PERGAMON

Int. J. Devl Neuroscience 20 (2002) 459–465

INTERNATIONAL JOURNAL of DEVELOPMENTAL NEUROSCIENCE

www.elsevier.com/locate/ijdevneu

Language transactions during development and intervention: theoretical implications for developmental neuroscience

Stephen Camarata*, Paul Yoder

John F. Kennedy Center for Research on Education and Human Development, P.O. Box 40, Peabody College, Nashville, TN 37202, USA

Received 19 March 2002; received in revised form 21 March 2002; accepted 21 March 2002

Abstract

Recent modeling of language development and intervention for children with disabilities has increasingly focused on the interactions between adults and children. These models have resulted in a number of recent advances in the behavioral treatment of language abilities in children with disabilities. Because these interventions are associated with substantial growth in a number of skills including speech, grammar and vocabulary, these paradigms may provide a useful model for studying neurological development of these aspects of language. The purpose of this paper is to discuss the potential neurodevelopmental ramifications of this type of theoretical model for facilitating language growth in children with and without disabilities. Indeed, because intervention can sometimes trigger rapid advances in language skills and presumably, associated neurological organization, this may prove to be a very useful paradigm for understanding the neurological correlates of language growth.

Keywords: Language disabilities; Specific language impairment; Down syndrome

1. Introduction

There is a relatively large literature suggesting that behavioral intervention for language disabilities often is associated with relatively high levels of language growth (Leonard, 1998; Yoder and McDuffie, in preparation). Interestingly, there have been relatively few attempts to examine these behavioral shifts in terms of neural development (Mills, 1998). This may be due, in part, to the difficulty completing dynamic neural imaging in young children. For example, fMRI technology is not often used in preschool children. This is problematic because the much of language growth in many children with language learning disabilities occurs prior to this age. Conversely, ERP imaging can be successfully completed in these children, but consistent, replicable findings at a detailed level of analysis are difficult to find. Because of this, specific models of neural development associated with language growth could result in innovative study designs that focus on predicted relationships between behavioral change and neural organization. The purpose of this review will be to provide an overview of key elements of natural language development and behavioral intervention that often result in relatively large treatment effects on standardized tests, and more importantly, with growth in several key aspects of language, including grammar, semantics, and phonology. These strong behavioral shifts often are observed within a relatively short time period, suggesting that any associated neural development may be relatively dramatic. Indeed there are reports of growth equivalent to several years of development within a few months (e.g. Merzenich et al., 1996; Yoder and McDuffie, in preparation).

One perhaps useful way of modeling neural development associated with language growth is to provide a description of the behavioral aspects of intervention and speculate on what this may mean for neural organization. The Section 1.1 will include a description of one widely used model of language intervention that may illustrate the potential associations between behavioral shifts in language ability and neural development processes. The following description of the transactional model of speech and language development is adapted from the presentation in Camarata and Gibson (1999) and Yoder and Warren (1993).

1.1. Transactional model of language acquisition

The debate on how children acquire language is ongoing, with nativist accounts which minimize the importance of language input (Chomsky, 1965, 1975; Pinker, 1984, 1989, 1994); contrasting with behavioral accounts that provide

* Corresponding author. Tel.: +1-615-322-8242; fax: +1-615-322-8236.
E-mail address: stephen.m.camarata@vanderbilt.edu (S. Camarata).

0736-5748/02/$22.00 © 2002 Published by Elsevier Science Ltd on behalf of ISDN.
PII: S0736-5748(02)00044-8

