Opinion

Syntactic bootstrapping

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Children use syntax to guide verb learning in a process known as syntactic bootstrapping. Recent work explores how syntactic bootstrapping works—how it begins, and how it interacts with progress in syntax acquisition. We review evidence for three claims about the mechanisms and representations underlying syntactic bootstrapping: (1) Learners are biased to represent linguistic knowledge in a usefully abstract mental vocabulary, permitting rapid generalization of newly acquired syntactic knowledge to new verbs. (2) Toddlers collect information about each verb's combinatorial behavior in sentences based on listening experience, before they know anything about the verb's semantic content. (3) Syntactic bootstrapping begins with an unlearned bias to map nouns in sentences one-to-one onto the participant roles in events. These lines of evidence point toward a picture of early verb learning in which shallow structural analyses of sentences are intrinsically meaningful to learners, and in which information about verbs' combinatorial behavior pervades the lexicon from very early in development.
 WIREs Cogn Sci 2010 1 143–149

Upon encountering a new verb, listeners need not try to determine its meaning solely by observing world events accompanying the verb. Verb interpretation is also guided by the syntactic structure of sentences in which each verb appears in a process known as syntactic bootstrapping.[1]

Syntactic bootstrapping depends on systematic relationships between verb syntax and meaning.[2–4] Part of the meaning of each verb is a semantic predicate-argument structure specifying how many and what type of participant-roles the verb involves. This semantic structure partly determines the syntactic structures licensed by the verb. Accordingly, verbs describing one participant's action on another are typically transitive, licensing two noun phrases in sentences (*Anna tickled Bill*). Verbs describing actions requiring only one participant are typically intransitive, licensing only one noun phrase (*Bill laughed*, not **Anna laughed Bill*). Cognition verbs license sentence complements spelling out the relevant thoughts (*Anna knew Bill laughed*).

Young children exploit these syntax–semantics relationship.[5,6] They assign appropriately different interpretations to new verbs presented in different sentence structures.[7–12] In one experiment, for example, 25-month-olds who heard the transitive sentence 'The duck is kradding the bunny' looked longer at an event in which a duck acted on a bunny than at an event in which the duck and bunny acted independently, while those who heard the intransitive sentence 'The duck and the bunny are kradding' did not.[9] In another experiment, 4-year-olds used sentence-complement syntax to assign cognitive-verb meanings to new verbs.[12]

More refined semantic information can be gathered from the set of syntactic structures licensed by a verb.[5] For example, causal alternation verbs can appear in both transitive (*Anna broke the lamp*) and intransitive sentences (*The lamp broke*); in intransitive sentences, the object acted upon (*the lamp*) becomes the subject of the sentence. Unspecified object verbs can also be transitive (*Anna dusted the lamp*) and intransitive (*Anna dusted*), but assign the actor (*Anna*) to subject position in both transitive and intransitive sentences.[3,4] Verbs of these two types differ in meaning: Causal alternation verbs denote actions causing a particular change in the object acted upon, while unspecified object verbs denote activities without specifying a particular result. By 28 months, children use these transitivity alternations to link new verbs with causal or contact activity events.[10,13]

Such findings have raised many questions about how syntactic bootstrapping works, and how it begins. In this article, we summarize evidence for three claims about the representations and mechanisms underlying syntactic bootstrapping:

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DOI: 10.1002/wcs.17

1. *Early abstraction*: Children are biased to represent experience with language in an abstract mental vocabulary, permitting rapid generalization of newly acquired syntactic knowledge to new verbs.
2. *Independent encoding of syntactic structure*: Toddlers gather distributional facts about unknown verbs from listening experience, even without an informative referential context.
3. *Structure-mapping*: Syntactic bootstrapping originates in an unlearned bias toward one-to-one mapping between referential terms in sentences and semantic arguments of predicate terms.

These three claims lead to a picture of the developing verb lexicon in which syntax guides sentence interpretation and verb learning essentially from the start.

