Varieties of implicativity

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Abstract

Recent work has attempted to derive implicative predicates' lexical entailments from more primitive notions—e.g. causal sufficiency and necessity. In this squib, I deploy recent methodological advances in experimental semantics to establish two results that are not explained by these recent accounts: (i) implicative predicates' lexical entailments are sensitive to whether negation is introduced analytically (e.g., *not remember to*) or synthetically (e.g., *forget to*); and (ii) these lexical entailment are sensitive to the syntactic position of analytic negation relative to the verb (e.g., *not know to* v. *know not to*). I then suggest potential future directions for current theories based on these results.

1 Introduction

Theoretical approaches to lexical entailment are currently undergoing a sea change akin to the one launched by Simons (2001) and Abusch (2002) in the domain of factivity. But while recent work has made descriptive (Karttunen, 2012, 2013) and analytical (van Leusen, 2012; White, 2014; Mari, 2015; Baglini & Francez, 2016; Nadathur, 2016) advances, some theoretically important phenomena have remained understudied, largely due to a lack of good methodologies for accessing them (though see Karttunen et al. 2014 on evaluative adjectives). In this squib, I deploy recent methodological advances in experimental semantics (Geurts & Pouscoulous, 2009; Chemla & Spector, 2011; Alxatib & Pelletier, 2011; Ripley, 2011; Sauerland, 2011; Serchuk et al., 2011; Abrusán & Szendroi, 2013; Zehr, 2014; Križ & Chemla, 2015; Schwarz, 2016) to study one classical locus in research on lexical entailment: *implicative predicates* (henceforth, simply *implicatives*).

Implicatives are a class of clause-taking predicates that systematically trigger inferences about the content of their embedded clause. In contrast to factive predicates (Kiparsky & Kiparsky, 1970; Karttunen, 1971b), which trigger similar inferences, the inferences that implicatives trigger are sensitive to matrix operators, such as polarity and questioning (Karttunen, 1971a). For instance, sentences containing *manage* entail the content of their embedded clause with positive matrix polarity (1a) → (2a), and they entail the negation of that content with negative matrix polarity (1b) → (2b). I henceforth refer to these entailments as *implicative entailments*.

(1) a. John managed to get a raise.
b. John didn't manage to get a raise.

(2) a. John got a raise.
b. John didn't get a raise.

My aim in this squib is to establish the existence of two previously undescribed phenomena that current theories of implicativity do not capture.

(3) **Findings**

a. Lexical entailment is sensitive to whether negation is introduced analytically (e.g., *not remember to*) or synthetically (e.g., *forget to*)

b. Lexical entailment is sensitive to the placement of analytic negation within the sentence (e.g., *not know to* v. *know not to*)

I establish the existence of these phenomena in three experiments, where I aim to produce high accuracy estimates of the strength of the inferential connections between sentences like (1) and sentences like (2) for a few key verbs. I show that obtaining such high accuracy estimates is not just an exercise in measurement for measurement's sake but can yield evidence of fine-grained differences among verbs that have theoretical ramifications. With this goal in mind, all three experiments use the exact same linguistic materials constructed from a core set of 14 verbs and tested under minutely varying conditions. I show that these variations have detectable and interesting effects that help in establishing these results.

I begin in Section 2 with a review of the implicatives literature, focusing in particular on recent accounts that attempt to derive, rather than stipulate, implicative entailments. In Section 3, I report on and analyze the three experiments. And in Section 4, I conclude with some discussion of these findings' implications for theories of lexical entailment.

2 Approaches to implicativity

In this section, I lay out two recent, and potentially complementary, approaches to implicative verbs: one dealing with what I refer to as *actional implicatives* (cf. Giannakidou & Staraki, 2013), such as *manage* and *fail*, and the other dealing with what I refer to as *attitudinal implicatives*, such as *remember* and *forget*. These two classes of predicates may well have a unified explanation, though current accounts treat them separately. It is sufficient for current purposes to assess them in isolation, though I return to prospects for a unified approach in Section 4.