detailed observation of mother–child interaction and social interaction characteristics that are believed to facilitate language learning (cf. Conti-Ramsden, 1990; Hart and Risely, 1996; Moerk, 1992; Nelson, 1989; Shatz, 1983). These elements include hundred of thousands of episodes of repetitive feedback to the child, extensive contextual support (i.e. routines), contingent responses to child productions (i.e. attention, verbal interaction), and reductions in the complexity of maternal language directed to the child (Moerk, 1992; Hart and Risely, 1996). The fundamental characteristic of the transactional model of social interaction (Sameroff, 1975) is that learning opportunities are most salient when they are coordinated in the learning environment (Nelson, 1989). More importantly from a social perspective, language learning is viewed as an ongoing transaction in child behaviors and parent behaviors that are mutually supporting and lead to advances in the child's language. A transaction is defined as a collection of interactions that charge over five wherein the adult and child affect one another. In this model, aspects of the child's productions prompt specific classes of responses from the parent. These parent responses are associated with language advances in the child, who then prompts a set of more advanced responses from the parent and so on, across the course of normal language development (Yoder and Warren, 1993, for a discussion of the pragmatics of prelinguistic transactions; Nelson, 1989, for a discussion of the pragmatics of syntactic and morphological transactions and Camarata, 2000 for a discussion of the role of transactions in the social use of language in children with specific language impairment (SLI)).

For example, when the child produces relatively frequent and clear speech-like vocalizations, parents will often respond with linguistic input (often lexical mapping; Locke and Snow, 1997; Yoder and Warren, 1993). When the child learns and uses early words, the parent often responds with two and three word utterances. Similarly, when the child strings two and three word utterances together, the parent responses will often include grammatical morphemes the child omitted (Nelson, 1989; Nelson et al., 1996). Although it is difficult to determine causality in these kinds of bi-directional associations, it is clear that a number of factors often coalesce during language learning. Because parent responses to child communication are a critical element in the transaction, the child's linguistic initiations are extremely important because these serve as antecedent events that trigger the parent response (Moerk, 1992). Similarly, in order for the transaction to occur, the linguistic level of the parent's response should add complexity to the child's form but also be sufficiently simple for the child to process the added information. Although one study has suggested that typically functioning children can learn language structures that are relatively advanced within these kinds of transactions (Nelson et al., 1996), there are substantially more data indicating that parent responses that are slightly ahead of the child's level are associated with language growth (Nelson, Carskaddon and Bonvillian, 1973;

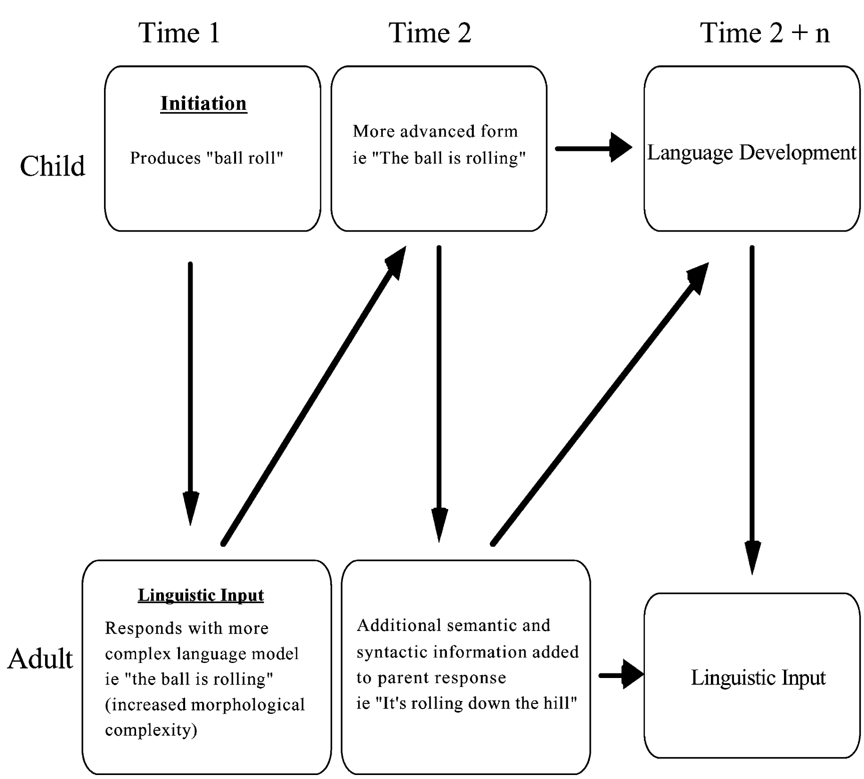

Fig. 1. The transactional model.

