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Critical Thinking about Critical Periods: Perspectives on a Critical Period for Language Acquisition

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Over many years Jacques Mehler has provided us all with a wealth of surprising and complex results on both nature and nurture in language acquisition. He has shown that there are powerful and enduring effects of early (and even prenatal) experience on infant language perception, and also considerable prior knowledge that infants bring to the language acquisition task. He has shown strong age effects on second-language acquisition and its neural organization, and has also shown that proficiency predicts cerebral organization for the second language. In his honor, we focus here on one of the problems he has addressed—the notion of a critical period for language acquisition—and attempt to sort out the current state of the evidence.

In recent years there has been much discussion about whether there is a critical, or sensitive, period for language acquisition. Two issues are implicit in this discussion: First, what would constitute evidence for a critical period, particularly in humans, where the time scale for development is greater than that in the well-studied nonhuman cases, and where proficient behavioral outcomes might be achieved by more than one route? Second, what is the import of establishing, or failing to establish, such a critical period? What does this mean for our understanding of the computational and neural mechanisms underlying language acquisition?

In this chapter we address these issues explicitly, by briefly reviewing the available evidence on a critical period for human language acquisition, and then by asking whether the evidence meets the expected criteria for critical or sensitive periods seen in other well-studied domains in human and nonhuman development. We conclude by stating what we think

the outcome of this issue means (and does not mean) for our understanding of language acquisition.

What Is a Critical or Sensitive Period?

Before beginning, we should state briefly what we (and others) mean by a critical or sensitive period. A critical or sensitive period for learning is shown when there is a relationship between the age (more technically, the developmental state of the organism) at which some crucial experience is presented to the organism and the amount of learning which results. In most domains with critical or sensitive periods, the privileged time for learning occurs during early development, but this is not necessarily the case (cf. bonding in sheep, which occurs immediately surrounding parturition). The important feature is that there is a peak period of plasticity, occurring at some maturationally defined time in development, followed by reduced plasticity later in life. In contrast, in many domains and systems, there may be plasticity uniformly throughout life (open-ended learning), or plasticity may increase with age as experience or higher-level cognitive skills increase.

As discussed in greater detail below, the mechanisms underlying critical periods are quite diverse in the systems in which they have been studied. Even without access to the underlying mechanisms, however, one can define and identify the relevant phenomena in behavioral terms. In this discussion we will not attempt to distinguish between a critical period and a sensitive period (sometimes distinguished by the abruptness of offset or the degree of plasticity remaining outside of the period); as we will also discuss in detail, most critical periods show more gradual offsets and more complex interactions between maturation and experiential factors than the original concept of a critical period included.

Overview of the Available Evidence Concerning a Critical or Sensitive Period for Language Acquisition

A number of lines of research, both behavioral and neural, suggest that there is a critical or sensitive period for language acquisition. First, many studies show a close relationship between the age of exposure to a language

and the ultimate proficiency achieved in that language (see, e.g., Newport, 1990; Emmorey and Corina, 1990; Mayberry and Fischer, 1989; Johnson and Newport, 1989, 1991; Krashen, Long, and Scarcella, 1982; Long, 1990; Oyama, 1976; Pallier, Bosch, and Sebastián-Gallés, 1997; Patkowski, 1980; and others). Peak proficiency in the language, in terms of control over the sound system as well as the grammatical structure, is displayed by those whose exposure to that language begins in infancy or very early childhood. With increasing ages of exposure there is a decline in average proficiency, beginning as early as ages four to six and continuing until proficiency plateaus for adult learners (Johnson and Newport, 1989, 1991; Newport, 1990). Learners exposed to the language in adulthood show, on average, a lowered level of performance in many aspects of the language, though some individuals may approach the proficiency of early learners (Birdsong, 1992; Coppetiers, 1987; White and Genesee, 1996).

These effects have been shown for both first and second languages, and for measures of proficiency including degree of accent, production and comprehension of morphology and syntax, grammaticality judgments for morphology and syntax, and syntactic processing speed and accuracy. For example, Johnson and Newport (1989, 1991) have shown that Chinese or Korean immigrants who move to the United States and become exposed to English as a second language show strong effects of their age of exposure to the language on their ability to judge its grammatical structure many years later, even when the number of years of exposure is matched. These effects are not due merely to interference of the first language on the learner's ability to acquire the second language: deaf adults, acquiring American Sign Language (ASL) as their primary language, show effects of age of exposure on their grammatical skills in ASL as much as 50 years later, even though they may not control any other language with great proficiency (Emmorey, 1991; Emmorey and Corina, 1990; Mayberry and Fischer, 1989; Mayberry and Eichen, 1991; Newport, 1990). These studies are also in accord with the famous case studies of individual feral or abused children, isolated from exposure to their first language until after puberty (Curtiss, 1977), where more extreme deficits in phonology, morphology, and syntax occur.

