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On the Plasticity of Semantic Generalizations: Children and Adults Modify Their Verb Lexicalization Biases in Response to Changing Input

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Languages differ in how they package the components of an event into words to form sentences. For example, while some languages typically encode the manner of motion in the verb (e.g., *running*), others more often use verbs that encode the path (e.g., *ascending*). Prior research has demonstrated that children and adults have lexicalization biases; that is, they assume that novel motion verbs will reflect the dominant pattern of their own language. These experiments explored the plasticity of these biases. In Experiments 1 and 2 we taught English-speaking adults motion verbs, varying the proportion of manner and path verbs in the training set; their interpretation of subsequent verbs closely reflected the probabilistic variation in the input. In Experiments 3 and 4, 5-year-old children also systematically shifted their lexicalization biases to reflect the verbs that they were taught. We conclude that lexicalization biases are adaptive inferences about verb meaning that are updated on the basis of experience.

Keywords: verb learning, lexicalization bias, semantic reorganization hypothesis, manner-path

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To acquire a language, children not only have to learn names for all the objects that they encounter, but they must also discover how to talk about the events and relations that these objects participate in. While objects are readily individuated by our perceptual systems, the boundaries of events are less clear. Multiple events can co-occur in time and space, and each is open to different construals (e.g., "Oscar threw the ball to Zane" vs. "Zane caught the ball"). Because of this conceptual and perceptual ambiguity, languages vary in how the conceptual components of events are packaged into lexical items, and thus there is substantial cross-linguistic variability in the meanings of relational words. Gentner (1982, 2003; Gentner & Boroditsky, 2001) proposed that to effectively learn these words, children must discover how their language chooses to package events. If these lexicalization patterns are systematic, children should be able to make generalizations that will facilitate subsequent word learning (Slobin, 2001).

The parade case for systematic cross-linguistic variation in lexicalization is the conflation patterns for verbs of motion (Talmy, 1985). A motion event has several conceptual components including a thing that is moving (the figure), the location it is moving relative to (the ground), the manner in which it is moving, and the path along which it moves. All languages have ways of expressing these elements, but how they do so varies. Manner languages (e.g., English and Russian) typically package the manner of motion in the verb and encode the path in a prepositional phrase ("He ran into the store"), a pattern Talmy (1985) calls *satellite-framed*. In contrast, path languages (e.g., Spanish and Greek) often encode path in the verb and fob off manner on an optional gerund ("Él entró en la tienda corriendo"), a pattern Talmy calls *verb-framed*. This cross-linguistic difference in verb use shows up in distributional analyses and production studies with both children and adults (Berman & Slobin, 1994; Naigles, Eisenberg, Kako, Highter, & McGraw, 1998).

This systematic difference in lexicalization patterns results in different biases in learning new motion verbs. English speakers extend novel verbs to other events with the same manner of motion

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but not to events with the same path (Hohenstein, 2005; Naigles & Terrazas, 1998). In contrast, Spanish speakers will extend the verb to events with the same path but not the same manner. These biases seem to emerge during the preschool years: The cross-linguistic differences are not seen in 2-year-olds (Maguire et al., 2010) or 3-year-olds (Hohenstein, 2005) but are seen in 4- and 5-year-olds (Maguire et al., 2010; Papafragou & Selimis, 2010).

The present study examines whether English-speaking children and adults can adjust their lexicalization biases to new patterns in the input. We motivate this question by describing the theoretical framework that drives much of the research on acquisition of relational words and by highlighting central questions that it leaves unanswered.

The Speech-Perception Metaphor

Several theorists have proposed that the acquisition of relational language is parallel to the acquisition of phonetic categories in two critical ways (Göksun, Hirsh-Pasek, & Golinkoff, 2010; Hespos & Spelke, 2007). First, in both domains, learners have an early universal sensitivity. In speech perception, infants begin with a set of perceptual distinctions that allows them to distinguish all of the phonetic contrasts used in the world's languages (Eimas, Siqueland, Jusczyk, & Vigorito, 1971). In the semantic domain, children begin with fine-grained event representations, which allow them to make all of the distinctions found in the world's languages, including the ability to distinguish a variety of paths and manners of motion (e.g., Hespos & Spelke, 2004; Lakusta, Wagner, O'Hearn, & Landau, 2007; Pruden, 2006; Pulverman, Golinkoff, Hirsh-Pasek, & Sootsman Buresh, 2008).

Second, in both domains, children learn which contrasts are relevant to their native language and show preferential processing of these contrasts. In the domain of speech perception, infants lose the ability to discriminate speech sounds that are not contrastive in their native language (e.g., Werker & Tees, 1984) and become more sensitive to those that are (Kuhl et al., 2006). Similarly, in the semantic domain, children discover which event components are habitually encoded by their language and how they map on to lexical and syntactic forms. This results in cross-linguistic differences in how children encode and describe events (see e.g., Bowerman & Choi, 2001). In the case of manner and path, this semantic knowledge goes beyond the acquisition of individual words to result in generalizations about the likely meaning of novel words (Hohenstein, 2005; Maguire et al., 2010; Naigles & Terrazas, 1998; Papafragou & Selimis, 2010).

The proposal that semantic development is analogous to the development of speech perception raises two critical questions. First, what is the nature of the change that occurs when children acquire the semantic categories of their language? Second, how permanent are these changes? Below we discuss both questions as they relate to manner/path lexicalization biases.

What Changes During Semantic Acquisition?

The metaphor between speech perception and relational language raises the question of whether the mechanisms of change are similar in the two cases. In the domain of speech perception, the debate has centered on whether development involves the modification of existing representations or the creation of new ones. For example, Werker (1995) has argued that native language speech perception results from the creation of new phonetic representations that coexist with the older perceptual ones. In contrast, Kuhl (2000) described this change as a warping of the existing perceptual space. The parallel issue in semantic development is whether acquisition involves altering the child's conceptual system or constructing a new, language-specific, semantic system (Jackendoff, 2002; Levinson, 1997).

In the case of the manner–path lexicalization bias, the evidence strongly suggests that acquisition involves the construction of new semantic mappings, rather than the loss of conceptual resources. All languages have ways of encoding both the manner and path of motion, but they vary in the grammatical devices that are available for this purpose (Beavers, Levin, & Tham, 2010; Talmy, 1985). As a result of these grammatical differences, languages also differ in the frequency with which these event components are included in verbal descriptions, the range of contexts in which manner verbs can occur, and the number of such verbs in the language (see e.g., Özçaliskan & Slobin, 1999; Papafragou, Massey, & Gleitman, 2002, 2006). Nevertheless, since speakers of all languages can (and do) talk about both dimensions (see e.g., Allen et al., 2007), they must retain the ability to conceptualize them. Furthermore, speakers of manner and path languages perform similarly in nonlinguistic tasks (see e.g., Gennari, Sloman, Malt, & Fitch, 2002; Papafragou et al., 2002), particularly when the use of verbal encoding strategies is blocked (Trueswell & Papafragou, 2010). For these reasons, we conceptualize lexicalization biases as changes in the semantic interface (see Jackendoff, 2002).

One intriguing hypothesis about how this kind of semantic bias develops comes from research on the development of the shape bias in noun learning. Smith and colleagues have argued that the shape bias is a generalization based on the words that the child has previously acquired (Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002). Children, they claimed, are initially unbiased learners who acquire their first nouns by patiently waiting for the situational concomitants of word use to tease apart the many alternate hypotheses about how a word might be extended. In this way, children manage to acquire a sizeable number of nouns, many of which are well organized by shape. The shape bias, they argued, is simply a second-order generalization over these known words.

Verb lexicalization biases could reflect the same kind of learning mechanism (see Slobin, 2008, for a related proposal). Children may slowly acquire their first verbs, open to the possibility that each word could encode a variety of possible dimensions. Then, on the basis of these early words, they might make second-order generalizations about the set of semantic dimensions that their language prefers to encode in verbs, placing greater prior probability on some dimensions (e.g., manner of motion in English) and downgrading the status of others (e.g., path). This account is consistent with developmental studies suggesting that language-specific manner–path lexicalization biases emerge only after children have acquired a sizeable stock of relevant verbs (Hohenstein, 2005; Maguire et al., 2010; Papafragou & Selimis, 2010).

