gonadectomized before puberty exhibited higher levels of play behavior, pointing to a functional role for the immature gonad in juvenile social behaviors (Paul et al., Figure 3 in [6]).

Prior work has categorized some changes in behavior and neural circuitry that emerge in adolescence as puberty-dependent (anxiety, altered ethanol intake, sex behavior, size of brain nuclei) or puberty-independent (social play, aggression; see [5] for review). The work described by Paul et al. [6] refines these classifications in substantial ways: first by elaborating them in a naturalistic manner, and also by identifying features of the hormonal environment that compel us to frame the question as less dichotomous. Rather than an either/or issue, the data show that it is the coordinated actions between these two classes of mechanisms that best characterize adolescent social development: puberty-independent processes regulate the timing of transitions, whereas puberty-dependent changes in hormone concentrations dial in absolute levels of behavior. Future utilization of this model system should materially advance specification of the substrates that mediate social behavior transitions at puberty.

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Word Learning: Associations or Hypothesis Testing?

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Children learn thousands of words in the first years of life, but the process supporting this feat is largely unknown. New neuroimaging results indicate that learning a word may be sudden rather than gradual, supported by hippocampal memory.

Our language ability is one of the most defining cognitive characteristics of humans. Yet language is not innate, but learned: infants learn to distinguish and then produce sounds of the language heard around them, and are soon learning words almost daily — even ones we don't especially mean to teach them. Much of this learning seems to be effortless in children, brought on simply through exposure to ordinary everyday interactions with caregivers and other
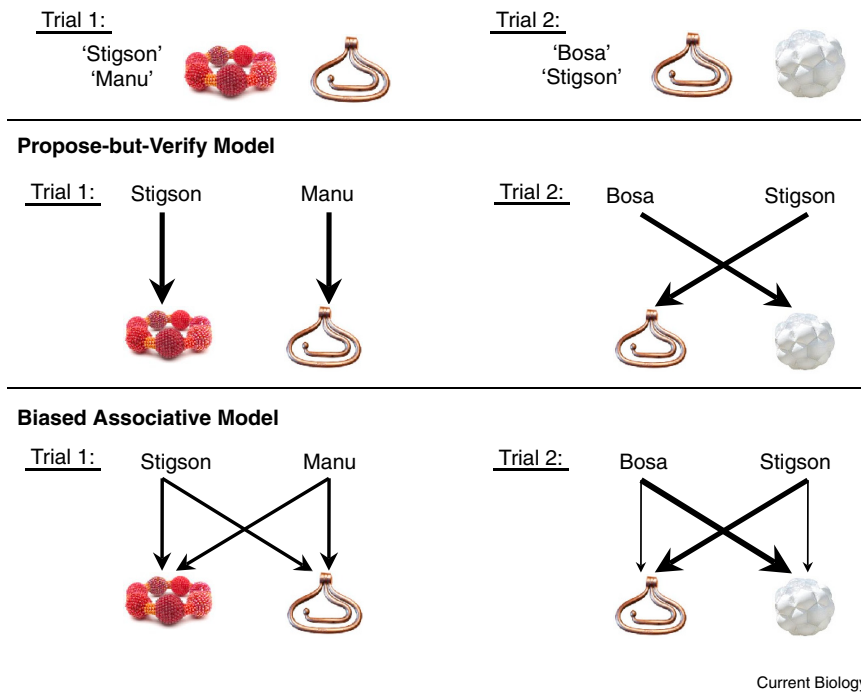
Figure 1. Disambiguating word meanings via hypotheses and associations.
Example of two trials (top), each showing two words and two objects, from which three word–object pairs can be learned cross-situationally. The propose-but-verify hypothesis-testing model makes an initial guess about the meaning of each word on trial 1, and then corrects the incorrect hypothesis for 'stigson' on trial 2, and correctly maps 'bosa'. The biased associative model equally associates each word with each referent on trial 1, and then focuses extra attention on both the familiar 'stigson' mapping, as well as on the novel 'bosa' mapping.

children. One way that children can learn a given word's meaning is by noticing which referents appear repeatedly with that word, across varying situations. For example, a parent may point out a bird in the sky to a child ("Look, a hawk!"), and the next day may see one perched in a tree ("See the hawk?"). If the child can recall what was common between the two scenes (the hawk) and the two utterances ('hawk'), she may learn the intended meaning. Adults may also leverage this cross-situational learning ability to learn words in a foreign language. A new study by Berens, Horst, and Bird [1] reported in a recent issue of *Current Biology* gives us a glimpse of adults' brains learning words *in vivo*, giving new insight into an age-old debate about how words are learned.

