Neuroscience Letters 666 (2018) 58–63

Contents lists available at ScienceDirect

Neuroscience Letters

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

Research article

Adults with Specific Language Impairment fail to consolidate speech sounds during sleep

F. Sayako Earle[a,b,*], Nicole Landi[c,d], Emily B. Myers[a,d]

[a] Department of Speech, Language, and Hearing Sciences, University of Connecticut, Storrs, CT, USA
[b] Communication Sciences and Disorders Program, University of Delaware, Newark, DE, USA
[c] Department of Psychology, University of Connecticut, Storrs, CT, USA
[d] Haskins Laboratories, New Haven, CT, USA

ARTICLE INFO

Keywords:
Specific Language Impairment
Memory
Sleep
Speech perception
Event related potentials

ABSTRACT

Specific Language Impairment (SLI) is a common learning disability that is associated with poor speech sound representations. These differences in representational quality are thought to impose a burden on spoken language processing. The underlying mechanism to account for impoverished speech sound representations remains in debate. Previous findings that implicate sleep as important for building speech representations, combined with reports of atypical sleep in SLI, motivate the current investigation into a potential consolidation mechanism as a source of impoverished representations in SLI. In the current study, we trained individuals with SLI on a new (nonnative) set of speech sounds, and tracked their perceptual accuracy and neural responses to these sounds over two days. Adults with SLI achieved comparable performance to typical controls during training, however demonstrated a distinct *lack* of overnight gains on the next day. We propose that those with SLI may be impaired in the consolidation of acoustic-phonetic information.

1. Introduction

Specific Language Impairment (SLI; also known as language learning disability) is a common idiopathic condition that affects an estimated 7% of the U.S. population [1]. The disorder is traditionally associated with impaired acquisition of grammar in childhood [2], however, subtle deficits in speech perception are found to persist throughout development [3–5]. Speech perception deficits are often linked to poor speech sound representations, that is, the mental instantiation of the sounds of speech, such as/d/or/u/. Substantial research suggests that impoverished speech representations may be central to the SLI etiology, and that the consequent inefficiency in speech processing prevents the timely acquisition of grammar [6,7]. Although several theoretical accounts now consider impoverished speech sound representations to be a hallmark of SLI, the precise mechanism(s) by which these representations become impoverished remains unknown. In the current investigation, we propose that differences in overnight consolidation, potentially driven by atypical sleep, contribute to atypical speech sound representations in SLI.

Sleep's importance in language learning is rapidly gaining empirical support [8–10]. One group of studies that track changes in perceptual ability on a trained nonnative contrast (dental/d̪/and retroflex/ɖ/stops in Hindi) suggests that sleep is crucial for forming new, functional speech sound categories [11–13]. For example, a ~12-h interval containing sleep, but not a comparable period of wake state, is observed to enhance accuracy on perceptual tasks and promote cross-talker generalization [11,12]. In a subsequent study [13], sleep duration was measured with a commercial EEG headband [14], and changes in neural sensitivity to the contrast were measured using the mismatch negativity (MMN) response of the electroencephalogram (EEG) [15]. MMNs are evoked by presenting a train of stimuli in an oddball paradigm, and the magnitude of the MMN response is considered a measure of pre-attentive detection of the designated oddball. Sleep duration was found to predict overnight changes to perceptual ability on a trained nonnative contrast. Moreover, the magnitude of behavioral changes correlated with changes in MMN amplitude. In other words, overnight changes to behavior seem to reflect changes in neural sensitivity to the distinctions between the trained sounds.

Interestingly, several lines of research suggest that SLI is associated with atypical EEG patterns during sleep [16,17], inviting the suggestion that offline consolidation may be impaired in SLI [18–21]. Therefore, the primary goal of this study was to determine if individuals with SLI demonstrate atypical patterns of overnight consolidation of speech information. We present an extension of data published previously on

* Corresponding author at: University of Delaware, STAR Health Sciences Complex, 540 S College Ave, Ste. 210BB, Newark, DE 19713, USA.
E-mail address: fsearle@udel.edu (F.S. Earle).

https://doi.org/10.1016/j.neulet.2017.12.030
Received 6 October 2017; Received in revised form 10 December 2017; Accepted 13 December 2017
Available online 15 December 2017
0304-3940/ Published by Elsevier Ireland Ltd.

typical adults [13], to include a concurrently collected dataset on adults with a history of SLI.[1] In the present study, we ask 1) if adults with SLI can be comparably trained to perceive nonnative speech with respect to controls, and 2) if so, does the SLI group demonstrate heightened sensitivity to the trained contrast following sleep-mediated consolidation, and finally, 3) does neural sensitivity, as measured by the MMN response, track with changes in behavioral sensitivity? If individuals with SLI show general deficits in learning non-native speech sound information, this points to a lingering issue with phonological learning and the component processes thereof. If initial training performance is typical, but overnight consolidation and retention of target information is atypical, a different source of the phonological deficit in SLI is implicated, namely one in which offline overnight consolidation plays a key role. Finally, obtaining MMN responses to the same contrast allows us to track training-induced changes to neural sensitivity that are independent of behavioral task performance. This is crucial, given that language impairment, by its nature, carries the potential that differences in metalinguistic task *strategy* might lead to differences in behavioral measures of perception. The answers to these questions have significant etiological and clinical consequences, in that the linguistic challenges experienced by those with SLI may reflect an impairment in the memory processes crucial to building functional linguistic categories.

