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Brief article

Consistent and cumulative effects of syntactic experience in children's sentence production: Evidence for error-based implicit learning

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ABSTRACT

Error-based implicit learning models (e.g., Chang, Dell, & Bock, 2006) propose that a single learning mechanism underlies immediate and long-term effects of experience on children's syntax. We test two key predictions of these models: That individual experiences of infrequent structures should yield both immediate and long-term facilitation, and that such learning should be consistent in individual speakers across time. Children (and adults) described transitive events in two picture-matching games, held a week apart. In both sessions, the experimenter's immediately preceding syntax (active vs. passive) dynamically influenced children's (and adults') syntactic choices in an individually consistent manner. Moreover, children showed long-term facilitation, through an increased likelihood to produce passives in Session 2, with speakers who were most likely to immediately repeat passives in Session 1 being most likely to produce passives in Session 2. Our results are consistent with an error-based syntactic learning mechanism that operates across the lifespan.

1. Introduction

Children's syntax is affected by their syntactic experiences, over a range of timescales. For example, children's acquisition of syntactic structures is affected by the structures' frequency not only within the language as a whole (e.g., Brandt, Diessel, & Tomasello, 2008; Kidd, Lieven, & Tomasello, 2010), but also within their individual caregivers' speech weeks or months earlier (Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Naigles & Hoff-Ginsberg, 1998). Equally, children are more likely to use a syntactic structure if they have had multiple experiences of that structure within the last month (Savage, Lieven, Theakston, & Tomasello, 2006) or the current conversation (Huttenlocher, Vasilyeva, & Shimpi, 2004), or even an individual experience of it in the previous utterance (Messenger, Branigan, McLean, & Sorace, 2012; Rowland, Chang, Ambridge, Pine, & Lieven, 2012). In this paper we investigate the proposal that these apparently disparate effects may reflect a common syntactic learning mechanism.

Although immediate effects of individual syntactic experiences can be explained in terms of transient fluctuations in the accessibility of syntactic structures (e.g., Pickering & Branigan, 1998), such an explanation is not compatible with long-lasting and cumulative effects of experience, which instead appear to implicate long-term changes to the syntactic system (e.g., Chang, Dell, & Bock, 2006; Reitter, Keller, & Moore, 2011). Chang et al. (2006) proposed that both immediate and long-term effects arise from a single error-based implicit learning mechanism.

In their Dual Path model, proposed to account for both children's acquisition of syntax and the tendency for (child and adult) speakers to repeat syntax across utterances (*syntactic priming*; Bock, 1986), the processor comprehends sentences by predicting the next word. It uses the difference (*error*) between the predicted and actual next word to adjust weights associated with syntactic knowledge in the underlying system, improving subsequent prediction accuracy. Less frequent (hence more unexpected) structures yield greater error than more frequent structures; they therefore cause a greater adjustment to the system. Weight adjustments persist until another related sentence is processed that gives rise to new adjustments. Each additional experience of a structure iteratively yields further adjustments, until ultimately the model's predictions accurately reflect the statistics of the input. Thus each experience of a structure immediately raises the likelihood of that structure's subsequent use, and the effects of multiple experiences accumulate over time.

The precise weight adjustments (hence, extent to which individual experiences affect subsequent behaviour) are determined by an individually-determined learning rate parameter. Chang

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et al. (2006) proposed this parameter to capture individual differences in susceptibility to syntactic experience, and suggested that it might involve factors such as motivation and attention (as well as initial strength of structural representations); subsequent research suggests that other relevant factors might include potentially more stable characteristics such as statistical learning ability and non-verbal IQ (Kidd, 2012a, 2012b). The learning rate decreases with age (necessary to avoid early acquired knowledge being overwritten by recent experiences; McClelland, McNaughton, & O'Reilly, 1995); see Peter, Chang, Pine, Blything, and Rowland (2015) for discussion. In this model, the extent to which an individual experience of a structure affects a speaker's subsequent behaviour is therefore a function of both his/her previous experience of that structure and his/her learning rate.

The Dual Path model is consistent with evidence that children's syntactic production is affected over a range of timeframes by multiple experiences of a syntactic structure (Huttenlocher et al., 2004, 2010; Kidd, 2012b; Vasilyeva & Waterfall, 2012), as well as evidence for immediate and cumulative effects of individual experiences within an experiment (Branigan & McLean, 2016; Garraffa, Coco, & Branigan, 2015; Messenger, Branigan, & McLean, 2011; Messenger et al., 2012; Peter et al., 2015; Rowland et al., 2012). It is also consistent with evidence for individual differences in immediate effects of individual experiences (Kidd, 2012a, 2012b).

