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ARTICLE

The effect of lexicalization biases on cross-situational statistical learning of novel verbs

Nathan R. George[1], Sabina Ciaccio[2], Lucia Berry[2] and Daniel J. Weiss[3]

[1]Derner School of Psychology, Adelphi University, Garden City, NY, USA; [2]Audiology, The City University of New York Graduate Center, New York, NY, USA; [3]The National Academies of Sciences, Engineering, and Medicine, Washington, DC, USA
Corresponding author: Nathan R. George; Email: ngeorge@adelphi.edu

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Abstract
Languages vary in the mapping of relational terms onto events. For instance, English motion descriptions favor manner (how something moves) verbs over path (where something move) verbs, whereas those of other languages, like Spanish, show the opposite pattern. While these lexicalization biases are malleable, adopting a novel lexicalization pattern can be slow for second language learners. One potential mechanism for learning non-native verb mappings is cross-situational statistical learning (CSSL). However, the application of CSSL to verbs is limited and does not explicitly examine how lexicalization biases may complicate adults' ability to resolve the referential uncertainty of multiple referents. We ask English-speaking monolingual adults to learn the mappings of ten verbs via CSSL. Verbs mapped onto either manner or path of motion, with the other event component held constant. Adults in both conditions demonstrated successful learning of novel verbs, with adults learning the manner verbs showing more consistent performance across accepting correct referents and rejecting incorrect ones. Our results are the first to demonstrate adults' use of CSSL to acquire verb meanings that both align with and cut against native lexicalization biases and suggest a limited influence of lexicalization biases on adults' learning in idealized CSSL conditions.

Keywords: cross-situational statistical learning; lexicalization; biases; path and manner; verbs

1. Introduction

The Gavagai problem reflects a signature challenge of language learning (Quine, 1960). In even the simplest of contexts, the environment around us contains numerous possible meanings for any novel word. In the classic example, a non-native speaker of a language witnesses a native speaker point at a rabbit in the forest

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and shout "gavagai!" Initially, the speaker might assume that "gavagai" refers to the rabbit. However, upon further contemplation, several possible meanings arise, including specific parts of the rabbit (e.g., long ears, tail), the actions of the rabbit (e.g., hop, scurry), and social directives (e.g., let us hunt, look there) to name a few. From this one instance alone, the non-native speaker will be unable to confidently pinpoint the meaning of "gavagai." However, with additional exposure to the language across multiple situations, a meaning is likely to become clearer (e.g., referring to a pet rabbit as "gavagai" likely eliminates the meaning of "let's hunt"). This process, whereby learners acquire information about the possible meanings of a label in one situation and use that information to narrow down the word's mapping when exposed to the same label in subsequent situations, has been called cross-situational statistical learning (CSSL; Yu & Smith, 2007).

Given that CSSL does not rely on prior knowledge of language, it has been touted as an important bottom-up process for first language acquisition, with many demonstrations of this approach focusing on infant and child populations (e.g., Scott & Fisher, 2012; Smith & Yu, 2008; Suanda et al., 2014; Vlach & Johnson, 2013; Yu & Smith, 2011). Yet, CSSL has also been documented in adults (e.g., Angwin et al., 2022; Bulgarelli et al., 2021; Kachergis et al., 2012; Poepsel & Weiss, 2014; Vlach & Sandhofer, 2014; Yu et al., 2012; Yu & Smith, 2007, 2012), and therefore may have continued utility for second language acquisition. Unlike infants, however, adults already possess intricate knowledge of a language system, which may affect their use of CSSL. As documented by Talmy's (1985, 2000) pioneering work in cognitive semantics, languages differ in the ways in which words are mapped onto the world. For instance, English favors *manner* information, or *how* agents move, in verbs (e.g., *dancing* or *walking*), whereas languages such as Spanish heavily rely on verbs to encode *path* information, or where something moves (e.g., *entrar* – enter, *bajar* – descend). These structures give rise to *lexicalization biases,* or assumptions regarding how words map onto the world; an English speaker will be more likely to assume a novel verb refers to how an agent is moving, as opposed to where (e.g., Shafto et al., 2013). When considering the process of CSSL, these biases can be helpful when languages share lexicalization patterns; they may direct adults' attention more strongly toward aspects of an event most likely to be encoded by that part of speech. However, when languages conflict in their lexicalization patterns, they may hinder an adult from learning, as their bias may draw their attention away from the target event component.

To date, research has not explicitly examined whether or how lexicalization biases affect how adults acquire statistics in the context of CSSL. Typically, CSSL paradigms utilize novel, concrete objects (in the case of nouns) to eliminate any differences based on prior exposure to vocabulary – an especially important control for work with infants and children. But this approach is agnostic about whether adults have an existing framework for interpreting new words. Verbs and relational terms offer an ideal focus for addressing this question. Not only are they still understudied in CSSL paradigms relative to nouns (see Monaghan et al., 2015; Rebuschat et al., 2021; Scott & Fisher, 2012), but it has been proposed that cross-linguistic variation may be most pronounced for relational language (e.g., Gentner, 1981; see also Malt & Majid, 2013). Furthermore, Talmy's analysis of relational language provides an extensive framework for a variety of language differences that can be explored within the CSSL paradigm, ranging from the packaging of elements in different parts of speech (e.g., Maguire et al., 2010; Song et al., 2016) to differences in the boundaries between linguistic categories (e.g., McDonough et al., 2003). Our work therefore seeks to better understand the role of lexicalization biases in adults'

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use of CSSL, as these effects may influence the early stages of adult second language acquisition.

