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Temporal Orientation is a Robust Cue to Attitude Class in Child-Directed Speech

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1. Introduction

Propositional attitude verbs such as *think*, *know*, and *want* pose questions for word learning: They describe mental states and do not map transparently to anything in the physical world. Yet, children are able to distinguish two subclasses of attitude verbs—desire verbs such as *want* and *need* and belief verbs such as *think* and *know*—by age four (Harrigan et al., 2019). There is evidence that, in the absence of cues from the physical world, children’s linguistic input plays a key role in allowing them to acquire components of attitude verb meaning (Gillette et al., 1999; Gleitman et al., 2005). In this paper, we present corpus results that aim to home in on which aspects of the language input act as reliable cues to the belief/desire split cross-linguistically. We find that a previously proposed syntactic bootstrapping strategy that compares the complement syntax to main clause syntax (Hacquard & Lidz, 2019, 2022) may not be sufficient to categorize common belief/desire verbs in European Portuguese. We propose that syntactic bootstrapping can be supplemented by additional semantic cues stemming from the temporal ordering of main clause and embedded clause events: Desire verbs tend to be future-oriented, while belief verbs can be past- and present-oriented. Our corpus results indicate that indeed, temporal orientation can be used to distinguish belief and desire verbs in both English and European Portuguese. These findings suggest that children may need to attend to both syntactic and semantic cues to successfully bootstrap attitude verb meanings.

2. Background

2.1 Acquiring attitude verbs

Even at an age when infants have very minimal linguistic knowledge, as early as seven months, nonverbal tasks have revealed an understanding of agents’ beliefs and desires, including false beliefs (Baillargeon et al., 2016; Kovács et al.,

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2010; Luo, 2011; Onishi & Baillargeon, 2005; Southgate & Vernetti, 2014). This provides evidence that infants already have in place a rich conceptual foundation relating to mental states. Yet, even as a mapping problem, matching individual words to their corresponding mental states is nontrivial: How do children figure out that a word like *want* corresponds to desire, and a word like *think* to belief?

While the nonlinguistic situational context is generally a poor cue to attitude verb meanings even for adult learners, linguistic input is much more promising. In order to initially identify attitude verbs, children can use the fact that a verb embeds complement clauses (e.g., *She glees that he has a book*) to hypothesize that it refers to mental states (Papafragou et al., 2007). This syntactic bootstrapping ability is plausibly rooted in an expectation that clause-embedding syntax corresponds to attitude verb semantics, which holds across languages.

As for zeroing in on specific attitude verb meanings, children begin to differentiate the two broad classes of desire verbs (*want*, *need*, *like*) from belief verbs (*think*, *know*, including speech verbs like *say* and *tell*) by age three to four. At three, they demonstrate understanding of desire reports that conflict with reality (Harrigan et al., 2018; Perner et al., 2003), but difficulty persists up to age four with false beliefs reported with *think* or *say* (e.g., Avis & Harris, 1991; Lewis et al., 2017; Wellman et al., 2001), suggesting that children distinguish the two classes of verbs. We will now compare two proposals about the specific cues children can pick up on in their input in order to do so.

2.2 Syntactic bootstrapping with main clause syntax

Hacquard & Lidz (2019, 2022) have proposed that children are able to make the belief/desire split by attending to the syntax of the complement clause. The proposal builds on the observation that cross-linguistically belief verbs tend to take complements that resemble declarative main clauses (however they are marked in a given language). In English, this is reflected by a difference in finiteness, where belief verbs typically take finite complements (with overt tense: e.g., *I think he went to the store*) and desire verbs typically take nonfinite complements (e.g., *I want you to go to the store*). In Romance languages, both desire and belief verbs can take finite complements, but belief verb finite complements tend to be in indicative mood—as are declarative main clauses—while desire verb finite complements tend to be in subjunctive mood. Hacquard & Lidz argue that children could take advantage of the similarities between belief verb complements and declarative main clause syntax by linking it to pragmatic knowledge: Declarative main clauses are typically used to make assertions, and children could reason that attitude verbs whose complements resemble declarative main clauses likely belong to the semantic class which lends itself to making indirect assertions—that is, belief verbs, which express a judgment of truth about their complement. This learning strategy accounts for how children can use linguistic information to identify belief and desire verbs despite the specific, relevant syntactic cues varying widely between languages.