One thing to note before moving on is that, at least since Bhatt 1999, research on implicatives and modals has been more or less intertwined—in large part because Bhatt proposes that ability modals, like *be able* are in fact implicatives. This has given rise to a large literature on *actuality entailment*—a cross-linguistically robust phenomenon wherein a sentence containing a root modal gives rise to entailments about the modalized content under certain syntactic and pragmatic conditions (Bhatt, 1999; Hacquard, 2006, 2008, 2009; Mari & Martin, 2007, 2009; Homer, 2010; Giannakidou & Staraki, 2013; White, 2014; Mari, 2015). This is relevant to the proposal I review regarding attitudinal implicatives, but since my focus is on implicatives more broadly, I forego extensive discussion of the actuality entailment literature in favor of pointing out how implicative entailments have been assimilated to actuality entailments.

2.1 Two puzzles

One explanation for the implicative entailments of *manage* is that *manage* encodes in its lexical entry something like (4).

(4) $\forall x, p : (\text{MANAGE}(x, p) \rightarrow p) \wedge (\neg\text{MANAGE}(x, p) \rightarrow \neg p)$

This explanation is not particularly satisfying, since neither does it make predictions about the range of possible implicatives nor does it relate the existence of these entailments to other proper-

ties of the lexical item—e.g. other entailments or presuppositions triggered by sentences containing the verb.

There are at least two puzzles that any account wishing to move beyond stipulations like (4) must capture. The first puzzle concerns the fact that *manage*—and other implicatives like *remember*—have 'inverted' counterparts. For instance, in perfect symmetry with sentences containing *manage*, sentences containing *fail* entail the content of their embedded clause with negative matrix polarity (5b) → (2a), and they entail the negation of that content with positive matrix polarity (5a) → (2b).

(5) a. John failed to get a raise.
b. John didn't fail to get a raise.

Thus, the lexical stipulation for *fail* that corresponds to (4) would be (6).

(6) $\forall x, p : (\text{FAIL}(x, p) \rightarrow \neg p) \wedge (\neg\text{FAIL}(x, p) \rightarrow p)$

I refer to the polarity of these entailments as the verb's *implicative direction* (relative to matrix polarity). Thus, the positive implicative direction of *manage* is positive, and the positive implicative direction of *fail* is negative.

The second puzzle concerns the fact that *manage* and *fail*—which are sometimes called *two-way implicatives* (Nairn et al., 2006; Karttunen, 2012)—have at least some conceivable *one-way* counterparts—i.e., verbs that only have an implicative direction with a single matrix polarity. For instance, as Bhatt (1999) notes, the negative implicative direction of *be able* is negative (7b) → (2b), like *manage*, but it has no positive implicative direction because sentences like (7a) do not entail sentences like (2a).

(7) a. John was able to get a raise.
b. John wasn't able to get a raise.

One promising approach to these two puzzles that goes beyond lexical stipulation is laid out by Baglini & Francez (2016) and, in an extension of Baglini & Francez's approach, Nadathur (2016).

2.2 Actional implicatives

Baglini & Francez's proposal starts from Karttunen's (1971a) observation that, beyond entailing the content of its complement, *manage* seems to presuppose effort on the part of the manager to make that complement true.[1] Their proposal has two components, which interact to give rise to implicative entailments. The first component is presuppositional: *manage* p triggers a presupposition that there is some lexically underspecified (but familiar) causally necessary but causally insufficient *catalyst* for bringing about p—e.g., effort on the part of the manager. The second component is assertive: a sentence containing *manage* entails that the aforementioned catalyst did in fact cause p to be true. Thus, *manage* p entails p. This proposal also explains why *not manage* p entails $\neg p$: since the catalyst is causally necessary, if it does not bring p about, then p is not true.[2]

As it stands Baglini & Francez's proposal only handles two-way implicatives like *manage*, whose implicative direction and matrix polarity match. Nadathur's (2016) proposal modifies it

[1] Coleman (1975) observes that this presupposition can actually take various forms dependent on the context. Baglini & Francez's approach nicely captures this presuppositional flexibility, though the exact form of the presuppositon is not important for current purposes.

[2] Baglini & Francez develop a rich model of causal dynamics based on Schulz 2011, which I do not address here, since this intuitive description is sufficient for current purposes.

to capture inverted two-way implicatives and one-way implicatives. It is useful to start by describing how she captures the two-way v. one-way distinction.