However, age of exposure does not affect all aspects of language learning equally. As reviewed in more detail below, the acquisition of

vocabulary and semantic processing occur relatively normally in late learners. Critical period effects thus appear to focus on the formal properties of language and not the processing of meaning. Even within the formal properties of language, though, various aspects of the language may be more or less dependent on age of language exposure. For example, late learners acquire the basic word order of a language relatively well, but more complex aspects of grammar show strong effects of late acquisition (Johnson and Newport, 1989; Newport, 1990). Very recent studies have reported that late learners may pick up information about lexical stress with impunity but show deficits in acquiring the phonetic information important in native-like pronunciation (Sanders, Yamada, and Neville, 1999). Further research is needed to characterize the structures which do and do not show strong effects of age of learning.

Age of exposure has also been shown to affect the way language is represented in the brain. Positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and event-related potential (ERP) studies all indicate strong left hemisphere activation for the native language in bilinguals (Dehaene et al., 1997; Perani et al., 1996; Yetkin et al., 1996). However, when second languages are learned late (after seven years), the regions and patterns of activation are partially or completely nonoverlapping with those for the native language. Neural organization for late-learned languages tends to be less lateralized and displays a high degree of variability from individual to individual (Dehaene et al., 1997; Kim et al., 1997; Perani et al., 1996; Weber-Fox and Neville, 1996; Yetkin et al., 1996). In contrast, the few studies that have observed early bilinguals or highly proficient late bilinguals report congruent results for native and second languages (Kim et al., 1997; Perani et al., 1998).

Some results indicate that there may be considerable specificity in these effects. For example, age of acquisition appears to have more pronounced effects on grammatical processing and its representation in the brain than on semantic processing (Weber-Fox and Neville, 1996). In Chinese-English bilinguals, delays of as long as sixteen years in exposure to English have very little effect on the organization of the brain systems active in lexical/semantic processing: when responding to the appropriateness of open-class content words in English sentences, all groups of learners show evoked potential components similarly distributed over the

posterior regions of both hemispheres. In contrast, when judging the grammaticality of English syntactic constructions or the placement of closed-class function words in sentences, only early learners show the characteristic anterior left hemisphere ERP components; learners with delays of even four years show significantly more bilateral activation (Weber-Fox and Neville, 1996). Similar effects appear for signed languages (Neville et al., 1997).

Comparable results also appear in ERP studies of English sentence processing by congenitally deaf individuals who have learned English late and as a second language (ASL was their first language) (Neville, Mills, and Lawson, 1992). ERP responses in deaf subjects to English nouns and to semantically anomalous sentences in written English are like those of hearing native speakers of English. In contrast, for grammatical information in English (e.g., function words), deaf subjects do not display the specialization of the anterior regions of the left hemisphere characteristic of native speakers. These data suggest that the neural systems that mediate the processing of grammatical information are more modifiable and vulnerable in response to altered language experience than are those associated with lexical/semantic processing.

Taken together, these results provide fairly strong evidence for a critical or sensitive period in acquiring the phonological and grammatical patterns of the language and in organizing the neural mechanisms for handling these structures in a proficient way. Nonetheless, the question of whether there is a critical period for language acquisition continues to be controversial. In the sections below we address some of the theoretical issues concerning what a critical or sensitive period for language acquisition might look like.

Empirical and Theoretical Questions Concerning a Critical or Sensitive Period for Language Acquisition

In response to the findings cited above, several questions have been raised about whether these age effects represent the outcome of a critical or sensitive period, or rather whether they might arise from other variables correlated with age but not with maturation. One set of questions concerns whether the behavioral function has the correct shape for a critical

or sensitive period. Does the decline in sensitivity extend over too many years to be called a critical period? Must a critical period involve an abrupt decline and a total loss of plasticity at the end?

A second set of questions concerns the range of proficiency achieved by late learners. In particular, does a critical period require that no late learner achieve native proficiency? What is the appropriate interpretation of finding some late-learning individuals with native or near-native proficiency? What is the significance of finding correlations between neural organization for language and the proficiency rather than age of the learner?

Third, how does one distinguish a critical period from an interference effect? Late learners of a second language have used their primary language for more years than early learners, and therefore may have a more "entrenched" proficiency in that language. Does this indicate that their difficulty acquiring a second language is due to interference rather than to a critical period?

Finally, if there are differing ages at which learning declines for different aspects of language (such as phonology vs. syntax, or different aspects of grammar), does this mean that there is no true critical period, or that there are multiple critical periods?

In the section below we address these questions by considering what the evidence and interpretations are for domains other than language, for example in the development of auditory localization or visual acuity, where our understanding of critical periods is believed to be more solid (or at least where there is somewhat less controversy in the field about whether the notion of a critical period is sensible). We then compare the evidence for language to that for these other domains, attempting to determine whether the data or outcomes for language are in fact different or the same as these more well-studied and familiar cases.

What Is the Status of These Issues in Our Understanding of Critical Periods in Other Domains?

Within the language acquisition literature, many researchers have expressed the expectation that, if there were a critical or sensitive period for learning, it would have to have a number of strong characteristics.

