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When Do Children Lose the Language Instinct? A Critical Review of the Critical Periods Literature

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Abstract

While it is clear that children are more successful at learning language than adults are—whether first language or second—there is no agreement as to why. Is it due to greater neural plasticity, greater motivation, more ample opportunity for learning, superior cognitive function, lack of interference from a first language, or something else? A difficulty in teasing apart these theories is that while they make different empirical predictions, there are few unambiguous facts against which to test the theories. This is particularly true when it comes to the most basic questions about the phenomenon: When does the childhood advantage dissipate, and how rapidly does it do so? I argue that a major reason for the lack of consensus is limitations in the research methods used to date. I conclude by discussing a recently emerging methodology and by making suggestions about the path forward.

INTRODUCTION

In the early days of modern language acquisition research, there was some question as to whether adults or children were more successful at learning language (Krashen et al. 1979). That question, at least, has been resolved in favor of children (Flege 2019, Mayberry & Kluender 2018, Werker & Hensch 2015). However, on the question of why, there does not appear to have been much progress, at least to judge from recent discussions, in which researchers variously cite greater neural plasticity, greater motivation, more ample opportunity for learning, superior cognitive function, lack of interference from a first language, or something else (e.g., compare Birdsong 2014, DeKeyser 2018, Flege 2019, Hernandez et al. 2021, Hyltenstam 2018, Mayberry & Kluender 2018, and Ullman 2015).

In this review, I argue that it is premature to weigh in on these questions because even the basic contours of the phenomenon remain unclear. One basic sortal that distinguishes accounts of why adults are less successful at learning language is those accounts' predictions about when this effect emerges, and how rapidly it does so. For instance, many accounts tie changes in learning ability to changes in other aspects of cognition (Newport 1988, Ullman 2015), specific physiological changes (Johnson & Newport 1989, Lenneberg 1967), amount of first language known (Hernandez et al. 2005), or other temporally specific phenomena. Many (not all) accounts that point to biological explanations predict a sudden, rapid decline, whereas many that point to environmental causes predict a more gradual decline (for discussion, see Hakuta et al. 2003, Vanhove 2013). Thus, to tease apart these accounts, it is critical to delineate when the childhood advantage dissipates, and how rapidly.

Unfortunately, the most obvious and most widely used methods are sharply limited. As a result, we know surprisingly little about when and where adults' difficulties with language learning emerge. In the next section, I review the most commonly used methods and describe their limitations. I then describe a new, promising method. Finally, I make suggestions about the path forward.

COMMON METHODS AND THEIR LIMITATIONS

Direct Measurement

The most obvious method of comparing adult and child language learning would be to bring them into the laboratory and measure their language-learning abilities in real time. Perhaps surprisingly, in laboratory experiments adults actually learn much faster than do children (Krashen et al. 1979). This result is not merely an artifact of the laboratory setting; in real-life immersion settings, preschoolers lag behind older children and adults even after a year of learning (Snow & Hoefnagel-Höhle 1978). Even among young children, older second-language learners learn faster (Snedeker et al. 2012). In retrospect, this initial advantage for older learners is perhaps not surprising; adults and older children have a variety of explicit and learned strategies for learning, not to mention more ability to stay on task and a better-developed first language to scaffold learning. (Note that no equivalent studies have been reported for late first-language learning, so it remains unknown whether older first-language learners have a similar initial advantage.)

Age-Related Changes in Native Speaker Knowledge

Other researchers have sought to study critical periods by studying early first-language acquisition. In particular, Werker & Hensch (2015) have argued for an early critical period for phonology based on evidence that infants are initially sensitive to a variety of phonemic contrasts but that, by 6–10 months, they selectively attend to phonemic contrasts in the language they are learning. The idea is that infants do not learn phonemic contrasts but rather start with all of them and then

selectively forget. However, the data are equally consistent with an alternative: By 6–10 months, infants have learned something about the phonetics of their language and selectively attend accordingly. That is, the data do not by themselves show that infants have become any worse (or better) at learning. More direct tests of that question come from studies showing that older infants learn previously unattested phonemic contrasts somewhat more slowly than do younger infants (e.g., Maye et al. 2002). However, these findings have to be treated with caution, given that brief laboratory studies of learning tend to not generalize to language learning "in the wild" (see above). In summary, while such studies have been argued to measure critical periods, they can also be explained by other factors and so are ambiguous at best.

