Specific Language Impairments in Children

Phonology, Semantics, and the English Past Tense

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ABSTRACT—*Theories of specific language impairment (SLI) in children turn on whether this deficit stems from a grammar-specific impairment or a more general speech-processing deficit. This issue parallels a more general question in cognitive neuroscience concerning the brain bases of linguistic rules. This more general debate frequently focuses on past-tense verbs, specifically, whether regular verbs (*bake-baked*) are encoded as rules, and whether irregular forms (*take-took*) are processed differently. Children with SLI have difficulties with past tenses, so SLI could represent an impairment to rules. An alternative theory explains past-tense deficits in SLI as resulting from a phonological deficit. Evidence for this theory has been obtained from connectionist models of past-tense impairments and from behavioral studies of language- and reading-impaired children. The data suggest that SLI is not an impairment to linguistic rules, that past-tense impairments can be explained as resulting from a perceptual deficit, and that a single processing mechanism is ideally suited to account for these children's difficulties.*

KEYWORDS—*specific language impairment; connectionism; English past tense; speech perception*

A key question in cognitive neuroscience concerns the neural mechanism by which humans encode the rules of language. The English past tense represents an interesting case of rulelike processes: Although regular patterns (*bake-baked*, *step-stepped*) appear to be rulelike, English also has a number of irregular forms (*take-took*, *sleep-slept*) that conflict with the rule that the past tense is formed by adding *-ed* to the present tense. Irregular forms are problematic to a rule-based approach because they call into question whether rules alone are sufficient for explaining linguistic phenomena, and whether a secondary mechanism is required for encoding these irregular forms. In 1986, Rumelhart and McClelland proposed a connectionist model in which both regular past tenses and exceptions were encoded within a single type of neural mechanism. The connectionist approach to cognitive neuroscience explains cognitive processes as arising from the behavior of simple neuronlike processing units. To the extent that Rumelhart and McClelland's approach to grammar proposed that rules are not necessary to explain systematic grammatical processes such as past-tense formation, it represented a radical departure from the accepted wisdom that language was processed within a symbolic rule-processing module, sparking a debate that continues to this day.

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Modern linguistics characterizes mental grammars as sets of symbolic rules. For example, rules are proposed to be the basis of grammatical morphology, a process by which words are created from "building blocks" such as stems, suffixes, and prefixes (*bake-d*, *hand-s*, *talk-ing*). One popular extension of this theory holds that past-tense morphology is encoded using two distinct types of neural mechanisms: a rule module that generates regular forms and an associative memory system that encodes exceptions case by case (Pinker, 1991). Recently, there has been some interest in studying this dual-mechanism theory from the perspective of developmental language disorders. Of particular interest are past-tense deficits in children with specific language impairment (SLI), an impairment marked by poor acquisition of grammar. Language problems in SLI cannot be explained by poor speech articulation, hearing loss, frank neurological deficit, or pervasive developmental disorder (Joanisse & Seidenberg, 1998; Leonard, 1998). If SLI is a grammar-specific disorder, as some linguists have indicated, it should exclusively affect regular past-tense forms while leaving irregular forms relatively intact (Pinker, 1991; van der Lely & Ullman, 2001). In this review, I discuss evidence regarding the pattern of past-tense impairment in SLI and suggest that the facts do not support the view of SLI as a rule-learning disorder. Instead, I present an alternative theory that explains SLI as an impairment in speech perception and processing. This deficit has important consequences for learning grammatical processes such as past-tense formation, and also makes interesting predictions about past-tense deficits in other populations of children.

THE CONNECTIONIST THEORY

The connectionist theory of morphology presented here builds on McClelland and Rumelhart's (1986) model of the past tense. It holds that all morphological forms are processed within one type of processing mechanism (connectionist networks) distributed across multiple brain regions (Joanisse & Seidenberg, 1999). The connectionist

