

## Age-related changes in implicit causality and consequentiality pronoun biases

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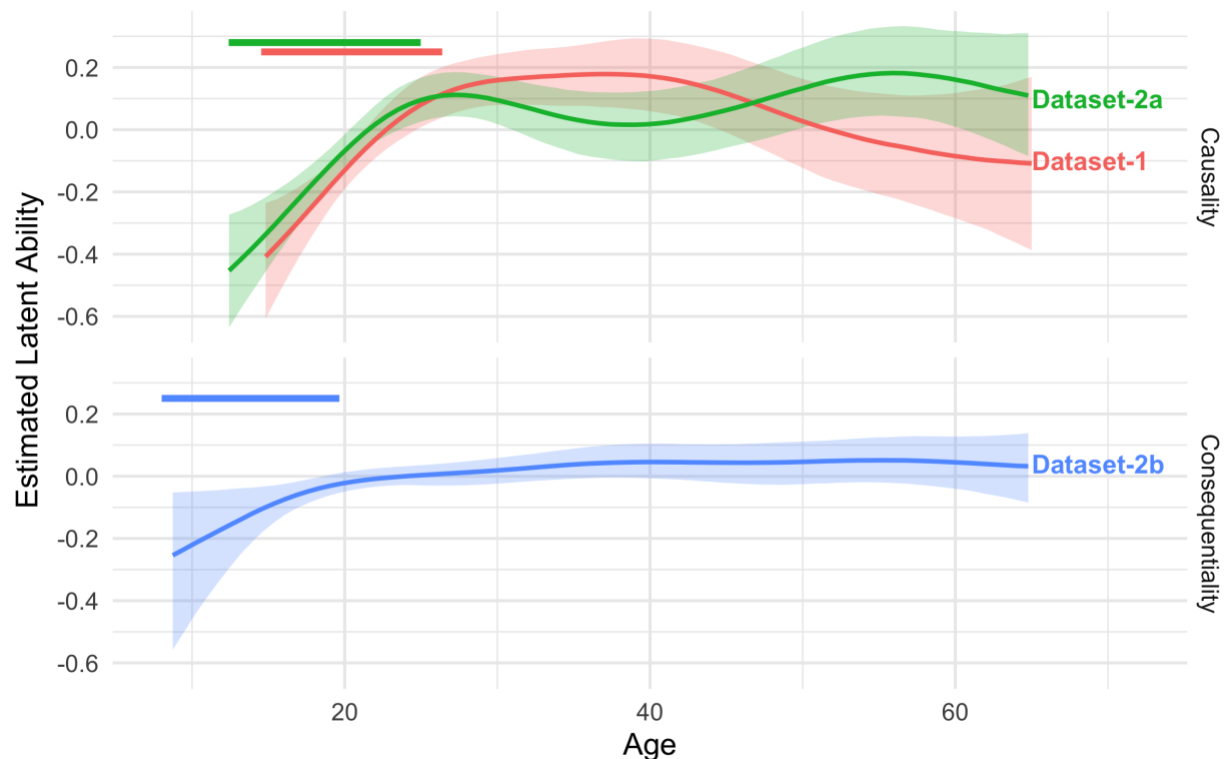
In contrast to other domains of language, later in development discourse-level learning remains largely unexplored. Pronouns offer a particularly useful window into discourse-level learning because they involve the generation of high-level inferences driven by the interplay of syntactic, semantic, and pragmatic discourse factors. We show that mastering this interplay involves a strikingly protracted learning trajectory, focusing on two well-studied pronoun interpretation biases: implicit causality and implicit consequentiality.

When adults encounter pronouns in sentences like “Sally frightened Mary because she...”, they typically resolve the pronoun to the inferred cause of the event, a phenomenon called implicit causality. Similarly, in sentences like “Because Sally frightened Mary, she...”, pronoun interpretation often reflects the inferred consequence of the event, known as implicit consequentiality.

**Methods.** We reanalyzed two publicly-available massive online cross-sectional studies: Dataset-1 included 1,074 native English-speakers from 16- to 66-years-old from Hartshorne & Snedeker (2013). Dataset-2 included 2,581 native English speakers from 8- to 73-years-old from Hartshorne et al. (2015). Dataset-1 examined the implicit causality pronoun bias, while Dataset-2 examined both implicit causality (Dataset-2a) and consequentiality (Dataset-2b) pronoun biases. For all experiments, participants read explanations (*A because B*) where the second clause included a pronoun that could not be disambiguated by gender or number (Dataset-1: *Sally VERBed Mary because she is a dax.*; Dataset-2a: *Sally VERBed Mary because she daxed.*; Dataset-2b: *Because Sally VERBed Mary she daxed.*). The verb was manipulated within and between subjects (265 verbs in Dataset-1, 502 verbs in Dataset-2). Participants were asked to identify the referent of the pronoun in each sentence. Responses were scored as 1 if they matched the modal response and 0 otherwise, yielding a measure of convergence with community-level pronoun interpretation.

**Results.** Because items varied across participants, we normalized differences in item difficulty across subjects using a 2-parameter item response theory model (Burkner, 2021; Frank, 2018). Following Erb et al. (2023), a thin-plate spline term was used to model non-linear effects of age and calculate the local slope of the curve. Each interval in which the 95% Credible Interval of the slope estimate did not overlap 0 represents significant developmental change. Dataset-1 and Dataset-2a showed significant improvements from childhood into the mid-20s and steady performance thereafter, though this was not strictly significant at the youngest ages tested, likely due to small samples and correspondingly greater uncertainty. Dataset-2b showed significant improvement from childhood until approximately age 20. Thus, implicit causality peaked slightly later in development than implicit consequentiality.

**Conclusions.** Across two datasets, we find that sensitivity to implicit causality and consequentiality in pronoun interpretation increases through middle childhood and adolescence, stabilizing only in early adulthood. This implies that the representations that support these biases also develop into early adulthood. Competing theoretical accounts make different predictions as to the source of this change, including event knowledge (Koornneef & Van Berkum, 2006), argument and discourse structure (Hartshorne & Snedeker, 2013), language statistics (Arnold, 2001). Future work could exploit these differences to make finer-grained predictions of later-learning trajectories, thereby clarifying the mechanisms underlying these pronoun interpretation biases. We will discuss these findings in terms of emerging evidence for protracted language development more broadly.



**Figure 1.** Estimated latent ability across age. Shading represents 95% credible intervals. Horizontal bars show age ranges where the estimated change in ability was significant.

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