For example, investigators have expected that a critical or sensitive period for language learning should have an abrupt end, at a well-defined and consistent age; and this age should be related to the onset of physical puberty (e.g., at about age 12 or 13) (Bialystok and Hakuta, 1994). It should permit no individual to achieve native or near-native proficiency after the critical period ends (Bialystok and Hakuta, 1994; Birdsong, 1992, 1999; White and Genesee, 1996). It should show no variation across different first language–second language combinations (Birdsong and Molis, 2000). It should limit the learning of a new second language, but there should not be accompanying loss or decrement of an early acquired first language (otherwise it would be better interpreted as an interference rather than a critical period effect) (Jia, 1998).

However, many of these strong or absolute characteristics are not true of critical or sensitive periods in other domains. Many critical or sensitive periods show more complex properties than have been expected or demanded in the case of language, and ongoing work in developmental neurobiology and psychobiology continually reveals that plasticity and learning may show quite complex and interacting effects of maturation, experience, stimulus salience or preferences, and the like. As discussed below, critical or sensitive periods in most (if not all) behavioral domains involve gradual declines in learning, with some (reduced, but not absent) ability to learn by mature organisms, and with more learning achieved during the waning portion of the critical period if the organism is presented with extremely salient or strongly preferred stimuli, or with learning problems similar to those experienced early in life. If such complex phenomena are expected and routinely found within critical periods in other domains, they should also be expected for language learning.

The Shape and Length of a Critical Period

Offset Time: Effects of Maturation vs. Experience As recent research has revealed, the time at which a critical period ends is influenced by both maturational and experiential factors, and therefore cannot be pegged to a precise age. The most widely studied effect of this type is that isolation will extend a critical period: animals reared in isolation from the stimuli crucial for learning during the sensitive period will retain the ability to

learn, post-isolation, at ages during which there is little or no plasticity in normally reared individuals. This effect occurs for a wide range of domains showing critical periods, including the establishment of neuromuscular junctions (whose critical period is extended if neural activity is suppressed: Oppenheim and Haverkamp, 1986), the development of ocular dominance columns in visual cortex (Hubel and Wiesel, 1970), imprinting in ducks (Hess, 1973), and song learning in many avian species (Nordeen and Nordeen, 1997). Conversely, the critical period may be shortened if the animal is exposed to strongly preferred stimuli, such as imprinting to a live duck rather than a decoy (Hess, 1973), or auditory localization calibrated with the ears normally open rather than with one ear plugged (Knudsen, 1988). While experience may alter the timing of the critical period to some degree, however, eventually plasticity will decline even if the animal is never exposed to preferred stimuli; this suggests that there is a maturational component underlying the change of plasticity, even though experience can modulate its timing.

Length of Critical Periods It is also clear that the absolute length of critical periods varies, and therefore that one cannot evaluate a critical period by whether it is very short and rapidly concluded, or gradual and extended over several months or years. In part, such variations would seem to depend on the rate at which the organism develops: slowly developing organisms, like humans, would be expected to show critical periods lasting orders of magnitude longer than those of frogs or cats, with both relative to the general rate of maturation of the organism. There may also be a relationship between how long, or when in development, a particular system takes to develop normally, and how long its critical period will be: systems which develop very early may have short periods of plasticity, whereas late-developing systems may have long critical periods. For example, in cat retina, the Y cells (which are more abundant in the periphery) develop later and more slowly than the X cells (clustered in the fovea), and are altered by visual experience over a longer period of time (Sherman, 1985).

Sharpness of the Decline in Plasticity A related point is that critical periods vary in how abruptly they end. Some critical periods (e.g., that in-

involved with the establishment of ocular dominance columns in cat visual cortex; Hubel and Wiesel, 1970) end very suddenly; differences of hours or days in the time of exposure to relevant input can lead to profound differences in the behavioral or physiological outcome. But the occurrence of such sudden and apparently complete termination of plasticity in some systems should not mislead us into expecting that every system with a sensitive period will likewise show such a dramatic change in receptivity to experience. Many well-studied critical or sensitive periods show a gradual decline in plasticity as the critical period closes, with learning during this period of decline being only partially successful or responsive only to the strongest stimuli. For example, auditory localization in the barn owl displays full adjustment to a monaural ear plug if the plug is inserted early; with later and later ages of plug insertion (during adolescence), there is a gradually reduced degree of error correction achieved; and adult barn owls show only a limited ability to correct for plugs (Knudsen, 1988). At the same time, the amount of correction shown at various ages is greater for removing an earplug than for inserting an earplug, suggesting that plasticity during the intermediate stages of development is also differentially responsive to experiences for which the system is best tuned (for the barn owl, apparently the "normal" settings, where both ears are open or balanced in the auditory input they receive) versus experiences for which the system is not. Similar gradual declines in learning, involving intermediate degrees of plasticity and differential sensitivity to strong or weak stimuli, are also found in imprinting (Hess, 1973) and in certain aspects of avian song learning (Eales, 1987; K. Nordeen, 2000, personal communication).