approach assumes that complex cognitive abilities arise from interactions among simple processing units (i.e., neurons), and that complex behaviors such as language reflect the more basic characteristics of these neural networks. In the case of the past tense, this approach assumes that word knowledge relies on information about sound (phonology) and meaning (semantics). Although the relationship between sound and meaning is usually arbitrary, morphology is a special case because morphologically related words share both phonological and semantic relationships; thus, morphology represents a "convergence of codes." For instance, *walk* and *walked* overlap both in phonology and in semantics ("to move by foot," "to move by foot in the past"). This convergence of codes means that it is not necessary for speakers to use linguistic rules per se in order for them to exhibit knowledge of morphology. Instead, they may encode rules as statistical regularities—patterns of semantics-phonology relationships. An interesting prediction of this theory is that impairments should affect word forms regardless of whether they are regular, because regular and irregular forms are encoded in the same way. Thus, a deficit in past-tense formation should affect both regular and irregular forms of the past tense, because in both cases phonological and semantic information is used to encode the relationship between present and past tense. Rather than resulting from an impairment in rule learning, the morphology deficits in SLI can be explained by a phonological impairment that affects all past-tense forms, but is especially deleterious in the case of forms that the speaker has not encountered previously.

IS SLI A RULE-LEARNING IMPAIRMENT?

The primary source of data about morphological deficits in children with SLI comes from studies using a sentence-completion task (e.g., *The girl likes to walk. She did the same thing yesterday; she* ____). Theories of SLI as a rule-learning disorder predict that children with this impairment will have difficulty producing the past tenses of regular verbs on this task, but will perform better with irregular verbs. Surprisingly, however, most studies of children with SLI have found either no difference between regular and irregular verbs or numerically worse performance on irregular verbs (van der Lely & Ullman, 2001). These results seem inconsistent with a rule-specific deficit, because the children seem just as impaired on forms that are not rule governed as on those that are. However, the results are not surprising in light of the fact that English-speaking children generally find irregular verbs difficult and tend to learn them later than regular verbs. It is possible, then, that children with SLI have difficulty on irregular verbs because of an overall delay in learning past tenses.

Other aspects of past-tense performance in children with SLI might be more informative, however. For instance, these children tend to make fewer overregularization errors (i.e., applying the regular past-tense form to an irregular verb, as in *sleeped* and *taked*) than normally developing children. Overregularization errors are thought to indicate the creative use of a past-tense rule, because they involve producing a form that has never been heard. The fact that children with SLI produce fewer overregularized forms than control children suggests that they have not acquired a rule for the past tense. Similarly, these children perform very poorly when asked to produce the past tenses of nonwords (for which the "correct" past tense is considered to be a regular ending, e.g., *wug-wugged*; Fig. 1). This is an ideal test of morphological knowledge because a speaker must use a rule creatively to answer correctly. (In contrast, a familiar form, like *walked*, might be recalled from memory.) Thus, the fact that children with SLI are poor at generating past tenses of nonwords again suggests that they have not encoded a rule for generating past tenses.

According to the rule-based account, the pattern of deficits in SLI indicates that regular past tenses are processed differently in children with SLI than in other children (Pinker, 1991; van der Lely & Ullman, 2001). There is clearly room for an alternative explanation, however. For instance, a rule-based account does not explain why children with SLI have difficulty with irregular verbs. Similarly, the traditional characterization of SLI as a grammar-specific deficit fails to capture the full range of impairments that have been discovered in these children; ideally, an account of SLI should also explain these children's delayed vocabulary development, impaired phonology, and impaired speech perception.

THE PHONOLOGICAL-DEFICIT HYPOTHESIS

The phonological-deficit hypothesis takes a different perspective on language impairments in SLI, proposing that a perceptual deficit leads to a phonological deficit that is the direct cause of the language deficits seen in this disorder. This hypothesis builds on the connectionist theory that past tenses normally arise through the integration of semantic and phonological information. A phonological deficit that is accompanied by relatively intact semantic representations will most severely impair the ability to generalize from known forms (*bug-bugged*) to novel ones (*wug-wugged*); intact semantic representations will help support some ability in the case of regular and irregular forms that are familiar, but do not come into play in the case of unfamiliar forms. Because connectionist theory posits that knowledge is implemented in a distributed and interactive neural system, the phonological-deficit hypothesis predicts that an impairment to any aspect of this system will tend to affect all word forms. However, because nonwords can rely only on phonology, these forms are predicted to be more severely impaired by a phonological deficit than true words are. Thus, this hypothesis explains why children with SLI do not show the same performance deficits for nonwords and familiar forms; in contrast, the rule-based theory predicts wholesale deficits on regular forms and intact performance on irregular forms.

