E. (2008). The importance of knowledge in vivid text memory: An individual-differences investigation of recollection and familiarity. *Psychonomic Bulletin & Review*, 15(3), 604–609. <https://doi.org/10.3758/pbr.15.3.604>
- Luckner, J. L., & Handley, C. M. (2008). A summary of the reading comprehension research undertaken with students who are deaf or hard of hearing. *American Annals of the Deaf*, 153(1), 6–36. <https://doi.org/10.1353/aad.0.0006>
- MacSweeney, M., Campbell, R., & Donlan, C. (1996). Varieties of short-term memory coding in deaf teenagers. *The Journal of Deaf Studies and Deaf Education*, 1(4), 249–262. <https://doi.org/10.1093/oxfordjournals.deafed.a014300>
- Mann, V. (1986). Phonological awareness: The role of reading experience. *Cognition* 24(1-2), 65–92. [https://doi.org/10.1016/0010-0277\(86\)90005-3](https://doi.org/10.1016/0010-0277(86)90005-3)
- Marschark, M. (1993). Origins and interactions in the social, cognitive, and language development of deaf children. In M. Marschark & D. Clark (Eds.), *Psychological perspectives on deafness* (pp. 7–26). Psychology Press. <https://doi.org/10.4324/9781410603302>
- Marschark, M., Sarchet, T., Convertino, C. M., Borgna, G., Morrison, C., & Remelt, S. (2012). Print exposure, reading habits, and reading achievement among deaf and hearing college students. *Journal of Deaf Studies and Deaf Education*, 17(1), 61–74. <https://doi.org/10.1093/deafed/enr044>
- Marschark, M., Sarchet, T., & Trani, A. (2016). Effects of hearing status and sign language use on working memory. *Journal of Deaf Studies and Deaf Education*, 21(2), 148–155. <https://doi.org/10.1093/deafed/env070>
- Mayberry, R. (2007). When timing is everything: Age of first-language acquisition effects on second-language learning. *Applied Psycholinguistics*, 28(3), 537–549. <https://doi.org/10.1017/s0142716407070294>
- Mayberry, R. I., Del Giudice, A. A., & Lieberman, A. M. (2011). Reading achievement in relation to phonological coding and awareness in deaf readers: A meta-analysis. *Journal of Deaf Studies and Deaf Education*, 16(2), 164–188. <https://doi.org/10.1093/deafed/enq049>
- McBride-Chang, C., & Suk-Han Ho, C. (2005). Predictors of beginning reading in Chinese and English: A 2-year longitudinal study of Chinese kindergartners. *Scientific studies of Reading*, 9(2), 117–144. https://doi.org/10.1207/s1532799xssr0902_2
- Meade, G., Midgley, K. J., Sehry, Z. S., Holcomb, P. J., & Emmorey, K. (2017). Implicit co-activation of American Sign Language in deaf readers: An ERP study. *Brain and Language*, 170, 50–61. <https://doi.org/10.1016/j.bandl.2017.03.004>
- Melby-Lervåg, M., & Lervåg, A. (2014). Reading comprehension and its underlying components in second-language learners: A meta-analysis of studies comparing first- and second-language learners. *Psychological Bulletin*, 140(2), 409–433. <https://doi.org/10.1037/a0033890>
- Miller, P. (1997). The effect of communication mode on the development of phonemic awareness in prelingually deaf students. *Journal of Speech, Language, and Hearing Research*, 40(5), 1151–1163. <https://doi.org/10.1044/jslhr.4005.1151>