Her basic idea is that the difference between *one-way* and *two-way* implicatives lies in whether they presuppose causal sufficiency of a catalyst. For Nadathur, all implicatives at least presuppose causal necessity of some catalyst, but in contrast to Baglini & Francez's *manage*, two-way implicatives furthermore presuppose causal sufficiency of that catalyst. The addition of the causal sufficiency presupposition for two-way implicatives would leave Baglini & Francez's explanation for the entailments of *manage* intact, since that proposal relies only on *manage* presupposing causal necessity, but since Baglini & Francez's proposal explains the entailments of *manage* with only the causal necessity presupposition, Nadathur's approach must explain why one-way implicatives, like *be able*, are not two-way, like *manage*.

To do this, Nadathur proposes that, rather than being used to assert that a contextually available catalyst actually caused p, implicatives are only used to assert that those catalysts exist. But because two-way implicatives make reference to causally necessary and sufficient catalysts, existence of the catalyst is enough to capture the positive and negative implicative directions of *manage* (and potentially *fail*).[3] It furthermore predicts that, if a predicate only presupposes causally necessary catalysts, it only has a single implicative direction. For instance, the negative implicative direction of *be able* under Nadathur's account is negative, since *be able* asserts that a particular causally necessary catalyst—i.e., ability—does not exist. And it has no positive implicative direction, since we cannot conclude from the existence of a single causally necessary catalyst, such as ability, that p is true.

Inverted implicatives—i.e. ones that encode synthetic negation, like *fail*—are captured by saying that a verb can presuppose causal necessity and sufficiency for $\neg p$. Thus, Nadathur straightforwardly predicts inverted two-way implicatives, like *fail*, as well as inverted one-way implicatives, like *hesitate*, whose negative implicative direction is positive—i.e. (8b) $\rightarrow$ (9a) but (8a) $\not\rightarrow$ (9b).

(8) a. John hesitated to join the fray.
b. John didn't hesitate to join the fray.

(9) a. John joined the fray.
b. John didn't join the fray.

Thus, combined, these two proposals make the following prediction about the range of possible implicatives.

(10) **Predictions for actional implicatives**
a. Two-way implicatives may either lock implicative direction to matrix polarity, like *manage*, or completely invert matrix polarity, like *fail*
b. One-way implicatives may only have a negative implicative direction, which can either be negative, like *be able*, or positive, like *refuse*

The combined proposal also potentially provides traction on a phenomenon that was noted by Bhatt (1999) for predicates like *be able* but which seems to be quite general to one-way implicatives: though one-way implicatives only have a single implicative direction, they tend to trigger sometimes quite strong inferences in the other direction—henceforth, *implicative inferences*. That is, (7a) does not entail (2a), but one tends to draw the inference from (7a) that (2a). Karttunen (2012)

[3]The specifics of Nadathur's account of two-way implicatives are more complicated. She does not employ a notion of sufficiency directly, rather relying on a form of circumscription reasoning (McCarthy, 1981) implemented using exhaustification (cf. Schulz & Van Rooij, 2006) and resulting in a form of conditional perfection (Geis & Zwicky 1971; cf. Karttunen 2012).

likens this inference to the one seen in *conditional perfection* (Geis & Zwicky, 1971), and Nadathur suggests that this is a consequence of pragmatically strengthening a necessary condition to a sufficient condition. Thus, a potential further prediction is that one-way implicatives should also be expected to show evidence of an inference in the positive direction.

(11) **Extended predictions for actional implicatives**

a. One-way implicatives trigger inferences in the positive direction that are the negation of their negative implicative direction

One thing this proposal does not capture, even in its extended form, are one-way implicative with positive implicative direction. Indeed, unmodified, it predicts such verbs should not exist. This prediction is incorrect for verbs like *refuse*, which have no negative implicative direction but whose positive implicative direction is negative—i.e. (12a) $\rightarrow$ (13b) but (12b) $\not\rightarrow$ (13a).[4]

(12) a. John refused to make the bed.
b. John didn't refuse to make the bed.

(13) a. John made the bed.
b. John didn't make the bed.

A second more general phenomenon that this proposal does not capture are propositional attitude predicates like *remember* and *forget*, which do not seem to presuppose anything about causal necessity or sufficiency, rather involving something more akin to deontic modality.