Nelson, 1989 and Yoder and Warren, 1993). The transactional model is summarized in Fig. 1 (adapted from Yoder and Warren, 1993). This figure illustrates the spiraling nature of language transactions as the child acquires new linguistic structures within a social context.

This example illustrates how grammatical acquisition can be facilitated within a series of transactions. These same principles apply to speech-intelligibility (phonological) acquisition as well (Camarata, 1996). Consider the following example. A toddler toddles to the refrigerator and gestures while saying “wa doo.” The social context indicates that the child is requesting something from the refrigerator, but the message is only partially intelligible. At this point, most parents may make a guess about the child’s request. In this case, they may say “want juice?” If the child acts as if this is correct, the adult is likely to repeat the form: “juice”, oh you want juice, here it is!” This latter point is crucial in the transaction. The adult could have given the child feedback on the incorrect mechanics of the production by saying “no, it is not “du” you have to say a “j” sound. Raise your tongue and release the air rather than holding it.” Or perhaps “not du, juice, say j” in order to model speech sound discrimination directly (as in Tallal et al., 1996). These latter responses appear a bit absurd in part because they are unnatural and there is no evidence that parents train speech-intelligibility or speech discrimination in this way. Rather, speech-intelligibility and speech discrimination acquisition appear to also follow a series of transactions within a meaningful social context. Consider the child’s task; they must generate an acoustic match using vocal folds that are shorter (and have a higher fundamental frequency) than the adult within a smaller vocal track with different resonant characteristics (Kent, 1993). Such acoustic matching and discrimination could also develop within the massed trials of a series of transactions between the adult and the child. Fig. 2 provides an example of the transactional model applied to speech intelligibility and speech discrimination.

1.2. Relationship to neural development

One may be wondering how this behavioral model of development and language intervention relates to developmental neuroscience. It appears to be widely accepted that visual input from the environment and, more importantly, perturbations in this input, can have a profound effect on the development of the neural system (Bates and Dick, 2002; Schall, 1999). Similarly the literature is replete with examples of neural plasticity during specific skill acquisition in primates (Merzenich et al., 1991) and as a neurodevelopmental response brain insult or other lesions or sensory deficits (Kaas, 2001; Neville, 1992). Given these parameters, it may be possible to examine the effects of adaptive transactions on the brain (Merzenich, 2001).

Consider the example for speech intelligibility and speech discrimination. In the transaction described above, the child’s “wa du” was followed by the adult’s “want juice.” This simple exchange potentially involves quite a range of neurological systems. Minimally, there must be discrimination of the speech sounds in the child and parent