- Miller, P. (2005). Reading comprehension and its relation to the quality of functional hearing: Evidence from readers with different functional hearing abilities. *American Annals of the Deaf*, **150**(3), 305–323. <https://doi.org/10.1353/aad.2005.0031>
- Morford, J. P., Kroll, J. F., Piñar, P., & Wilkinson, E. (2014). Bilingual word recognition in deaf and hearing signers: Effects of proficiency and language dominance on cross-language activation. *Second Language Research*, **30**(2), 251–271. <https://doi.org/10.1177/0267658313503467>
- Morford, J. P., Wilkinson, E., Villwock, A., Piñar, P., & Kroll, J. F. (2011). When deaf signers read English: Do written words activate their sign translations?. *Cognition*, **118**(2), 286–292. <https://doi.org/10.1016/j.cognition.2010.11.006>
- National Center for Education Statistics. (2005). *The nation's report card: 12th grade reading and mathematics*. https://nces.ed.gov/nationsreportcard/pdf/main2005/2007468_2.pdf
- National Institute of Child Health, & Human Development (US). (2000). *Health disparities: Bridging the gap*. PsychEXTRA Dataset. <https://doi.org/10.1037/e302762004-001>
- Ormel, E., & Giezen, M. (2014). Bimodal bilingual cross-language interaction. In M. Marschark, G. Tang, & H. Knoors (Eds.), *Bilingualism and bilingual deaf education* (pp. 74–101). Oxford University Press. <https://doi.org/10.1093/acprof:oso/9780199371815.003.0001>
- Padden, C. & Ramsey, C. (2000). American Sign Language and reading ability in deaf children. In R. I. Mayberry (Ed.), *Language acquisition by eye*, (pp. 165–189). Mahwah, NJ: Lawrence Erlbaum Associates.
- Peng, P., Barnes, M., Wang, C., Wang, W., Li, S., Swanson, H. L., & Tao, S. (2018). A meta-analysis on the relation between reading and working memory. *Psychological Bulletin*, **144**(1), 48. <https://doi.org/10.1037/bul0000124>
- Perfetti, C., Cao, F., & Booth, J. (2013). Specialization and universals in the development of reading skill: How Chinese research informs a universal science of reading. *Scientific Studies of Reading*, **17**(1), 5–21. <https://doi.org/10.1080/10888438.2012.689786>
- Perfetti, C. A., Beck, I., Bell, L., & Hughes, C. (1987). Phonemic knowledge and learning to read are reciprocal: A longitudinal study of first-grade children. *Merrill-Palmer Quarterly*, **33**, 283–319.
- Perfetti, C. A., & Sandak, R. (2000). Reading optimally builds on spoken language: Implications for deaf readers. *Journal of Deaf Studies and Deaf Education*, **5**(1), 32–50. <https://doi.org/10.1093/deafed/5.1.32>
- Perry, C., Ziegler, J. C., & Zorzi, M. (2007). Nested incremental modeling in the development of computational theories: the CDP+ model of reading aloud. *Psychological Review*, **114**(2), 273. <https://doi.org/10.1037/0033-295x.114.2.273>
- Perry, C., Ziegler, J. C., & Zorzi, M. (2010). Beyond single syllables: Large-scale modeling of reading aloud with the Connectionist Dual Process (CDP++) model. *Cognitive Psychology*, **61**(2), 106–151. <https://doi.org/10.1016/j.cogpsych.2010.04.001>
- Piñar, P., Carlson, M. T., Morford, J. P., & Dussias, P. E. (2017). Bilingual deaf readers' use of semantic and syntactic cues in the processing of English relative clauses. *Bilingualism: Language and Cognition*, **20**(5), 980–998. <https://doi.org/10.1017/s1366728916000602>
- Pisoni, D. B., & Cleary, M. (2004). Learning, memory, and cognitive processes in deaf children following cochlear implantation. In F. G. Zeng, A. N. Popper, & R. R. Fay (Eds.), *Cochlear implants: Auditory prostheses and electric hearing* (pp. 377–426). Springer, New York, NY. https://doi.org/10.1007/978-0-387-22585-2_9
- Pisoni, D. B., Kronenberger, W. G., Chandramouli, S. H., & Conway, C. M. (2016). Learning and memory processes following cochlear implantation: The missing piece of the puzzle. *Frontiers in Psychology*, **7**, 493. <https://doi.org/10.3389/fpsyg.2016.00493>
- Pisoni, D. D., & Geers, A. E. (2000). Working memory in deaf children with cochlear implants: Correlations between digit span and measures of spoken language processing. *The Annals of Otolaryngology, Rhinology & Laryngology*, **109**(12_suppl), 92–93. <https://doi.org/10.1177/0003489400109s1240>
- Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review*, **103**(1), 56–115. <https://doi.org/10.1037/0033-295x.103.1.56>
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, **32**(1), 3–25. <https://doi.org/10.1080/0033558008248231>
- Pressley, M. (2002). *Reading instruction that works: The case for balanced teaching*. New York, New York, US: Guilford Press.
- Raven, J.C. (1962). *Advanced progressive matrices (Set II)*. London, England: Lewis.