2.3 Attitudinal implicatives

As traditionally described, the propositional attitude verbs *remember* and *forget* (when taking infinitivals) are analogous in their implicative entailments to *manage* and *fail*. The implicative directions of *remember* match its matrix polarity, like *manage*, and the implicative directions of *forget* invert its matrix polarity, like *fail*.

(14) a. John remembered to make the bed.
b. John didn't remember to make the bed.

(15) a. John forgot to make the bed.
b. John didn't forget to make the bed.

Attitude verbs like *remember* and *forget* are challenging to explain on a causal necessity/sufficiency story like the Baglini & Francez-Nadathur account for two reasons. First, their presuppositions are different: the sentences in (14) and (15) seem to presuppose some (possibly weak) obligation or goal to make the bed. This contrasts with *manage* and *fail*, whose presuppositions more plausibly involve causal notions, such as effort. Second, memory of, e.g., some obligation or goal to make the bed is not a candidate for a necessary or sufficient condition for actually making the bed. This can be seen in the fact that it is completely fine to say either (16b) or (17a) in a context where John did in fact make the bed or (16a) or (17b) in a context where John did not in fact make the bed. And though (16b) and (17a) do invite the inference that he did not make the bed and (16a) and (17b) invite the inference that he did, these inferences seem weaker than the purported entailments associated with (14) and (15).

[4] *Refuse* is sometimes referred to as a two-way implicative analogous to *fail*. As I show below, it is actually more akin to one-way implicatives like *think* and *know*.

(16) a. John remembered that he had to make the bed.
b. John didn't remember that he had to make the bed.

(17) a. John forgot that he had to make the bed.
b. John didn't forget that he had to make the bed.

To my knowledge, there are two accounts that attempt to derive attitudinal implicative entailments. The first, van Leusen's (2012), explicitly rejects the standard judgment that *remember* is two-way; rather, claiming its positive implicative direction is positive and it has no negative implicative direction.[5] From this, she argues that *remember* presupposes that memory of p is a sufficient condition (in context) to make p come about. I do not pursue this account further (i) because it is hard to see what the predictions for other verbs would be, since the sufficiency presupposition amounts to a stipulation about *remember* and (ii) because I present empirical evidence below that it is based on incorrect judgments.

The second account, White's (2014), proposes that attitudinal implicative entailments arise from an interaction between an embedded root modal contributed by the infinitive functional structure (cf. Bhatt, 1999; Wurmbrand, 2014) and the restructuring properties of the predicate (cf. Hacquard, 2008; Grano, 2012). As evidence for the presence of such a root modal, he relies on (i) the fact that the presuppositions of, e.g., *remember* and *forget* involve root modality and (ii) the fact that *remember* and *forget* with a finite complement are factive, arguing that the presuppositions of (14) and (15) are analogous to the presuppositions of (16a) and (17a).

Though the implementation itself is somewhat complex, this proposal amounts to a reduction of attitudinal implicative entailments to actuality entailments of a root modal. Actuality entailments are generally taken to be bidirectional in languages that have them robustly, and so one potential prediction of White's proposal is that attitudinal implicatives, insofar as they are all derived as an interaction of embedded root modality and restructuring, should be two-way.

A second prediction is that their implicative entailments will be dependent on whatever grammatical factors interact to give rise to actuality entailments with modals. One such important factor is aspect—actuality entailments seem to depend heavily on perfective aspect (Bhatt 1999; Hacquard 2006, 2009; though see Mari & Martin 2007, 2009; Homer 2010; Giannakidou & Staraki 2013).

A third prediction is that, insofar as embedded negation can scope above the proposed covert modal (cf. Hackl & Nissenbaum, 2012), one should find distinctions in the presuppositional content of different verbs and possibly also the implicative entailments.

(18) **Predictions for attitudinal implicatives**
a. Attitudinal implicatives are always two-way
b. The existence of an implicative entailment is dependent on other grammatical factors such as aspect
c. Presuppositions and implicative entailments are sensitive to the scope of embedded negation with respect to the covert modal

The first of these predictions is too strong, since there are also one-way attitudinal implicatives, like *think* and *know*. The negative implicative direction of *know* and *think* is negative, but they have no positive implicative direction (though they appear to be like *be able* in that they tend to trigger positive direction inferences).