1.1. Cross-situational learning

CSSL has been most extensively explored in the context of noun learning. Studies have documented the successful use of CSSL for mapping nouns onto concrete objects by infants as young as 12 months of age (Smith & Yu, 2008), with more recent work extending these findings to applied settings (e.g., Yu & Smith, 2011) and later stages of language acquisition (e.g., Suanda et al., 2014; Vlach & Johnson, 2013), including children with developmental language disorders (Ahufinger et al., 2021) and autism (Hartley et al., 2020). Adults have also been shown to utilize CSSL to learn novel concrete nouns. Yu and Smith (2007) first demonstrated CSSL in adults, with subsequent work deepening our understanding of the contexts and mechanisms supporting CSSL (e.g., Angwin et al., 2022; Bulgarelli et al., 2021; Poepsel & Weiss, 2014; Vlach & Sandhofer, 2014; Yu et al., 2012; Yurovsky & Yu, 2008). For instance, much work has aimed to tease apart the underlying process of CSSL, including differentiating between an associative learning (i.e., tracking co-occurrences between a word and multiple possible referents across multiple contexts, until gathering enough statistics to determine the correct referent; e.g., Kachergis et al., 2012; Suanda & Namy, 2012) and "propose but verify" account (i.e., forming a hypothesis about a word-referent mapping on first encounter and either verifying or rejecting the hypothesis upon subsequent encounters; e.g., Trueswell et al., 2013).

While many studies have examined the CSSL of concrete nouns, fewer studies have applied cross-situational statistics to other parts of speech. Verbs and other relational terms are particularly important to study through this mechanism, as actions and relations can offer different challenges when compared to concrete objects. Demonstration of this added challenge can be seen in the results of work on the human simulation paradigm (Gillette et al., 1999), a parallel line of research investigating the utility of cross-situational consistency in word learning. In the human simulation paradigm, adults view interactions between parent and child with the audio removed. A tone is played corresponding to when a target word, either noun or verb, was uttered in the original interaction. Multiple instances of the target word are demonstrated and adults are asked to guess the word being isolated. When the target referent was a concrete object, adults succeeded 45% of the time. Verbs, however, were correctly identified only 15% of the time, possibly indicating more difficulty in assigning verb meanings from cross-situational statistics alone (see also Piccin & Waxman, 2007; Zhang et al., 2020).

Several explanations may shed light on why verb meanings are less clear than concrete nouns. For one, actions are more fleeting than the concrete objects typical of CSSL studies, and their boundaries may be less clear than the perceptual boundaries of objects (Hirsh-Pasek & Golinkoff, 2006). Verbs are also relational; in order to decode their meaning, an understanding of the meaning of the concrete nouns in a phrase is often required (Scott & Fisher, 2012). As noted by Gleitman (1990), verbs such as giving and receiving, without linguistic context, will look the same. Furthermore, while specific objects, such as a child's favorite ball, can be repeatedly labeled, verb learning necessarily involves multiple different exemplars, as exact replication of an action demonstration is implausible (absent a video recording that can be replayed; Scott & Fisher, 2012). Noun learning also benefits from documented

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assumptions that guide the selection of meanings, such as biases for words to label whole objects and basic level categories (e.g., Markman, 1991). In contrast, studies utilizing the human simulation paradigm show that the average number of named referents for a novel verb is high, reflecting more ambiguity (Zhang et al., 2020). Thus, extending CSSL to verbs holds significant importance to our understanding of this process in the broader picture of language acquisition.

To our knowledge, Scott and Fisher (2012) is the first study to demonstrate the CSSL of verbs. Toddlers viewed two actions alongside two verbs presented in sentence frames (e.g., "Look she's pimming and she's nading!"), given the stated importance of sentence frames for understanding the relational referents of verbs. Across trials, the action pairs differed, allowing children to disambiguate the meanings of the novel verbs. Exemplars also varied across trials (e.g., different actors), mirroring the requirement to abstract across perceptually varied instances in learning relational terms. After several exposures, children looked significantly longer at the correct action when hearing each nonce word, having used cross-situational statistics to determine their meanings.

More recently, CSSL has also been applied to adult verb learning. Monaghan et al. (2015) demonstrated that adults can learn nouns and verbs via CSSL, even simultaneously, when provided with a sentence structure during the learning phase (see also Rebuschat et al., 2021). Furthermore, they document the added challenge for verbs, with verb learning lagging behind noun learning across learning conditions. This work suggests that, with the incorporation of grammar into the paradigm, CSSL can successfully support the acquisition of novel verbs, despite the unique challenges associated with relational language.

1.2. CSSL and lexicalization biases

CSSL is shown to support the acquisition of novel vocabulary regardless of grammatical category. Adults' use of CSSL suggests that this process may be an important one for second language learning, especially in contexts such as immersion that are rich with implicit learning opportunities. However, the context of second language learning introduces another important variable for the study of CSSL: the preexisting language knowledge of the learner. Unlike infants, adult learners bring with them a wealth of experience with language already, including knowledge of a grammar and assumptions regarding how language refers to objects or events in the world. Because languages often differ in these respects (e.g., Talmy, 1985, 2000), this experience may or may not be valuable to learning a new language.