2. Materials and methods

2.1. Participants

Participants provided informed written consent in accordance with the University of Connecticut Institutional Review Board. All participants were monolingual, native speakers of American English, 18–24 years of age. Participants reported no history of neurological, socioemotional, or attention disorders, and passed a pure tone hearing screening. Participants obtained a standard score > 85 for nonverbal IQ on the Wechsler Abbreviated Scale of Intelligence [22], and were not on mood-altering medications, at the time of the study. See Table 1 for assessment and demographic profiles of our participants.

Control (n = 25): The description of the control cohort has been reported previously [13]. In addition to meeting all inclusionary criteria, those included in this cohort were good readers (obtained scores no lower than 1 SD below the mean on reading measures).

SLI (n = 19): Participants in the SLI cohort reported a history of receiving language and/or reading services, and were identified as being language impaired by the procedures described in [23]. This method has been widely used to identify adults with SLI [e.g. 24,25] and is emerging as the standard by which researchers identify adults with SLI. Adults who met criteria for SLI, but who also met criteria for developmental dyslexia [26,27], were excluded from analyses, as partially distinct mechanisms are thought to underlie the phonological deficits observed in SLI and dyslexia [28].

Our sample size was pre-determined prior to study completion based on a power analysis conducted for our repeated measures design ($\alpha = 0.05$, 2-tailed), assuming bivariate normal distributions of variables and an r^2 of 0.5. This calculation suggested a minimum of 16 participants/Group, and we therefore aimed to enroll 22–26 participants/Group, anticipating the potential for attrition of up to 20%. To note, this sample size is comparable to others who have investigated a consolidation mechanism in SLI [18,19].

[1] As the present focus is not whether or not the overnight effects are sleep-specific (as previously established in [11,12]), but rather whether overnight effects differ between SLI and controls, we did not include a wake-state control for the current work.

Table 1
Participant demographics.

		Control (n = 25)	SLI (n = 19)
Demographics			
	Age	20.52 (1.33)	20.60 (1.50)
	Sex	15 F, 10 M	15 F, 4 M
	Handedness	27 R, 1 L	18 R, 1 L
Assessment scores			
WASI	Nonverbal IQ	110.4 (9.80)	100 (7.67)*
WRMT − III	Word ID	108.24 (8.16)	98.11 (8.31)*
	Word Attack	110.96 (9.92)	97.05 (12.02)*
	Passage Comprehension	109 (8.98)	95.33 (12.61)*
TOWRE	Sight Word Efficiency	105.72 (8.24)	95 (11.36)*
	Phonemic Decoding	112.76 (7.83)	96.95 (10.16)*
	Total	110.76(6.73)	95.47 (11.52)*
Language screen	Spelling (raw)	13.24 (6.27)	7.32 (1.87)*
	Modified Token Test (raw)	39 (6.15)	35.05 (4.07)
	Index	−1.42 (.86)	0.44 (.44)*
WAIS-IV	Digit Span Composite	11.56 (3.32)	8.95 (2.01)
BRIEF	Global Executive Composite	47.79 (6.94)	51.56 (7.72)
RAN	Numbers	112.44 (6.12)	110.78 (6.39)
	Letters	112.08 (6.21)	108.89 (5.25)
	2-Set	114.92 (8.72)	112.11 (7.05)

Participant demographic and assessment profiles. Tests were administered and scored by the first author or a trained graduate student, and rescored by one of two trained undergraduate students. Discrepancies in scoring were flagged by the second scorer and resolved by the first author.
WASI: Wechsler Abbreviated Scale of Intelligence [22]; WRMT-III: Woodcock Reading Mastery Tests – III [47], TOWRE: Test of Word Reading Efficiency [38]; RAN: Rapid Automatized Naming Test [27]; WAIS-IV: Wechsler Adult Intelligence Scale – Fourth Edition [39]; BRIEF: Behavior Rating Inventory of Executive Function—adult Version [40].
*Denotes statistically significant difference between Control and SLI at .05 level after Bonferroni correction.
Note: Our samples differed on nonverbal IQ, due to above-average IQ by Controls, combined with average performance by SLI. This is consistent with the proposal that a relative weakness in nonverbal IQ is an inherent characteristic of SLI [41].

2.2. Procedures

The study took place on two consecutive days, in the evening (7–9 PM; Day 1), and the following morning (8 10 AM; Day 2; see Fig. 1a). On Day 1, participants completed screening measures, followed by an EEG/ERP pre-training session for a baseline biomarker of discrimination ability, defined as the ability to detect a difference between the two sounds being trained. The session ended with category identification training of the nonnative contrast, in which participants were presented with two 'words' (/d̪ug/and/ɖug/) to map onto novel visual objects. During trials, participants were played a 'word', and were asked to indicate the object to which the word belongs. We measured category identification ability at two time points: immediately after training, and on the next day. We also tracked perceptual ability through behavioral discrimination (indicating if two sounds played in sequence are the same or different) at three time points: immediately before training, immediately after training, and on the next day. As participants were trained in identification, post-training discrimination scores reflect cross-task generalization of phonetic learning.

On Day 2, behavioral reassessments were followed by a second EEG/ERP session, and then by the administration of the remaining language/reading tests. As per journal guidelines, procedures described elsewhere are omitted from the present paper. Please refer to [13] for methodological details pertaining to the perceptual training of nonnative speech, and the recording and preprocessing procedures for the EEG/ERP experiment.

Participants were provided with commercial sleep-monitoring