How Flexible Is Semantic Reorganization?

One of the central characteristics of speech perception is that there is limited plasticity after the period of primary acquisition. Second-language learners generally perform poorly on contrasts

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that are absent in their native language, even if they acquired their second language in childhood and are highly proficient (Pallier, Bosch, & Sebastián-Gallés, 1997; Sebastián-Gallés & Soto-Faraco, 1999). Curiously, there has been little discussion of plasticity in semantic acquisition. Theorists who have used the speech-perception metaphor have identified some of its limitations: Adults can detect semantic contrasts that are not systematically encoded in their native language and can learn words that violate their lexicalization biases (Göksun et al., 2010; Hespos & Spelke, 2004). These abilities show that adults retain the ability to make the relevant conceptual distinctions, but they do not reveal whether the semantic biases that develop in childhood can be revised in light of subsequent evidence. We see two broad possibilities, both compatible with the prior research.

Stable Reorganization Hypothesis

One possibility is that changes to the semantic interface are highly stable and resistant to change. This hypothesis takes the metaphor between speech perception and relational language as a deep one that reflects underlying parallels in the function of the systems and the mechanisms by which they develop. Stability and severely limited plasticity are robust properties of speech perception, suggesting that they are not accidental. If semantic reorganization occurs for similar reasons (e.g., to limit the number of distinctions that need to be encoded) or via similar mechanisms (e.g., the creation of new and stable higher level representations), then one might expect that it would also be very stable.

Permanent alterations to the semantic interface could be implemented in ways which would allow for the flexibility previously described. For example, mappings between linguistic forms and concepts could be altered so that some conceptual dimensions would be less accessible as candidates for verb meanings. These concepts would still be available for use in nonlinguistic tasks or as the meanings of other parts of speech. After reorganization, the learner would even be able to acquire verbs with dispreferred meanings (e.g., *ascend*) by trial and error, but the bias for preferred dimensions in verb learning would be unalterable.

Flexible Inferences Hypothesis

The second possibility is that lexicalization biases are flexible hypotheses about the meanings of words, which are updated on the basis of experience. According to this hypothesis, lexicalization biases are not a stable developmental achievement; they are merely learners' current best guess about what a word is likely to mean, given the other words that they have learned. If these biases are rational inferences, then one should expect them to be updated as new words are encountered and to be sensitive to (or conditioned on) other features of the input, such as the syntactic frame in which the verb appears (Gleitman, 1990; Naigles & Terrazas, 1998). Such flexibility would come at a price—linguistically mature individuals would have to continue entertaining the possibility that verbs might encode dispreferred dimensions and continue monitoring input for changes in bias. But this flexibility would also have advantages—learners would be able to acquire lexicalization biases that were specific to particular syntactic (or pragmatic contexts) and update those biases if they were no longer valid.

The existing research does not definitively support either of these hypotheses. Two lines of work are particularly relevant. The first explores language production in second-language learners to explore how they use semantic patterns not present in their native language. There is some evidence of flexibility: Advanced second-language learners use many of the lexical and syntactic resources of their new language and produce patterns that are distinct from those in their native language. For example, native Spanish speakers primarily use manner verbs when describing events in English but primarily use path verbs when describing the same events in Spanish (Brown & Gullberg, 2011; Cadierno & Ruiz, 2006; Navarro & Nicoladis, 2005). This achievement, however, is not inconsistent with the stable reorganization hypothesis; after many years learners may acquire individual verbs and their pattern of use by trial and error without ever acquiring the English lexicalization bias.

In fact, other findings seem to favor the stable reorganization hypothesis. Speakers of path languages who later acquire a manner language use more path verbs than do native speakers (Brown & Gullberg, 2011; Hohenstein, Eisenberg, & Naigles, 2006). Speakers of manner languages who later acquire a path language use more manner verbs than do native speakers, produce manner verbs where they are prohibited, and produce unnecessary prepositions and particles that redundantly mark path (Cadierno, 2004; Cadierno & Ruiz, 2006; Hendriks, Hickmann, & Demagny, 2008; Inagaki, 2001; Navarro & Nicoladis, 2005). However, these errors may reflect incomplete acquisition instead of, or in addition to, cross-linguistic transfer: Native speakers of one path language who acquire a second path language make similar mistakes (Cadierno & Ruiz, 2006).

The second line of work, by Kersten and colleagues (2010), uses a concept learning task to explore how experience affects the acquisition of new words and/or categories. They found that Spanish–English bilinguals learn manner concepts better when they are tested in English than in Spanish (Kersten et al., 2010). This suggests that they have some knowledge of the lexicalization pattern in their second language, which would require some degree of plasticity in the semantic interface. The bilinguals in that study, however, had learned English as children and had had many years to acquire the English pattern. Thus these findings do not reveal what degree of plasticity is present or whether it is maintained in adulthood. Another study (Kersten, Goldstone, & Schaffert, 1998) explored whether the concepts learned on one set of trials can influence subsequent learning. While this design is conceptually similar to ours, the stimuli used were different from those used in other studies on lexicalization biases: The verbs were presented in isolation (e.g., *wugging*), the task involved simultaneous mastery of several related concepts, and the manner concepts were subtle. This may explain the findings, which are surprising given the prior literature on lexicalization biases. The participants initially had great difficulty learning manner verbs, even though they spoke a manner language (English). Performance on manner verbs was better when participants had prior experience learning other manner verbs, but it was also better when they had prior experience learning path verbs. The authors explained this pattern with two mechanisms (persistence and contrast). In sum, while some of the findings are consistent with the flexible inferences hypothesis, these studies did not tap into existing lexicalization biases, and

thus it is not clear that they reflect the mechanisms by which these biases are acquired, altered, and maintained.

Experimental Goals

The present studies explored the plasticity of lexicalization biases, testing four predictions of the flexible inferences hypothesis.

First, if lexicalization biases are inferences rather than commitments, then they should continue to change throughout life in response to the verbs that are learned. Experiments 1 and 2 tested this prediction by teaching English-speaking adults novel motion verbs, which encoded either manner or path, and examining whether their lexicalization biases changed over the course of the experiment. If lexicalization biases are flexible, adults should develop a path bias after learning several path verbs and should retain or strengthen their manner bias after learning several manner verbs.

Second, if lexicalization biases are adaptive, shifts should also occur in response to probabilistic biases in the input. In Experiments 1 and 2, we tested this prediction with additional groups of adults, who learned both manner and path verbs in varying proportions (25%, 50%, and 75% path verbs). We expected that probabilistic input would result in shifts in lexicalization bias but that these shifts would be weaker than in the 0% or 100% conditions.

Third, if this paradigm is tapping the modification of existing lexicalization biases (rather than strategies specific to this experiment), then these biases should reflect the prior linguistic experiences of our English-speaking participants and be influenced by the syntactic contexts in which the novel verbs are used (Naigles & Terrazas, 1998). In a series of corpus analyses and a sentence completion study (see the supplemental materials), we found that the prepositional frame (e.g., "She is torging up the hill") was frequently used to describe motion events and strongly associated with manner verbs. Consequently, we expected that there would be a strong initial manner bias for novel verbs in this frame, which would be fully overridden only by consistent path input (Experiment 1). However, in English the direct-object frame (e.g. "She is torging the hill") is far less frequently used for motion events and is not strongly associated with either manner or path. Thus we expected that there would be no initial manner bias for novel verbs used in direct-object frames and that the bias in this condition would come to closely reflect the input encountered during the study (Experiment 2).

Finally, if lexicalization biases are adaptive inferences, then this flexibility should also be present in children over the age of 4 years. As noted above, language-specific lexicalization biases appear to be present at this age. If our paradigm taps the process by which these biases are created and maintained, then shifts in response to verb learning should be seen in children of this age. Experiments 3 and 4 tested this prediction by using a simplified version of this paradigm with 4- and 5-year-olds.