In work that has greatly influenced the study of language learning, Talmy (1985, 2000) documented several ways in which languages differ in their packaging of relational information into words. In some respects, languages can be quite similar, such as a persistent bias for goal information over source information when describing motion events (e.g., Lakusta & Landau, 2005). But in many respects, languages are quite different in mapping word to world. Some variations are at the categorical level. For example, the English relational category of *on* is subdivided into three separate categories in Dutch: *op* (i.e., resting on; e.g., book on desk), *aan* (i.e., point-to-point attachment; e.g., berries on bush), and *om* (i.e., encirclement with contact; e.g., belt on waist; Gentner & Bowerman, 2009). Other differences concern the packaging of similar relational concepts into different parts of speech. For example, motion events contain both path and manner information. Path refers to the "…trajectory of an

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action in respect to the ground" (e.g., over, through), while manner refers to "how the action is performed" (e.g., running, skipping; Göksun et al., 2010, p. 34). In satellite-framed languages, such as English and Chinese, the main verb typically describes manner of motion and the path is expressed in the surrounding 'satellites' or prepositional phrases (e.g., "The student *marched into* class."). However, in verb-framed languages, such as Spanish, French, and Japanese, the bias favors path information in the verb, with manner more typically expressed within adverbial phrases (e.g., "The student *entered* class *marchingly.*"; Talmy, 1985, 2000). These differences can be stark. Naigles et al. (1998) found that English speakers utilized manner verbs to describe motion events in 91% of utterances, compared to only 33% for Spanish speakers. Such disparities are also entrenched in each language's vocabulary, with English having hundreds of manner verbs compared to approximately 75 manner verbs in Spanish (Slobin, 2006).

Of interest to the study of CSSL, these patterns yield *lexicalization biases,* or assumptions regarding how words map onto relations in events (e.g., George et al., 2014; Göksun et al., 2010; Shafto et al., 2013). When presented with a novel verb, Spanish speakers will be more likely to associate the verb with path of motion, while an English speaker will map it onto manner of motion. Such biases emerge relatively early in development. Maguire et al. (2010) presented English-speaking, Spanish-speaking, and Japanese-speaking children with an animation of a starfish performing an action containing both a path and manner of motion. The animation was accompanied by a novel word. When given the choice between a path and manner interpretation of the word's meaning, two-year-olds favored path verb interpretations no matter their native language. However, by the preschool years, children favored the lexicalization pattern of their native language (see also Hohenstein, 2005). Such shifts are part of a larger process of semantic reorganization, in which infants learn to attend to an array of relations in events underlying the world's languages, before shifting to language specific biases through language exposure (George et al., 2014; Göksun et al., 2010).

When an adult's native and target languages do not share the same lexicalization pattern, the differences challenge adults to shift their native biases to effectively acquire vocabulary and utilize it in a manner similar to a native speaker. Indeed, greater proficiency in a second language is observed when one's native language shares the lexicalization patterns of the language to be learned (Han & Cadierno, 2010). When biases must be shifted, the process can take considerably more time and effort. Song et al. (2016) find that English second language learners (SLLs) of Spanish require an average of seven semester long courses before they demonstrate lexicalization biases similar to those of native Spanish speakers. A hurdle in shifting to novel lexicalization patterns may be the use of compensation strategies; SLLs utilize second language vocabulary according to the patterns of their native language, such as a native Spanish speaker using more path verbs, even with redundant path prepositional phrases (e.g., *entered into* the building), when speaking English as a second language (e.g., Han & Cadierno, 2010; Negueruela et al., 2004).

Despite these findings, lexicalization biases are malleable, and some experiences may hold greater value in helping adults to discover novel mapping patterns. In contrast to the seven full semesters of coursework necessary to shift these biases, research suggests that only five weeks of immersion can accomplish a similar outcome (Song et al., 2016). Among the many benefits of immersion may be abundant opportunities for implicit learning, with exposure to new words in a variety of rich contexts. Shafto et al. (2013) tested if English-speaking adults could shift their

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bias favoring manner of motion in verbs, given sufficient exposure to verbs encoding path. Participants were shown an animation containing both a path and manner of motion (e.g., *bouncing over*) accompanied by a novel verb (e.g., *blicking*). Prior to any disambiguating information, participants were given a pretest to assess their interpretation of the verb's meaning (path or manner). Following the pretest, participants were provided disambiguating information; the word was presented over five successive animations in which the original path was the same (e.g., over) but the manner varied (e.g., spinning, jumping jacks, etc.). Participants then completed a posttest of the verb's meaning. Not only were English speakers able to learn the path meanings of these novel verbs, they began to favor path interpretations at pretest in subsequent trials. Thus, adults can utilize statistics to not only learn verbs that follow a non-native lexicalization pattern but also actually shift their biases to more efficiently acquire subsequent vocabulary.

Shafto et al. (2013) show the use of statistics to learn vocabulary that does not conform to English speakers' native lexicalization biases, but this study, by design, presents very unambiguous learning trials; each learning phase focuses on teaching a single path verb, with no other possible path referents present. Such an exposure does not mirror the complexity of real-world environments in which an adult may have to decipher the meaning of many co-occurring words and actions. When multiple potential referents are introduced, as in traditional CSSL studies, it remains possible that English speakers' bias to encode manner information in verbs could enhance their ability to track co-occurrences between verbs and manner referents. Such a finding would help to explain why adults have greater success in acquiring a language when that language matches the lexicalization patterns of their native tongue (Han & Cadierno, 2010).

One study to our knowledge has examined the use of CSSL by English-speaking monolinguals to acquire verbs in an artificial language that differs in its structure from English. Rebuschat et al. (2021) examined the CSSL of additional grammatical categories, including nouns, verbs, adjectives, and other grammatical markers. Participants learned not only the novel terms but also the structure of the grammar presented, an analogue to Japanese syntax in which verbs always occurred in the final position of the sentence. Thus, by learning the grammar, adults demonstrated the ability to utilize CSSL to acquire non-native aspects of language. However, this study did not explicitly incorporate lexicalization patterns. While Japanese favors path information in verbs, all verbs in the study mapped onto manners of motion (e.g., jumping, hiding, lifting, pushing), a pattern more closely matching English lexicalization patterns (though not entirely inconsistent with Japanese). Furthermore, while prior work does show that monolingual English-speaking adults are capable of learning path verbs as well (Monaghan et al., 2015), there still exists no direct comparison of CSSL across the two lexicalization patterns. Such a comparison is valuable in further elucidating whether or not CSSL is affected by lexicalization patterns, potentially assisting or slowing learning for adults seeking to acquire a new language.