- Sandler, W., & Lillo-Martin, D. (2006). *Sign language and linguistic universals*. Cambridge, MA, US: Cambridge University Press. <https://doi.org/10.1017/cbo9781139163910>
- Sarchet, T., Marschark, M., Borgna, G., Convertino, C., Sapere, P., & Dirmyer, R. (2014). Vocabulary knowledge of deaf and hearing postsecondary students. *Journal of Postsecondary Education and Disability*, 27(2), 161.
- Scales, A.M., Rhee, O. (2001). Adult reading habits and patterns. *Reading Psychology*, 22, 175–203. <https://doi.org/10.1080/027027101753170610>
- Scott, J. A., & Hoffmeister, R. J. (2017). American Sign Language and academic English: Factors influencing the reading of bilingual secondary school deaf and hard of hearing students. *The Journal of Deaf Studies and Deaf Education*, 1–13. <https://doi.org/10.1093/deafed/enw065>
- Seidenberg, M. (2017). *Language at the speed of sight: How we read, why so many can't, and what can be done about it*. New York, NY: Basic Books.
- Silverman, R. D., Speece, D. L., Harring, J. R., & Ritchey, K. D. (2013). Fluency has a role in the simple view of reading. *Scientific Studies of Reading*, 17(2), 108–133. <https://doi.org/10.1080/10888438.2011.618153>
- Snow, C. E., Burns, S. M., & Griffin, P. (1998). Predictors of success and failure in reading. In *Preventing Reading Difficulties in Young Children*, 100–134. Washington, D.C: The National Academies Press. <https://doi.org/10.17226/6023>
- Spencer, L. J., & Oleson, J. J. (2008). Early listening and speaking skills predict later reading proficiency in pediatric cochlear implant users. *Ear and Hearing*, 29(2), 270. <https://doi.org/10.1097/01.aud.0000305158.84403.f7>
- Spencer, P.E., & Marschark M. (2010) *Evidence-based practice in educating deaf and hard-of-hearing students*. New York, NY, US: Oxford University Press.
- Stahl, S.A., & Murray, B.A. (1994). Defining phonological awareness and its relationship to early reading. *Journal of Educational Psychology*, 86(2), 221–234. <https://doi.org/10.1037/0022-0663.86.2.221>
- Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly* 21(4), 360–407. <https://doi.org/10.1598/rrq.21.4.1>
- Stanovich, K. E., & West, R. F. (1989). Exposure to print and orthographic processing. *Reading Research Quarterly*, 24(4), 402–433. <https://doi.org/10.2307/747605>
- Tai, J. H. Y. (2008). The nature of Chinese grammar: Perspectives from sign language. In M. Chan & H. Kang (Eds.), *Proceedings of 20th North American conference on Chinese linguistics 1*, (pp. 21–40). Columbus, OH, US: Ohio State University.
- Thierfelder, P., Wigglesworth, G., & Tang, G. (2020). Sign phonological parameters modulate parafoveal preview effects in deaf readers. *Cognition*, 201, 104286. <https://doi.org/10.1016/j.cognition.2020.104286>
- Traxler, C. B. (2000). The Stanford Achievement Test: National norming and performance standards for deaf and hard-of-hearing students. *Journal of Deaf Studies and Deaf Education*, 5(4), 337–348. <https://doi.org/10.1093/deafed/5.4.337>
- Tse, C. S., & Altarriba, J. (2014). The relationship between language proficiency and attentional control in Cantonese-English bilingual children: evidence from Simon, Simon switching, and working memory tasks. *Frontiers in Psychology*, 5, 954. <https://doi.org/10.3389/fpsyg.2014.00954>
- Tunmer, W. E., & Rohl, M. (1991). Phonological awareness and reading acquisition. In D. Sawyer & B. Fox (Eds.), *Phonological awareness in reading: The evolution of current perspectives* (pp. 1–30). New York: Springer-Verlag. https://doi.org/10.1007/978-1-4612-3010-6_1
- Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, 37(3), 498–505. <https://doi.org/10.3758/bf03192720>
- Venezky, R. L. (1970). *The structure of English orthography*, 82. Walter de Gruyter. <https://doi.org/10.1515/9783110804478>
- Wang, L. (2003). The cultivation of the spelling ability and English study among Chinese upper grade elementary students. [Master Thesis, Northeast Normal University, China].
- Wang, M., Park, Y., & Lee, K. R. (2006). Korean-English biliteracy acquisition: Cross-language phonological and orthographic transfer. *Journal of Educational Psychology*, 98(1), 148. <https://doi.org/10.1037/0022-0663.98.1.148>
- Wenting, Z. (2019, January 24). *Children make early start at learning English*. China Daily. <https://www.chinadaily.com.cn/a/201901/24/WS5c48f51da3106c65c34e629f.html>