The phonological-deficit hypothesis grew out of earlier perception-based theories of SLI, which held that the language difficulties of children with SLI stem from a perceptual deficit that makes it difficult for them to perceive certain grammatical markers, such as the past-tense marker (Leonard, 1998; Tallal, Miller, & Fitch, 1993). The hypothesis proposes that phonological deficits are the key link between perceptual and grammatical impairments. The hypothesis further suggests that children with SLI show morphological impairments not only because they have difficulty perceiving grammatical markers that occur in difficult-to-perceive contexts, such as the endings of words, but also because they have difficulty translating the auditory forms of words into a phonological code necessary for learning word forms.

Regular and Irregular Forms in Aphasia

The theory that inadequate phonological representations can impair grammar has been previously tested in adults with aphasia (language impairments following brain damage). Like SLI, Broca's aphasia

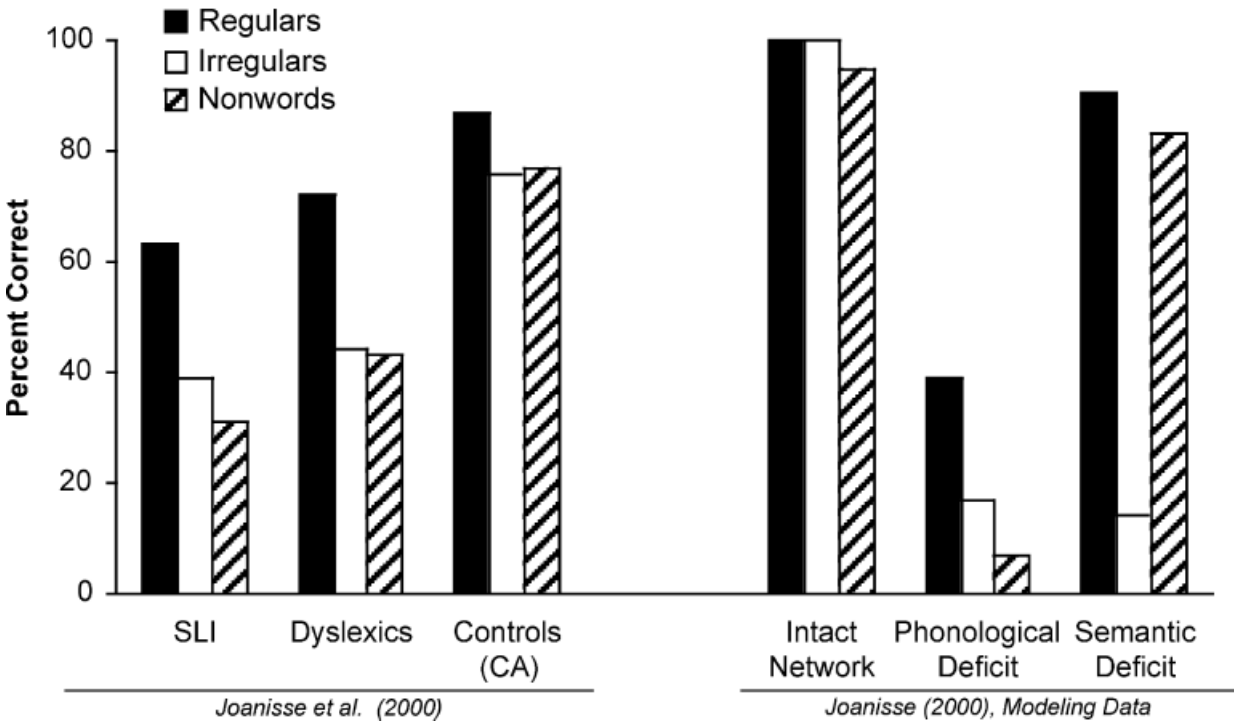

Fig. 1. Ability to form past tenses of regular verbs, irregular verbs, and nonwords. The left side of the graph shows percentage correct for children with specific language impairment (SLI), dyslexic children, and same-age (CA) control children. The right side of the graph presents data from normally developing and language-impaired connectionist networks; a phonological deficit yielded an SLI-like deficit, whereas a semantic deficit resulted in a different pattern of impairment. The data on the left are adapted from ''Language Deficits in Dyslexic Children: Speech Perception, Phonology, and Morphology,'' by M.F. Joanisse, F.R. Manis, P. Keating, and M.S. Seidenberg, 2000, *Journal of Experimental Child Psychology*, 77, pp. 30–60. Copyright 2000 by Elsevier. Adapted with permission. The data on the right are from Joanisse (2000).