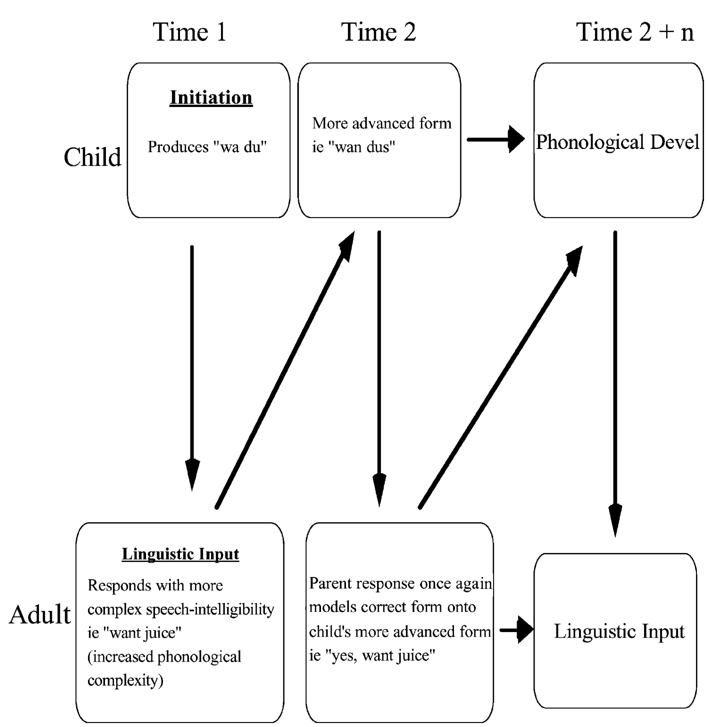

Fig. 2. The transactional model applied to speech intelligibility and speech discrimination.

production. In this case, the differences include the deletion of the final cluster "nt" in the word "want," and substitution of w/j and deletion of the "s" in the word "juice." This discrimination process has been associated with a number of cortical functions in children and adults (Merzenich, 2001). For example, in a study of processing of meaningful speech subjected to systematic time compression, Poldrack et al. (2001) reported significant activation in the left inferior frontal (Broca's) and left superior temporal regions (Wernicke's), and the right inferior frontal cortex in the adults studied during this task. One could speculate that repeated exposure to the auditory contrast within a transaction contest may generate the shifts in neural organization described in primates and in humans when subjected to decontextualized massed trials of auditory stimuli designed to train discrimination of individual speech sounds (Kilgard and Merzenich, 1998; Merzenich et al., 1996).

With regard to phonological output, increased accuracy in the behavioral realm is likely also associated with shifts in the neural organization associated with speech production. This may parallel the report of Xerri et al. (1999) which demonstrated that when a nonhuman primate was taught the relatively simple task of finger tapping a motor sequence, there were systematic changes in cortical areas 3b, 3a, 1, 2, and SII, both in terms of numbers of cells dedicated to this task and in terms of the recruitment of additional cortical sites as the primate become more efficient with the task. One could speculate that the improvements in motor speech production are similarly associated with increased activation in Broca's area and perhaps in the recruitment of associated, secondary speech areas. In addition, Sauger and Merzenic (2000) have speculated that inefficient sensory representations can be directly associated with abnormal motor behavior. Conversely, one can speculate that increasingly accurate sensory representations (development of speech perception, Ohde, 1997) may be directly related to increasingly accurate motor production. Intervention paradigms that focus on improving these sensory skills may be utilized to test these hypotheses and study associated neural development as the child becomes more proficient in phonological production and perception.

Because this development occurs very quickly in young children and is often largely completed before the child is amenable to fine grained imagining techniques it has heretofore been difficult to study the neurological correlates of language development. However, some classes of disabilities may prove interesting in this regard as they display either uneven or slowed development. In addition, and perhaps of even more use, the effects of specific treatments designed to have a direct effect on one or more tightly defined behaviors may yield a paradigm that allows for study of the development of circuits and neural systems at the child's speech and language becomes more proficient. Examples from two disability typologies, SLI and also Down syndrome (DS) will be discussed to illustrate this.

1.3. Specific Language Impairment: a promising population for observing neural development during language growth

SLI is defined as a weakness in the production of grammatical markers, vocabulary, complex sentences and/or the social use of language in the absence of any neurological insult, general mental retardation, or pervasive developmental disorder (such as autism) (see the review in Leonard, 1998). SLI includes the DSM-IV categories expressive language disorder and mixed expressive-receptive language disorder (APA, 1994). This is an intriguing population because these children do not display general intellectual deficits or behavior disorders and so could potentially cooperate with the types of tasks often employed in neural imaging. In addition, static imaging studies have failed to turn up any replicated pattern of lesion (Plante, 1997, but see also Trauner, 2001). But, many children with SLI who have both grammatical (Leonard et al., 1992; Tallal et al., 1985) and phonological disorders have been found to process speech relatively poorly. Inefficient speech processing may cause grammatical and phonological disorders because such children may be less likely to develop rich representations of the grammatical or phonological rules underlying intelligible, grammatical speech. Intervention studies have indicated that children with SLI often respond favorably to treatment and that rapid shifts in language skill are often observed (Camarata et al., 1994). Note that this results in a compressed time window for studying language acquisition in children who are more mature and potentially more cooperative that younger typically developing children. That is, treatment of SLI provides a unique opportunity to observe language development and neural organization associated with language development. Speculations abound on the nature and relationship of sensory deficits and the output difficulties (see Leonard, 1998 and also Bishop, 1997), but developmental neuroscience provides the paradigms for ultimately unraveling these relationships.