- Wu, X., Li, W., & Anderson, R. C.** (1999). Reading instruction in China. *Journal of Curriculum Studies*, 31(5), 571–586. <https://doi.org/10.1080/002202799183016>
- Xu, F.** (2002). Development and its relationship of children's Chinese and English phonological awareness [Doctoral dissertation, Zhejiang University].
- Yang, J., Ye, J., Wang, R., Zhou, K., & Wu, Y. J.** (2018). Bilingual contexts modulate the inhibitory control network. *Frontiers in Psychology*, 9, 395. <https://doi.org/10.3389/fpsyg.2018.00395>
- Yovanoff, P., Duesbery, L., Alonzo, J., & Tindal, G.** (2005). Grade-level invariance of a theoretical causal structure predicting reading comprehension with vocabulary and oral reading fluency. *Educational Measurement: Issues and Practice*, 24(3), 4–12. <https://doi.org/10.1111/j.1745-3992.2005.00014.x>

Appendix A: Background Questionnaires

BACKGROUND QUESTIONNAIRE (HEARING)

Contact information:

Name:

Sex: Male/Female

Home address:

DOB:

Age:

Phone number: TTY Voice

E-mail address:

Are you left or right handed (circle one)? Left Right

Is anyone in your immediate family left-handed?

Have you ever had a serious neurological problem (stroke, epilepsy, coma, head injury, etc.)?

No Yes (please describe)

Are you willing to be contacted for future research? Yes No

All the information you provide in this questionnaire will be kept safe and confidential.

We may contact you to clarify some items about this experiment.

If you give us permission, we may also contact you about future experiments.

About you:

Do you have any sign language background?

NO YES

–If YES, please describe your sign language background:

(e.g., know fingerspelling, took high school class, know SEE/PSE/Total Communication/ASL, etc.)

–If YES, please describe your fluency with sign language (e.g., Native, Fluent, Conversational, Beginner):

Do you have any deaf family members?

NO YES

–If YES, please describe their relationship to you:

(e.g., father, grandmother, cousin, brother, aunt, etc.)

–If YES, does your family member know sign language?

NO YES

What was your first language(s)?

What is your preferred language(s)?

What spoken language(s) do you understand?

What written language(s) can you read?

What language(s) do you speak with your parents?

–Please rate your fluency with this language (7=Native Speaker, 6=Fluent, 5=Fluent Conversational, 4=Conversational, 3=Almost Conversational, 2=Still Learning, 1=Beginner):

7 6 5 4 3 2 1

What language(s) do you speak?

–Please rate your fluency with the language and indicate which language: (7=Native Speaker, 6=Fluent, 5=Fluent Conversational, 4=Conversational, 3=Almost Conversational, 2=Still Learning, 1=Beginner):

Language:

Fluency (circle one): 7 6 5 4 3 2 1

Language:

Fluency (circle one): 7 6 5 4 3 2 1

Language:

Fluency (circle one): 7 6 5 4 3 2 1

Other information:

Place of birth:

Years of education (12 for HS plus 1 year for each year beyond).

Major (if declared).

Language learned first.

Other languages spoken/signed.

Age when learned: first language second language.

Do you have any known problems with hearing, speech, or reading?

If yes, please explain:

Socioeconomic status:

Please indicate your yearly income:

\$0–20,000

\$20,000–40,000

\$40,000–\$60,000

\$60,000–\$80,000

\$80,000–\$100,000

\$100,000 or more I'd rather not say

Please indicate your parents' yearly income:

\$0–20,000

\$20,000–40,000

\$40,000–\$60,000

\$60,000–\$80,000

\$80,000–\$100,000

\$100,000 or more I'd rather not say

Race (optional – for government records):

American Indian or Alaskan native Black (not Hispanic)

Asian White (not Hispanic)

Native Hawaiian or Other Pacific Islander Hispanic

BACKGROUND QUESTIONNAIRE (DEAF)

Contact information:

Name: Home address:

Sex: Male/Female

DOB:

Age:

Phone number: TTY Voice

E-mail address:

Are you left or right handed (circle one)? Left Right

Is anyone in your immediate family left-handed?