Experiment 1

Each adult participant was taught 12 new motion verbs. For every novel verb, they first saw a single ambiguous scene with a salient path and manner of motion and then were tested to determine their initial interpretation of the verb (the bias test trials). After the bias test, they saw five additional instances of the new verb which disambiguated its meaning (e.g., five scenes with the same manner but a novel path) and were tested again to ensure that they had learned the verb (verb-learning test trials). Throughout the study the verbs appeared in a prepositional construction (e.g., "She is morging around the tree").

Critically, whether the verb encoded a path or a manner was manipulated by changing the five disambiguating scenes. Some adults were taught only manner verbs and some only path verbs, while those in the three remaining conditions received verbs of both types, with the percentage of path verbs set at 25%, 50%, or 75%. We expected that participants would be able to learn both manner and path verbs. Our primary measure was the responses to the bias test trials. Because a single verb-scene pair is consistent with either a manner or a path interpretation, these responses revealed the participants' verb lexicalization bias. We expected that they would begin with an initial bias to interpret the novel verbs as encoding a manner of motion but that over the course of the session their responses would shift to reflect the distribution of verbs in the experiment.

Method

Participants. Participants were 50 native-English-speaking adults, recruited on the MIT campus or through the Harvard University psychology subject pool. Participants indicated that they had learned English at home prior to age 6, but no other demographic information (including gender) was collected. Adults were assigned to one of five conditions which differed in the proportion of the novel verbs that encoded the path of motion (0%, 25%, 50%, 75%, or 100%), with a total of 10 in each condition. Because our goal was to determine how previously learned verbs influence the interpretation of future verbs, we eliminated 16 additional adults who failed to learn five or more of the 12 novel verbs after viewing the disambiguating scenes. (The criterion for learning a verb was accepting the test clip that matched the training videos along the dimension that was invariant across them and rejecting the test clip that did not.) These participants were distributed across the conditions, and their responses suggested that they were answering randomly.

Stimuli and procedure. Adults saw short video clips of live-action motion events. Each video clip was approximately 5 s long and depicted an actor moving in a salient manner and in a salient path with respect to some reference object (e.g., a woman walking tip-toe behind a large sign). The clips were videotaped in a single shot with the actor and the full path of motion in view at all times. The actors, reference objects, and settings varied across the clips both within and between verbs. All the sentences and questions that accompanied the videos were presented as written text.

Twelve manner and 12 path concepts were used as target verb meanings. Some concepts corresponded to English verbs and some to English prepositions, and some had no monomorphemic English equivalent. The path verb meanings were *around, between, down, up, in front of, along, in, diagonal to, over, across, out of*, and *behind*. The manner verb meanings were *crab-walk, crawl, twirl, flap-walk (walking with arms flapping), hop on 1 foot, hop on 2 feet, march, run, skip, stoop-walk (walking hunched over), tiptoe,* and *walk (regular walking)*.

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Stimuli were presented on a computer using custom software. Participants were told that they would be watching videos that would teach them new words and would be answering questions about these words. They were presented with a block of videos for each of the 12 novel verbs. Each block was identical in layout and consisted of four phases: an initial ambiguous scene, two bias test questions, a training phase, and two verb-learning test questions. A sample test block for a manner verb is shown in Table 1, and a sample for a path verb is shown in Table 2.

In the ambiguous scene, adults saw a written sentence containing a novel verb (e.g., "She is going to torg through the door"), followed by a video illustrating the sentence (e.g., a woman crab-walking out the door). As the video ended, a second sentence appeared (e.g., "She torged through the door").

The bias test consisted of two clips presented sequentially. Participants were asked if each clip was an instance of the new verb ("Is this torging?"). One test clip showed a new actor moving in the same manner as the original ambiguous event but along a different path. The second clip showed another new actor moving in a manner that differed from the ambiguous event but along a path of the same kind (though the reference object had changed).

During the training phase, adults were presented with five video clips that disambiguated the meaning of the word. If the verb was being taught as a path verb, then all five clips showed the same path as the ambiguous training clip but varied in their manner. If the word was being taught as a manner verb, the reverse was true. In the training phase, the verbs were accompanied with sentences that paralleled those used with the ambiguous scene ("She is going to torg around the chair" and later "She torged around the chair").

The verb-learning test paralleled the bias test; one video matched the path of the ambiguous clip, the other matched it in manner. This test allowed us to determine whether the participant had succeeded in learning the verb. For both the bias test questions and the verb-learning test questions, a participant could respond "yes" to the manner match and "no" to the path match (suggesting a manner interpretation) or "no" to the manner match and "yes" to the path match (suggesting a path interpretation), or they could give the same response to both questions. The order and side of the two clips for the bias and verb-learning test trials was counterbalanced across verbs but stable across conditions and participants.

Table 1
Sample Verb Trial for the Manner Condition (Experiments 1–4)

	Target concept: Crab-walk	
Phase	Manner	Path
Initial video		
Ambiguous scene	Crab-walk	Out
Bias test question		
Manner match	Crab-walk	Behind
Path match	Skip	Out
Training phase		
Training 1	Crab-walk	Front
Training 2	Crab-walk	In
Training 3	Crab-walk	Between
Training 4	Crab-walk	Across
Training 5	Crab-walk	Diagonal to
Verb-learning test		
Forced choice	Crab-walk	Between
	March	Out

Table 2
Sample Verb Trial for the Path Condition (Experiments 1–4)

	Target concept: Out	
Phase	Manner	Path
Initial video		
Ambiguous scene	Crab-walk	Out
Bias test question		
Manner match	Crab-walk	Behind
Path match	Skip	Out
Training phase		
Training 1	Hop on 2 feet	Out
Training 2	Walk	Out
Training 3	Run	Out
Training 4	Stoop-walk	Out
Training 5	Dance	Out
Verb-learning test		
Forced choice	Crab-walk	Between
	March	Out

Each manner verb was arbitrarily paired with a path verb. The paired verbs had the same initial ambiguous scene, bias test, and verb-learning test (see Tables 1 and 2). Only the disambiguating videos differed. Pairing the items in this way allowed us to examine how participants with different verb-learning experiences responded to identical stimuli. The 12 verb pairs were randomly ordered, and half of the adults in each condition were tested with the novel verbs in reverse order.

Results and Discussion

Our analyses focused entirely on responses to the bias test questions. To explore how verb bias changed over the course of the experiment, we examined responses to the first four verbs and the last four verbs. This analysis reflected our assumption that the first four bias trials would reflect the participants' prior lexicalization bias, while the last four would reflect the experimental input. Responses were converted to path bias scores by taking the proportion of verbs where the adult accepted the path match and subtracting the proportion of verbs where they accepted the manner match. This number would be -1 for a perfect manner bias and $+1$ for a perfect path bias.

To examine differences in bias across conditions, we used the Jonckheere-Terpstra test (test statistic J), a nonparametric statistic which tests for differences across groups that form an ordinal scale (analyses using the Kruskal-Wallis test, which assumes a nominal independent variable, yield the same pattern of findings). If a significant difference was found, the source of this difference was identified by a stepwise step-down procedure to identify homogenous subsets, with splitting occurring only when the Jonckheere-Terpstra test for a given subset indicated nonhomogeneity at $p < .05$. All within-subject paired comparisons were made with the Wilcoxon signed-ranks test (test statistic W); z scores are reported for each nonparametric statistic.

The analysis of bias responses for the first four verbs revealed that these English-speaking adults began with a strong manner bias ($M = -0.66$, $W = -920$, $z = -5.19$, $p < .001$). While 76% accepted the manner video, only 5% accepted the path video. However, contrary to expectation, there were also differences between the training conditions ($J = 708$, $z = 4.01$, $p < .001$),

indicating that the verbs in the training set were already shaping the adults' interpretations of the initial ambiguous scenes. This effect was driven by adults in the 100% path condition, who had no systematic bias on these early verbs ($M = 0.01$), resulting in two homogenous subsets (0%, 25%, 50%, and 75% $<$ 100%), which were robustly different from one another (Mann-Whitney $U = 362$, $z = 4.42$, $p < .001$).