1.4. Children with Down syndrome

Children with DS (Trisomy 21) often display a number of developmental delays in physical, social, and mental development. Preschoolers with DS tend to have deficits in productive syntax and intelligibility that is below that expected for their mental age, comprehension level, and even vocabulary level (Miller, 1999; Miller and Leddy, 1999). Deficits in short-term auditory memory have been hypothesized as one cause of deficit grammatical production (Gathercole and Baddeley, 1993; Chapman, 1995). Many believe that the speech intelligibility problems of children with DS are due to motor constraints (Miller and Leddy, 1999) and unique vocal tract structures (Leddy, 1999). However, an alternative or additional explanation is that impoverished phonological knowledge due to inefficient speech processing could play a role in poor intelligibility in these children.

As described above, the transactional model emphasizes language acquisition as an outcome of a large, accumulating data-base of language experienced or used in communicative contexts in which the speaker's meaning is clear or in which expectations can be confirmed or disconfirmed. Information stored in memory that can later be accessed as event representations that occur as a function of child experience and talk about those experiences co-occurring (Chapman et al. 1992). However, short-term auditory memory problems of many children with DS could make more contexts sufficiently complex that processing of linguistic input is compromised. For example, children with DS were as able as mental-age-matched peers to fast map words in a simple hiding game (Chapman et al., 1990), but not in a more complex story-listening task (Chapman et al., 1991). If short-term auditory memory deficits make many contexts sufficiently complex that children with DS do not efficiently process speech, both grammar and intelligibility would suffer.

Citing the ChildTalk model, which is similar to the transactional model in many ways, (Chapman, 1999) asserted that using routine event contexts to support communicative learning is expected to be especially effective in facilitating acquisition and generalization in children with DS. Verbal routines are familiar, predictable turn-taking conversations or games in which both members of the dyad have spoken turns (Yoder et al., 1995). Scripts are more sophistocated verbal routines that have a particular sequence and often an end-product. Both may aid children in processing linguistic input because the repetitive nature and predictability of the exchange increases their comprehension of adult utterances and their role in the interaction (Shatz, 1983).

If this is true, then perhaps some aspect of ERP imaging can be used to predict the speech-intelligibility and grammatical intervention outcome for children with DS that is associated with behavioral treatment that includes routines and follows the basic structure discussed in the transactional model. The main components likely to be of interest are N1 and mismatch negativity (MMN), because N1 is thought to represent processes that detect transitions in the sensory environment. MMN is observed as a deflection peaking between 200 and 300 ms in the difference waveform between a deviant and background stimulus. MMN is thought to represent the detection of change by processes that compare a current stimulus with a preceding stimuli. Within the framework of the transactional model, for learning to occur, the child must detect the difference between their own production and that of the adult (hence, MMN) and more basically, that a transition has occurred in the sensory environment (hence, N1).

In children with SLI, no consistent relationship has been found between latency of the auditory brainstem response (ABR) components and language ability (Mason and Mellor, 1984; Tonnquist-Uhlen, 1996), whereas, in DS there are decreases in ABR latencies (Diaz and Zurron, 1995; Seidl et al., 1997). It has been suggested that individuals with DS have difficulty in habituating to stimuli. This may be because the initial sensory information is inadequately processed so that there is less information available to later change detection processes. In other words, in DS the delay in N1 may be a result of degradation of the input quality. It has been suggested that the longer N1 latency in children with SLI may be due to maturational delay, however, some children with SLI do not show age related decreases in NI latency (Tonnquist-Uhlen et al., 1996).