Have you ever had a serious neurological problem (stroke, epilepsy, coma, head injury, etc.)?

No Yes (please describe)

Are you willing to be contacted for future research? Yes No

All the information you provide in this Questionnaire will be kept safe and confidential.

We may contact you to clarify some items about this experiment.

If you give us permission, we may also contact you about future experiments.

About you:

When did you learn ASL?

From whom did you learn ASL? (Check off as many as apply)

Parents

Brothers/Sisters

Friends

Teachers

Other person (describe)

What language do you use with your parents?

What language do you use with your brothers/sisters?

What language do you use with your friends?

What language do you use with your children, if you have any?

What language do you prefer for communication?

What kind of language(s) did you use in school (circle below):

-Elementary school: ASL SEE home sign signed English oral English

-Junior high school:

ASL

SEE

home sign

signed English

oral English

-High school: ASL SEE home sign signed English oral English

-College (if any):

ASL

SEE

home sign

signed English

oral English

What language(s) do you speak or sign?

-Please rate your fluency with the language and indicate which language: (7=Native Speaker, 6=Fluent, 5=Fluent Conversational, 4=Conversational, 3=Almost Conversational, 2=Still Learning, 1=Beginner):

Language:

Fluency (circle one): 7 6 5 4 3 2 1

Language:

Fluency (circle one): 7 6 5 4 3 2 1

Language:

Fluency (circle one): 7 6 5 4 3 2 1

Are YOU deaf? Yes No

If so, please fill out the following:

When did you become deaf?

What was the cause?

dB loss left ear:

dB loss right ear:

Other Information:

Place of Birth

Years of Education (12 for HS plus 1 year for each year beyond)

Major (if declared)

Language learned first

Other languages spoken/signed

Age when learned: first language second language.

Do you have any known problems with hearing, speech, or reading?

If yes, please explain:

Socio-economic Status:

Please indicate your yearly income:

\$0-20,000

\$20,000–40,000
 \$40,000–\$60,000
 \$60,000–\$80,000
 \$80,000–\$100,000
 \$100,000 or more I'd rather not say
 Please indicate your parents' yearly income:
 \$0–20,000
 \$20,000–40,000
 \$40,000–\$60,000
 \$60,000–\$80,000
 \$80,000–\$100,000
 \$100,000 or more I'd rather not say
 Race (optional – for government records):
 American Indian or Alaskan native
 Black (not Hispanic)
 Asian
 White (not Hispanic)
 Native Hawaiian or Other Pacific Islander
 Hispanic

Appendix B: Complete Descriptive Statistics

Table B1. ML descriptive statistics

Variable	N	Minimum	Maximum	Mean	Std. Deviation
AvgComp	216	4.2	9.8	7.881	1.0751
NelsonD	207	17	74	49.96	14.143
PhonAcc	214	46	75	68.8	5.593
OrthAcc	214	133	144	140.33	2.41
GoNoGo	76	270	300	290.75	6.676
Rspan	215	16	56	38.14	8.36
AlphSpan	212	40	97	73.24	11.516
WordFluency	216	12	50	27.95	6.931
LiteracyPractice	216	1	5	3.57	0.972
Raven	215	18	48	34.94	5.792

Table B3. NS descriptive statistics

Variable	N	Minimum	Maximum	Mean	Std. Deviation
AvgComp	31	4.4	9.6	6.961	1.5535
NelsonD	31	23	77	46.16	15.284
PhonAcc	31	39	69	51.87	7.928
OrthAcc	31	71	144	140.1	12.908
GoNoGo	31	255	298	286.35	9.229
Rspan	30	10	61	29.7	13.303
AlphSpan	31	12	92	55.77	19.138
WordFluency	31	11	34	24.26	5.33
Recognition	31	1	19	10.18	4.449
KBIT	31	19	33	27.74	3.245
AoAASL	31	0	4	1.1	1.248
dBLoss	28	26	120	84.75	18.992

