Revisiting a critical period for syntax in a second language: New analyses provide the same results

People who begin learning a language in adulthood are often saddled with an accent and conspicuous grammatical errors. The question of *why* has been subject to intense investigation, without much agreement. Does children's advantage come from superior neural plasticity, an early start that gives them additional year of learning, limitations in cognitive processing that prevent them from being distracted by irrelevant information, a lack of interference from a well-learned first langauge, a greater willingness to experiment and mae errors, a greater desire to conform to their peers, a greater likelihood of learning through immersion in a community of native speakers, or something else?

One reason these possibilities have been hard to disentangle is that, until very recently, researchers were unable to measure when the ability to learn syntax begins to change. Instead, researchers have focused on tangential questions like the age at which someone must start learning a new language in order to eventually reach native-like proficiency (e.g., Johnson & Newport, 1989). Unfortunately, it can be shown that such data have no bearing on the core question of when children begin to lose the ability to learn syntax (Hartshorne, Tenenbaum, & Pinker, 2018).

Hartshorne, Tenenbaum, and Pinker (2018; henceforth HTP) addressed this issue through the combination of a massive dataset — syntax test results for 669,498 English learners — and a novel analytic model designed to disentangle the age at which the individual began learning English, their current age, the number of years they had been learning English, and whether they learned in an immersion context. Specifically, they modeled syntax acquisition as a simple exponential learning process:

$$g(t) = 1 - e^{\int_{t_e}^{t} -Erdt} \tag{1}$$

where g is grammatical proficiency, t is current age, t_e is age of first exposure, r is the learning rate, and E is an experience discount factor, modeled separately for monolinguals, simutaneous bilinguals, immersion learners, and non-immersion learners. Critically, r is allowed to vary as a function of age:

$$r(t) = \begin{cases} r_0 & t \leq t_c \\ r_0(1 - \frac{1}{1+e^{-\alpha(t-t_c-\delta)}}) & t > t_c \end{cases} \tag{2}$$

where r_0 is the initial learning rate for children, which begins to decline sigmoidally at critical age t_c, with shape parameters α and δ. (t_e is age of exposure.) The model inferred a sharp, discontinuous drop in learning rate at 17.4 years old.

We re-analyzed the (publicly available) dataset to address concerns raised by Frank (2018) and others. First, HTP treated (elogit-transformed) test accuracy as a measure of each subject's syntactic knowledge. Frank (2018) suggests instead applying a psychometric Item Response Theory (IRT) model to the data, which would result in a more precise estimate of syntactic knowledge. Second, one may reasonably worry that HTP's observation of a discontinuity at 17.4 years could be an artifact of (2), which cannot represent a sharp but continuous decline that later tapers off (see Fig. 1). Thus, we replaced (2) with a function that glues together two sigmoids, a more flexible option that can infer a wider variety of shapes (Fig. 1):

$$r = \begin{cases} r_0(1 - \frac{1}{1+e^{-a_1(t-t_e-d_1)}}) & t \leq t_a \\ r_0(1 - \frac{1}{1+e^{-a_2(t-t_e-d_2)}}) & t > t_a \end{cases} \tag{3}$$

where:

$$t_a = \frac{a_1 * d_1 - a_2 * d_2}{a_1 - a_2} \tag{4}$$

Both improvements to the analysis cause slight changes to the results, but without changing the headline: a fairly sharp decline starting around 17-18 years (Figs. 2-3; Table 1). Thus while we believe the new analyses present a step forward in precision, the results should increase confidence in the robustness of HTP's findings. We discuss other potential concerns about analysis of critical period data and how they might be addressed.