On the final four verbs of the experiment, the bias test trials were clearly shaped by the set of verbs that adults had learned (see Figure 1; $J = 837$, $z = 6.16$, $p < .001$). Adults in the 100% path condition developed a strong, consistent path bias ($M = 0.85$), and those in the 0% and 25% path conditions showed an equally clear manner bias ($M = -1.00$, $M = -0.85$, respectively). In the 50% and 75% path conditions, adults continued to have a mild preference to interpret new verbs as encoding manner, suggesting that they had partially adapted to the new input but were still influenced by the lexicalization bias of English ($M = -0.55$, $M = -0.35$, respectively). This resulted in three nonoverlapping homogenous subsets (0% and 25% $<$ 50% and 75% $<$ 100%), which were different from each other (all Us > 190, zs > 3.70, ps $< .001$). To ensure that these differences were not solely attributable to the conditions with categorical biases, we conducted a planned comparison of the 25% and 75% path conditions and found a reliable difference ($U = 82$, $z = 2.42$, $p = .016$).

Finally, to assess how lexicalization biases changed over the course of the experiment, we compared the results of the first four verbs and the final four verbs by calculating the change in path bias for each participant (see Figure 2). Across conditions there was an increase in path bias ($M = 0.20$, $W = 256$, $z = 2.18$, $p = .029$), but the presence or magnitude of this change differed across conditions ($J = 703$, $z = 3.62$, $p < .001$). Adults in the 100%, 75%, and 50% conditions showed an increase in path bias, while those in the 25% and 0% conditions retained their manner bias. This resulted in two nonoverlapping homogenous subsets (0% and 25% $<$ 50%, 75%, and 100%), which were robustly different from one another ($U = 452.5$, $z = 3.17$, $p = .002$).

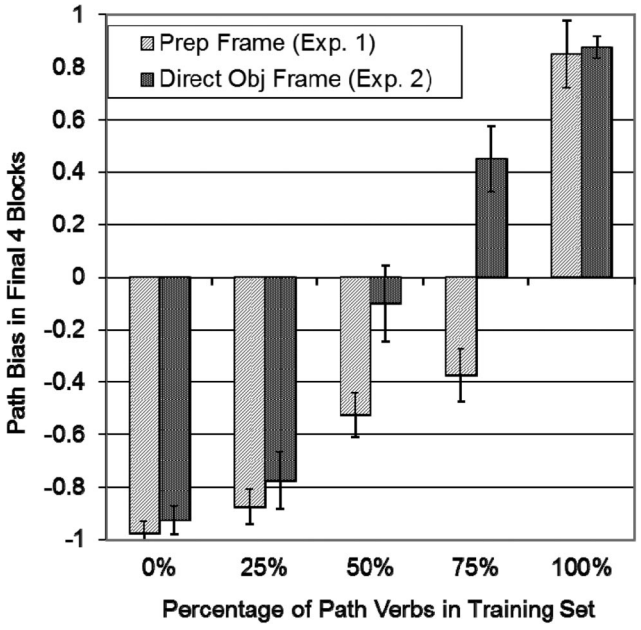

Figure 1. Path bias for the final four verbs in Experiments 1 and 2 (adults). Error bars indicate the standard error of the mean. Prep = preparation; Obj = object; Exp. = experiment.

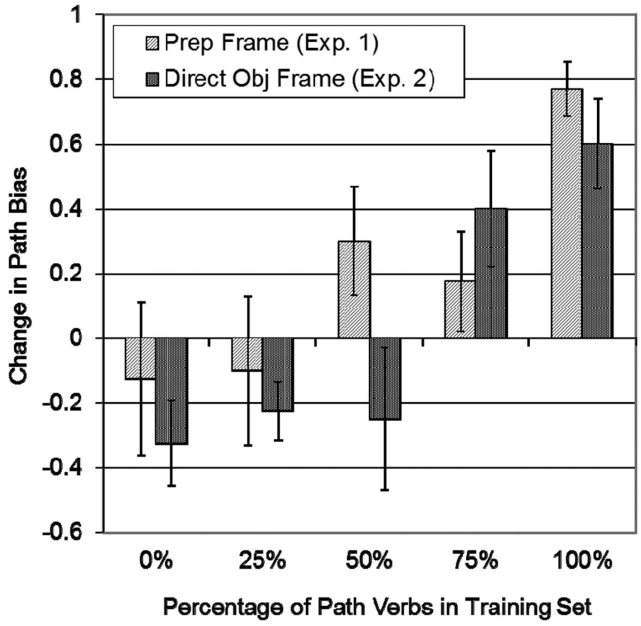

Figure 2. Change in path bias (the difference between the final four verbs and the first four verbs) in Experiments 1 and 2 (adults). Error bars indicate the standard error of the mean. Prep = preparation; Obj = object; Exp. = experiment.

Summary. Adults began the experiment with a manner bias, consistent with the pattern of use for the prepositional frame in English. When they learned verbs that reinforced this bias (0% and 25%), it was retained. When they learned verbs that provided probabilistic evidence that a manner bias was not warranted, they began to abandon it, and when they consistently learned verbs that encoded path, they shifted to a robust path bias.

Experiment 2

Experiment 2 examined whether these effects of training generalize to direct-object frames. Naigles and Terrazas (1998) found that, while English speakers have a systematic manner bias for verbs in the prepositional frame, they have no strong bias for verbs in the direct-object frame. Our corpus analyses and sentence completion study (see the supplemental materials) indicate that this construction is not strongly associated with motion events and is equally compatible with the two verb types. If the lexicalization biases that we are measuring reflect participants' prior experience with English, then the manner bias should be absent in this condition and participants' final biases should closely match the verbs learned in the experiment.

Method

Participants. The participants were 50 English-speaking adults recruited as in Experiment 1. As in Experiment 1, no demographic information was collected other than verification that

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participants had learned English at home prior to age 6. Responses from two additional adults were excluded because they failed to learn five or more of the 12 verbs. The final sample consisted of 10 adults in each of the five conditions (100%, 75%, 50%, 25%, or 0% path verbs).

Stimuli and procedure. The procedure and stimuli were identical to those in Experiment 1 except that verbs were used in simple transitive frames ("He torged the stairs").

Results and Discussion

When the novel verbs were presented in transitive frames, there was no longer a reliable preference for manner in the initial four verb blocks ($M = -0.14$, $W = -276$, $z = -1.61$, $p = .107$). However, even in these early trials, there were strong differences between the training conditions ($J = 721.5$, $z = 3.82$, $p < .001$). Adults in the 0% and 25% path conditions had a clear manner bias ($M = -0.60$, $M = -0.55$, respectively), while those in the 50%, 75%, and 100% path conditions had no systematic bias ($M = 0.15$, $M = 0.05$, $M = 0.28$, respectively), resulting in two homogenous subsets, which were different from one another ($U = 507.5$, $z = 4.14$, $p < .001$).

By the final four verbs, the adults' biases closely matched the set of words they had learned (see Figure 1). As a result, there was a reliable difference between the training conditions ($J = 904.5$, $z = 7.05$, $p < .001$) and a fractionation of adults into four homogenous subsets (0% and 25% < 50% < 75% < 100%), which were each different from the others (all Us > 80, zs > 2.50, ps < .05). Adults in the 0% and 25% path conditions had a strong manner bias ($M = -0.93$, $M = -0.78$, respectively), those in the 50% condition were unbiased ($M = -0.15$), those in the 75% condition had a modest path bias ($M = 0.45$), and those in the 100% condition had a strong path bias ($M = 0.88$).

To examine how lexicalization biases changed over the course of the experiment, we calculated the difference score for the path bias to the final four verbs versus the first four verbs (see Figure 2). Overall, there was no reliable increase in path bias from the first to the final trials ($M = 0.03$, $W = 66$, $z = .45$, $p > .5$). Instead, the direction and magnitude of the change in bias varied across the conditions ($J = 724$, $z = 3.88$, $p < .001$). Adults in the 100% and 75% path conditions showed an increase in path bias, while those in the 50%, 25%, and 0% conditions showed an increase in manner bias. This resulted in two homogenous subsets (0%, 25%, and 50% < 75% and 100%), which were different from one another ($U = 513.5$, $z = 4.28$, $p < .001$).