Prior work has found support for Hacquard & Lidz’s proposal. Computational modeling has shown that a simulated learner that identifies the syntactic hallmarks of declarative main clauses and attends to their presence in attitude verb complements can successfully acquire the belief/desire split in both English (White et al., 2018) and Mandarin (Huang et al., 2022), which has much sparser morphosyntax. In addition, Harrigan et al. (2019) provides evidence that children are able to distinguish between belief and desire verbs based on their complement syntax. In the study, four-year-olds heard sentences containing *hope*, which is relatively unfamiliar to children and has both desire and belief semantic components. Children heard *hope* with one of two types of complements, shown in (1):

- (1) a. Froggy hopes to get a star! (nonfinite, desire-like)
 b. Froggy hopes that it’s a star! (finite, belief-like)

Upon hearing sentences like (1b), children made more false-belief errors—indicating that they interpreted *hope* like a belief verb—than upon hearing sentences like (1a). Harrigan et al. (2019) argue that the finite complement in (1b), which resembles declarative main clauses in English, pushed four-year-olds to interpret *hope* more like a belief verb, while the nonfinite complement in (1a) leads them to treat it like a desire verb (see also Lidz et al., 2017). These findings suggest that the evidence needed for the main clause syntax account is available in children’s input, and that English-speaking children may be able to use these cues in their interpretation of attitude verbs.

However, further work is needed to determine whether such a strategy can apply to other languages. Here we examine a Romance language, European Portuguese (EP), in which both desire verbs and belief verbs such as *pensar* ‘think’ can take finite subjunctive complements, meaning that neither finiteness nor mood is sufficient to distinguish belief and desire verbs. Moreover, some belief verbs can take infinitival (non-declarative-like) complements quite often—particularly *saber* ‘know’, which yields a *know how* reading with an infinitival complement. Our first corpus study investigates whether the distribution of these cues may mislead a learner about belief/desire verb classifications in EP.

2.3 Temporal orientation

We will also explore an alternative learning strategy that is inspired by work on the acquisition of modal auxiliaries, such as *might* and *must*, which describe possibilities and necessities. Modals divide into root readings (desire/obligation, e.g. *You must do your homework*) and epistemic readings (belief, e.g. *He must have left earlier*), which do not have clear surface syntactic differences. However, there is a difference in temporal orientation: the time of evaluation of the complement relative to the time of evaluation of the modal. Root modals tend to be future-oriented, while epistemic modals can be past- or present-oriented (Condoravdi, 2002; Rullmann & Matthewson, 2017; Werner, 2006). Based on children’s input, tracking temporal orientation has been argued to be the only cue

learners could use to figure out that modal auxiliaries can have both root and epistemic meanings (van Dooren et al., 2022).

Attitude verbs show a similar contrast in temporal orientation between desire and belief verbs (Klecha, 2016). Like root modals, desire verbs are typically future-oriented, since desires tend to apply to future states of affairs. For instance, *I want to travel* describes a present desire to travel in the future. Belief verbs show variable temporal orientation (past: *I think she left*; present: *I think she's leaving*; future: *I think she'll leave*). Due to the principled differences in temporal orientation between belief and desire verbs, mirroring the contrasts observed for epistemic and root modals, we ask whether temporal orientation may also be a useful cue in the acquisition of attitude verbs.

Notably, a learning strategy based on temporal orientation can also explain the findings in Harrigan et al. (2019) and Lidz et al. (2017), since *Froggy hopes to get a star* is future-oriented (suggesting desire semantics for *hope*) while *Froggy hopes that it's a star* is present-oriented (suggesting belief semantics for *hope*). Thus, it is not clear whether children in the study were attending to finiteness (as predicted for the main clause syntax strategy), temporal orientation, or both.