ABSTRACT REPRESENTATIONS OF LINGUISTIC KNOWLEDGE

A core prediction of the syntactic bootstrapping theory is that each advance in learning the syntactic features of the native language offers new constraints on verb interpretation. For example, once English learners can use word order to interpret sentences, this should further constrain the interpretation of new verbs. Armed with knowledge of English word order, listeners should infer not only that a transitive verb invokes two participant-roles, but also that the subject names the agent of the action, whatever that action may be. This inference depends on language-specific learning: in Japanese, children learn that case markers convey agent–patient role information.

This prediction depends on a strong assumption about how children represent what they learn. The extension of new syntactic knowledge to unknown verbs requires functionally abstract representations of linguistic experience. This assumption is at odds with some accounts of early syntactic knowledge.

Lexical accounts propose that early language use is guided by syntactic and semantic representations that are tied to particular words.[14,15] A lexical account learner might learn that a noun preceding the word 'kiss' names the one doing the kissing, and a noun following 'kiss' names the one kissed. Learning where 'kissers' and 'kissees' belong in sentences with 'kiss' has no clear consequences for understanding sentences containing other verbs. On lexical accounts, useful syntactic abstractions such as subject and object, or preverbal and postverbal noun, and useful semantic abstractions such as agent and patient, emerge slowly via comparison across many verbs learned one at a time. Young children's apparent failures to generalize syntactic knowledge to new verbs, in comprehension and production, have been interpreted as evidence for lexical accounts.[15]

Early abstraction accounts propose that children learn about individual words, but are also predisposed to represent linguistic knowledge in a usefully abstract format.[4,16,17] An early abstraction learner might represent the positions of nouns in sentences with 'kiss' as preverbal and postverbal nouns (rather than only pre- and post-'kiss'); their semantic-role representations might indicate that kissers are agents, and kissees are patients. Given these representations, children learn from the start where agents and patients belong in sentences; this predicts rapid transfer of syntactic knowledge to new verbs.

Compelling evidence that children are biased to represent linguistic experience in usefully abstract terms comes from the phenomenon of 'home sign'.[18] Deaf children who are not exposed to conventional languages invent gestural communication systems exhibiting core properties of conventional languages. Home signers commonly use gesture order to mark abstract agent and patient roles.[18,19] This suggests that children need not learn from linguistic exposure to detect the similarity between the agents and patients of kissing and throwing, or to link these abstract role categories with fundamental aspects of sentence structure (in this case, order in a gesture string).

Gertner et al.[20] tested the predictions of lexical versus early-abstraction accounts by asking whether toddlers used English word order to interpret sentences containing unknown verbs. For example, 21-month-olds viewed side-by-side videos depicting different caused motion events (Figure 1). Both events involved a boy and a girl, but differed in the assignment of the boy and girl to agent versus patient roles. Upon hearing 'The girl is kradding the boy!' or 'The boy is kradding the girl!', children looked longer at the matching video—the one in which the agent matched the subject of the sentence. A similar effect of word order emerged when children heard sentences containing only one full noun phrase (e.g., 'Who is kradding the boy?'). Using knowledge of English word order, these children correctly inferred that, whatever the new verb meant, it must involve the actions of the subject referent on the object referent, rather than the reverse (see Ref 21 for similar findings with German-speaking toddlers).

Further evidence of early abstraction comes from studies of syntactic priming.[22–24] In comprehension and production, 3-year-olds (like adults) tend to reuse

FIGURE 1 | Sample stimuli from Gertner, Fisher, and Eisengart.[20] Children aged 21 months viewed two caused motion events while hearing a novel transitive verb. The children looked reliably longer at the event in which the agent–patient role assignments were appropriate for the word order of the sentence they heard.

syntactic analyses that they have recently generated to process other sentences, even when prime and target sentences contain different verbs. For example, 3-year-olds who heard double-object dative prime sentences ('Give the lion the ball!') tended to interpret a temporarily ambiguous postverbal noun in a later target sentence as a recipient. This priming effect facilitated comprehension of target sentences with the same structure ('Show the horse the book'), but delayed comprehension of sentences with a contrasting structure ('Show the horn to the dog'; see Ref 24).