Plasticity Outside of the Critical Period

Degree of Plasticity after the Critical Period Ends It is also the case that some systems may continue to show plasticity, though reduced, after the critical period is over and the organism has reached an asymptotic adult state. For example, while ocular dominance columns do not appear to retune themselves to changes in binocular experience during adulthood (Hubel and Wiesel, 1970), auditory localization in the barn owl does show some (limited) recalibration in the adult: while young barn owls

can correct errors introduced by earplug insertion up to as much as twenty degrees of arc, adult barn owls can correct such errors up to five or ten degrees (Knudsen, 1988). Similarly, songbirds may acquire some new syllables after the sensitive period for sensory acquisition is over and depend critically on auditory feedback throughout life to maintain adult song patterns (Nordeen and Nordeen, 1992), though (in critical period learners) most of the acquisition of song structures occurs during the critical period.

Individual Success in Learning beyond the Critical Period Even though there may be some plasticity in many systems after their critical or sensitive periods close, it is argued by some in the language acquisition literature that it would not be compatible with the concept of a critical period if any individuals (or any substantial number of individuals) could achieve native proficiency from exposure after the critical period ends (Birdsong, 1992; Birdsong and Molis, 2000; White and Genesee, 1996). Virtually every study on this topic has shown that the number of individuals from an unselected population who are first immersed in the language during adulthood and yet who approach native proficiency is relatively small (Birdsong, 1992; Birdsong and Molis, 2000; Coppeters, 1987; Johnson and Newport, 1989, 1991; Newport, 1990; White and Genesee, 1996). Nonetheless, some investigators have questioned whether a critical or sensitive period would allow anyone (Joseph Conrad is a favorite example) to do so.

There are a number of reasons why such high proficiency might be achieved outside of a critical period by some individuals. First, while the precise mechanisms underlying a critical period for language learning are unknown, it is clear that maturational changes in this domain are gradual and probabilistic, with adults capable of learning many things about a new language. One should not be surprised, then, if, in addition, there is a normal distribution of variation among individuals in their capacity to learn, even though the mean outcome is substantially lower for learning in adulthood as compared with childhood. As with any other variable, individuals vary in the timing and extent of various maturational processes (e.g., the rate at which they undergo physical growth or experience menarche), and therefore should be expected to show variation in the

timing and extent of whatever cellular and/or cognitive variables produce the decline in language learning during development. Individual variability appears in all animal studies, particularly during the waning portion of the critical period or after; see, for example, variation among zebra finches in the effects of heterospecific tutors (Eales, 1987) or of deafening on song maintenance. Second, in adult humans (though perhaps not in ducks or cats or birds, who lack our general brain power), there is always the possibility of learning by mechanisms other than the ones originally suited for the task, and other factors (such as a good "ear" for languages, strong formal analytic skills, or extensive conscious learning and practice) might be responsible for the skills of outstanding adult learners.

Finally, adult language learners in all of these studies are always facing a *second*-language learning task during adulthood, not a first.¹ Even though the first and second languages may be quite different from one another, the fact that all languages share many properties (and that the language systems have been engaged and used for language learning and analysis during childhood) is likely to mean that in many ways adult language learning is not an entirely new learning task; and re-learning or transfer during adulthood of skills experienced during early life might be expected to show some resilience and success. A somewhat related phenomenon has been demonstrated in auditory localization: barn owls that wear visual prisms (shifting accurate visual and auditory localization) for a brief period during early development show an unexpected ability to adjust to the same prisms applied during adulthood, after the usual critical period for recalibration is over. Moreover, early experience with one set of prisms permits some recalibration to other prisms in adulthood, if the two sets of prisms share the same direction and similar magnitude of shift (Knudsen, 1998).

Maturation vs. Interference

Whenever one finds age effects on the acquisition of proficiency in a domain, there are always a number of interpretations of these effects, and a number of underlying mechanisms which might be responsible. For example, there might be maturational changes in the plasticity of the system, so that learning is reduced or no longer possible after the critical period, no matter what the early experiences of the organism. There

might also be effects of early experience which change the capacity of later experiences to affect the system further. In the language acquisition literature, such accounts (known as maturational vs. interference effects) have been considered competing alternatives. But in the developmental psychobiology literature, where it has become increasingly clear that early experience always interacts with maturation and produces biological consequences, both types of accounts are considered critical or sensitive period effects.

Bateson (1979) discusses these two types of explanations for the critical period for imprinting in birds. One of his explanations is that, with maturation, the imprinting mechanism no longer functions. A second explanation, however, is that early experiences specify (and thus narrow) the range of objects the bird considers familiar, and correspondingly lead novel objects first experienced late in life to elicit fear and flight (rather than following). On this account, birds isolated in their cages during the critical period are not deprived of early experience, but will learn from whatever they are exposed to. They become imprinted on the pattern of their cage bars and will fear other novel objects, and, as a result, they will not be capable of undergoing the crucial experience (following) required for imprinting to other objects. In short, no matter what the early experiences of the organism might be, learning from these experiences will occur and will have priority over learning late in life.