To explore the effects of the syntactic frame on lexicalization biases and their plasticity, we directly compared performance in Experiments 1 and 2. For these analyses, we calculated the *deviation score* by (1) determining the path bias that would be expected in each input condition if adults precisely matched the probability of path and manner interpretations that were present in the input (% of path verbs in input – % of manner verbs in input) and (2) subtracting this expected bias from the adults' actual path bias scores. Thus the difference score measures the degree to which adults in each condition had biases that were not motivated by the experimental input. At the beginning of the study, adults in Experiment 1 had a strong manner preference, while those in Experiment 2 did not, resulting in a reliable difference in the deviation score for the first four verbs ($U = 1{,}743$, $z = 3.40$, $p < .001$). This difference in bias was most robust in the 50% and 75% path conditions (Us > 75, zs > 2, ps < .05). By the end of training, adults in Experiment 2 approximated the bias of the training set in all five conditions, while those in Experiment 1 continued to show a manner bias ($U = 1{,}640.5$, $z = 2.69$, $p = .006$). This difference was reliable in the 75% path condition ($U = 90$, $z = 3.02$, $p = .002$) but did not reach significance in the 50% path condition ($U = 72.5$, $z = 1.70$, $p = .09$).

Summary. The adults in this study heard verbs in direct-object frames. They initially had no strong preference for either the manner or path match, consistent with prior results for English speakers (Hohenstein, 2005; Naigles & Terrazas, 1998). Over the course of the experiment, their biases shifted to closely match the input they had received. This resulted in probabilistic biases in the 25% and 75% path conditions, as predicted by the flexible inferences hypothesis. A comparison of the two experiments confirmed that participants showed a stronger manner bias for the prepositional frame and had biases which more closely matched the experimental input when the verbs appeared in the direct-object frame.

Experiment 3

Experiments 1 and 2 demonstrated that adults are able to shift their lexicalization biases on the basis of newly encountered verbs. Several features of these data suggest that adults were adjusting their existing lexicalization biases rather than developing a strategy for solving this specific experimental task: Their initial biases showed the patterns observed in previous studies with English speakers, their ability to acquire the experimental bias depended upon the syntactic frame, and probabilistic input resulted in more graded biases. Nevertheless, adults have rich metalinguistic skills that they might employ in this task. If our paradigm is tapping the development and modification of lexicalization biases, then we should also see these effects in children 4 years of age and older. Experiment 3 tested this prediction using a simplified version of our paradigm.

Method

Participants. The participants were 20 native English-speaking children aged 4 years 6 months to 5 years 6 months ($M =$ 5 years 1 month) and 20 English-speaking adults. The adults were recruited via the Harvard University psychology subject pool and had learned English in the home before age 6. The children were recruited from the database of the Laboratory for Developmental Studies at Harvard University. English was their first language and the primary language used in their homes. No other demographic information (including gender) was collected. Participants were assigned to either the manner verb training (all six verbs encoded manner) or the path verb training condition (all six verbs encoded path).

Stimuli and procedure. Participants heard the target verb in a prepositional frame (as in Experiment 1). This frame was selected because the transitive frame in English is used to encode many meanings other than directed motion (e.g., contact, caused change of state and perception; see the supplemental materials). If children consider these other hypotheses first, they might fail to learn the verbs from the six exemplars and thus fail to get the intended input to bias learning. Critically, adults judge both man-

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ner and path verbs to be grammatical in the prepositional frame (see supplemental materials). The procedure was identical to that in the prior experiments with the following exceptions.

First, to reduce session length, we selected six novel verb pairs from the 12 used in Experiments 1 and 2. The path verb meanings were *around, down, up, over, in*, and *behind*. The manner verb meanings were *twirl, flap-walk, run, skip, stoop-walk,* and *walk*. The six verbs were randomly ordered in a single presentation list. Given the rapid effects of bias training in the first two experiments, we expected that the experimentally induced bias could begin to emerge as soon as the second bias test trial. Thus, we used the first bias trial to measure the participants' initial lexicalization bias, and we pooled the remaining five bias trials to get a more sensitive measure of experimentally induced changes in bias.

Second, rather than asking children to make separate yes/no judgments on a manner match and a path match, we used a two-alternative forced-choice task. Specifically, for both the bias test trials and the verb-learning test trials, participants were shown a split screen with the manner match test clip on one side and the path match on the other, and they were asked to choose the side of the screen that matched the novel verb (e.g., "Which one is glipping?"). The onscreen location of the correct clip (for the verb-learning test question) and of the path match (for the bias test question) was counterbalanced across trials.

Third, while all verbal descriptions and questions appeared on the screen (as in Experiments 1 and 2), these descriptions were read aloud to the child participants.

Results and Discussion

To determine whether the participants had learned the verbs, we examined responses to the verb-learning test questions. The adults answered 98% of these correctly, while the children answered only 78% correctly ($U = 296$, $z = 2.60$, $p = .009$). Nevertheless, both groups performed significantly above chance (both Ws $= 210$, zs $= 3.912$, ps $< .001$), with 90% of the adults and 45% of the children choosing the correct video for all six verbs.

On the bias test question for the very first novel verb (prior to verb training), none of the adults and only 30% of the children chose the path match, suggesting that the English-speaking participants had an initial manner bias. This preference was greater than chance for the adults ($p < .001$ by two-tailed binominal test) but not for the children ($p = .103$). A Fisher's exact test confirmed that the manner bias was more systematic in adults than in children ($p = .02$).

Performance on the subsequent bias test trials was shaped by the verbs that participants had learned in the study (see Figure 3). Responses were converted to path bias scores by taking the proportion of verbs where the participant extended the novel verb to the path of motion and subtracting the proportion of verbs where they extended the novel verb to the manner of motion. This resulted in a scale parallel to that used in Experiment 1. For both the adults and children, the average bias score for Verbs 2 through 6 was significantly greater for the path condition than the manner condition, indicating that their lexicalization biases changed as new verbs were learned ($U = 99$, $z = 3.70$, $p < .001$; $U = 86.5$, $z = 2.76$, $p = .004$, respectively).

To compare the adults and children, we calculated the percentage of bias test responses that were consistent with the training

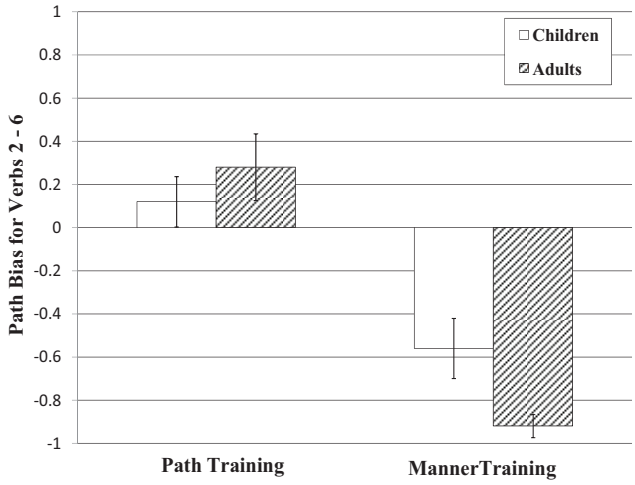

Figure 3. Children's and adults' path bias on the bias test questions for Verbs 2 through 6 in Experiment 3. Error bars indicate the standard error of the mean.

condition. Although the difference between the two groups was not significant, there was a trend toward better performance in adults than in children ($M = 80\%$ and $M = 67\%$, respectively; $U = 266$, $z = 1.79$, $p = .074$). Critically, bias matching in the children was related to verb learning; those who learned more verbs had biases that more closely matched the verbs in the training set ($r_T = .360$, $p = .012$, using Kendall's τ_b). In fact, those children who learned all of the verbs answered the bias test questions in a manner consistent with their training condition 78% of time and thus performed similarly to adults.

Summary. Like adults, children trained on manner verbs were more likely to extend new novel verbs by manner of motion, while children trained on path verbs extended meaning by path of motion more often. Thus, lexicalization biases are flexible in young children. Unsurprisingly, children were worse at verb learning than adults, but there was no reliable difference in their propensity to shift their lexicalization bias in response to the input. Taken together, these results suggest that children's lexicalization biases are influenced by new verbs in much the same way as those of adults.