These patterns offer striking support for early abstraction accounts. Young children's representations of the form and meanings of sentences are not strictly tied to particular words. Such abstract representations allow children to detect general patterns in the native language input, and extend them to new verbs, thereby gaining progressively finer-grained constraint on sentence and verb interpretation.

LEARNING COMBINATORIAL FACTS ABOUT VERBS

Knowledge of a verb's syntactic behavior guides its interpretation. But only highly abstract semantic hints can be gleaned from syntax. Observations of the number and type of syntactic constituents appearing with a verb yield cues to aspects of verb meaning having to do with the number and type of participant-roles involved—the verb's semantic structure, not its semantic content. Knowing that a verb is transitive tells children only that it involves two participant-roles, and that its subject referent plays a more agentive role than does its object referent.[25] Given only these clues, the child cannot tell whether the verb means bake or tickle. Information about semantic content must come from observation of events.

Is event observation also necessary for children to derive the verb's semantic structure from observations of that verb in sentences? Yuan and Fisher[26] and Scott and Fisher[13] found evidence that it is not: children keep track of the syntactic structures in which a new verb appears, even without a concurrent scene that provides cues to the verb's semantic content. They later use that syntactic-combinatorial information to constrain interpretation of the verb when they encounter it in a referential setting.

Yuan and Fisher[26] showed 28-month-olds dialogues in which two women used a made-up verb in transitive (e.g., *Jane blicked the baby*!) or intransitive sentences (*Jane blicked*!). In a later test-phase, the children heard the verb in isolation (*Find blicking*!) while viewing videos depicting a one-participant action and a two-participant action (Figure 2). Children's interpretations of the novel verb were guided by the preceding dialogue: those who had heard the verb used transitively looked reliably longer at the two-participant event than did those who had heard the verb used intransitively. This dialogue effect held when children were tested the next day, but disappeared if no novel verb accompanied the test events.

To figure out verbs' combinatorial privileges, children need to learn more than which verbs are transitive. Finer constraint on verb interpretation comes from the set of structures in which each verb appears. Can children keep track of multiple structural options for a single verb? Can they keep track of other aspects of the verb's combinatorial properties, including the categories of nouns appearing as its arguments?

This last question is crucial, because some of the sentence alternations that are informative about verb semantic structure are not purely syntactic. As mentioned above, both causal alternation verbs (*Anna broke the lamp; It broke*) and unspecified object verbs (*Anna dusted the lamp; She dusted*) can be transitive and intransitive. In their syntactic structures alone, the two verb classes are indistinguishable. These classes differ in the semantic roles they assign to their intransitive subjects. Unspecified object verbs

Transitive dialogue
A: Guess what? Jane blicked the baby!
B: Hmm. She blicked the baby?
A: And Bill was blicking the duck.
B: Yeah, he was blicking the duck.

Intransitive dialogue
A: Guess what? Jane blicked!
B: Hmm. She blicked?
A: And Bill was blicking .
B: Yeah, he was blicking.

Two-participant test event

One-participant test event

Experimental condition: Where's blicking?
Control condition: What's going on?

FIGURE 2 | Sample stimuli from Yuan and Fisher.[26] Two-year-olds watched dialogues in which they heard a novel verb in transitive or intransitive sentences. Next, they viewed test event while hearing the verb in isolation. Children who had heard transitive dialogues looked longer at the two-participant event than did those who had heard intransitive dialogues. This dialogue effect disappeared in a control condition in which children heard only neutral audio during the test phase.

assign the actor role to subject position in intransitive sentences (*Anna dusted*); but causal alternation verbs assign the undergoer to this position (*The lamp broke*).

Scott and Fisher[13] found that role-relevant surface properties of sentences could be used to distinguish causal and unspecified object verbs in corpora of child-directed speech. The feature that proved most powerful in separating these classes was intransitive subject animacy. In principle, learners could distinguish causal from unspecified object verbs if they learned not only about verb transitivity but also linked lexical knowledge, perhaps especially noun phrase animacy, with this syntactic information.