[5]Note that, if this were true, it would run directly counter to the predictions of the Baglini & Francez-Nadathur account. Perhaps fortunately for that account, this judgment is not shared by native English speakers in the experiments reported below.

(19) a. John {knew, thought} to make the bed.
b. John didn't {know, think} to make the bed.

And crucially, similar to *remember* and *forget*, *know* and *think* trigger presuppositions that involve some sort of deontic or teleological modality, suggesting that they are not different from *remember* and *forget* in the relevant respect.[6]

The second of these predictions is somewhat hard to test, since English does not have a clean aspectual distinction with which to test it. White suggests that the contrast between (20a) and (20b) may be relevant here.

(20) a. I'm just now remembering that I have to go to the store.
b. ?I'm just now remembering to go to the store.

The idea is roughly that *remember to*, in contrast to *remember that*, somehow disprefers imperfective aspect (insofar as the English progressive is indicative of imperfective aspect), and so one tends to parse sentences containing *remember to* as though they contain a perfective aspect.

The third of these prediction appears not to be borne out for the presuppositions of attitudinal implicatives: there is no detectable distinction between the presuppositions of (21a) and (21b). If *to* marks the position of the modal, we might expect that (21a) would have an possibility reading.

(21) a. John remembered not to use the dull knife.
b. John remembered to not use the dull knife.

Nonetheless, the placement of negation has a clear effect on the implicative entailments, since both (21a) and (21b) entail that John did not use the dull knife. This becomes particularly interesting in the case of the one-way implicatives, since it could be either that the strength of the implicative inference for the embedded negation case tracks the positive direction or the negative direction. I show below that this is modulated by the verb: *know* does the former, while *think* does the latter.

3 Experiments

In this section, I describe three experiments aimed at producing, for a few key verbs, high accuracy estimates of the strength and type of inferential connection between sentences containing those verbs and the content of those verbs' embedded clauses. The three experiments are nearly identical in design and materials, with the major difference being a manipulation of the response prompt and associated response options that participants receive.

I present evidence for the following findings, neither of which is handled by the accounts described in Section 2.

(3) **Findings**

a. Lexical entailment is sensitive to whether negation is introduced analytically (e.g., *not remember to*) or synthetically (e.g., *forget to*)
b. Lexical entailment is sensitive to the placement of analytic negation within the sentence (e.g., *not know to* v. *know not to*)

[6] The strength of this modality is somewhat unclear. *know* seems plausibly to have the same (weak) necessity presupposition as *remember* and *forget* while *think* has a presupposition that verges on a possibility modality. I suggest below that this difference in presupposition may help explain some of the experimental data.

I begin by describing the experimental design, procedure, and participants along with three preprocessing steps that are important for understanding the analysis. I then turn to the results, which are broken into two sections: (i) a methodological validation section, where I show that manipulation of the three prompts, discussed further in the next section, does indeed have the desired effect; and (ii) a section establishing the results listed in (3).

3.1 Design

The task in all three experiments is to judge the (asymmetric) relationship between two sentences. On each trial, participants receive a biclausal sentence (the *antecendent sentence*) as well as a monoclausal sentence (the *consequent sentence*) whose lexical content is identical with the embedded clause of the antecedent sentence.

For instance, (22a) is an antecedent sentence used in our experiment, and (22b) is an associated consequent sentences used in the experiment.

(22) a. The businessperson managed to close the sales deal.
b. The businessperson closed the sales deal.

3.1.1 Prompts

The three experiments differ in the prompt that is used to elicit judgments. The exact wording of these prompts can be found in Appendix A. The *likelihood prompt* aims to measure how likely to be true the consequent sentence is, assuming that a trustworthy speaker asserts the antecedent (cf. Ripley 2011; Sauerland 2011; Zehr 2014; see also Chemla 2009); the *implicature prompt* aims to measure whether a trustworthy speaker implicates the consequent sentence in asserting the antecedent; and the *entailment prompt* aims to measure whether there is a logical connection between consequent and the antecedent.

The implicature prompt and the entailment prompt—and in particular, the implicature prompt—are similar to prompts used in previous experiments (Geurts & Pouscoulous, 2009; Chemla & Spector, 2011; Alxatib & Pelletier, 2011; Serchuk et al., 2011; Abrusán & Szendroi, 2013; Karttunen et al., 2014; Križ & Chemla, 2015; Schwarz, 2016). To attempt to distinguish implicature and entailment, which of course will be highly correlated, the implicature prompt was written to explicitly mention speakers and their intents, whereas the entailment prompt makes mention only of sentences and their logical connections.