The MMN component has been shown to be a reliable marker of auditory discrimination. Kraus et al. (1996) used just-noticeable difference (JND) scores to group children with SLI into "good" /ba/-/wa/ discriminators who were "good" or "poor" /da/-/ga/ discriminators. A MMN was found in all the difference waves for the /ba/-/wa/ contrast and for the /da/-/ga/ contrast of "good" discriminators. No MMN was found for the /da/-/ga/ contrast of "poor" discriminators. In typical adults, Kraus et al. (1995) have also shown that discrimination training results in larger magnitude MMN. The use of MMN to study children with DS has yet to be pursued.

1.5. Conclusions

Although much is known about the behavioral development of language in typically developing children and to some extent in children with disabilities and there have interesting and important inroads into the understanding of the biological processes associated with neural organization, the integration of the biological and the behavioral parameters remains a very intriguing area of inquiry (Merzenich, 2001). The purpose of this review has been to provide a theoretical framework for exploring the relationship between speech and language development in children with disabilities and the organization of neural resources as the child becomes more proficient in speaking. Moreover, response to behavioral treatment may prove to be a particularly useful paradigm to study this question because tightly controlled behavioral interventions allow for analysis of specific input (as in the transactional model) as it relates to neural changes. Because children with disabilities often display slow development while also often responding favorably to treatment, these children are likely to be important in understanding both normal and deviant neural development and organization.

Acknowledgements

The authors express appreciation to Dennis Molfese and Michael Davis for helpful discussions during the development of this manuscript. Support from the National Institutes of Health (Grants P3015052 from the NICHD and P50DC03282 form the NIDCD) and the Scottish Rite Foundation of Nashville for this research is gratefully acknowledge.

References

American Psychiatric Association 1994. The Diagnostic and Statistical Manual of Mental Disorders, 4th Edition.

Bates, E., Dick, F., 2002. Language, gesture, and developing brain. Dev. Psychobiol. 40, 293–310.

Bishop, D., 1997. Uncommon Understanding: Development and Disorders of Language Comprehension in Children. Psychology Press, Erlbaum (UK); Taylor & Francis, Hove, England.

Camarata, S., 1996. On the importance of integrating naturalistic language, social intervention, and speech-intelligibility training. In: Koegel, L., Koegel, R., Dunlap, G. (Eds.), Positive Behavior Supports. Brookes, Baltimore, pp. 333–351.

Camarata, S., 2000. The pragmatics of pediatric language intervention: issues and analysis. In: Muller, N. (Ed.), Pragmatics in Speech and Language Pathology. John Benjamins Publishing Company, Philadelphia, pp. 139–136.

Camarata, S., Gibson, T., 1999. Pragmatic language deficits in attention-deficit hyperactivity disorder (ADHD). J. Mental Retard. Dev. Disab. Res. Rev. 5, 207–214.

Chapman, R., 1999. Language development in children and adolescents with Down syndrome. In: Flectcher, P., MacWhinney, B. (Eds.), Handbook of Child Language. Blackwell Publishers, Oxford, England, pp. 641–663.

Chomsky, N., 1965. Aspects of a Theory of Syntax. MIT Press, Cambridge, MA.

Chomsky, N., 1975. Reflections on Language. Pantheon, New York.

Conti-Ramsden, G., 1990. Maternal recasts and other contingent replies to language-imparied children. J. Speech Hear. Disord. 55, 262–274.

Diaz, F., Zurron, M., 1995. Auditory evoked potentials in Down's syndrome. Electroencephalogr. Clin. Neurophysiol. 96, 526–537.

Gathercole, Baddeley, 1993. Working Memory and Language. Lawrence Erlbaum Associates, Mahwah, NJ.

Hart, Risley, 1996. Meaningful Differences. Paul H. Brookes, Baltimore.