1.3. Current study

Here we adapt the CSSL paradigm to examine the effects of lexicalization biases on adults' ability to learn novel verbs. English-speaking monolinguals are presented with ten novel verbs, referring to either ten distinct paths of motion or ten distinct manners of motion. Across learning trials, participants view two actions paired with

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two corresponding nonce verbs presented in a random order. In the path condition, actions vary with respect to path, with manner held constant. The reverse is true of the manner condition. Similar to prior work (Suanda et al., 2014; Suanda & Namy, 2012), we also manipulate the pairings of nonce verbs across trials to create varying degrees of competition among referents, ranging from distractors that co-occur with a referent 50% of the time, to distractors that never appear in the same trial with a given referent. Across both conditions, we anticipate that learners will struggle more to disambiguate correct referents from distractors that co-occur with the target more frequently, highlighting adults' reliance on cross-situational statistics in verb learning. Furthermore, we expect that English-speaking monolinguals will be able to learn both path and manner verbs, but will more quickly and more accurately identify verb meanings in the manner condition compared to the path condition. Such a result would demonstrate that CSSL is affected by lexicalization biases, a finding that would help to explain why adults show greater difficulties in acquiring languages that possess differing lexicalization patterns (Han & Cadierno, 2010).

2. Methods

2.1. Participants

Participants consisted of 77 monolingual English-speaking adults (M = 24.49 years; 38 female, 36 male, 3 nonbinary) divided across path (N = 39) and manner (N = 38) conditions. Participants were predominately White (74%), but also included Black (11.6%), American Indian/Alaskan Native (3.9%), Asian (3.9%), and Mixed Race (6.5%) individuals (1.2% other). Additionally, 7.8% of participants reported being Hispanic or Latino. In terms of education, 50.6% of participants had achieved an associate degree or higher. Participants were recruited from the website Prolific utilizing a screener to identify monolingual English speakers. An additional three participants were excluded for failing multiple attention checks.

2.2. Materials

A total of ten paths of motion and ten manners of motion were recorded for use as stimuli (see Table 1). Inspiration was taken from prior work (e.g., Maguire et al., 2010), with an emphasis on maximizing distinctiveness (e.g., *through* could be conflated with *exit* or *enter* and thus was omitted). When recording path videos, the manner of motion was consistent across all recordings (e.g., walking *across,* walking *into*, etc.). The same was true of path for the manner videos (e.g., *walking* across, *hopping* across). All videos contained the same female actress and actions lasted six seconds each (Figure 1).

Ten nonce verbs were recorded by a single female speaker. Nonce words were marked as verbs with the -ing ending (e.g., *blicking, hirshing*) and were presented in isolation. In each condition, each nonce word was assigned one of the ten target actions as the label for that referent.

2.3. Procedure

The experiment proceeded in four blocks, each with a learning and test phase.

Table 1. Target paths and manners of motion

Manners	Paths
Bending (at waist)	across
Crawling	around
Dancing	between
Hopping	down
Jumping jacks	enter
Lunging	exit
Side-stepping	over
Skipping	towards
Spinning	under
Walking	up

Figure 1. Examples of training videos from the manner (*jumping jacks;* left frame) and path condition (*exiting;* right frame).

2.3.1. Learning phases

Learning phases exposed participants to verb–action mappings. In each trial of a learning phase, two motion events were displayed simultaneously, one on the right side of the screen and the other on the left. Approximately one second after the videos began playing, a nonce verb was presented auditorily, corresponding to one of the two motion events (left or right). The verb was presented with no accompanying sentence frame (e.g., "*Blicking*!"). The videos then looped a second time, with the second nonce verb presented auditorily, again one second after the videos began playing. The order of the nonce verbs was counterbalanced across trials such that the order of the nonce verbs did not reliably correspond to the placement of the videos (i.e., the first nonce word sometimes referred to the motion event on the right, but in other trials was mapped onto the motion event on the left). A one-second black screen was then presented prior to the onset of the next trial.

Each of the ten verb–action pairings occurred six times per learning phase, yielding a total of 60 trials. The order of trials was randomized, outside of the restriction that the same verb–action pairing never appear in adjacent trials. The presentation of multiple verbs for each learning trial meant that nonce verbs co-occurred both with their intended referent actions, but also with other actions that served as distractors. As was the case in prior work (Suanda et al., 2014; Suanda & Namy, 2012), we manipulated the frequency with which each distractor event occurred with each nonce verb to create distractors of different strengths. Specifically,

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across the six presentations of each nonce verb, one distractor event co-occurred with the verb on three trials (termed *high-distractors*), and three different distractor events each co-occurred with the verb on a single trial (termed *low-distractors*). The remaining five possible motion events served as *non-distractors*, as they never appeared together with the target nonce verb.

Four different versions of the learning phase were created. Each version maintained the same verb–action mappings and the same high-, low-, and non-distractor relations. However, for each phase, a new random trial order was created, with the same restriction against verb–action pairings appearing in adjacent trials. In the second version of the learning phase, the order of the nonce verbs in each trial was flipped (i.e., second nonce verb presented first; first nonce verb presented second). In the third version, the placement of the motion events was flipped (i.e., left video moved to the right; right video moved to the left). In the fourth version, both the word order and placement of the motion events were flipped.