Ultimate Attainment Analysis

By far the most popular method—pioneered by Asher & Garcia (1969) and popularized by Johnson & Newport (1989)—involves comparing the linguistic competency of highly experienced users of a language based on their age when they began learning it (**Figure 1*a***). If the proficiency of mature learners (ultimate attainment) declines continuously with respect to onset age, this is interpreted as meaning that learning rate/ability declines continuously with age. In contrast, a sharp discontinuity (e.g., with ultimate attainment falling off dramatically after some onset age X) is taken to mean a sharp discontinuity in learning ability/rate as a function of age. This method has been applied widely to both syntax learning and phonology learning.

While intuitive, this logic does not hold. Ultimate Attainment Analysis is useful for determining the age at which learning must begin in order to reach native-like proficiency. However, by measuring learning with a number (ultimate attainment), the actual trajectory of learning is obscured (**Figure 1**). Intuitively, just as knowing an adult's current height tells you very little about how quickly that individual was growing at any given age during childhood, knowing their current knowledge of a language does not tell you when they learned it or how quickly. This intuition is detailed quantitatively by Hartshorne et al. (2018), who show that the results of any given Ultimate Attainment Analysis are consistent with a number of theoretically distinct proposals about how language-learning ability changes with age.

For example, Hakuta et al. (2003) report that ultimate attainment declines continuously with age at immigration, which they treat as a proxy for age at onset of learning. This finding is

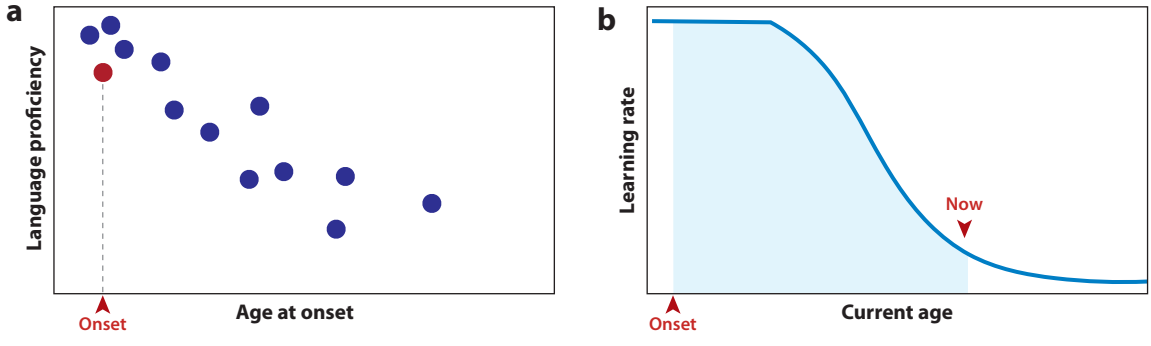

Figure 1

A common method of studying critical periods is to compare subjects' language proficiency scores against the age at which they began learning the target language (*a*). The results do not directly reflect how quickly the subject was able to learn at the age of onset. Rather, their current score is related to an integral under the learning rate curve from age of onset until the present day (*b*). The relationship is further obscured by ceiling effects: There is only so much language to learn.