For a bootstrapping strategy based on temporal orientation to be viable, it would need to reliably track the belief/desire split in children's input, and would furthermore need to be signaled by surface morphosyntactic cues (e.g., tense and aspect) that children could observe and make use of. As prior work has found that children have an understanding of tense and certain aspectual cues in place by two to three years old (Harner, 1976; Valian, 2006; van Hout, 2016; Wagner, 2001; Weist et al., 1991), we expect that they would have the necessary linguistic knowledge in place to attend to these cues. In our second corpus study, we focus on whether temporal orientation is an observable and reliable indicator of attitude class in English and European Portuguese.

3. Corpus study 1: Testing the main clause syntax proposal in European Portuguese

First, we tested whether the main clause syntax proposal does in fact run into trouble with EP. This allowed us to see whether children might need to make use of another cue, such as temporal orientation, to accurately classify belief and desire verbs.

3.1 Method

To examine children's input in EP, we used the Santos corpus (Santos, 2006; Santos et al., 2014), which contains longitudinal recordings of child-adult interactions for three children between the ages of 1;5 and 3;11 who are learning European Portuguese. We included utterances from any speaker except the child, and examined two sets of sentences.

First, we needed to establish a baseline for EP main clauses. Therefore, we randomly extracted 546 sentences with either declarative or imperative main clauses.¹ We extracted imperative clauses as well because, while not the core prediction of the main clause syntax view, prior modeling work has made the additional assumption that desire verb complements will resemble imperative main clauses (Huang et al., 2022; White et al., 2018). A native speaker annotated each sentence for the following syntactic features: finiteness, mood (indicative or subjunctive), and presence of an overt subject.

Then, we extracted all 2,553 sentences containing one of the 11 most frequent attitude verbs in EP with a clausal complement (see Table 2 for attitude verb list). We coded for the same set of syntactic features in the attitude verb complement.

To test how reliable a cue is for a given category, we used cue validity: $P(\text{Category}|\text{Cue})$, which is calculated by taking: $(N \text{ Category} \ \& \ \text{Cue}) / (N \text{ Cue})$. For example, if Category A occurs 10 times total—8 times with Cue X and 2 times with Cue Y—then Cue X would have 80% cue validity for Category A: $(N=8 \text{ Category A} \ \& \ \text{Cue X}) / (N=10 \text{ Cue X})$. To test for significant differences between distributions, we used Chi-square tests.

3.2 Results

Table 1 contains the results of the main clause sampling in EP.² Almost all declarative clauses (99%) and most imperative clauses³ (94%) are finite and exhibit indicative morphology. However, when subjunctive mood does appear, it is a reliable cue that the clause is imperative, i.e. non-declarative (86% cue validity). Main clauses are never infinitival, so looking ahead to attitude verb complements, a high proportion of infinitival clauses would result in dissimilarity to the declarative clause distribution. As for overt subjects, when an overt subject is present, it is a highly reliable cue that the clause is declarative (98% cue validity).

Thus, we can examine both finiteness/mood and overt subjects as separate cues indicating that an attitude verb’s complements are declarative-like or non-declarative-like. For finiteness/mood, a skew away from finite indicative clauses (with a higher proportion of either finite subjunctive or infinitival clauses) indicates that an attitude verb’s complements are non-declarative-like, the signature of a desire verb under the main clause syntax proposal. For overt subjects, a relatively (but not necessarily absolutely) high proportion of overt subjects signals that an attitude verb’s complements are declarative-like, the signature of a belief verb.

¹ Interrogatives and sentence fragments were manually filtered out.

² Table 2 is placed immediately below Table 1 for ease of comparison.

³ While the imperative is often analyzed as a mood, it borrows indicative and subjunctive morphology, and we assume that learners are attending to this surface morphosyntax.