(caused by damage to Broca's area in the left hemisphere) is accompanied by difficulty producing past tenses of nonwords. This finding has been taken as evidence that separate neural mechanisms underlie regular and irregular morphology (Ullman et al., 1997). Using a connectionist network, Seidenberg and I tested the competing theory that this impairment occurs because of a phonological deficit (Joanisse & Seidenberg, 1999). We created artificial lesions in the network by randomly cutting connections in specific areas of the model. In this way, we were able to simulate different aphasic syndromes. Specifically, we found that a phonological lesion simulating damage to Broca's area resulted in marked degradation of the past tense, especially for nonwords. The pattern of deficits was remarkably similar to what is observed in Broca's aphasics, and was also consistent with these patients' phonological difficulties. Interestingly, a semantic lesion yielded a dramatically different deficit pattern, marked by poorer performance on irregular form than regular forms and nonwords, precisely what is observed in patients with damage to the brain's left temporal lobe. The results support the claim that different forms of the past tense can be susceptible to different types of brain damage.

Modeling SLI

The explanation of past-tense deficits in SLI is a similar one: Children with SLI have specific difficulty producing past tenses of nonwords because of the importance of phonological representations in generalizing to novel forms. Using a connectionist model (Fig. 2), I tested this theory by investigating the effect of a perceptual deficit on leaning past tenses (Joanisse, 2000). The network was trained to associate the meanings and sounds of English present- and past-tense verbs, such that inputting a phonological form would generate a semantic form, and vice versa. During training, the network showed a slight delay in learning irregular forms relative to regular forms, a pattern seen in normally developing children. At the end of training, it had learned all tasks accurately, and was able to generate the past tenses of nonwords at a level of accuracy similar to that of normal adults.

Small amounts of random noise were added to the phonological representations of the training words, thus simulating a deficit in the perception of speech. This added noise had the effect of making it difficult for the network to develop crisp phonological categories (e.g., the distinction between "d" and "t"). As Figure 1 shows, the result was a pattern of past-tense impairments consistent with SLI: Compared with the intact model, this model was poorer at learning all three types of past tenses, but it was particularly poor at generating the past tenses of nonwords. The network also produced errors that were consistent with SLI: It generated very few overregularizations (2%, vs. 22% in the intact network) and a greater tendency toward zero-marking errors, that is, repeating the present tense as the past tense (5%, vs. none in the intact network). In contrast, when the same network was trained with a semantic impairment, it produced a remarkably different deficit that specifically affected irregular verbs, along with a different pattern of errors (18% overregularization errors, no zero-marking errors).

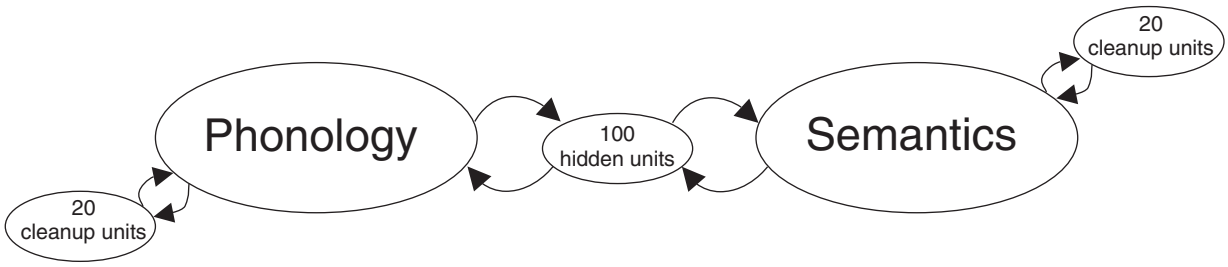

Fig. 2. A connectionist model of past-tense learning. Ellipses represent layers of artificial neurons that are used to encode information as patterns of activation across these neurons. Arrows indicate weighted connections that are used to pass information between layers. The phonology and semantics layers encode information about a word's sound and meaning, respectively; hidden and cleanup layers are extra computational capacity that the network uses to encode information. The network is used to simulate the task of producing and recognizing present- and past-tense verbs. For instance, the meaning of a verb can be presented to the semantics layer, and the network will output the phonological form of the verb. The basis of language-learning impairments can be tested in this model by distorting the information that the network receives as inputs, or by limiting its computational capacity (e.g., removing units from the cleanup or hidden layers).