2.3.2. Test phases

After each learning phase, participants were tested on the mappings of five of the ten nonce verbs. Test trials presented a single motion event from the learning phase. Approximately one second into the motion event, a nonce verb was presented auditorily. The participant was asked to indicate whether the nonce verb correctly referred to the motion event presented. Each motion event appeared in four test trials per block: once paired with the assigned nonce verb, once paired with the high-distractor nonce verb, once paired with one of the low-distractor nonce verbs, and once paired with a non-distractor nonce verb. Each block contained a total of 20 test trials. Trial orders were randomized for each participant in each block.

Blocks alternated in the verb–action pairings tested, with blocks one and three testing the same five nonce verbs, and blocks two and four testing the remaining five nonce verbs. In two of the blocks, an attention check question was also presented, in which the audio played over a motion event asked the participant to leave the question blank.

2.3.3. Design

Participants first completed the CSSL task. Following the final test phase, participants completed a demographics questionnaire. Two versions were created in each of the path and manner conditions. The versions counterbalanced both the order various learning phases (e.g., the baseline, verb-flipped, video-flipped, and both-flipped phases), and test phases (e.g., which five verbs were tested in blocks one and three versus blocks two and four).

2.4. Analytic plan

All data for replication purposes can be accessed at https://osf.io/8mtyw/?view_only=None

2.4.1. Data cleaning

One low-distractor test trial was removed from both the second and fourth test blocks for all participants in the manner condition, due to experimenter error.

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2.4.2. Word effects

Chi-squared tests revealed no differences in performance based on the action, $X^2(9, 6360) = 4.910$, $p = .842$, or word, $X^2(9, 6360) = 11.100$, $p = .268$, presented at test. Thus, neither variable was included in the models presented below.

2.4.3. Calculating d'

We accounted for individual response patterns (e.g., accepting or rejecting all word-action pairings) using signal detection theory. d' (hit rate – false alarm rate) indexed each participant's sensitivity to correct verb–action pairings. *Hits* were defined as a "yes" response for any test trial presenting a verb's correct referent. A "yes" response on any of the remaining test trials (high-distractor, low-distractor, non-distractor) was counted as a *false alarm*. Subsequently, *d'* was calculated by subtracting the standardized acceptance of verbs applied to distractor actions from the standardized acceptance of verbs applied to referent actions ($d' = z[P(\text{"yes"}|\text{referent trials})] - z[P(\text{"yes"}|\text{distractor trials})]$). A d' of 0 indicates chance performance (i.e., guessing), while a d' above 0 indicates learning (i.e., more often accepting correct referents and rejecting distractor referents).

2.4.4. Mixed models

Two mixed models were conducted in Jamovi (v. 2.3.21). The first model focused on the effects of condition on changes to d' scores over time. In the model, d' was specified as the dependent variable. Block (continuous, mean centered), Condition (dummy coded: path, manner) and an interaction between Block and Condition were entered as fixed factors. Both fixed and random intercepts were included in all models. We compared models both with and without random slopes (1+ Block | Participant), selecting the model with random intercepts only ($BIC_{intercept} = 949.18$; $BIC_{intercept + slope} = 959.21$).

The second model examined how performance differed as a function of distractor strength. A logistic distribution was selected, with the accuracy of each test trial set as the dependent variable. Condition (dummy coded: path, manner), Block (continuous, mean centered), Test Type (categorical: referent, high-distractor, low-distractor, non-distractor), and interactions between Condition and Block as well as Condition and Test Type were entered as fixed effects. We made no prediction regarding differing learning rates for the different test trial types, so all interactions between Block and Test Type were omitted. Both fixed and random intercepts were included in all models. We again compared models both with and without random slopes (1+ Block | Participant), selecting the model with random slopes included ($BIC_{intercept} = 5772.237$; $BIC_{intercept + slope} = 5692.559$).

3. Results

3.1. Rate of learning across conditions

Results from the first model (see Table 2) show that participants did improve the accuracy of their word mappings across the experiment as indexed by their d' scores (see Figure 2), $\beta = .254$, $p < .001$. However, neither condition, $\beta = .101$, $p = .730$, nor the interaction of Condition and Block, $\beta = .009$, $p = .907$, were significant, suggesting that participants learned path and manner verbs at equal rates across the experiment.

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Table 2. Model 1 estimates fixed effects

Fixed effects	Estimate	SE	95% Confidence interval	
			Lower	Upper
(Intercept)	1.558***	0.146	1.273	1.843
Block	0.254***	0.039	0.178	0.330
Condition	0.101	0.291	−0.470	0.671
Block* Condition	0.009	0.078	−0.143	0.161

Note: $R^2_{marginal}$ = .038; $R^2_{conditional}$ = .733.
*p < .05;
**p < .01;
***p < .001.

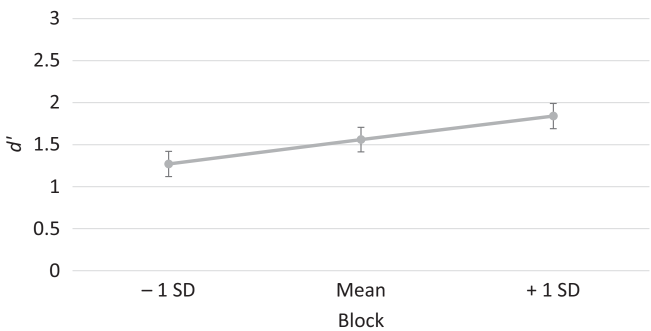

Figure 2. Performance on test blocks over time. Error bars represent standard error.