One important consequence of this view is that maturational change vs. interactions between early and later learning are extremely difficult, if not impossible, to distinguish, and may in fact be different descriptions of the same process. Researchers studying second-language acquisition have tried to argue against a critical or sensitive period for language acquisition by suggesting that age effects arise from interference of the first language on the second (Flege, 1999; McCandliss et al., 1998). On first consideration it would appear that this argument does not apply as well to the age effects seen in late first-language acquisition (Emmorey and Corina, 1990; Mayberry and Eichen, 1991; Mayberry and Fischer, 1989; Newport, 1990) as to those seen in late second-language acquisition: why should the late acquisition of a first language be limited if there has been no prior learning of another language? However, if one hypothesizes that early linguistic input (or its absence) inexorably narrows the language

systems to what has been experienced, late first- or second-language acquisition should both suffer, and maturational and interference accounts merge. Both accounts share an assumption that early experience has primary foundational effects and thus are both critical period accounts.

Multiple Critical Periods vs. Stimulus Differences in Producing Plasticity

A final issue concerns whether there are multiple critical periods for distinct components of language acquisition, and more generally how to interpret finding different age functions for different types of linguistic properties.

Interaction between Quality of Stimuli and Degree of Plasticity An important and interesting property of critical or sensitive periods is that, as plasticity declines and the critical period comes to a close, strong stimuli may still lead to learning, whereas weak stimuli do not. This was described briefly above, to illustrate the gradual nature of the decline in plasticity at the end of many critical periods. But more generally there is an interaction throughout the critical period between the age or maturational state of the learner and the strength or salience of the stimuli from which the animal might learn. Strong stimuli for which the system is best tuned produce strong learning during the peak of the critical period, continue to produce learning even when the critical period would otherwise be over, and may close the critical period to subsequent learning from weaker stimuli. In contrast, weak stimuli—those from which the system is capable of learning, but which are not preferred—may produce learning during the peak of the critical period but no learning at all during the waning portions of the period.

One example, already described, is that the barn owl can re-calibrate auditory-visual localization when an earplug is inserted in one ear (or when prisms are introduced on the eyes) up to about sixty days of age, but it can re-calibrate back to normal settings, when the earplug (or prism) is removed, up to 200 days (Knudsen, 1988). An even more striking example, discovered only recently, is that these ages limiting plasticity in the barn owl are those derived from procedures allowing the animal to recover in a small individual cage. In contrast, when the owl is allowed to recover in a group aviary, where it can fly and interact freely with other

owls, successful re-calibration after the addition of prisms continues up to 200 days, while successful re-calibration after the removal of prisms can be done throughout life (Brainerd and Knudsen, 1998). In other words, the experience required to produce normal localization abilities changes with age, with much flexibility on environmental requirements for learning in early development but more stringent 'enriched' conditions required for learning in later life. Similarly, sparrows can learn from the playback of recorded sparrow song up to about fifty days of age, but can continue to learn later than this from a live tutor (Baptista and Petrino-vich, 1986; Marler, 1970).

An important consequence of this interaction between the quality of stimuli and the degree of plasticity they produce is that the function relating age of exposure to degree of learning will look quite different when measured for strong, preferred stimuli than for weak, less preferred stimuli, and may give the impression of two quite different timetables for the critical period.

Discriminating Multiple Critical Periods from Complex Interactions between Plasticity, Stimuli, and Task In the language acquisition literature, a number of investigators have found different ages of decline in plasticity for syntax vs. phonology or for other aspects of language (Flege, Yeni-Komshian, and Liu, 1999) and have suggested that there are multiple critical periods for different aspects of language (Flege, Yeni-Komshian, and Liu, 1999; Hurford, 1991; Long, 1990; Scovel, 1988; Singleton, 1989). Even more striking contrasts have been found between the formal (phonological or grammatical) aspects of language vs. those that deal with meaning (semantic or lexical), where the former show strong changes in acquisition over age, while the latter appear to show little or no effect of age of learning (Johnson and Newport, 1989; Weber-Fox and Neville, 1996).

There are well-attested multiple critical periods, arising from separate neural mechanisms, outside of language. For example, in the visual system, the development of acuity, orientation, stereopsis, and photopic vs. scotopic vision show different critical periods for sensitivity to visual experience, and these different developmental timetables correspond to distinct psychophysical and neural subsystems (Harwerth et al., 1986). But

in some areas of vision (e.g., for Vernier acuity vs. grating acuity) there are controversies about whether differences in age effects arise from separate subsystems, or rather result from the differing difficulty of tasks used to measure the function (Skoczenski and Norcia, 1999).

For language, it is not always clear when differing age effects are the result of distinct subsystems, each with its own critical period (or no critical period), and when they are the result of differing degrees of complexity in the linguistic structure tested (or the task used for testing) and therefore different levels of performance in a single critical period function. The contrast in developmental plasticity between formal (phonological and grammatical) vs. semantic aspects of language appears to be widespread and consistent with other types of evidence suggesting separately developing subsystems (Goldin-Meadow, 1978; Newport, 1981; Newport, Gleitman, and Gleitman, 1977). But it is less clear whether there are different critical periods for phonology and syntax. Does phonology appear to show an earlier decline in plasticity, as compared with syntax, because it truly has a different critical period? Or does it show these differences because the aspects of phonology we have tested are more difficult than those we have tested for syntax, or the measurements more refined? Future research will need to consider how to distinguish a contrast across subsystems, displaying different developmental timetables and types of plasticity, from effects of stimulus strength and complexity.