But the Dual Path model makes a further powerful claim that has yet to be directly tested: that there should be a systematic relationship between a child's immediate response to an individual experience, and the larger pattern of their behaviour across time. Here, we test two specific aspects of this claim. First, if a single error-based learning mechanism underlies immediate and long-term effects of syntactic experience, then the effect of an individual experience of an infrequent structure should be detectable both in the child's immediate behaviour, and in their behaviour at a later point in time. Concretely, exposure to an individual instance of an infrequent structure should yield both an increased immediate tendency to use that structure (*immediate priming*), and an increase in its overall likelihood of use beyond the current context based on long-term cumulative and persistent effects of multiple experiences (*cumulative learning*). This tendency should hold even when the child is exposed equally to the more frequent alternative structure within the same session.

Second, children's immediate susceptibility to be affected by individual experiences should be stable across time (*individual consistency*): An individual child's likelihood of immediate priming at one timepoint should correlate positively with their likelihood of immediate priming at a different timepoint. Equally, children who show a stronger influence of an individual experience should also show a higher likelihood of using a structure following multiple experiences. These predictions arise from two aspects of the model. They follow from the assumption that the learning mechanism is governed by an individually-determined learning rate, so that children differ in the extent to which they adjust the weights associated with syntactic knowledge on the basis of individual experiences. They also follow from the assumption that the extent to which children are affected by individual experiences is modulated by their existing knowledge, so that children with less experience of a structure should be consistently more strongly influenced when exposed to that structure than children with more experience of a structure, because their relative lack of experience would yield a higher prediction error and a correspondingly greater weight adjustment.

We tested these hypotheses in an experiment in which three- and four-year-old children (and control adults) described transitive events in two sessions, a week apart. In each session, the experimenter and participant took turns describing picture cards as part of a competitive picture-matching game (Branigan, McLean, & Jones, 2005). We manipulated the structure (active vs. passive) of the experimenter's *prime* descriptions in a within-participants manipulation, and measured the structure of the participant's *target* descriptions.

In each session, we examined whether children showed immediate priming, producing more passives immediately following a passive than an active prime. More critically, we tested whether children showed cumulative learning, displaying an increased likelihood of producing passives in Session 2 after experiencing passives (as well as actives) in Session 1. Furthermore, we investigated whether children showed individual consistency of experience across time, such that children who showed a higher likelihood of immediate priming in Session 1 also showed a higher likelihood of immediate priming in Session 2, and whether children who showed a higher likelihood of priming in Session 1 also showed higher overall production of passives in Session 2.

Chang et al.'s (2006) model assumes the same learning mechanisms apply to children's syntactic acquisition and adult processing, but that adults have a lower learning rate. We would also expect adults' prediction error to be lower than children (because of their greater experience of the language). We therefore expected that adults would show immediate priming effects that would be consistent across time within individuals; however, they might show weaker overall effects of experience than children, so that they might be less susceptible to immediate priming within a session, and to cumulative learning across sessions.

2. Experiment

2.1. Method

2.1.1. Participants

Twenty-two children (3;4–4;10 years; mean 4;2; no reported developmental or language delays) participated in two sessions 5–9 (mean 7) days apart. Two further children who did not complete both sessions were excluded. Twenty-four University of Edinburgh students participated voluntarily in two sessions 7–9 (mean 7.3) days apart. Participants/caregivers provided informed consent.

2.1.2. Materials

We created 32 experimental items, each comprising a prime picture/description, and a target picture.

The items depicted transitive events corresponding to eight verbs (*bite*, *chase*, *kick*, *kiss*, *lift*, *pat*, *pull*, *push*), each used in four primes and four targets (see Appendix A). Each prime description had an active and passive version (Fig. 1). In order to increase the overall likelihood of passive descriptions, all agents were animals (14 animal characters) and all patients were humans (14 human characters; Branigan, Tanaka, & Pickering, 2008). Prime-target pairs had no open-class lexical overlap. The items were distributed across two sets, each containing 16 prime-target pairs; set order was counterbalanced across participants, such that half of the participants were exposed to Set A in Session 1 and Set B in Session 2, and half were exposed to Set B in Session 1 and Set A in Session 2.

There were two lists per set; across lists each target occurred once in each priming condition, and within lists eight targets occurred in each priming condition.[1] Each set also contained 16 ditransitive filler items, and eight intransitive 'snap' items (where the experimenter and participant had identical pictures). Each participant experienced an individually randomized order of experimental items (hence, a randomized order of active and passive

[1] Owing to a randomization error, one set contained 7 items (active or passive) in one condition and 9 in the other.