Table 1. Distribution of syntactic features for European Portuguese main clauses.

Clause type	Finiteness & mood			Prop. Overt subject	N
	Finite, indicative	Finite, subjunctive	Infinitival		
declarative	.99	.01	0	.41	403
imperative	.94	.06	0	.01	143

Table 2. Distribution of syntactic features for European Portuguese belief and desire verbs. For belief verbs, shaded cells indicate that the distribution is significantly different from the declarative main clause distribution.

	Attitude verb	Finiteness & mood			Prop. Overt subject	N
		Finite, indicative	Finite, subjunctive	Infinitival		
Belief	saber ‘know’	.39	0	.61	.22	419
	achar ‘think’	.99	.01	0	.42	549
	pensar ‘think’	.75	.25	0	.23	112
	ver ‘see’	.93	.02	.05	.42	133
	lembrar ‘remember’	.33	0	.67	.67	12
	dizer ‘say/tell’	.85	0	.15	.31	147
Desire	querer ‘want’	0	.17	.82	.17	1044
	gostar ‘like’	0	.13	.87	.09	99
	tentar ‘try’	0	0	1	0	7
	precisar ‘need’	0	.06	.94	.05	19
	mandar ‘order’	0	0	1	.08	12

Table 2 contains the distribution of syntactic cues in the complements of the 11 EP attitude verbs we examined. We compared each attitude verb’s features to the declarative main clause features for (a) finiteness and mood and (b) overt subjects, using Chi-square tests⁴ to determine whether the distributions were significantly different.

For every belief verb except *achar* ‘think,’ the distribution of finiteness and mood in their complements is significantly different from the declarative main clause distribution ($p < 0.01$). Furthermore, for *saber* ‘know,’ *pensar* ‘think,’ and *dizer* ‘say/tell,’ the proportion of overt subjects is significantly lower than it is for declarative main clauses ($p < 0.05$). Therefore, for these verbs, a learner might conclude from the two sets of cues that they are not likely to be belief verbs.

For the desire verbs, all of their distributions are significantly different from the declarative main clause distribution, both for finiteness/mood and overt subjects ($p < 0.05$). Note that the distributions do not share a strong resemblance

⁴ In a few cases, counts were too low for a Chi-square test, in which case Fisher’s exact test was used instead.

with imperative clauses either, due to the very high proportions of infinitival clauses, but this is not strictly necessary under the main clause syntax proposal.

It is possible, however, that a computational implementation of the syntactic bootstrapping proposal might have more success. In particular, a model that makes the assumption that it is sorting attitude verbs into two subclasses (belief and desire) might be able to pick up on the fact that belief verb complements still resemble declarative main clauses to a greater degree than desire verbs—especially with desire verbs never taking finite indicative complements, when every belief verb does at least some of the time. Nonetheless, with the frequency of finite indicative complements being fairly low for *saber* ‘know’ and *lembrar* ‘remember’ compared to other belief verbs, and with their high frequency of infinitival complements (comparable to those seen for desire verbs), we suspect that a computational model would encounter some difficulty in EP.

Overall, this study provides initial evidence that the main clause syntax learning strategy may struggle with accurately classifying belief verbs in EP. Several of the most frequent belief verbs have complements that differ significantly from declarative main clauses in both their finiteness/mood distributions and likelihood of having an overt subject. These cues could conspire to mislead a learner into classifying them as desire verbs.

4. Corpus study 2: Temporal orientation in English and European Portuguese

Because we have some evidence that the main clause syntax proposal may not be sufficient for EP, we now turn to temporal orientation. First, we ask whether it is in fact the case that in child-directed English and EP, desire verbs tend to be future-oriented while belief verbs can be past-, present-, or future-oriented. Second, we ask which surface tense/aspect cues are available in attitude verb complements to signal temporal orientation.