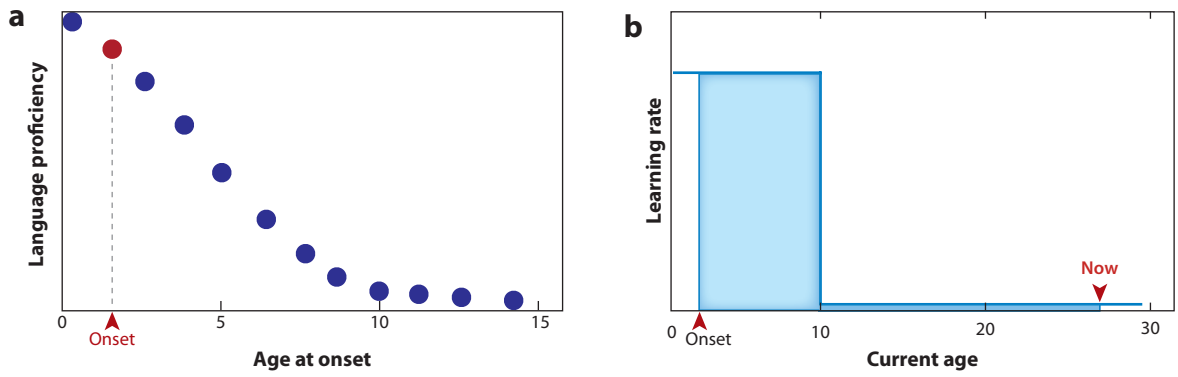

Figure 2

Although a continuous decrease in ultimate attainment (*a*) is often interpreted as meaning a steady decrease in learning ability/rate, this need not be the case. Suppose it takes 10 years to fully acquire a language, and the ability to learn drops sharply at age 10 (*b*). This will result in the steady decline in ultimate attainment for learners who begin learning between ages 0 and 10 observed in panel *a*.

consistent with learning ability/rate declining continuously from birth (their preferred interpretation), but it is also consistent with a sharp drop at age 10 (**Figure 2**). To see why, suppose that learners asymptote after 10 years of experience with the target language. For native speakers, all 10 of those years will be at the high initial learning rate. Individuals who begin learning at age 1 will have only 9 years at the high initial rate and so will achieve a slightly lower ultimate attainment. Individuals who begin at age 2 will have only 8 years and fare even worse. And so on.

Conversely, consider Mayberry & Eichen's (1991) finding that deaf children who were not exposed to language until 4–6 years of age performed significantly worse than native speakers in a sentence repetition task. This result is consistent with any of the following scenarios:

- Children's ability to learn language stops abruptly at age 3, but only 2 years of learning is required for mastery.
- Children's ability to learn language stops abruptly at age 10, but 14 years of learning is required for mastery.
- Children's ability to learn language declines continuously from birth, with more time required to reach mastery for learners who start at age 1, even more time for learners who start at age 2, and yet more time for learners who start at age 3; learners who start at age 4 "age out" of the study before reaching native-like mastery.

Indeed, Hartshorne et al. (2018), using a method described below (see the section titled A New Option: Learning-Curve Modeling), found that second-language learners needed to start learning English by approximately age 10 in order to reach native-like proficiency, but that the actual rate of learning did not decline until approximately age 17.

Johnson & Newport (1989) introduced a second form of Ultimate Attainment Analysis to identify the age, if any, at which language-learning ability ceases to decline. The idea is that for learners who begin learning after that age, it should not matter how long after: There is no difference between starting to learn 2, 5, or 20 years after the closure of the critical period. While the logic is sound, this analysis cannot answer questions about the age at which learning begins to decline or how rapidly it does so, and thus provides only a weak constraint on theory. In any case, different researchers have obtained very different results using similar methods, probably due in part to low power (Hartshorne et al. 2018, Vanhove 2013).

Both types of Ultimate Attainment Analysis are also subject to a potential confound. A critical part of the technique involves identifying learners who are at asymptote and no longer gaining proficiency. Otherwise, early learners may outperform later learners simply because, all else equal, they have had more practice with the target language. However, if there is no improvement in proficiency after *X* years, then we can ignore years of experience so long as all subjects have used the target language for at least *X* years. Unfortunately, this only works if a sufficiently large *X* is chosen, which has generally not been the case.

For instance, Hakuta and colleagues (2003), who analyzed self-report English proficiency recorded by the US Census, set *X* at 10 years. However, analysis of census data shows that these proficiency ratings do not reach asymptote even after 40 years (Stevens 1999).[1] This finding is perhaps not surprising, since the census data are a holistic assessment of linguistic knowledge, and individuals' knowledge of vocabulary, at least, is known to continue to improve into their retirement years (Hartshorne & Germine 2015).

Researchers investigating critical periods specifically in syntax have applied thresholds of anywhere from 2 to 16 years (Hartshorne et al. 2018, figure 5), whereas subjects do not reach asymptote on comprehension exams (the primary method for assessing syntax in this literature) for about 30 years (Hartshorne et al. 2018). Frank (2018) questions whether this is an underestimate, arguing on theoretical grounds that there should not be an asymptote for syntax knowledge. In any case, Hartshorne and colleagues (2018) report simulations quantifying how much this confound distorted prior reports, showing that it likely accounts for at least some of the discrepancies between studies (low statistical power is likely a larger factor; see below).