Additionally, a series of Bonferroni-corrected (p < .0125) one-sample t-tests compared performance to chance (d' = 0) for each test block. For these analyses, we collapsed across condition, given the lack of differences across path and manner verbs in the prior model. Participants were above chance at all four timepoints, Block 1: $t(77)$ = 7.58, p < .001, d = .86; Block 2: $t(76)$ = 8.00, p < .001, d = .91; Block 3: $t(77)$ = 11.100, p < .001, d = 1.25; Block 4: $t(75)$ = 12.00, p < .001, d = 1.38.

3.2. Performance by test type across conditions

The second model (see Table 3) further showed that performance improved across blocks, e^{β} = 1.805, p < .001. Performance also differed by test type (see Figure 3). Participants performed better on referent test trials relative to non-referent test trials, e^{β} = 2.012, p < .001, which is best understood in the context of an interaction with condition, e^{β} = .384, p < .001. Bonferroni-adjusted (p < .004) contrasts were conducted to further describe the differences between performance on referent and non-referent trials across conditions.

We first examined whether participants performed better on referent trials compared to each type of distractor trial within each condition (see Table 4). The odds of answering correctly for participants in the path condition increased by approximately 378% for referent trials compared to high-distractor trials, e^{β} = 4.777, p < .001, approximately 128% for referent trials compared to low-distractor trials, e^{β} = 2.277, p < .001, and approximately 214% for referent trials compared to non-distractor trials, e^{β} = 3.142,

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Table 3. Model 2 estimates fixed effects

Fixed effects	Estimate	SE	Exp(β)	95% Exp(β) Confidence interval	
				Lower	Upper
(Intercept)	1.990***	.284	7.317	4.190	12.776
Condition	.462	.551	1.587	.539	4.671
Block	.591***	.112	1.805	1.450	2.248
Test Type					
Referent – (HD, LD, ND)	.699***	.080	2.012	1.719	2.355
HD – (LD, ND)	−.631***	.080	.532	.455	.623
LD – ND	−.087	.095	.917	.761	1.105
Condition*Block	.130	.191	1.139	.783	1.657
Condition*Test Type					
Manner*Referent – (HD, LD, ND)	−.956***	.161	.384	.281	.526
Manner*HD – (LD, ND)	−.101	.160	.904	.661	1.236
Manner*LD – ND	−.817***	.190	.442	.304	.641

Note: Reference groups: Path (Condition), Referent (Test Type). $R^2_{marginal}$ = .071; $R^2_{conditional}$ = .676.
*p < .05;
**p < .01;
***p < .001.

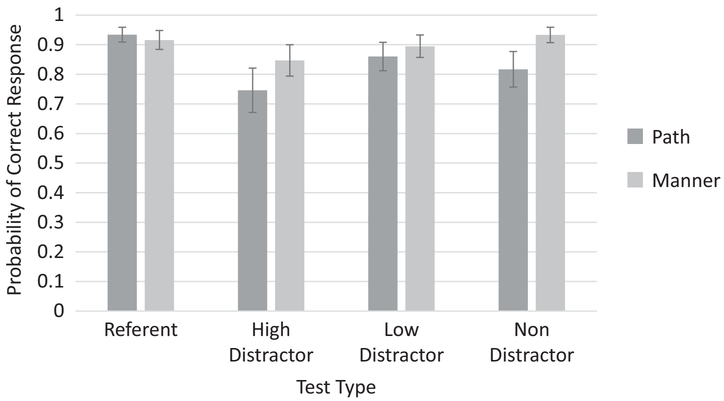

Figure 3. Performance on test trials (marginal means), broken down by trial type. Error bars represent standard error. See Tables 4-6 for comparisons of significance

Table 4. Contrasts exploring differences between referent and distractor test trials by condition

Contrasts	Exp(β)	SE	*z*	*p*
Path				
Referent-HD	4.777*	.646	11.562	< .001
Referent-LD	2.277*	.307	6.106	< .001
Referent-ND	3.142*	.422	8.532	< .001
Manner				
Referent-HD	1.964*	.266	4.989	< .001
Referent-LD	1.273	.178	1.722	.085
Referent-ND	.776	.110	−1.791	.073

*Note: *Significant at Bonferroni-corrected p < .004*

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Table 5. Contrasts for effects of test type by condition

Contrasts	Exp(β)	SE	*z*	*p*
Path				
LD-ND	1.380	.172	2.577	.010
Manner				
LD-ND	.610*	.087	−3.458	< .001

*Note: *Significant at Bonferroni-corrected p < .004*

Table 6. Contrasts for effects of condition by test type

Contrasts *(Path-Manner)*	Exp(β)	SE	*z*	*p*
Referent	1.291	.731	.452	.651
High-distractor	.531	.298	−1.129	.259
Low-distractor	.722	.407	−.579	.563
Non-distractor	.319	.180	−2.027	.043

*Note: *Significant at Bonferroni-corrected p < .004*

Table 7. Marginal means

				95% Confidence Interval	
Condition	Test Type	Probability	SE	Lower	Upper
Path	Referent	.934	.025	.864	.969
Manner	Referent	.916	.032	.830	.960
Path	HD	.746	.075	.574	.865
Manner	HD	.847	.053	.714	.925
Path	LD	.860	.048	.738	.931
Manner	LD	.895	.038	.793	.950
Path	ND	.817	.060	.672	.907
Manner	ND	.933	.026	.862	.969

p < .001. Similarly, the odds of answering correctly for participants in the manner condition increased by approximately 96% for referent trials compared to high-distractor trials, $e^{\beta} = 1.964$, $p < .001$; however, no such differences were found between performance on referent trials and low-distractor or non-distractor trials, *ps* > .07.