4.1 Method

For EP, we again used the Santos Corpus, focusing now only on the 2,009 sentences containing one of the three most frequent attitude verbs with a clausal complement (*saber* ‘know,’ *achar* ‘think,’ and *querer* ‘want’); coding for the remaining attitude verbs is in progress. For English, we used the Gleason Corpus (Masur & Gleason, 1980), which contains recordings of play sessions and dinner table conversations from 21 children between the ages of 2;1 and 5;2. We extracted 3,426 sentences containing one of the 10 most frequent English attitude verbs with a clausal complement.

We first coded the temporal orientation of each attitude verb based on the full context; recall that temporal orientation is the time of evaluation of the complement relative to the time of evaluation of the attitude verb. Examples of the coding for temporal orientation in English are given in Table 3.

Table 3. Examples of coded temporal orientation in English.

Example	Attitude subclass	Temporal orientation
You wanted to go back to the car.	Desire	future
Would you like to listen to it after dinner?	Desire	future
Remember we went to the fruit stand?	Belief	past
Do you know who that is, Charlie?	Belief	present
Do you think you're going to eat my dinner?	Belief	future
I thought I didn't let it rise enough.	Belief	ambiguous present/past

We then coded the specific tense/aspect/modal markers that contribute to determining temporal orientation. These were split by finiteness, as different markers are available in finite and nonfinite complements. In finite complements, we coded for future-marking (future tense, *is gonna*, or a future-oriented modal) and past/present-marking (past or present tense, perfect aspect). In nonfinite complements, temporal orientation is dependent on lexical and grammatical aspect. We coded for bare eventive infinitives (e.g., *I want to leave*), stative infinitives which are typically present-oriented (e.g., *I want to be there*), and progressive/perfect marking which confers present or past orientation (e.g., *She likes to be eating by now*).

4.2 Results

Figure 1 presents the proportion of non-future-oriented uses of each attitude verb. Because both belief and desire verbs can be future-oriented, but desire verbs are rarely past- or present-oriented, non-future orientation is a cue to beliefhood. Therefore, we combined cases of unclear temporal orientation (of which there were very few) with future-oriented uses.

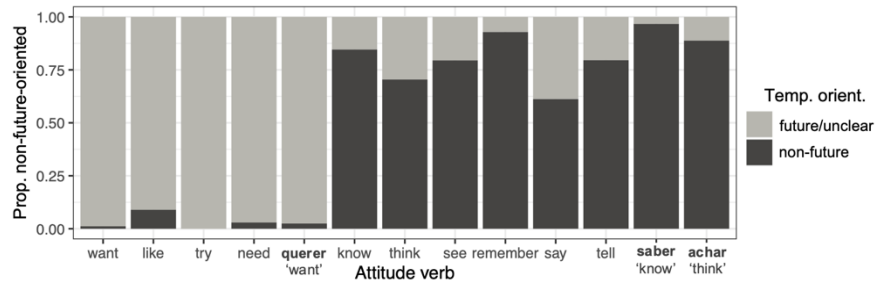


Figure 1. Proportion of non-future orientation (black bar) by attitude verb. European Portuguese verbs are bolded.

As shown in Figure 1, desire verbs are overwhelmingly future-oriented (>91% each verb). Belief verbs have future-oriented uses, but are mostly past- or

present-oriented (>61% each verb). The presence of past or present orientation is a highly reliable cue to beliefhoo (98% cue validity in both English and EP).

As for the surface morphosyntactic cues that are available to signal temporal orientation, these are graphed in Figure 2. We discuss finite and nonfinite complements separately before exploring the implications of taking them together.