Table B2. CEB descriptive statistics

Variable	N	Minimum	Maximum	Mean	Std. Deviation
AvgComp	27	4	9.6	7.157	1.6371
NelsonD	27	9	77	48.48	16.308
PhonAcc	27	34	73	53.56	11.653
OrthAcc	26	126	144	138.54	4.32
GoNoGo	25	253	298	287.56	9.211
Rspan	26	3	75	41.92	18.776
AlphSpan	27	2	89	54.78	28.4
WordFluency	27	8	40	19.57	6.967
Recognition	27	1	13	4.04	3.472
KBIT	27	24	33	29.85	2.507
AoAEnglish	26	3	16	9.85	2.781

Table B4. NNS descriptive statistics

Variable	N	Minimum	Maximum	Mean	Std. Deviation
AvgComp	57	2	10	6.408	1.814
NelsonD	57	18	77	39.98	14.267
PhonAcc	57	25	74	51.12	12.459
OrthAcc	56	70	144	136.54	17.161
GoNoGo	54	252	300	283.48	11.838
Rspan	56	0	72	23.3	14.6
AlphSpan	56	5	85	48.59	19.062
WordFluency	57	6	41	22.6	7.85
Recognition	57	0	28	8.86	6.243
KBIT	55	15	33	26.93	3.661
AoAASL	55	1	23	9.87	6.752
dBLoss	47	26	120	80.91	18.351

Appendix C: Complete Correlation Matrices

Table C1. ML correlations

	AvgComp	NelsonD	PhonAcc	OrthAcc	GoNoGo	Rspan	AlphSpan	Word Fluency	Literacy Practice
NelsonD	.498**								
<i>p</i>	0.000								
PhonAcc	.461**	.507**							
<i>p</i>	0.000	0.000							
OrthAcc	.151*	.218**	.320**						
<i>p</i>	0.027	0.002	0.000						
GoNoGo	−0.104	0.022	−0.103	0.160					
<i>p</i>	0.373	0.851	0.378	0.170					
Rspan	.353**	.236**	.224**	.145*	−0.018				
<i>p</i>	0.000	0.001	0.001	0.034	0.880				
AlphSpan	.368**	.346**	.271**	0.094	−0.057	.517**			
<i>p</i>	0.000	0.000	0.000	0.174	0.625	0.000			
Word Fluency	.252**	.351**	.346**	0.109	0.001	.172*	.381**		
<i>p</i>	0.000	0.000	0.000	0.111	0.991	0.012	0.000		
Literacy Practice	.221**	.416**	.180**	0.097	0.056	0.126	0.105	0.033	
<i>p</i>	0.001	0.000	0.008	0.156	0.628	0.066	0.127	0.633	
Raven	.209**	.164*	.150*	0.013	0.019	.239**	.278**	0.119	−0.007
<i>p</i>	0.002	0.018	0.029	0.855	0.868	0.000	0.000	0.083	0.920

**Correlation is significant at the 0.01 level (two-tailed).

*Correlation is significant at the 0.05 level (two-tailed).

Table C2. CEB correlations

	AvgComp	NelsonD	PhonAcc	OrthAcc	GoNoGo	Rspan	AlphSpan	Word Fluency	Recognition	KBIT
NelsonD	.627**									
<i>p</i>	0.000									
PhonAcc	0.299	.420*								
<i>p</i>	0.129	0.029								
OrthAcc	.640**	.539**	.516**							
<i>p</i>	0.000	0.004	0.007							
GoNoGo	0.351	0.228	0.037	.456*						
<i>p</i>	0.086	0.273	0.862	0.025						
Rspan	0.252	0.158	.392*	0.212	0.280					
<i>p</i>	0.214	0.440	0.048	0.308	0.186					
AlphSpan	.415*	0.365	0.288	0.219	0.196	.584**				
<i>p</i>	0.031	0.061	0.145	0.283	0.348	0.002				
Word Fluency	.477*	.575**	0.351	.395*	0.194	0.266	0.268			
<i>p</i>	0.012	0.002	0.073	0.046	0.353	0.189	0.177			
Recognition	.550**	.619**	0.259	.448*	0.218	0.271	.405*	.510**		
<i>p</i>	0.003	0.001	0.192	0.022	0.295	0.181	0.036	0.007		
KBIT	0.155	0.034	0.023	0.039	-0.113	-0.049	0.064	0.202	0.027	
<i>p</i>	0.440	0.867	0.911	0.850	0.592	0.813	0.752	0.311	0.893	
AoAEnglish	-0.067	-0.304	-0.217	-0.111	0.000	-0.016	-0.222	-0.210	-0.264	-0.116
<i>p</i>	0.746	0.131	0.287	0.598	1.000	0.940	0.276	0.302	0.193	0.573

**Correlation is significant at the 0.01 level (two-tailed).

*Correlation is significant at the 0.05 level (two-tailed).