Scott and Fisher[13] reported evidence that 2-year-olds could do so as stated above. Children aged 28 months watched dialogues in which interlocutors used a novel verb in sentences exhibiting the distributional profile of causal alternation or unspecified object verbs (Figure 3). The cues manipulated were those found useful in the corpus analysis, including intransitive subject animacy. Next, the children viewed a caused motion event and a contact activity event, accompanied by the novel verb in a transitive sentence ('The girl is dacking the boy!'). The children assigned different interpretations to the same transitive verb, depending on which dialogue they had heard. Children who had heard the causal alternation dialogue looked longer at the causal event than did those who had heard the unspecified object dialogue. This dialogue effect disappeared when the test events were accompanied by a different novel verb ('The girl is pimming the boy!').

The findings reviewed here testify to young children's flexibility in exploiting distributional information about new words, despite considerable referential ambiguity. Faced with sentences they could not understand ('Matt dacked the pillow?'), 2-year-olds learned what they could about the new verb—its transitivity, annotated with information about the nouns filling various argument positions. Toddlers then used these combinatorial facts to constrain later verb interpretation.

THE ORIGINS OF SYNTACTIC BOOTSTRAPPING

How could observations of verbs' syntactic properties inform children about their semantic structures? We and others have proposed that syntactic bootstrapping originates in a powerful bias toward one-to-one mapping between nouns in sentences and participant-roles in events.[7,27] As a result of this bias, children treat the number of nouns in the sentence as a cue to its semantic predicate-argument structure. We call this procedure structure-mapping.

To illustrate, even a toddler, hearing an utterance containing two familiar nouns, could conclude that the utterance conveys some conceptual relation involving two participent-roles. Upon hearing only one familiar noun in the sentence, she could infer that the sentence's meaning involves one participant-role. Such inferences

Causal dialogue
A: Matt dacked the pillow.
B: Really? He dacked the pillow?
A: Yeah. The pillow dacked.
B: Right. It dacked.

Unspecified-object dialogue
A: Matt dacked the pillow.
B: Really? He dacked the pillow?
A: Yeah. He dacked.
B: Right. He dacked.

Contact-activity test event

Causal test event

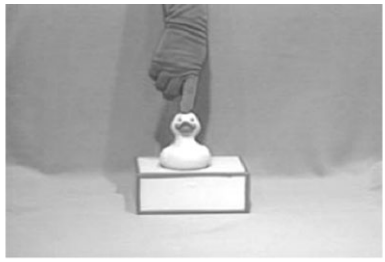
Same-verb: "The girl is dacking the boy. Find dacking."
Different-verb: "The girl is pimming the boy. Find pimming."

FIGURE 3 | Video stimuli from Scott and Fisher.[13] Two-year-olds viewed dialogues in which a new verb appeared in sentences with the distributional characteristics of causal alternation or unspecified object verbs. This dialogue experience affected their interpretation of the same verb when they later encountered it in a transitive sentence: children who had heard causal dialogues now looked longer at the causal event than did children who had heard the unspecified-object dialogues.

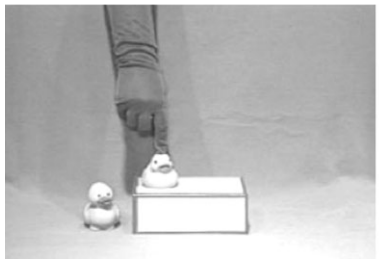
would provide an initial probabilistic distinction between transitive and intransitive verbs.

The structure-mapping account makes several strong predictions. Perhaps most strikingly, it predicts that the number of nouns in a sentence should guide interpretation of any argument-taking predicate, not just verbs. Learning that a word predicts some number of nouns in sentences tells children that the word is an argument-taking predicate, not whether it is a verb (*Alice followed Bill*), adjective (*I'm happy for you*), or preposition (*It's under the table*). All predicate terms take noun phrase arguments, and all encode semantic relations among the referents of those arguments. All should therefore be interpretable in the same fashion—by interpreting each sentence as conveying a conceptual predicate involving the participants named in the sentence.