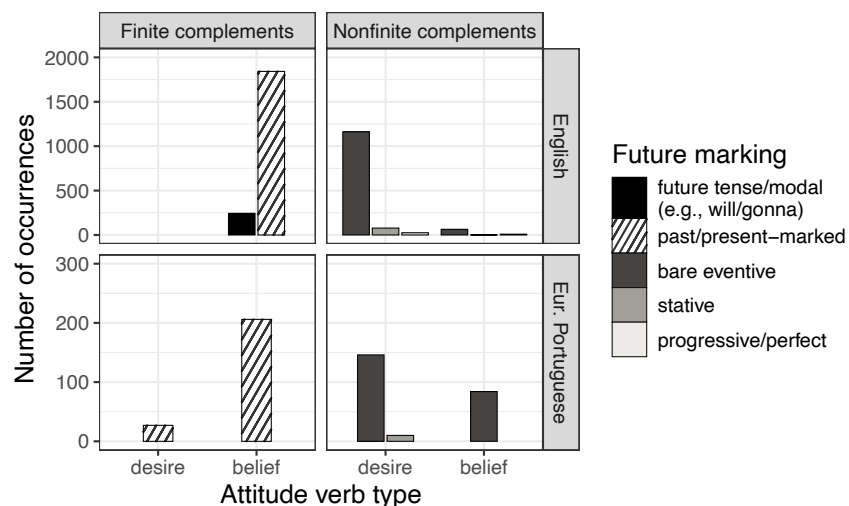


Figure 2. Distribution of surface temporal-aspectual cues to temporal orientation, in finite complements (left) and nonfinite complements (right), for English (top panel) and European Portuguese (bottom panel).

In finite complements, which are mostly taken by belief verbs, overt past-and present-marking is robustly available in both languages. It is an extremely reliable cue to beliefhoo in English (100% cue validity) and somewhat less reliable but still strong in EP (88% cue validity).

Nonfinite complements (which are generally infinitival) are taken almost entirely by desire verbs in English, but more commonly by belief verbs (35%) in EP. Most nonfinite complements are bare eventive infinitives in both English (92%) and EP (96%), but the temporal properties of bare eventive infinitives vary between languages. In English, they are almost always future-oriented (96%), but in EP, this tendency is much weaker (62%), largely due to the *know how* uses of *saber* ‘know,’ which are present-oriented. Thus, it is difficult to recognize the temporal orientation of attitude verbs which embed bare eventive infinitives prior to understanding the meaning of the embedding attitude verb itself. Furthermore, stative infinitives and past/present-marking are relatively rare in nonfinite complements, but when they do appear in this context they are not reliable cues—and in fact are actively misleading—about beliefhoo (9% cue validity in English; 0% in EP).

With this complex pattern of results for nonfinite complements, we can conclude that they likely would not provide useful information for a learner who is attempting to make the belief/desire split based on temporal orientation. Based on the surface syntax alone, children might not be able to detect desire verbs' strong skew toward future orientation, because the temporal properties of bare eventive infinitives are unpredictable. Instead, most of the available signal is from past/present-marking in finite complements of belief verbs. However, this signal is still extremely reliable: If a learner were only paying attention to overt past and present markers—regardless of finiteness—such markers strongly track beliefhood (95% cue validity in English; 88% in EP).

Overall, the results of our second corpus study provide support for the viability of a bootstrapping strategy based on temporal orientation. In both English and EP, belief and desire verbs clearly differ in temporal orientation, with desire verbs almost always being future-oriented and belief verbs mostly being past- or present-orientated. In addition, surface temporal-aspectual cues are available to indicate past or present orientation for belief verbs.

5. Discussion

Previous work has established that children's linguistic input provides a key source of information for learning the meanings of propositional attitude verbs such as *want*, *think*, and *know* (Gillette et al., 1999; Gleitman et al., 2005; Papafragou et al., 2007). In these two corpus studies, we have asked which linguistic cues children attend to in order to categorize attitude verbs as belief or desire verbs, which they can do by age four (Harrigan et al., 2019; Lidz, 2017).

We have compared two proposals for how children make the belief/desire split. The first is a syntactic bootstrapping account, which posits that children compare the morphosyntactic features of attitude verb complements to the features of declarative clauses in their language, identifying belief verbs by their resemblance to declarative main clauses (Hacquard & Lidz, 2019, 2022). The second proposes that, similar to how children may distinguish root and epistemic meanings of modals (van Dooren et al., 2022), they can attend to the temporal orientation of attitude verbs: Desire verbs tend to be future-oriented, while belief verbs can have past or present orientation.