Kaas, J., 2001. The mutability of sensory representations after injury in adult mammals. In: Shaw, C., McEachern, J. (Eds.), Toward a Theory of Neuroplasticity. Philadelphia, PA, USA, Psychology Press, pp. 323–334.

Kent, R., 1993. Sonority theory and syllable pattern as key to sensory–motor–cognitive interactions in infant vocal development. In: de Boysson-Bardies, B., de Schonen, S. (Eds.), Developmental Neurocognition: Speech and Face Processing in the First Year of Life. In: NATO ASI Series D: Behavioural and Social Sciences, Vol. 69, pp. 329–339.

Kilgard, M., Merzenich, M., 1998. Plasticity of temporal information processing in the primary auditory cortex. Nat. Neurosci. 1, 727–731.

Kraus, N., McGee, T.J., Carrell, T.D., King, C., Tremblay, K., Nicol, T., 1995. Central auditory system plasticity associated with speech discrimination training. J. Cogn. Neurosci. 7, 25–32.

Kraus, N., McGee, T.J., Carrell, T.D., Zecker, S.G., Nicol, T.G., Koch, D.B., 1996. Auditory neurophysiologic response and discrimination deficits in children with learning problems. Science 273, 971–973.

Leonard, L., 1998. Specific Language Impairment. MIT Press, Cambridge, MA.

Leonard, L., McGregor, K., Allen, G., 1992. Grammatical morphology and speech perception in children with specific language impairment. J. Speech Hear. Res. 35, 1076–1085.

Locke, J., Snow, C., 1997. Social influences on vocal learning in human and nonhuman primates. In: Snowdon, C., Hausberger, M. (Eds.), Social Influences on Vocal Development. Cambridge, MA, Cambridge University Press, pp. 274–292.

Mason, S.M., Mellor, D.H., 1984. Brain-stem, middle latency and late cortical evoked potentials in children with speech and language disorders. Electroencphalogr. Clin. Neurophysiol. 59, 297–309.

Merzenich, M., 2001. Cortical plasticity contributing to child development. In: McClelland, J., Siegler, R. (Eds.), Mechanisms of Cognitive Development: Behavioral and Neural Perspectives. Carnegie-Mellon Symposia on Cognition. Mahwah, NJ, Lawrence Erlbaum Associates, pp. 67–95.

Merzenich, M., Jenkins, W., Johnston, P., Schreiner, C., Miller, S., Tallal, P., 1996. Temporal processing deficits of language-learning impaired children ameliorated by training. Science 271, 77–81.

Moerk, E., 1992. A first language taught and learned. Baltimore: Brookes.

Nelson, K.E., 1989. Strategies for first language teaching. In: Rice, M., Schiefelbush, R. (Eds.), Teachability of Language. Paul Brookes, Baltimore, MD, pp. 263–310.

Nelson, K., Carskaddon, G., Bonvillian, J., 1973. Syntax acquisition: impact of experimental variation in adult verbal interaction with the child. Child Dev. 44, 497–504.

Nelson, K.E., Camarata, S., Welsh, J., Butkovsky, L., Camarata, M., 1996. Acquisition of absent syntactic structures by children with specific language impairment . J. Speech Hear. Res. 39, 850–859.

Neville, H., Mills, D., Lawson, D., 1992. Fractionating language: different neural subsystems with different sensitive periods. Cereb. Cortex 2, 244–258.

Ohde, R., Haley, K., 1997. Stop-consonant and vowel perception in 3- and 4-year old children. J. Acous. Soc. Am. 102, 3711–3722.

Pinker, S., 1984. Language Learnability and Language Development. Harvard University Press, Cambridge, MA.

Pinker, S., 1989. Resolving a learnability paradox in the acquisition of the verb lexicon. In: Rice, M., Schiefelbusch, R. (Eds.), The Teachability of Language, Brookes, Baltimore.

Pinker, S., 1994. The Language Instinct. MIT Press, Cambridge, MA.