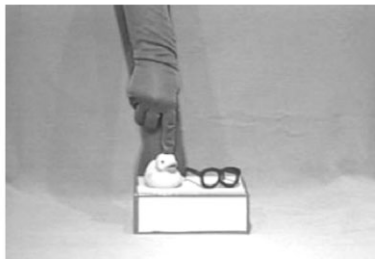
Consistent with this prediction, 2-year-olds use sentence structures to learn new prepositions.[28] Two-year-olds watched as a hand placed a duck on a



Training: This is acorp (my box)!



Object match screen



Location match screen

Test: This is acorp (my box)! What else is acorp (my box?)

FIGURE 4 | Sample stimulus items, Fisher et al.[28] Children saw training trials in which a hand pointed to a duck on a box, while the new word was presented as a noun or as a preposition. At test, children saw two test events: in each, the hand pointed to another duck on the box, while children heard the test sentence for their condition. The location-match screen showed a different object (a non-duck) on the box, and the object-match screen showed another duck beside the box.

box, and pointed to it as a new word was uttered (Figure 4). Half the children heard the word presented as a noun (*This is a corp!*), while half heard it as a preposition (*This is acorp my box!*). After these training trials, children saw two test events: one showed another duck beside the box (object-match), and the other showed a different object (e.g., eyeglasses) on the box (location-match). Looking preferences revealed effects of sentence context: two-year-olds with high vocabularies in the preposition condition looked longer at the location-match; those in the noun condition looked longer at the object-match. These findings reveal the straightforward relationship between nouns in sentences, and semantic predicate-argument structure. Adding a noun after an unknown word informed children it must be a predicate term; observation of training events informed children that it described a spatial relation.

Do learners approach language expecting nouns in sentences to line up one-to-one with semantic roles, or do they acquire this expectation from language experience? Striking evidence for an unlearned bias toward one-to-one mapping between nouns and participant-roles can be seen in home sign.[18] Children invent signs that behave like verbs in conventional languages, occurring with predictable sets of noun-like arguments. For example, a sign meaning 'give' has three argument slots. Thus, children need not learn from linguistic exposure to map each predicate's arguments one-to-one onto referential terms in sentences.

Further evidence that children do not need to learn to link nouns in sentences with participant-roles in conceptual structures comes from cross-linguistic examinations of verb learning. In Mandarin Chinese, nouns whose referents are already established in the discourse can be omitted from sentences. Mandarin sentences therefore provide less compelling evidence for the link between nouns in sentences and verb arguments. Nevertheless, Mandarin-learners put their faith in noun-number as a cue to a sentence's semantic predicate-argument structure.[29] Lidz et al.[27] tested learners of Kannada, a language in which morphology provides a stronger cue to causal meaning than does noun-number.[a] Young Kannada-speakers, nevertheless, treated noun-number as the strongest determiner of causal meaning. These data point to the conclusion that the fundamental relationship between nouns in sentences and argument slots in semantic predicate-argument structures is anticipated by learners, rather than constructed via linguistic experience.

CONCLUSION

We have reviewed evidence for three strong claims about early verb learning. First, children represent linguistic knowledge in an abstract format, permitting them to extend new syntactic knowledge to new verbs. Even 21-month-olds extend knowledge of native-language word order to new verbs. Second, toddlers encode combinatorial facts about new verbs before they gain information about their semantic content, based simply on hearing them used in sentences. Third, we argue that syntactic bootstrapping originates in an unlearned bias to map nouns in sentences one-to-one onto participant-roles in events. This bias renders simple aspects of sentence structure inherently meaningful to children. Verbs, and other predicate terms, signal their relational meanings by their combinatorial behavior in sentences. As a result, syntax guides sentence interpretation from the start, and each fragment of new knowledge, either about the combinatorial properties of particular verbs, or the syntactic patterns of the native language, provides further constraint on verb interpretation.

NOTES

[a]Noun-number does not indicate causal meaning in particular (as opposed to other two-participant meanings). Lidz et al.[27] argue that children take transitive sentences as probabilistic indicators of causal meaning when interpreting motion verbs.

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