This experiment, however, had two clear limitations. First, the number of children in each condition was small, and thus more fine grained analyses were not feasible. For example, we could not investigate the contingency between verb learning and performance on the bias test within each training condition. Second, because only one presentation list was used, item and serial position were perfectly confounded, and we could not explore how bias developed over the course of the experiment. In Experiment 4, we tested a much larger sample of children to resolve these limitations and ensure that our primary findings were replicable.

Experiment 4

Method

Participants. Participants were 64 native English-speaking children between 4 years 6 months and 5 years 6 months ($M = 5$

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years 0 months) recruited in the same manner and from the same population as in Experiment 3. There were 32 children in each of the two conditions (eight in each order). Five additional children were tested but excluded because English was not their first language. No additional demographic information was collected.

Stimuli and procedure. The stimuli and procedure were identical to those in Experiment 3, with two exceptions. First, four orders were created such that each verb appeared equally often in the first and last halves of the experiment. Training condition (manner or path) was fully crossed with order, resulting in eight presentation lists.

Second, children were provided with feedback on the verb-learning test question. Specifically, if children answered this question incorrectly (i.e., chose the manner match after receiving path training), they were corrected by the experimenter and asked to try again. Once children chose the correct screen, they moved on to the next novel verb. Only their first response was coded and analyzed. No feedback was provided on the bias test questions. This change to the procedure was made to ensure that the children realized that the verb-learning questions did have a correct answer, which we hoped would encourage them to respond more carefully. However, this change ended up having no effect on correctness or bias.

Results and Discussion

Performance on the verb-learning test trials was similar to that in Experiment 3, with children answering 77% of the verb-learning test questions correctly. In total, 39% of the children chose the correct video on all six trials and 22% chose the correct video for five of the six verbs. Verb-learning performance was above chance in both the path training condition ($M = 68\%$; $W = 233$, $z = 2.95$, $p = .001$) and the manner training condition ($M = 86\%$; $W = 430$, $z = 4.64$, $p < .001$). As Figure 4 illustrates, from the first verb-learning trial, children in the path and manner conditions responded differently, indicating that they were using the information from the training trials to determine the meaning of the verb.

Figure 5 graphs the proportion of path responses on the bias test trials from Verb 1 to Verb 6. On the bias test trial for Verb 1, 41% of the children chose the path match. While this preference for manner was not reliably different from chance ($p > .1$), when we collapsed across Experiments 3 and 4, the proportion of children selecting the manner match on the first bias test trial did reach significance ($p = .04$), suggesting that there was a small initial manner bias for these stimuli in English-speaking children.

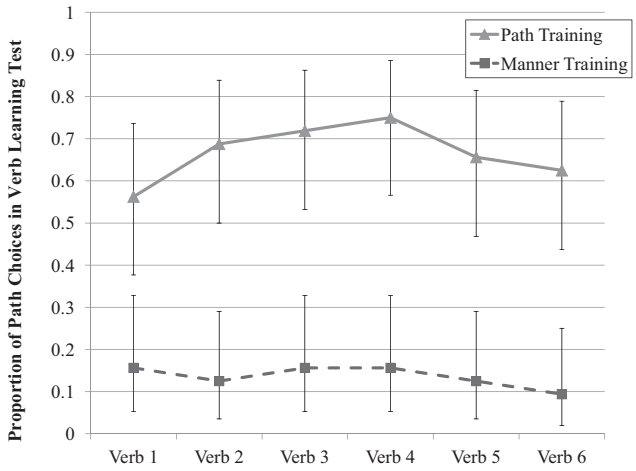

Figure 4. Children's responses on the verb-learning test trial in Experiment 4. Error bars indicate 95% binomial confidence intervals.

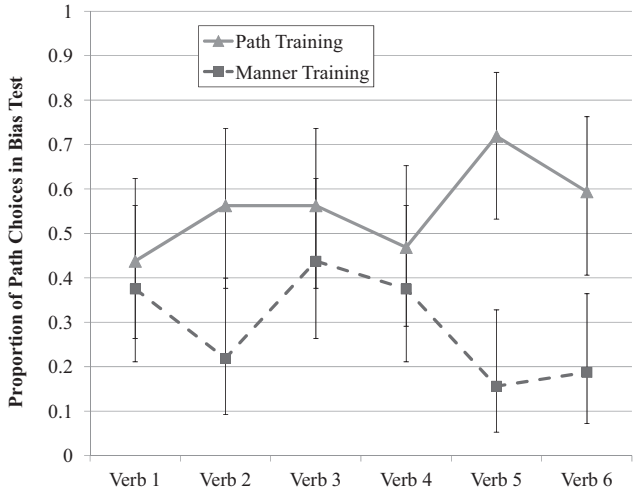

Figure 5. Children's responses on the bias test trials in Experiment 4. Error bars indicate 95% binomial confidence intervals.

After the first verb, performance on the bias test questions was shaped by the verbs that children learned in the study. The proportion of path responses for Verbs 2 through 6 was higher for the path condition than the manner condition ($U = 764.5$, $z = 3.39$, $p < .001$). As Figure 5 suggests, the difference in bias was present for Verbs 2 through 4 ($U = 668.5$, $z = 2.10$, $p = .036$) but became more robust in the final two trials after more verbs had been learned ($U = 856.5$, $z = 4.63$, $p < .001$). Critically, in the last two trials, the bias was different from chance in both the path training condition ($W = 85$, $z = 2.13$, $p = .03$) and the manner training condition ($W = 294$, $z = 3.53$, $p < .001$). To explore whether this shift in lexicalization bias was mediated by verb learning, we correlated the percentage of correct responses in the verb-learning trials with the percentage of training-consistent responses on Verbs 2–6. This correlation was reliable for the complete data set ($r_T = .462$, $p < .001$, by Kendall's τ_b) and for the manner and path conditions individually ($r_T = .411$, $p = .007$, and $r_T = .381$, $p = .008$, respectively). Children who learned all six verbs gave training-consistent responses 79% of the time.

Summary. These results confirm that 4- and 5-year-old children can update their lexicalization biases on the basis of newly learned verbs. The additional analyses demonstrate that children are able to learn both manner and path verbs from the outset of the study and that the change in bias begins in the early trials but becomes more robust as the experiment progresses. In both training conditions, changes in lexicalization bias were predicted by verb learning, consistent with the predictions of the flexible inferences hypothesis.

General Discussion

Taken together these experiments provide strong evidence for the plasticity of lexicalization biases in both adults and young

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children. Our findings provide support for four predictions of the flexible inferences hypothesis.

First, lexicalization biases remain plastic even in adulthood (Experiments 1–3). English-speaking adults who were taught novel verbs encoding path quickly came to expect that new motion verbs would also encode path. In contrast, those who were taught novel verbs encoding manner retained or strengthened their bias to assume that new verbs would encode manner.

Second, lexicalization biases are flexible in the sense that they do not merely allow or disallow a particular hypothesis but can reflect graded differences in the input (Experiments 1 and 2). Specifically, when adults were given probabilistic input, they showed shifts in bias that reflected the input but were weaker than the shifts observed in response to deterministic input.

Third, these lexicalization biases deviate from the experimental input in ways that systematically reflect our participants' prior experience as English speakers. This is expected according to the flexible inferences hypothesis because the biases that emerge during a study are hypothesized to result from participants' using the experimental input to alter the lexicalization biases that they brought with them. Specifically, when adults heard motion verbs in prepositional frames, they initially had a strong preference to interpret those verbs as encoding manner (Experiments 1 and 3). This preference has been found in prior studies with no learning component (Hohenstein, 2005; Naigles & Terrazas, 1998), and it reflects the statistics of English (Slobin, 2004; Talmy, 1985). Furthermore, this manner bias was not fully overridden by the experimental input; even at the end of the experiment, adult participants in the probabilistic bias conditions interpreted verbs as encoding manner more often than the stimulus set warranted (see Figure 1). In contrast, when adults heard verbs in direct-object frames, they initially had no preference (see Experiment 2), consistent with prior studies with English speakers (Hohenstein, 2005; Naigles & Terrazas, 1998). In English, motion events without an external cause are seldom described with transitive sentences and when they are the verb is as likely to encode path as it is to encode manner (see the supplemental materials). Thus, any bias participants brought into the study for the direct-object frames should have been weak and easily overturned.