In our first corpus study, we investigated whether European Portuguese would pose a challenge to the syntactic bootstrapping account. We found that indeed, several of the most common belief verbs had complements whose distributions of finiteness/mood and overt subjects differed from declarative main clauses. This is due notably to *saber*'s tendency to take infinitival complements (corresponding to *know how* readings) and *pensar*'s relatively high frequency of subjunctive complements. We did not find evidence that a learner who observed these distributions would conclude that these verbs are belief verbs. However, computational modeling could test implementations of the syntactic bootstrapping hypothesis with additional assumptions that might be able to overcome these obstacles. Currently, we are conducting experimental work with preliminary

results which suggest that EP-learning children have a similar understanding of belief verbs as English-learning children (making the same kinds of false-belief errors with both *achar* ‘think’ and *pensar* ‘think,’ regardless of the mood of the complement). This would indicate that children acquiring EP do have sufficient information to differentiate belief and desire verbs—if not through syntactic bootstrapping, then on the basis of some other cue.

In our second corpus study, we turned to temporal orientation and evaluated its strength as a cue to belief/desire semantics in both English and EP. We found that annotator-judged temporal orientation strongly tracked the belief/desire split as predicted, with desire verbs being overwhelmingly future-oriented and belief verbs being majority past- or present-oriented. We next took a closer look at the specific temporal-aspectual cues that a learner could attend to in order to infer temporal orientation. Prior studies have found that children can understand various tense/aspect morphemes by two to three years old (Harner, 1976; Valian, 2006; van Hout, 2016; Wagner, 2001; Weist et al., 1991), so we expect that children could interpret these cues. We found that most of the signal stemmed from overt past or present markers in finite complements of belief verbs, as nonfinite complements have more varied temporal properties. This is still a highly reliable cue, but it does limit the scope of the temporal orientation proposal, because children would not have much clear information about the temporal orientation of desire verbs.

One way to potentially overcome this limit is through situational/pragmatic information, as there may be cases where the future orientation of desire reports is particularly transparent (for instance, talking about wanting to go to the park immediately before going there). But such cases would require the child to go beyond the “here and now” and to take into consideration additional factors besides the surface syntactic and semantic cues. We are currently conducting experiments to determine at what age children understand the temporal properties of nonfinite embedded clauses in both English and EP. Assuming nonfinite complements do not have transparent temporal orientation, both the temporal orientation account and the syntactic bootstrapping account derive evidence primarily from belief verbs, since the syntactic bootstrapping strategy relies mainly on an expectation that belief verb complement clauses will resemble declarative main clauses.

We believe it is plausible that both syntactic bootstrapping via comparison to main clauses and temporal orientation play a role in children’s acquisition of the belief/desire split. Our results suggest that syntactic bootstrapping may not be sufficient in EP, but it is unclear if a strategy relying on temporal orientation alone would generalize across a wide range of languages. For instance, computational modeling indicates that syntactic bootstrapping can succeed in Mandarin (Huang et al., 2022), but because Mandarin has no overt tense, the feasibility of using temporal orientation depends on children’s ability to infer the timing of events from context and from the available aspectual/modal morphemes.

If children are able to integrate both sources of information to differentiate belief/desire verbs, it would demonstrate that they can draw on a wealth of

syntactic, semantic, and pragmatic resources. The syntactic bootstrapping proposal depends on an expectation rooted in pragmatics, that the complement syntax of attitude verbs used to make assertions will resemble declarative main clauses (which are also canonically used for assertions). The temporal orientation proposal requires that children draw on conceptual-semantic knowledge about the timing of beliefs and desires. Future research can pit the two sets of cues against one another to determine whether children predominantly rely on one strategy over the other, or whether they are sensitive to both in the acquisition of attitude verb meanings.

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