Poldrack, R., Temple, E., Protopapas, A., Nagarajan, S., Tallal, P., Merzenich, M., Gabrieli, J., 2001. Relations between the neural bases of dynamic auditory processing . J. Cogn. Neurosci. 13, 687–697.

Sameroff, A., 1975. Transactional models in early social relations. Hum. Dev. 18, 65–79.

Seidl, R., Hauser, E., Bernert, G., Marx, M., Freilinger, M., Lubec, G., 1997. Auditory evoked potentials in young patients with Down syndrome event-related potentials (P3) and histaminergic system. Cogn. Brain Res. 5, 301–309.

Shatz, M., 1983. On transition, continuity, and coupling: an alternative approach to communicative development. In: Golinkoff, R. (Ed.), The Transition from Prelinguistic to Linguistic Communication. Erlbaum, Hillsdale, NJ.

Tallal, P., Stark, R., Mellits, D., 1985. Identification of language impaired children on the basis of rapid perception and production skills. Brain Language 25, 314–322.

Tonnquist-Uhlen, I., 1996. Topography of auditory evoked cortical potentials in children with severe language impairment. Scand. Audiol. Suppl. 44, 1–40.

Tonnquist-Uhlen, I., Borg, E., Persson, H.E., Spens, K.E., 1996. Topography of auditory evoked cortical potentials in children with severe language impairment: the N1 component. Electroencephalogr. Clin. Neuropsychol. 100, 250–260.

Xerri, C., Merzenich, M., Jenkins, W., Santucci, S., 1999. Representational plasticity in cortical area 3b paralleling tactualmotor skill acquisition in adult monkeys. Cereb. Cortex 9, 264–276.

Yoder, P., McDuffie, A., in preparation. Treatment of primary language disorders in early childhood: evidence of efficacy, in preparation.

Yoder, P.J., Warren S.F., 1993. Can the prelinguistic intervention enhance the language development of children with developmental delays. In: Kaiser, A. (Ed.), Enhancing Children's Communication: Research Foundations for Early Language Intervention. Brookes, Baltimore, pp. 35–62.

Yoder, P.J., Spruytenburg, H., Edwards, A., Davies, B., 1995. Effect of verbal routine contexts . Language Speech Hear. Services School 26, 21–32.

Further Reading

Camarata, S., 1995. A rationale for naturalistic speech intelligibility intervention. In: Fey, M., Windsor, J., Warren, S. (Eds.), Language Intervention: Preschool Through the Early School Years. Brooks, Baltimore, pp. 63–84.

Merzenich, M., 2000. Seeing in the sound zone. Nature, 404, 820–821.

Merzenich, M., deCharms, R., 1996. Neural representations, experience, and change. In: Llinas, R., Churchland, P. (Eds.), The Mind-Brain Continuum: Sensory Processes. The MIT Press, Cambridge, MA, USA.

Mills, D., Coffey-Corina, S., Neville, H., 1994. Variability in cerebral organization during primary language acquisition. In: Dawson, G., Fishcher, K., Kurt, W. (Eds.), Human Behavior and the Developing Brain. The Guilford Press, New York, NY, pp. 427–455.

Mills, D., Coffey-Corina, S., Neville, H., 1993. Language acquisition and cerebral specialization in 20-month-old infants. J. Cogn. Neurosci. 5, 317–334.

Neville, H., Mills, D., 1997. Epigenesis of language. J. Mental Retard. Dev. Disab. Res. Rev. 3, 282–292.

Ohde, R., Scharf, D., 1993.

Sanger, T., Merzenich, M., 2000. Computational model of the role of sensory disorganization in focal task-specific dystonia. J. Neurophysiol. 84, 2458–2464.

Schall, J., 2000. Decision making: from sensory evidence to a motor command. Curr. Biol. 10, R404–406.

Zhang, L., Bao, S., Merzenich, M., 2001. Persistent and specific influences of early acoustic environments on primary auditory cortex. Nat. Neurosci. 4, 1123–1130.