Finally, we found that 4- and 5-year-old children were also quick to adapt their lexicalization biases to the experimental input (see Experiments 3 and 4). This is fully predicted by the flexible inferences hypothesis, which posits that the mechanism used to update lexicalization biases in our study is the same mechanism that produces the cross-linguistic differences in lexicalization that were observed in prior studies with children of this age (Maguire et al., 2010; Papafragou & Selimis, 2010).

In the remainder of the General Discussion, we explore the implications of these data for: the stable reorganization hypothesis, typological proposals, theories of verb learning, and accounts of conceptual structure.

Revisiting the Stable Reorganization Hypothesis

Many theories of semantic development have been built on a metaphor to speech perception. Scientific metaphors serve a variety of functions. Some are mnemonic devices that capture surface similarities between two domains, while others are implicit hypotheses about the functions of the systems or the mechanisms that underlie them. If the parallels between speech perception and semantic acquisition do, in fact, reflect parallel mechanisms or parallel functions, then we should expect that semantic reorganization, like phonetic reorganization, will be characterized by stability and limited plasticity (the stable reorganization hypothesis).

The present findings provide strong evidence that this construal of the metaphor is wrong, at least as it applies to the manner–path lexicalization bias. All four experiments showed reliable shifts in this bias after acquiring just three or four novel verbs. Our findings contrast sharply with those of training studies on nonnative phoneme perception. For example, Ingvalson, McClelland, and Holt (2011) attempted to teach Japanese speakers the distinction between /r/ and /l/, using 4,000 trials with stimuli that were carefully manipulated to highlight the perceptual feature that would most reliably distinguish the two categories. Despite this, performance was unaffected by training, unless adults were first taught to use the relevant acoustic cue with nonspeech stimuli, which then became more speechlike over time. In contrast, we used a training set that was three orders of magnitude smaller, yet we observed a change in bias which led English speakers (in the path condition) to show lexicalization preferences that were comparable to those previously observed in native Spanish- and Greek-speaking adults (Naigles & Terrazas, 1998; Papafragou & Selimis, 2010).

While diverse mechanisms have been proposed for semantic reorganization, none of them can account for our findings, if they result in stable alterations of the semantic interface. The least restrictive theory (Göksun et al., 2010) is one in which reorganization is semantic (rather than conceptual) and graded (rather than binary). Such a theory can explain how the participants in our studies learned path verbs; although they have a language-specific preference to map verbs to manner of motion, they still have the conceptual wherewithal to represent paths, allowing them to consider this possibility when the input rules out the more highly ranked interpretation. However, this proposal, by itself, cannot account for the changes that we observed in the bias trials. One must also posit that this graded semantic bias is highly plastic and can be rapidly overridden when circumstances change. If this is true, then lexicalization biases should not be viewed as stable developmental achievements or permanent alterations of the semantic interface but rather as flexible and rational inferences about the meanings of words.

This argument assumes that the lexicalization biases observed in this study are actual reflections of semantic interpretation rather than experimentally-induced strategies. There are four reasons for believing that this is true. First, the method used to probe lexicalization biases in these experiments is very similar to the methods used in prior studies. Second, the responses of the adults systematically deviated from the experimental input in ways that suggest that participants were integrating this input with what they already knew about their language. Specifically, for the prepositional frames, there was an initial manner bias and a final response pattern with systematically fewer path responses than would be predicted on the basis of the experimental input alone. In contrast, verbs in direct-object frames had no such bias. If participants were developing strategies based solely on the experimental input, one would not expect to see this asymmetry, particularly at the end of the study. Third, shifts in lexicalization bias were seen in 4- and 5-year-old children, who are less inclined to develop novel strategies and less capable of the metacognitive reasoning that this

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would require (Gombert, 1992; Schneider, 2008). In fact, while the children were worse at learning the verbs than the adults, they were no worse at developing a bias that was consistent with the input.

Finally, recent work has provided further evidence that these changes in bias are spontaneous and automatic. If these shifts were solely due to a strategy for answering the test questions, then one would expect that the strategy would be triggered by the bias test and would not affect how participants processed the initial ambiguous scene. Instead, Geojo and Snedeker (2009) found that, during the initial ambiguous event, participants in the path bias condition looked significantly more at the reference object (which defines the path) than did participants in the manner condition. This pattern has been previously observed in a comparison of speakers of Greek (a path dominant language) and English (Papafragou, Hulbert, & Trueswell, 2008), and it is consistent with our claim that these shifts in bias reflect spontaneous changes in lexical interpretation that influence participants' encoding of the initial ambiguous verb. Thus, we conclude that manner–path lexicalization biases are quite labile and that semantic development is not analogous to phonetic perception in this respect.

It is critical to note that our findings, and thus our conclusions, are limited to a single test case. This test case has been central in theoretical discussions of typological variation and language development. Because manner and path are relevant to acquiring a large number of words (Slobin, 2004), this is the parade case for theories in which semantic reorganization guides word learning (e.g., Gentner & Boroditsky, 2001). In contrast, the other test cases in this arena involve the acquisition of specific lexical items (e.g., English prepositions *on* and *in*) and the concepts that they encode rather than broad generalizations (Choi, 2006; Hespos & Spelke, 2004; McDonough, Choi, & Mandler, 2003). This distinction may be central in understanding semantic development and plasticity. The links between individual word forms and concepts could be stable over time and difficult to rearrange later in life (perhaps because they are used frequently), while the broader mappings which guide word learning could be more plastic (perhaps because they are used less often or because each syntactic form maps onto multiple conceptual distinctions).

Lexicalization Biases and Theories of Typology

Various linguistic theories have been proposed to account for the typological difference in the encoding of motion events. While the current theories have enough degrees of freedom to account for our data, our findings provide strong constraints on the further development of these theories, and thus they are relevant to typologists.

Talmy's famous proposal (1985, 2000) is that there is a two-way distinction between satellite-framed languages, which encode manner of motion in the verb and path of motion in a satellite of the verb (a particle or affix), and verb-framed languages, which encode path of motion in the verb and manner in an adjunct clause. A binary, categorical distinction like this lends itself to a parameter-setting theory, and many linguists have pursued this possibility. On the face of it, our data are hard to reconcile with parameter theories. If the lexicalization bias for motion events were directly controlled by a binary parameter, there would be two possible settings (rather than a graded bias) and a rational learner should be unwilling to change the parameter setting on the basis of just a handful of examples. However, the syntactic parameters that have been proposed are only loosely yoked to lexicalization biases. For example, Snyder (2001) and Mateu and Rigau (2002) proposed that the relevant parameter prevents verb-framed (or path) languages from using manner verbs with prepositional phrases that encode a result (e.g., the crossing of a boundary; see Aske, 1989). This parameter does not dictate the meanings that a verb can have, but it could indirectly shape lexicalization biases. Languages which allow manner verbs to be used with result prepositional phrases are likely to make frequent use of this tight packaging. As a result, manner verbs will be more useful in such languages and their numbers will increase (Slobin, 2004). In contrast, speakers of path languages will be unable to use this construction and instead will typically describe boundary crossing events using path verbs, leaving the manner to be inferred (Slobin, 2004). Thus, languages of both types are expected to have both path verbs and manner verbs (and most do), but they are expected to vary in the frequency with which they use verbs of each kind and the syntactic contexts in which they appear. Consequently, the input to learners in these two environments could support the acquisition of biases that are probabilistic and conditioned on the syntactic context in which the verb occurs, like those that we observed.

Recently, however, several researchers have argued that parametric theories cannot account for the full range and subtlety of typological variation (Beavers et al., 2010; Slobin, 2004; Son & Svenonius, 2008). Many languages have constructions for describing motion events that do not fit neatly into either of Talmy's typological categories (Talmy, 1985, 2000). For example, Thai and Mandarin have serial verb constructions which allow manner and path to be expressed by separate verbs in the same clause (Beavers et al., 2010). In addition, within each class of languages there is variation in the devices available to express manner and path. For example, Japanese has consistently been classified as a verb-framed (or path) language, but, unlike European verb-framed languages, it has a large class of ideophones which can be used to express manner of motion. As a result, Japanese-speaking children often produce sentences in which the manner and path of an event are concisely packaged into a single clause (Allen et al., 2007).