The sum effect of these considerations is to preclude any conclusions from ultimate attainment studies about differences in child and adult learning success other than that children are generally more successful.

Interim Summary

Many of the debates about critical periods have revolved around questions about the phenomenon itself: At what age do individuals start learning less successfully? How quickly does this ability tail off? What aspects of language does it affect? For second-language learning, does it matter how similar the first and second languages are? Prior studies have supported wildly varying conclusions, probably because of very low statistical power (Hartshorne et al. 2018, Vanhove 2013). However, increasing statistical power would not by itself solve the problem, since the most common methods suffer from insuperable confounds that render their results uninformative with respect to the key questions raised above.

A NEW OPTION: LEARNING-CURVE MODELING

Recently, Hartshorne and colleagues have developed an alternative method that addresses the limitations described above (Chen & Hartshorne 2021, Hartshorne et al. 2018). The first step is to measure the linguistic proficiency of a large number of learners who began learning at different

[1] Curiously, Hakuta and colleagues justify their choice of 10 years based on analyses by Stevens (1999), who they report "found that her sample of immigrants reached asymptotic levels of self-reported English proficiency after 10 years" (Hakuta et al. 2003, p. 32). I was unable to identify the source of this claim. In fact, Stevens (1999, p. 573) reports that "the probability of immigrants speaking English 'very well' steadily increases past two decades of residence," and her figures 2 and 6 both show clear effects of age through the entire analysis window of just under 40 years.

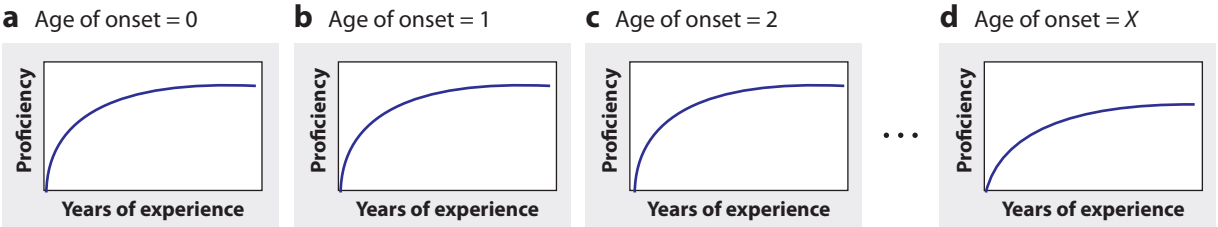

Figure 3

Four learning curves plotting language proficiency against number of years spent learning the language. These curves can be based on cross-sectional or longitudinal data. The curves may be identical for learners who began learning at age 0, 1, or 2, but there is necessarily some age *X* such that the learning curve is more shallow (otherwise, adults would be as successful at learning as children are). Learning-Curve Modeling reconstructs the empirical learning curves based on latent variables, including one that represents the individual's language-learning ability as a function of their age.

ages and have been learning for varying lengths of time. From this, we can construct empirical learning curves conditioned on the age at onset of learning (**Figure 3**). We then fit these data to a novel analytic model. The mathematical details can be found in the original papers (Chen & Hartshorne 2021, Hartshorne et al. 2018), but the intuition is that how quickly somebody learns depends on (*a*) how much there is left to learn (initially, they learn quickly but slow down as there is less left to learn), (*b*) the proportion of their input that is in the target language, and (*c*) a rate parameter *r* that depends on age.

Hartshorne and colleagues (2018) applied this model to data from 700,000 respondents to an online English grammar quiz. In the quiz, subjects judged the grammaticality of sentences like *I told the story* and *The people is angry*. The authors' analysis suggested a sharp drop in *r* (the age-dependent learning rate) at around 17 years of age. This finding was more recently confirmed by Chen & Hartshorne (2021) based on an extended data set of 1.1 million subjects and a more precise model. Both models fit the data extremely well, mitigating the standard concern about model-based results: that they depend on the quality of the model (for discussion, see Frank 2018; Chen & Hartshorne 2021).

Prior estimates of the age at which learning ability for syntax declines ranged widely from "birth" to "never" (see Hartshorne et al. 2018). The fact that none prior to Hartshorne and colleagues (2018) had pegged late adolescence/early adulthood illustrates just how misleading the traditional methods are.