Both infants and adults are able to disambiguate word meanings across situations in the laboratory (e.g., [2,3]), but the learning mechanism remains a matter of debate. In one view, the problem of word learning is a vast inference problem, requiring learners to

first hypothesize the intended meaning of a word and subsequently verify or amend that hypothesis with more experience [4,5]. In this view, for each unknown word a learner will select a single referent from a given situation, perhaps limited by logical constraints (e.g., not selecting a referent that is already mapped to another word). This hypothesis-testing view of word learning is used in the formal analysis of language acquisition (e.g., [6]), and stems from logic-based approaches to human concept learning [7] and a long line of inferential methods in the philosophy of science. Many developmental theories of language acquisition are built upon a rationale of hypothesis testing (e.g., [8,9]). One common intuition among these approaches is that the world and perhaps the language environment are far too complex (cf. [10]) for learners to be able to store, track, and update a multitude of associations between words and referents (e.g., [4]). In the propose-but-verify model of word learning [5], when encountering a new word the

model chooses a single hypothesized object to store (Figure 1). When a word is heard again, the previous guess is recalled with some probability. If the recalled hypothesis is present on the trial, the probability of future recall is increased. If the object fails to be recalled, or is recalled but not present, a new referent is selected from objects that are not currently linked to a word. The propose-but-verify model is thus a hypothesis-testing model, storing only a single hypothesized referent for each word, and correcting them as needed.

Another class of theories holds that language acquisition operates based on the same associative learning mechanisms that operate in non-linguistic domains [11–13]. These accounts appeal to the wide array of models that explain much about human and animal learning using multiple graded associations between cues and outcomes. These models store and update associations between all co-occurring words and referents in a scene, approximately tracking correlations between each word and all referents. In the biased associative model of word learning, attention is drawn to words/referents that are already familiar and well-known, as well as to stimuli with uncertain mappings (e.g., novel ones) [11]. Thus, although all associations are registered to some extent, extra attention to some word-referent pairings can make learning faster in some cases, as when a new word–referent pair is introduced alongside a familiar pair (Figure 1, bottom) [11]. Although early learning in associative models is gradual, as all words become associated with all referents, as contexts begin to vary more in overall familiarity, learning for a given pair may become sudden, mimicking the inference of hypothesis-testing models. With their ability to track all co-occurring words and referents, associative models may sound more powerful than single-hypothesis models, but the host of associated referents for each word (or referent) often serves to make it difficult to identify the intended referent (or word).

A variety of behavioral studies have investigated whether hypothesis-testing or associative models better account for human word learning,

sometimes finding evidence in favor of multiple associations [14,15], and other times in favor of single hypotheses [4,5]. The present study [1] for the first time uses functional MRI data collected during a cross-situational word learning task to weigh in on the issue. By examining the similarity of neural representations for learned and unlearned words over time, Berens *et al.* [1] assessed whether learning looked more gradual, as proposed by associative accounts, or rapid, as predicted by hypothesis-testing accounts. The analyses specifically compared the predictions of the biased associative model [11] and the propose-but-verify [5] hypothesis-testing model, and found that patterns of activity in the left hippocampus were consistent with the propose-but-verify model. Their analysis also indicated involvement of brain areas that are implicated in working memory, attention, and reward processing tasks, which often require explicitly forming associations [16]. By combining behavioral and neuroimaging data with model-based analyses, Berens *et al.* [1] offer evidence that a hypothesis-testing mechanism mediated by the hippocampus may underlie cross-situational word learning. Indeed, 10 of the 19 participants reported using a strategy related to hypothesis-testing, while others did not report any particular strategy.

The present study paves the way for further studies that are needed to integrate these findings with earlier behavioral results. The design of the behavioral experiment was constrained significantly by the demands of the fMRI analysis. As such, the experiment included only a small number of words and objects (9) for learning, presenting each of them quite often during training (18 times), although most of them were learned within the first quarter of training. It may be that learning such a small number of words and objects engages a different learning process than is used

when more words and referents must be tracked — as in other behavioral experiments (e.g., [3,11,14,15]), and as is surely the case in real-world learning contexts. A larger number of stimuli may make it harder for adult learners to engage an explicit hypothesis-testing strategy, which may be a strategy that is either unavailable to or not used by child word learners. Finally, the need to pre-familiarize all of the words and objects before the training procedure makes the learning process less like previous evaluations of the models, where the novelty of stimuli during training might draw attention to particular associations, as assumed in some models [11,12]. It may be that gradual learning of multiple associations takes place in some of these contexts, or even simultaneously alongside explicit hypothesis-testing. Future studies should include a larger set of stimuli, with a range of familiarity, perhaps by varying the number of repetitions. The apparent involvement of the hippocampus raises questions about how memory supports cross-situational word learning: are single word-referent hypotheses stored, or does the representation include contextual information? Memory ability has been shown to be related to children's word learning ability [17], but the nature of the dependency is not understood. Nonetheless, this first glimpse at the brain doing cross-situational word learning granted by Berens *et al.* [1], characterized by a rapid representational shift in the hippocampus, already does much to inform theories of word learning.

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