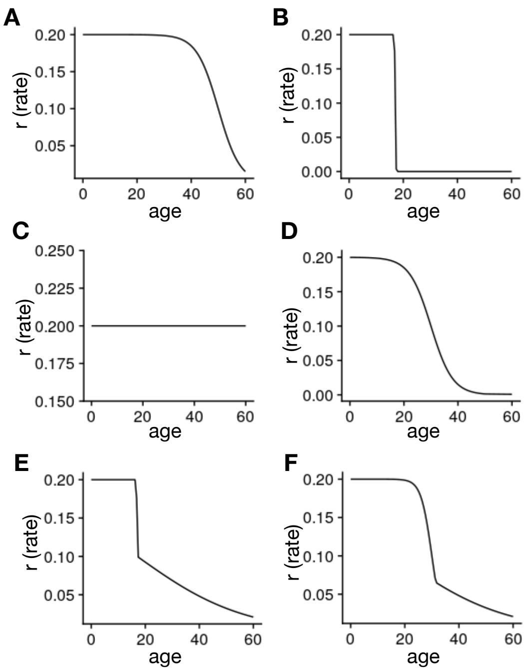

Figure 1: HTP's model could learn functions for r with a number of shapes (Panels A-E). However, it was incapable of inferring a rapid and continuous decline followed by a more gentle decline (Panel F; compare witih Panel E). The revised learning rate equation (3-4) can capture all of the above shapes, among others.

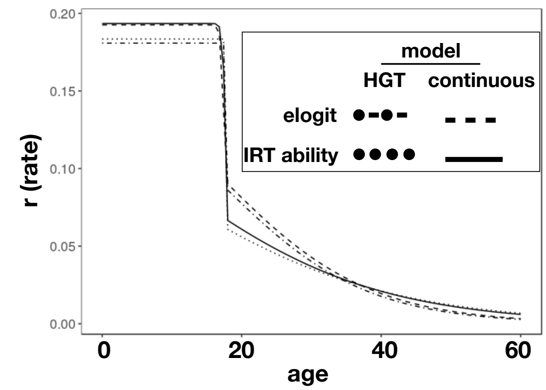

Figure 2: Inferred age-related changes in learning rates, using the original HTP learning rate model or the new model, and using accuracy or IRT-inferred ability.

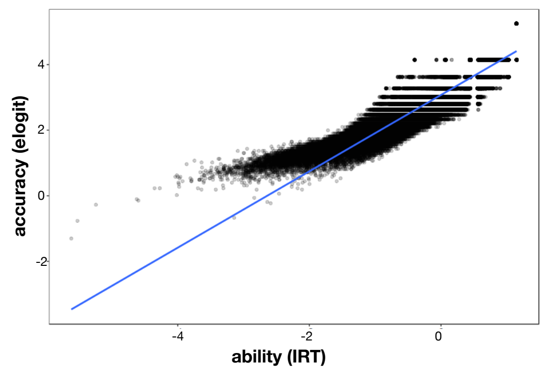

Figure 3: Accuracy (empirical logit) vs. ability as inferred by a 3-factor Item Response Theory model. The correlation is less than 1 because IRT weights each test item according to its (inferred) informativeness.

Ability Estimate	Model Type	R^2	age at 90% of max	age at 95% of max	age at 99% of max
Elogit	HTP	.911	17.8	17.8	17.8
Elogit	continuous	.911	17.1	16.95	16.5
IRT	HTP	.902	17.7	17.7	17.7
IRT	continuous	.902	17.3	17.1	16.7

Table 1: Table of R^2 values and critical period inferences for the four analyses. Note that while HTP's model infers a specific age at which learning rate begins to decline, the new continuous model declines at all ages, albeit potenitally very slowly. Thus, to compare the models, we found the age at which learning rate falls to 90%, 95%, or 99% of the learning rate at birth.

References **Frank, M. C.** (2018). With great data comes great (theoretical) opportunity. Trends in cognitive sciences. **Hartshorne, J. K., Tenenbaum, J. B., & Pinker, S.** (2018). A critical period for second language acquisition: evidence from 2/3 million English speakers. Cognition, 177, 263-277. **Johnson, J. S., & 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(1), 60-99.