The biggest limitation of this work is that so far it has been applied to only one data set. That is, we know that the ability to learn syntax as a whole declines precipitously at around 17 years of age. Beyond that, nothing can yet be known. The structure of the stimuli used in the studies by Hartshorne and colleagues (Chen & Hartshorne 2021, Hartshorne et al. 2018) did not allow the authors to test whether their findings apply to all of syntax or only certain parts, or whether in fact there are different critical periods for different aspects of syntax that simply average to what was detected by Hartshorne and colleagues. The diverse subject pool did not allow for clear comparison of learners whose first language was more or less similar to English. Finally, the method has not yet been applied to critical periods in phonology or word learning.

A hurdle in running more studies is that this method requires large numbers of subjects. That said, it is easy to underestimate how many subjects are required for run-of-the-mill analyses (Bakker et al. 2016). For instance, a common analysis in the critical periods literature is to ask whether a certain group of later learners is indistinguishable from native speakers. This requires interpreting a null result. While the dictum that null results are uninterpretable is not quite right (Sainani 2013), it is true that null results are informative only if the study has enough

statistical power to reliably detect an effect if there is one. Vanhove (2013), following Sedlmeier & Gigerenzer (1989), suggests obtaining at least 95% power. Vanhove (2013) notes that to obtain that level of power to rule out an average-sized effect requires 105 subjects per condition—an order of magnitude more than what is typically used. A reasonable threshold for the smallest effect of theoretical significance is one-twentieth of a standard deviation (e.g., the average late learner scoring worse than 52% of native speakers), which would require 10,397 subjects per condition.[2] While 20,000 subjects is fewer than 700,000, it is still more than one can feasibly test in the laboratory, so either way, new methods are needed. I return to this point in the next section.

NEXT STEPS

Above, I have painted a gloomy picture of the current state of knowledge. Despite half a century of research, we know fairly little about when and where older learners struggle to acquire language, much less why. The glass-half-full viewpoint is that the half-century of research has bequeathed us with well-articulated questions, and we now have a robust method for answering (some of) those questions.

While the massive online data set reported by Hartshorne and colleagues (Chen & Hartshorne 2021, Hartshorne et al. 2018) is unusual in the context of critical periods research, massive online studies have become increasingly common as researchers develop increasingly robust paradigms for running them (Germine et al. 2012, Hartshorne 2020, Hartshorne et al. 2019, Miller 2012, Reinecke & Gajos 2015). They are also not the only way to obtain large data sets. Indeed, massive data sets of language learning already do or could exist, including data collected by governments, schools, standardized testing groups, immigrant relocation programs, and language-learning apps (Berzak et al. 2014, Hakuta et al. 2003, Schepens et al. 2020, Stevens 1999, von Ahn 2013). These resources have been significantly underused.

Massive data sets are of course only part of the solution. A difficulty facing critical periods research that I have not yet discussed is that many of the theoretically important factors are difficult if not impossible to deconfound. Individuals who begin learning a second language at different ages typically do so for different reasons (e.g., entry into school, immigration, employment opportunities), in different venues (e.g., on the playground, at work, in school), and with varying degrees of explicit instruction, deliberate study (e.g., flashcards), and motivation (older adults have a well-developed first language and will, for actuarial reasons, derive less benefit from learning a new one) (Birdsong 2018, Flege 2019, Pfenninger & Singleton 2019, Singleton 2005). More broadly, adult second-language learners have more leeway to choose their linguistic environment: Most younger immigrants must attend school in the local language, whereas adults may seek out neighborhoods, jobs, and friendships with others of the same linguistic background. There are related confounds for age of first-language learning: Most later learners are deaf individuals not born to signing parents and thus are usually not acquiring language at home from native-speaking caregivers. Any of the factors mentioned in this paragraph might distort age-related differences in language learning.

Because these factors cannot be easily isolated, another strategy is to measure them and model their interaction. This is the approach taken by the Learning-Curve Modeling method to disentangle current age, age at onset of learning, and years of experience—three numbers that are linearly related. Similarly, one could measure differences in inputs to adult and child learners

[2]This sentence roughly follows an argument I first read in a paper that I cannot now find. I regret the lack of the citation.

(cf. Flege 2019) and incorporate those differences in a principled way into the analytic model to test its importance.

We have good questions and well-developed theories. What we need now is robust data.

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