Within non-referent trials (i.e., high-, low-, and non-distractor), the odds of answering correctly were approximately 47% worse for high-distractor trials relative to low- and non-distractor trials (Table 3), $e^{\beta} = .532$, $p < .001$. No interactions were observed, suggesting similar patterns across the path and manner conditions. In contrast, there were differences between the path and manner conditions when comparing performance across low-distractor and non-distractor trials, as indicated by a significant interaction, $e^{\beta} = .442$, $p < .001$. While the odds of answering correctly across these trials did not differ for those learning path verbs, the odds of a correct answer for those learning manner verbs were approximately 39% worse in low-distractor trials compared to non-distractor trials (See Table 5), $e^{\beta} = .610$, $p < .001$.

Finally, a second set of Bonferroni-adjusted ($p < .004$) contrasts assessed differences within each type of test trial, based on whether participants learned path or manner verbs. No differences between the conditions were seen for any of the test types (see Table 6). Marginal means for each level of Condition and Test Type can be found in Table 7.

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4. Discussion

We had two main objectives for this work. First, given the relatively few CSSL studies focused on verbs (Monaghan et al., 2015; Rebuschat et al., 2021; Scott & Fisher, 2012), we sought to extend prior investigations to consider multiple types of verbs – specifically path and manner verbs – in the same paradigm. Second, we sought to incorporate Talmy's (1985, 2000) cognitive semantics into the study of CSSL by testing whether or not native lexicalization biases affect the way in which adults take in cross-situational statistics. Our results further underscore the utility of CSSL for verbs, with limited influence of the English manner bias on adults' performance.

4.1. CSSL of verbs

Our results add to a growing literature on the use of cross-situational statistics to learn novel verbs. While prior work has documented the utility of CSSL for verbs (e.g., Monaghan et al., 2015; Rebuschat et al., 2021; Scott & Fisher, 2012), our results are unique in several ways beyond the investigation of lexicalization biases. First, prior work has isolated and presented either path (Monaghan et al., 2015) or manner information (Rebuschat et al., 2021; Scott & Fisher, 2012) in isolation. Our work showcases that English speakers are able to acquire path or manner verbs in identical learning contexts and with both path and manner present in each set of stimuli. The result begins the work of broadening the study of verb acquisition via CSSL to further consider the complexity of referents for relational terms. Our study is also the first to our knowledge to present novel verbs without an accompanying noun. Only a grammatical marking (i.e., −ing) signified the grammatical category of nonce words in our study. Prior work has utilized nouns in verb learning studies given the proposed value of nouns in scaffolding verb meanings (Gleitman, 1990; Scott & Fisher, 2012). While this is undoubtedly necessary for some verbs, such as the complementary actions of giving and receiving, our results suggest that nouns are not always necessary for the CSSL of path and manner verbs.

Another valuable element of our results is the manipulation of distractor strength, a practice previously employed in the study of noun learning (e.g., Suanda & Namy, 2012; Suanda et al., 2014). While nonce verbs in our study perfectly correlated with their assigned referent, they also co-occurred with competing referents to varying degrees. Our expectation was that participants would struggle the most to discount high-distractors (co-occurred with target verb on 50% of trials), compared to low-distractors (co-occurred with target verb 17% of the time) or non-distractors (never co-occurred with target verb). This pattern was largely confirmed: participants struggled more to reject high-distractors in comparison to low-distractors and non-distractors, though results were more mixed when comparing low-distractors and non-distractors, with the advantage for non-distractors present only for manner verbs. However, the overall trends suggest that participants demonstrate tendencies to accept a verb–referent pairing more often on the basis of the frequency with which that pair co-occurred during training, with high-distractors proving particularly challenging to discount. Thus, participants appear to be tracking the relative frequencies of verb–referent pairings, adding credence to accounts that stress the importance of cross-situational statistics over single trial learning (see also Suanda et al., 2014; Suanda & Namy, 2012).

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4.2. Lexicalization biases

Beyond further extending the study of CSSL in verb learning, ours is the first CSSL study to systematically manipulate the relations between the lexicalization patterns of the learner's native language and the language to be learned. Building from Talmy's (1985, 2000) account of verb-framed and satellite-framed languages, we examined whether English speakers perform better on a CSSL task when asked to learn manner verbs, a common mapping in English, compared to path verbs, a mapping more common in languages such as Spanish. In line with past work that isolated either manner (Rebuschat et al., 2021; Scott & Fisher, 2012) or path (Monaghan et al., 2015) as targets for verb learning, we show that adults are successful in mapping novel verbs onto either referent. However, our results further allow for comparisons between the two mappings. While we hypothesized that English-speaking monolinguals would show greater success in acquiring manner verbs, we found no such advantage here.

In light of the absence of a broad advantage for manner verbs at test, it may be that lexicalization biases are not influential in the acquisition of path and manner verbs. Indeed, satellite-framed languages such as English do utilize both manner and path verbs (Talmy, 1985, 2000) and thus path verbs are familiar to English-speaking adults. Lexicalization biases may be more influential in situations where the novel mapping of relational language onto events is less familiar. For example, the Korean verb *kkita* refers to tight-fitting relations (e.g., ring on finger, piece in puzzle) collapsing across the common English boundary between *put in* and *put on* (e.g., McDonough et al., 2003). Such a category is not systematically encoded in the English language, possibly posing a more significant challenge for second language learning. While CSSL may effectively help adults to shift their focus toward mappings that are not as salient, but still present in their native language (e.g., path verbs for English speakers), perhaps more stark differences would slow the process of CSSL, demonstrating a clearer effect of lexicalization biases.