These connectionist simulations demonstrate the importance of phonology in the past tense, especially in generalizing the past tense to novel forms. The simulations also explain why a perceptual deficit does not specifically impair regular forms or the ability to produce consonants at the ends of words, as in the case of the regular past tense: Poor phonology leads to a general degradation in past-tense performance, but affects nonwords most severely. This is a remarkably different pattern from what is predicted by a dual-mechanism account, but appears to be the correct one.

OTHER TEST CASES

Past Tense and Dyslexia

Children with dyslexia also represent an interesting test of the phonological-deficit hypothesis. They are commonly acknowledged to have phonological deficits that are the cause of their reading problems. This raises an interesting question: Do phonological deficits in dyslexia lead to SLI-like past-tense deficits? This question was addressed in a recent study of language-impaired and dyslexic children (Joanisse, Manis, Keating, & Seidenberg, 2000). The study demonstrated a similar pattern of language deficits in the two groups of children, though the deficits were by definition weaker in the dyslexics (because the traditional definition of dyslexia precludes more general problems with spoken language). In particular, a similar pattern of past-tense deficits, marked by difficulties with nonword and irregular past tenses, was observed in the language-impaired and the dyslexic children (Fig. 1), supporting the theory that phonological deficits play a key role in past-tense impairments.

Because reading deficits in dyslexia are explained as stemming from phonological deficits, the phonological-deficit theory also predicts that children with SLI should have dyslexia-like reading problems. Indeed, studies have indicated that children with SLI are at greater risk of reading impairment than normally developing children. Moreover, the types of reading deficits observed in SLI are consistent with dyslexia, marked by poor reading of nonwords and phonological processing difficulties (Briscoe, Bishop, & Norbury, 2001; Joanisse et al., 2000). These data raise the possibility that dyslexia and SLI are caused by similar underlying deficits, though the deficits are not necessarily identical in their severity or exact nature. In a broader sense, these data help to tie explanations of language and reading impairment to a broader theory of the role of phonological information in language learning and representation.

Difficult Cases

Two populations of children currently represent a challenge to the phonological-deficit theory. The first are children with so-called grammatical SLI (G-SLI), whose language impairments are claimed to not be accompanied by nongrammatical deficits. It remains unclear whether these children actually represent a distinct subtype of SLI, however. We expect there to be some variation in nonlinguistic deficits in SLI, just as the degree of linguistic impairments varies in these individuals. Children with G-SLI may simply represent the small percentage of children with SLI who are at the high end of the continuum of nonverbal skills; this does not mean they are qualitatively different from other children with SLI. The second challenge comes from children with mild to moderate sensorineural hearing loss (SNH). These children have difficulty discriminating speech sounds and repeating nonwords that are spoken to them, but have relatively normal grammatical comprehension and ability to form past tenses (Briscoe et al., 2001). This pattern of deficits seems to conflict with the phonological-deficit hypothesis, which predicts that poor perception will lead to grammatical deficits. One explanation is that only a specific type of perceptual deficit that goes beyond a general hearing loss can lead to the grammatical deficits found in SLI. For instance, SLI might involve a subtle deficit in processing rapid temporal auditory information, which specifically interferes with the ability to perceive phonetic cues in speech (Tallal et al., 1993). In contrast, a more general hearing loss would impair auditory acuity, leading to poor repetition and discrimination of speech while leaving grammatical development relatively intact.

CONCLUSION

Despite early claims that SLI is a rule-learning deficit, the evidence indicates that children with SLI have problems with all past-tense forms. Connectionism lends an intriguing perspective on these deficits by framing knowledge of the past tense not as rules and exceptions,

but as the convergence of phonology and semantics. In this sense, SLI is a useful test case of how phonology affects the acquisition and use of past tense. The phonological-deficit hypothesis also casts SLI within a broader framework of language ability and impairment, giving useful insights into how SLI relates to other impairments, such as aphasia and dyslexia.

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