Table C3. NS correlations

	AvgComp	NelsonD	PhonAcc	OrthAcc	GoNoGo	Rspan	AlphSpan	WordFluency	Recognition	KBIT	AoAASL
NelsonD	.791**										
<i>p</i>	0.000										
PhonAcc	.475**	.551**									
<i>p</i>	0.007	0.001									
OrthAcc	-0.101	-0.028	0.124								
<i>p</i>	0.588	0.882	0.506								
GoNoGo	-0.018	-0.159	-0.181	-0.097							
<i>p</i>	0.924	0.394	0.329	0.603							
Rspan	0.349	.402*	.480**	0.071	-0.021						
<i>p</i>	0.059	0.028	0.007	0.710	0.910						
AlphSpan	0.139	0.091	-0.052	.438*	-0.327	0.342					
<i>p</i>	0.455	0.626	0.781	0.014	0.073	0.064					
WordFluency	0.280	0.277	0.210	-0.140	-.468**	0.069	0.009				
<i>p</i>	0.127	0.131	0.257	0.453	0.008	0.715	0.964				
Recognition	.650**	.704**	0.271	0.083	-0.062	0.136	0.280	0.135			
<i>p</i>	0.000	0.000	0.140	0.656	0.742	0.475	0.128	0.470			
KBIT	0.344	.412*	.408*	-0.052	0.045	0.310	0.043	.360*	.464**		
<i>p</i>	0.058	0.021	0.023	0.782	0.808	0.095	0.818	0.046	0.009		
AoAASL	-0.121	-0.167	0.116	0.006	0.263	-0.221	-0.091	-0.042	-0.147	0.006	
<i>p</i>	0.517	0.370	0.535	0.976	0.153	0.240	0.626	0.821	0.429	0.973	
dBloss	-.366	-0.256	-.427*	-0.073	0.309	-0.231	-0.183	-0.138	-0.300	-0.292	-0.044
<i>p</i>	0.056	0.189	0.023	0.710	0.110	0.246	0.352	0.483	0.120	0.131	0.822

**Correlation is significant at the 0.01 level (two-tailed).

*Correlation is significant at the 0.05 level (two-tailed).

Table C4. NNS correlations

	AvgComp	NelsonD	PhonAcc	OrthAcc	GoNoGo	Rspan	AlphSpan	WordFluency	Recognition	KBIT	AoAASL
NelsonD	.603**										
<i>p</i>	0.000										
PhonAcc	.634**	.512**									
<i>p</i>	0.000	0.000									
OrthAcc	0.091	−0.092	0.222								
<i>p</i>	0.506	0.502	0.100								
GoNoGo	0.039	−0.031	.278*	−0.108							
<i>p</i>	0.778	0.824	0.042	0.440							
Rspan	.351**	0.180	.305*	0.142	−0.026						
<i>p</i>	0.008	0.184	0.022	0.300	0.854						
AlphSpan	.627**	.516**	.410**	−0.017	−0.049	.294*					
<i>p</i>	0.000	0.000	0.002	0.905	0.726	0.029					
WordFluency	.399**	.593**	.433**	0.025	−0.009	0.177	.434**				
<i>p</i>	0.002	0.000	0.001	0.853	0.950	0.192	0.001				
Recognition	.491**	.674**	.423**	0.000	−0.084	0.166	.477**	.599**			
<i>p</i>	0.000	0.000	0.001	0.998	0.548	0.221	0.000	0.000			
KBIT	.469**	.370**	.339*	0.082	0.016	0.170	.484**	.372**	0.251		
<i>p</i>	0.000	0.005	0.011	0.555	0.908	0.220	0.000	0.005	0.064		
AoAASL	0.023	0.167	0.127	−0.035	0.024	0.126	−0.141	0.042	0.113	−0.035	
<i>p</i>	0.870	0.222	0.355	0.800	0.863	0.365	0.308	0.760	0.413	0.806	
dBLoss	−0.110	−0.104	−0.179	0.037	−0.065	−0.022	0.046	0.057	0.004	−0.030	−0.091
<i>p</i>	0.463	0.486	0.229	0.806	0.670	0.882	0.763	0.705	0.977	0.844	0.550

**Correlation is significant at the 0.01 level (two-tailed).

*Correlation is significant at the 0.05 level (two-tailed).