The complexity of these patterns has led theorists to propose that typological variation is the result of multiple overlapping constraints linked to the following: the syntactic devices that are available in a given language, the stock of prepositions and case markers, the verbs that already exist, and the discourse habits of the community (Beavers et al., 2010; Slobin, 2004; Son & Svenonius, 2008). On the face of it, these theories appear to be compatible with our findings. They predict that learners will have to acquire probabilistic biases (to correctly capture the gradient differences between languages), which should depend on the construction in which a word occurs (first serial verb vs. sole verb). However, the predictions that such theories make about plasticity diverge depending on the mechanisms that support typological stability.

As Beavers and colleagues (2010) pointed out, the challenge for a theory like theirs is to explain why the typological data look as categorical as they do. Given the diverse range of encoding options in most languages and the large number of relevant variables, it is surprising that we see stable cross-linguistic differences in language use which fall roughly in line with Talmy's proposal (see e.g., Berman & Slobin, 1994; Papafragou et al., 2006; Slobin,

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2004). Beavers and colleagues (2010, p. 34) tentatively floated the hypothesis that "a language's preference for certain types of lexemes" may account for this stability. If by this the authors meant *the language user's lexicalization biases*, then our data indicate that this conjecture is wrong. Children and adults change their biases at the first sign of trouble, so these biases are unlikely to contribute to typological stability. Our data are also inconsistent with theories in which typological stability results from changes in the conceptualization of events or the accessibility of particular concepts over development.

However, our data are compatible with accounts in which typological stability results from the syntactic resources of a language and the effects these have on the historical development of the lexicon. For example, Son and Svenonius (2008) proposed that verb-framed languages typically lack prepositions that encode path (e.g., *into*) and instead have prepositions that encode the place of an action (e.g., *in*). In such languages, manner verbs cannot be used to express directed motion along a path. Path verbs, however, have an intrinsic path feature, which allows them to convert a prepositional complement from a place to a path. In such languages, the absence of path prepositions and the attribution of the path feature to the verb are mutually reinforcing. The constraints of this system, and the need to communicate paths, would create an incentive to coin path verbs but reduce the incentive to coin manner verbs.

Lexicalization Biases and Verb Learning

The flexibility of lexicalization biases raises questions about the role that they play in lexical development. Gentner's (1982) relational relativity hypothesis proposes that children initially have difficulty learning verbs because they do not know how their language packages and categorizes events. After acquiring these stable mappings, language acquisition is facilitated because children can narrow their hypothesis space by focusing on the semantic elements that are preferentially encoded by verbs in their language, a process Slobin (2001, 2008) called *typological bootstrapping*. This could result in biases that allow verbs to be fast-mapped to their referents, much like nouns (Maguire et al., 2010; Naigles et al., 1998).

Two aspects of our data limit the reach of this hypothesis. First, if the acquisition of stable lexicalization patterns is necessary for efficient verb learning, then our participants should have had little success in learning path verbs. After all, in this respect, they are in a worse situation than the linguistic novice. They do not merely lack knowledge of whether the verb encodes manner or path, but instead they have an existing hypothesis (verbs encode manner) that leads them in the wrong direction. Nevertheless, adults were nearly perfect in the path verb-learning trials, and the performance of children was well above chance. Apparently, the disambiguating information provided by the five training events was enough to allow them to discard their preferred hypothesis and sift through the remaining possibilities. Since infants hear many verbs thousands of times before using them, typological ignorance cannot be the only thing that is slowing them down.

Second, the rapid adjustment of lexicalization biases in the present study demonstrates that these biases are not a stable developmental achievement, as Gentner's theory (1982, 2003) suggests, but instead are flexible inferences about the mapping between linguistic forms and concepts. This flexibility seems necessary for the task that children face. There are robust cross-linguistic differences in how languages encode events, but within every language there is also enormous flexibility in how a scene can be parsed into events and how those events can be described (Gleitman, 1990). For example, one can refer to an event in which a girl kicks a ball to her mother as *giving, passing, kicking, rolling, receiving, moving, playing,* or *practicing* depending on the components of meaning that are encoded, the perspective that is being taken on the scene, and what is known about the protagonists. To cope with this variation, children must be flexible, both in their construal of the scene and in their beliefs about the language.

If language-specific semantic mappings cannot eliminate the ambiguity inherent in events, then how do children ever become rapid and efficient verb learners? We believe that two factors are at play. First, children may improve in their ability to use cross-situational observation. The concepts encoded in verbs appear to be grouped into semantic fields, which are organized as a cross-cutting lattice of concepts (Behrend, 1995; Talmy, 1985). Identifying a single referent event identifies a point in this multidimensional conceptual space, but it does not tell the observer which dimensions of the event are encoded in the verb. Multiple exemplars, however, can be used to rule out the relevance of some dimensions and provide convergent evidence for the importance of others. In this respect, nouns are quite different from verbs; they typically pick out concepts which form a taxonomic tree and are mutually exclusive at a given level (Markman, 1989). This structure helps bridge the gap between reference and meaning. Once the observer has correctly picked out the referent of the noun, then its meaning can be limited to concepts on the path from the individual exemplar up to the top of the hierarchical tree. If there is a conceptually privileged basic level, a single referent can provide enough information to identify the word's meaning.

Second, children's verb learning also benefits from their increasingly sophisticated representations of the utterances in which new verbs appear. Initially children must learn the meanings of new words by observing the nonlinguistic contexts in which those words are used. This information source provides ample support for noun learning but provides inadequate information about meanings of many verbs (see e.g., Snedeker & Gleitman, 2004). As children learn new words and acquire the syntax of their language, the sentential environments in which the verb occurs can provide increasingly fine grained information about its meaning.

Conceptual Structure

The present study also makes a small contribution to the empirical study of conceptual structure. Underlying every discussion of lexicalization biases is the theoretical assumption that there are superordinate event concepts, such as PATH or MANNER. This assumption is inherited from the linguistic research on verb semantics (e.g., Jackendoff, 1983; Levin & Rappaport Hovav, 2011; Pinker, 1989), which adopts a neoclassical theory of concepts (Laurence & Margolis, 1999). In the neoclassical approach, the meaning of a verb is decomposed into a small set of conceptual primitives (such as CAUSE, ACT, and GO), which determine the syntactic realization of the verb's arguments, and a potentially infinite set of verbal *roots,* which fill in the holes of this structure but play no role in syntax. These verbal roots belong to different

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ontological types, and these types limit the roles that they can play in lexical–conceptual structure. Thus, there are superordinate conceptual categories, such as MANNER or PATH, that pick out sets of verbal roots (and form the conceptual dimensions of the lattice discussed above). This theory of conceptual structure has been constructed primarily by observing the kinds of sentences that a verb can appear in, within and across languages. Studies like the present one provide converging evidence about the organization of event concepts.

Prior studies of lexicalization biases have demonstrated that speakers of different languages have preferences for particular concepts over others (particular manners and particular paths). This has allowed *researchers* to make the generalization that speakers of a given language have an overall preference for encoding manner or path in the verb. However, studies of this kind do not show that the speakers themselves have a superordinate category of MANNER or PATH—although this might be the most plausible explanation of their findings—because the tasks do not require generalization across this category. In contrast, the present findings clearly demonstrate that both children and adults have the superordinate event concepts MANNER and PATH. These categories are broad enough to allow for generalizations across diverse event types (e.g., from *around* and *up* to *in*) and salient enough to be accessed after just two or three trials. These categories are *linguistic* in the sense that they are being employed in the service of language comprehension and word learning. But they are also necessarily *conceptual*: They allow children and adults to map words onto classes of perceptually experienced events. In short, the notions of MANNER and PATH are not only part of our theory of typology, but they are also features of our conceptualization of events, which are readily accessible to both adult and child learners.

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