This distinction also appears in the responses participants could choose. In the implicature task, participants were provided with a polar question—e.g. (23)—and asked to "respond *yes*, *maybe or maybe not*, or *no* based on what someone is likely to be implying by making the [antecedent] statement."

(23) Did the businessperson close the sales deal?

In contrast, in the entailment task, participants were given, e.g., the sentences in (22) and asked to "say whether, if the first sentence is true, the second *must be true*, *must be false*, or *could be true or false*." We show that this distinction produces statistically significant effects in the direction one would expect if the entailment prompt were measuring entailment and the implicature prompt were measuring exntailment+implicature.

3.1.2 Experimental factors

In all three experiments, two factors were manipulated within subjects: (i) the EMBEDDING VERB and (ii) the position of negation (or lack thereof) in the antecedent sentence (ANTECEDENT POLARITY).

(24) ANTECEDENT POLARITY
- a. *positive*: NP Ved to VP.
- b. *matrix negative*: NP didn't V to VP.
- c. *high embedded negative*: NP Ved not to VP.
- d. *low embedded negative*: NP Ved to not VP.

In addition, in the experiment that used the *entailment prompt*, a third factor was manipulated: whether the consequent sentence included negation or not (CONSEQUENT POLARITY).

(25) CONSEQUENT POLARITY
- a. *positive*: NP VPed.
- b. *negative*: NP didn't VP.

For the purposes of comparing the entailment and implicature experiments, I normalize responses across this latter factor (see Section 3.5).

3.2 Materials

12 implicative verbs (*manage*, *opt*, *remember*, *think*, *know*, *hasten*, *hesitate*, *mean*, *refuse*, *forget*, *neglect*, *fail*) were selected from the Stanford CSLI simple implicative database such that each was implicative with only control complements. Two nonimplicative, nonfactive control verbs (*want*, *hope*) were also selected to act as baselines. No embedding adjectives—e.g. *be able*—were included to guard against effects of syntactic category, which can be quite complex (Karttunen et al., 2014).

Each of these 14 verbs were crossed with ANTECEDENT POLARITY for the likelihood and implicature experiments, yielding 56 conditions, and ANTECEDENT POLARITY and CONSEQUENT POLARITY for the entailment experiment, yielding 112 conditions.

For each of the resulting conditions in each experiment, 4 items were created using the same four subject-embedded predicate contexts for each verb, yielding 224 total test items the likelihood and implicature experiments and for 448 total test items for the entailment experiment. Table 1 gives these four contexts. For all the test items, **Matrix subject** and **Embedded VP** replace NP and VP, respectively, in both (24) and (25). **Embedded subject** is only relevant to the filler items.

For each experiment, a number of filler items equal to the number of test items was constructed by crossing a subset of the 14 verbs with other possible sentential embedding frames they could occur in. There were six such frames, which are listed in (26), each followed by the verbs used in that frame.

(26) FILLER FRAMES
- a. NP1 Ved NP2 to VP (*want*)
- b. NP1 Ved for NP2 to VP (*want*, *hope*)
- c. NP1 Ved that NP2 VPed (*hope*, *remember*, *forget*, *know*, *think*)
- d. NP1 Ved whether NP2 VPed (*remember*, *forget*, *know*)
- e. NP1 Ved about VPing (*hesitate*)
- f. NP1 Ved to say that NP2 VPed (*neglect*, *mean*)

Matrix subject	Embedded subject	Embedded VP
The customer	the employee	talk to the manager
The businessperson	her colleague	close the sales deal
The student	her friend	take the professor's class
The author	her agent	return the publisher's call

Table 1: Four contexts used to create items

For all experiments, the item lists that participant saw were constructed subject to the following constraints: (i) half the items were test items and half were fillers; (ii) each verb showed up in two test items, with (iia) every 2-combination of ITEM POLARITY×FOLLOWUP POLARITY represented in some list and (iib) no repeated subject-embedded predicate contexts for a specific verb in a list. Item order was randomized on each presentation of a list.