Appendix D: Complete Games–Howell Post Hoc Results**Table D1.** Games–Howell post hoc results

Test	(I)	(J)	Means (I–J)	Std. error	Sig. ^a	95% CI	
						Lower	Upper
AvgComp	ML	CEB	0.72	0.32	0.136	–0.16	1.61
	ML	NS	0.92	0.29	0.015	0.14	1.70
	ML	NNS	1.47	0.25	0.000	0.81	2.14
	CEB	NS	0.20	0.42	0.966	–0.92	1.31
	CEB	NNS	0.75	0.40	0.244	–0.30	1.80
	NS	NNS	0.55	0.37	0.442	–0.42	1.52
NelsonD	ML	CEB	1.48	3.29	0.969	–7.44	10.40
	ML	NS	3.80	2.92	0.567	–4.03	11.63
	ML	NNS	9.98	2.13	0.000	4.40	15.56
	CEB	NS	2.32	4.17	0.944	–8.73	13.38
	CEB	NNS	8.50	3.66	0.108	–1.27	18.27
	NS	NNS	6.18	3.33	0.259	–2.64	14.99
PhonAcc	ML	CEB	15.25	2.28	0.000	9.03	21.47
	ML	NS	16.93	1.47	0.000	12.95	20.91
	ML	NNS	17.68	1.69	0.000	13.21	22.15
	CEB	NS	1.69	2.66	0.920	–5.40	8.77
	CEB	NNS	2.43	2.78	0.818	–4.95	9.81
	NS	NNS	0.75	2.18	0.986	–4.97	6.46
OrthAcc	ML	CEB	1.79	0.86	0.188	–0.57	4.15
	ML	NS	0.23	2.32	1.000	–6.09	6.55
	ML	NNS	3.79	2.30	0.360	–2.30	9.88
	CEB	NS	–1.56	2.47	0.921	–8.19	5.07
	CEB	NNS	2.00	2.45	0.845	–4.44	8.44
	NS	NNS	3.56	3.26	0.695	–5.00	12.12
GoNoGo	ML	CEB	2.85	1.97	0.480	–2.49	8.20
	ML	NS	4.06	1.80	0.125	–0.76	8.87
	ML	NNS	6.93	1.76	0.001	2.32	11.55
	CEB	NS	1.21	2.48	0.962	–5.37	7.78
	CEB	NNS	4.08	2.45	0.350	–2.39	10.55
	NS	NNS	2.87	2.31	0.602	–3.20	8.95

(Continued)

Table D1. (Continued)

Test	(I)	(J)	Means (I-J)	Std. error	Sig. ^a	95% CI	
						Lower	Upper
RSpan	ML	CEB	-3.78	3.73	0.742	-14.00	6.43
	ML	NS	8.44	2.50	0.010	1.68	15.20
	ML	NNS	14.84	2.03	0.000	9.48	20.20
	CEB	NS	12.22	4.41	0.039	0.45	24.00
	CEB	NNS	18.62	4.17	0.000	7.44	29.79
	NS	NNS	6.40	3.12	0.180	-1.82	14.61
AlphSpan	ML	CEB	18.89	5.54	0.010	3.75	34.04
	ML	NS	17.90	3.55	0.000	8.31	27.49
	ML	NNS	25.08	2.70	0.000	17.97	32.19
	CEB	NS	-1.00	6.46	0.999	-18.23	16.23
	CEB	NNS	6.19	6.03	0.735	-10.02	22.39
	NS	NNS	7.19	4.28	0.343	-4.11	18.48
WordFluency	ML	CEB	8.38	1.42	0.000	4.53	12.22
	ML	NS	3.69	1.07	0.006	0.84	6.53
	ML	NNS	5.34	1.14	0.000	2.35	8.34
	CEB	NS	-4.69	1.65	0.032	-9.07	-0.31
	CEB	NNS	-3.03	1.70	0.289	-7.52	1.46
	NS	NNS	1.66	1.41	0.646	-2.05	5.36

^aSignificance evaluated with Bonferroni correction at $p < .0083$

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