Summary

In sum, the properties of plasticity in language acquisition are similar to those in other well-studied systems believed to display critical or sensitive periods. First, there is a strong relationship between the age at which learners are exposed to a language and the proficiency they attain in its phonological and grammatical structures: early exposure results in peak proficiency, with a gradual decline in proficiency as age of exposure increases. As in other systems, the mean level of proficiency declines with age of exposure, but this effect combines with increasing individual variation as age increases, and with different degrees of proficiency achieved for different aspects of the language, depending on the type or complexity of the construction (in other systems, this is characterized as stimulus strength or preference) and the similarity to other experiences of early life.

Different aspects of language display somewhat different age functions; further research is needed to reveal whether these are separate critical periods or the result of different measures of plasticity at intermediate ages.

Finally, some (few) individuals may achieve native or near-native proficiency even though their exposure to the language does not occur until adulthood. While other systems do show individual variation during the end of the critical period and some remaining plasticity after the critical period closes, it is not common to observe full learning by individuals exposed to the experience only late in life. However, language learning in humans is also unlike imprinting, song learning, or vision in two important ways. First, humans bring many high-level cognitive abilities to the task of learning a language, and might be capable of using systems to acquire a second language other than the ones they use for primary language acquisition. Second, for all but the few case studies of feral children, human language learning late in life is the second (or third or fourth) learning experience in the domain, whereas critical periods in other domains are typically studied by observing learning after extreme deprivation of experience in the domain during early life. The level of proficiency achieved in adult language learning might thus be best compared to studies of adult barn owls whose prisms or earplugs are switched at various ages, rather than to those first exposed to sound during adulthood.

In short, we believe that the acquisition of formal systems in language does show a critical or sensitive period, like that of other well-studied systems.

What Does It Mean to Demonstrate a Critical or Sensitive Period from the Point of View of Overall Issues in Language Acquisition?

One of the reasons discussions of critical periods in language acquisition have been extremely heated is that the demonstration of a critical period for language is interpreted by many researchers to signal or support a particular view of the language acquisition mechanism. As a final note, it may be important to clarify what we think such a demonstration actually means about acquisition, what it leaves open, and what its significance might be for more general issues in language acquisition.

A convincing demonstration of a critical or sensitive period for language acquisition would necessarily entail that some maturational factors are crucial to the acquisition process, and that not every hard-working language learner can achieve native proficiency. It does not, however, support any one particular view of the acquisition mechanism (e.g., the one held by Chomsky, 1965, 1981, 1995, often associated with the concept of a critical period in the language acquisition literature). As already noted, there are often several different accounts of the possible mechanisms underlying a critical or sensitive period in any domain (cf. Bateson, 1979, for discussion of various mechanisms underlying the critical period for imprinting; and Newport, 1990, for discussion of the Less-is-More hypothesis for language acquisition), all of which might be compatible with observing a systematic relationship between age and plasticity. In addition, demonstrating that there is a critical or sensitive period for language acquisition does not show that experiential variables, such as length of experience, similarity between first and second language, or motivation, have no effect on acquisition. Careful studies of age effects have usually tried to match for or eliminate such variables, in order to see whether an age effect remains; but maturational effects in acquisition certainly coexist with effects of experiential variables in real learners. Moreover, as we have discussed above, critical period effects in most domains show strong interactions between age or maturational state and experiential variables like stimulus strength or length of isolation.

The main reason to be interested in whether there is a critical or sensitive period for language acquisition, in our opinion, is because it tells us something about the type of learning involved. It is, of course, a truism that all learning involves both nature and nurture, both biological and experiential factors. But within this obvious generalization, there are at least two broadly different types of systems. Some systems are extremely open-ended, with relatively little specified or favored in advance about how the system will be organized. Such systems typically can be formed or re-formed by experience at virtually any time in life, with little or no relationship between their developmental status and their ability to be molded by new experiences. Other systems, in contrast, are more narrowly predisposed and developmentally tuned. For these systems, certain stimuli are favored in learning (i.e., certain stimuli may naturally be more

salient to learners or require fewer trials to achieve strong learning), and certain states may be the natural "settings" even without stimulus exposure. Most relevant to the present discussion, such systems are often ones with sensitive periods, during which they are open to fairly extensive modification by the environment, but with strong constraints on the developmental moments during which this plasticity is available.

The available evidence suggests that different parts of language may diverge in this dichotomy. It appears that certain basic aspects of the semantic and lexical parts of language may be plastic in the first sense. In contrast (and here there is much more evidence), the formal parts of language appear to be plastic in the second sense, with both favored stimuli and developmental limits on plasticity. To repeat a point already made above, this does not tell us precisely what type of biological mechanisms underlie the acquisition process, or whether (or where) they are entirely specific to language learning or derived from more general serial order or pattern-learning mechanisms. But it does direct us toward some general classes of mechanisms. Most important, it puts the formal aspects of language learning in the large and diverse category of systems—like imprinting in ducks, auditory localization in the barn owl, and song learning in birds—whose neural and behavioral plasticity is beginning to be understood.