It is worth noting, however, that we did observe a potentially meaningful difference across conditions. Participants who were taught path verbs performed more poorly in test trials that asked them to reject incorrect mappings compared to those that required affirming the correct referent. Participants taught manner verbs, on the other hand, were able to reject low- and non-distractor words with similar success as they were able to correctly accept correct referents. This variation could reflect that participants' understanding of path verbs was in some way underdeveloped compared to participants' understanding of manner verbs, leading them to struggle to ascertain the bounds of novel verb meanings. Such a pattern may be attributable to the role of lexicalization biases, with English speakers' familiarity with manner verbs facilitating attention to fine-grained details between similar manners like *walking* and *skipping*, but not supporting similar fine-grained distinctions between paths. For instance, the novel verb *glorping* may have been correctly mapped to the referent action of *approaching,* but later overextended to the action of *crossing* due to perceived similarities in these actions (i.e., *crossing* the sidewalk versus *approaching* the other side of the sidewalk). Given that such patterns did not yield differences in the overall learning of path and manner verbs, however, future research is needed to see if speakers of verb-framed languages face similar challenges in their differentiation of manner verb referents.

Further clarity on the role of lexicalization biases in CSSL may also come from the study of more complex learning situations. In the present study, manner of motion

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was held constant when teaching path verbs, with the same true of path when teaching manner verbs. Such a manipulation allowed us to examine how well adults resolved referential uncertainty within each component of events. However, the lack of competition between the event components may have also dampened the effects of lexicalization biases. For instance, even if a participant in the path condition gave more weight to the action of walking when considering the mapping of the first nonce verb, the presentation of different words alongside additional demonstrations of walking would quickly eliminate this erroneous mapping, focusing the participants solely on path information. It is possible that we would observe more of an influence of native lexicalization biases if both components varied more freely, with each component serving as a more viable distractor for the other. Such a paradigm would also more closely replicate real-world learning, where both components vary more randomly across different learning episodes.

If the differences observed here are amplified in more complex CSSL paradigms, the observed effects of lexicalization biases on CSSL could explain, in part, the previously documented advantages for SLLs in learning vocabulary congruent with their native languages' lexicalization biases, compared to vocabulary that follows a unique lexicalization pattern (Han & Cadierno, 2010). In situations such as language immersion, it may take more time to accurately acquire verb meanings via processes such as CSSL when they follow a different lexicalization pattern, as biases regarding a verb's likely mapping may direct adult's attention away from relevant information in the event. These implications could further extend to the compensation strategies seen in SLLs (e.g., Han & Cadierno, 2010; Negueruela et al., 2004), with adults more readily acquiring and using novel verbs that follow their native lexicalization patterns, leading to over-using those verbs in languages where such mappings are less common.

4.3. Future directions

As discussed in Scott and Fisher (2012), verb learning is different from noun learning in its necessity to abstract across multiple exemplars. While the same object can be presented multiple times to facilitate learning, even repeated actions will look different in each instance. A limitation of our study is the use of a single exemplar for each verb across both training and test trials. Varying exemplars in both the learning and test phases of future experiments is thus an important next step in this work to enhance the external validity of the findings, ensuring that participants are focused on the referent relations and not surface features of these videos.

Our design also eliminated the use of a sentence frame, with the goal of minimizing cues to a verb's meaning based on English sentence structure. However, it is possible that such an approach still influenced participants' mappings. Though different from our paradigm, Naigles et al. (1998) found that the use of a minimal sentence frame (e.g., "Look, she's kradding!") biased both English and Spanish speakers toward manner interpretations of novel verbs, whereas the influence of native lexicalization biases were revealed in response to a variety of more informative frames. While any such effect in our study did not appear to lead to pronounced advantages in learning manner verbs, future work, especially with speakers of verb-framed languages, should consider comparing differing frames to more extensively document when and how lexicalization biases affect CSSL.

Our work also points to avenues for future research. In addition to examining other event components (e.g., the tight-fitting category in Korean) and varying both path and manner in future CSSL studies, this work can also be expanded through the investigation of speakers of other languages. Studying speakers of verb-framed languages, which favor path verbs, is an important contrast with which to compare the results of the current study. Additionally, future work should examine how adults fare when asked to learn both path and manner verbs in the same session. With the appropriate grammatical cues (e.g., assigning each element to a unique part of speech), it is possible that learning would mirror that observed in studies requiring participants to acquire words across different grammatical categories (e.g., Monaghan et al., 2015; Rebuschat et al., 2021). However, as languages also contain both path and manner verbs, it is also worth examining whether adults are able to map multiple verbs onto a single event and whether such learning is similar to trajectories seen for multiple noun mappings (e.g., Poepsel & Weiss, 2014; Yurovsky & Yu, 2008).

4.4. Conclusion

CSSL is an important mechanism for word learning in both first and second language acquisition. To date, much of the work on CSSL has focused on noun learning; however, the study of verbs presents novel challenges that may affect CSSL learning trajectories. Here, we add to a growing body of work demonstrating that CSSL is an effective mechanism for verb learning. We also move the field forward through the merging of CSSL research with well-established findings from the field of cognitive semantics. Specifically, we show that adults can utilize CSSL to learn novel verbs regardless of whether they map onto the world in a way consistent with their native tongue. Furthermore, when the lexicalization patterns of one's native language contradict those of the language to be learned, discerning the bounds of a word's referent through CSSL may pose a greater challenge. This work improves our understanding of CSSL in the context of second language learning and opens the door for continued fruitful work at the intersection of CSSL and cognitive semantics.

Data availability statement. All stimuli as well as data suitable for replication can be found at https://osf.io/8mtyw/?view_only=3457584683234fd1a31321f56d3d180c.

Competing interest. The authors declare none.

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