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Note

1. Compared with birds reared in isolation from song or ducks reared in isolation from moving objects, even delayed first-language acquisition (the late acquisition of sign language by deaf adults who have no other full language) is relatively more similar to experiences of early life, which typically include exposure to non-linguistic gesture and often the regular use of family home sign systems.

References

- Baptista, L. F., and Petrinovich, L. (1986). Song development in the white-crowned sparrow: Social factors and sex differences. *Animal Behavior*, 34, 1359–1371.
- Bateson, P. (1979). How do sensitive periods arise and what are they for? *Animal Behavior*, 27, 47–48.
- Bialystok, E., and Hakuta K. (1994). *In other words: The science and psychology of second language acquisition*. New York: Basic Books.
- Birdsong, D. (1992). Ultimate attainment in second language acquisition. *Language*, 68, 706–755.
- Birdsong, D. (Ed.) (1999). *Second language acquisition and the critical period hypothesis*. Mahwah, NJ: Erlbaum.
- Birdsong, D., and Molis, M. (2000). *On the evidence for maturational constraints in second language acquisition*. Unpublished manuscript, University of Texas, Austin.
- Brainerd, M. S., and Knudsen, E. I. (1998). Sensitive periods for visual calibration of the auditory space map in the barn owl optic tectum. *Journal of Neuroscience*, 18, 3929–3942.
- Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge: MIT Press.
- Chomsky, N. (1981). *Lectures on government and binding*. Dordrecht: Foris Publications.
- Chomsky, N. (1995). *The minimalist program*. Cambridge: MIT Press.
- Coppieters, R. (1987). Competence differences between native and near-native speakers. *Language*, 63, 544–573.
- Curtiss, S. (1977). *Genie: A psycholinguistic study of a modern-day "wild child."* New York: Academic Press.
- Dehaene, S., Dupoux, E., Mehler, J., Cohen, L., Perani, D., van de Moorlele, P.-F., Leherici, S., and Le Bihan, D. (1997). Anatomical variability in the cortical representation of first and second languages. *Neuroreport*, 17, 3809–3815.
- Eales, L. A. (1987). Do zebra finch males that have been raised by another species still tend to select a conspecific song tutor? *Animal Behavior*, 35, 1347–1355.
- Emmorey, K. (1991). Repetition priming with aspect and agreement morphology in American Sign Language. *Journal of Psycholinguistic Research*, 20, 365–388.
- Emmorey, K., and Corina, D. (1990). Lexical recognition in sign language: Effects of phonetic structure and morphology. *Perceptual and Motor Skills* 71, 1227–1252.
- Flege, J. E. (1999). Age of learning and second-language speech. In D. Birdsong (Ed.), *Second language acquisition and the critical period hypothesis*. Mahwah, NJ: Erlbaum.

- Flege, J. E., Yeni-Komshian, G. H., and Liu, S. (1999). Age constraints on second language acquisition. *Journal of Memory and Language*, 41, 78–104.
- Goldin-Meadow, S. (1978). A study in human capacities. *Science*, 200, 649–651.
- Harwerth, R., Smith, E., Duncan, G., Crawford, M., and von Noorden, G. (1986). Multiple sensitive periods in the development of the primate visual system. *Science*, 232, 235–238.
- Hess, E. H. (1973). *Imprinting: Early experience and the developmental psychology of attachment*. New York: Van Nostrand Reinhold.
- Hubel, D. H., and Wiesel, T. N. (1970). The period of susceptibility to the physiological effects of unilateral eye closure in kittens. *Journal of Physiology*, 206, 419–436.
- Hurford, J. R. (1991). The evolution of the critical period for language acquisition. *Cognition*, 40, 159–201.
- Jia, G. X. (1998). *Beyond brain maturation: The critical period hypothesis in second language acquisition revisited*. Unpublished doctoral dissertation, New York University, New York.
- Johnson, J. S., and Newport, E. L. (1989). Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. *Cognitive Psychology*, 21, 60–99.
- Johnson, J., and Newport, E. L. (1991). Critical period effects on universal properties of language: The status of subadjacency in the acquisition of a second language. *Cognition* 39, 215–258.
- Kim, K. H. S., Relkin, N. R., Lee, K.-M., and Hirsch, J. (1997). Distinct cortical areas associated with native and second languages. *Nature*, 388, 171–174.
- Knudsen, E. I. (1988). Sensitive and critical periods in the development of sound localization. In S. S. Easter, K. F. Barald, and B. M. Carlson (Eds.), *From message to mind: Directions in developmental neurobiology*. Sunderland MA: Sinauer Associates.
- Knudsen, E. I. (1998). Capacity for plasticity in the adult owl auditory system expanded by juvenile experience. *Science*, 279, 1531–1533.
- Krashen, S. D., Long, M. H., and Scarcella, R. C. (1982). Age, rate, and eventual attainment in second language acquisition. In S. Krashen, R. C. Scarcella, and M. Long (Eds.), *Child-adult differences in second language acquisition* (pp. 161–172). Rowley, MA: Newbury House.
- Lenneberg, E. H. (1967). *Biological foundations of language*. New York: Wiley.
- Long, M. (1990). Maturational constraints on language development. *Studies in Second Language Acquisition*, 12, 251–285.
- Marler, P. (1970). A comparative approach to vocal learning: Song development in white-crowned sparrows. *Journal of Comparative Physiological Psychology*, 71, 1–25.

- Mayberry, R., and Eichen, E. (1991). The long-lasting advantage of learning sign language in childhood: Another look at the critical period for language acquisition. *Journal of Memory and Language*, 30, 486–512.
- Mayberry, R., and Fischer, S. D. (1989). Looking through phonological shape to lexical meaning: The bottleneck of non-native sign language processing. *Memory and Cognition*, 17, 740–754.
- McCandliss, B. D., Fiez, J. A., Conway, M., Protopapas, A., and McClelland, J. L. (1998). Eliciting adult plasticity: Both adaptive and non-adaptive training improved Japanese adults' identification of English /r/ and /l/. *Society for Neuroscience Abstracts*, 24, 1898.
- Neville, H. J., Coffey, S. A., Lawson, D. S., Fischer, A., Emmorey, K., and Bellugi, U. (1997). Neural systems mediating American Sign Language: Effects of sensory experience and age of acquisition. *Brain and Language*, 57, 285–308.
- Neville, H. J., Mills, D., and Lawson, D. (1992). Fractionating language: Different neural subsystems with different sensitive periods. *Cerebral Cortex*, 2, 244–258.
- Newport, E. L. (1981). Constraints on structure: Evidence from American Sign Language and language learning. In W. A. Collins (Ed.), *Minnesota symposium on child psychology*. Hillsdale NJ: Erlbaum.
- Newport, E. L. (1990). Maturational constraints on language learning. *Cognitive Science*, 14, 11–28.
- Newport, E. L., Gleitman, H., and Gleitman, L. R. (1984). Mother, I'd rather do it myself: Some effects and non-effects of maternal speech style. In C. E. Snow and C. A. Ferguson (Eds.), *Talking to children: Language input and acquisition* (pp. 109–356). Cambridge, UK: Cambridge University Press.
- Nordeen, K. W., and Nordeen, E. (1997). Anatomical and synaptic substrates for avian song learning. *Journal of Neurobiology*, 33, 532–548.
- Oppenheim, R. W., and Haverkamp, L. (1986). Early development of behavior and the nervous system: An embryological perspective. In E. M. Blass (Ed.), *Handbook of behavioral neurobiology*. Vol. 8. New York: Plenum Press.
- Oyama, S. (1976). A sensitive period for the acquisition of a nonnative phonological system. *Journal of Psycholinguistic Research*, 5, 261–283.
- Pallier, C., Bosch, L., and Sebastián-Gallés, N. (1997). A limit on behavioral plasticity in speech perception. *Cognition*, 64, B9–B17.
- Patkowski, M. (1980). The sensitive period for the acquisition of syntax in a second language. *Language Learning*, 30, 449–472.
- Perani, D., Dehaene, S., Grassi, F., Cohen, L., Cappa, S. F., Dupoux, E., Fazio, F., and Mehler, J. (1996). Brain processing of native and foreign languages. *Neuroreport*, 7, 2439–2444.
- Perani, D., Paulesu, E., Galles, N. S., Dupoux, E., Dehaene, S., Bettinardi, V., Cappa, S. F., Fazio, F., and Mehler, J. (1998). The bilingual brain: Proficiency and age of acquisition of the second language. *Brain*, 121, 1841–1852.

Sanders, L., Yamada, Y., and Neville, H. J. (1999). Speech segmentation by native and non-native speakers: An ERP study. *Society for Neuroscience Abstracts*, 25, 358.

Scovel, T. (1988). *A time to speak*. New York: Newbury House.

Sherman, S. M. (1985). Development of retinal projections to the cat's lateral geniculate nucleus. *Trends in Neuroscience*, 8, 350-355.

Singleton, D. (1989). *Language acquisition: The age factor*. Clevedon, England: Multilingual Matters.

Skoczenski, A. M., and Norcia, A. M. (1999). Development of VEP Vernier acuity and grating acuity in human infants. *Investigative Ophthalmology and Visual Science*, 40, 2411-2417.

Weber-Fox, C., and Neville, H. J. (1996). Maturation constraints on functional specializations for language processing: ERP and behavioral evidence in bilingual speakers. *Journal of Cognitive Neuroscience*, 8, 231-256.

White, L., and Genesee, F. (1996). How native is near-native? The issue of ultimate attainment in adult second language acquisition. *Second Language Research*, 12, 238-265.

Yetkin, O., Zerrin, Y. F., Haughton, V. M., and Cox, R. W. (1996). Use of functional MR to map language in multilingual volunteers. *American Journal of Neuroradiology*, 17, 473-477.

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