3.3 Procedure

The experiment began with a four item practice with feedback. Two practice items included emotive factive verbs (*love*, *amaze*) with *that*-clause complements, and two included nonfactive, non-implicative predicates (*tell*, *be willing*) with infinitival complements (and in the case of *tell* an NP complement). The feedback was intended to help participants calibrate their responses to what the particular prompt was asking them to do. Participants did not receive feedback during the actual experiment and were told they would not before the test phase began.

3.4 Participants

900 participants (300 per experiment) were recruited through Amazon's Mechanical Turk (AMT) platform using a standard HIT template designed for externally hosted experiments and modified for the specific tasks. Prior to viewing the HIT, participants were required to score seven or better on a nine question qualification test assessing whether they were a native speaker of American English. Along with this qualification test, for all three experiments, participants' IP addresses were required to be associated with a location within the United States, and their HIT acceptance rates were required to be 95% or better. After finishing the experiment, participants received a 15-digit hex code, which they were instructed to enter into the HIT. Once this submission was received, participants were compensated for their participation.

3.5 Preprocessing

Prior to analysis, I apply three forms of preprocessing to the data: reaction time-based participant filtering, ordinal scale normalization, and categorical response normalization. Of the three, the last is the most important to understand; readers not interested in the former two can likely skip these section without consequence.

3.5.1 Participant filtering

When collecting data on a crowd-sourcing platform like AMT, pre-analysis filtering is often necessary to remove subjects that were not doing the task as directed. These participants fall into two camps: (i) those who generate random responses—often at higher than average overall response rate—and (ii) those who may not be devoting their full attention to the task.

To exclude the first type of participant, those whose median log reaction time was below the Tukey interval for median log reaction time for the experiment were excluded. (Participants with reaction times above the Tukey interval were not excluded, as long as they don't show high or low variability.) This excluded 6 participants in the likelihood experiment, 8 participants in the implicature experiment, and 7 participants in the entailment experiment.

To exclude the second type of participant, participants for whom the interquartile range (IQR) of their log reaction times is below or above the Tukey interval for IQR was excluded. This excluded 18 additional participants in the likelihood experiment, 8 additional participants in the implicature experiment, and 13 additional participants in the entailment experiment.

3.5.2 Ordinal scale normalization

Prior to statistical analysis of the ordinal scale likelihood judgments, I apply by-participant ridit scoring (see Agresti, 2014). (For the purposes of plotting the data, I retain the ordinal scale.) Ridit scoring is similar to z-scoring, which attempts to normalize participants' ratings to take account of the differing way participants use the ordinal scale, but it has two additional benefits that z-scoring does not: (i) it's underlying assumptions are likely more realistic (cf. White et al., 2016); and (ii) it is easier to interpret relative to proportion data, since it maps judgments to the [0,1] interval.

3.5.3 Categorical response normalization

Prior to analyzing the data from the implicature and entailment experiment, I map the values to *positive* (+), *negative* (–), or *null*. This mapping is straightforward for the implicature experiment: *yes* is mapped to *positive*; *no* is mapped to *negative*, and *maybe or maybe not* is mapped to *null*.

The mapping is more complex for the entailment judgment experiment because half of the responses are to a negative consequent sentence. If a participant responded *could be true or false*, their response is mapped to *null* regardless of the consequent sentence they were responding to. If the participant responded *must be true* to a positive consequent sentence, their response was mapped to *positive*, and if they responded *must be false* to a positive consequent sentence, their response was mapped to *negative*. If the participant responded *must be true* to a negative consequent sentence, their response was mapped to *negative*, and if they responded *must be false* to a negative consequent sentence, their response was mapped to *positive*.

3.6 Results

I now turn to the results of the three experiments. Figure 1 shows the distribution of ordinal scale responses in the likelihood experiment, plotted by VERB and ANTECEDENT POLARITY; Figure 2 shows the analogous distribution of normalized responses in the implicature experiment; and Figure 3 shows the analogous distribution of normalized responses in the entailment experiment.

I begin by providing validation that the results in the entailment experiment are consistent with that experiment assessing entailment. To do this, I contrast the results of the entailment experiment with those of the likelihood and implicature experiments. After this validation, I analyze the results of that experiment to establish the two findings mentioned at the beginning of this section.

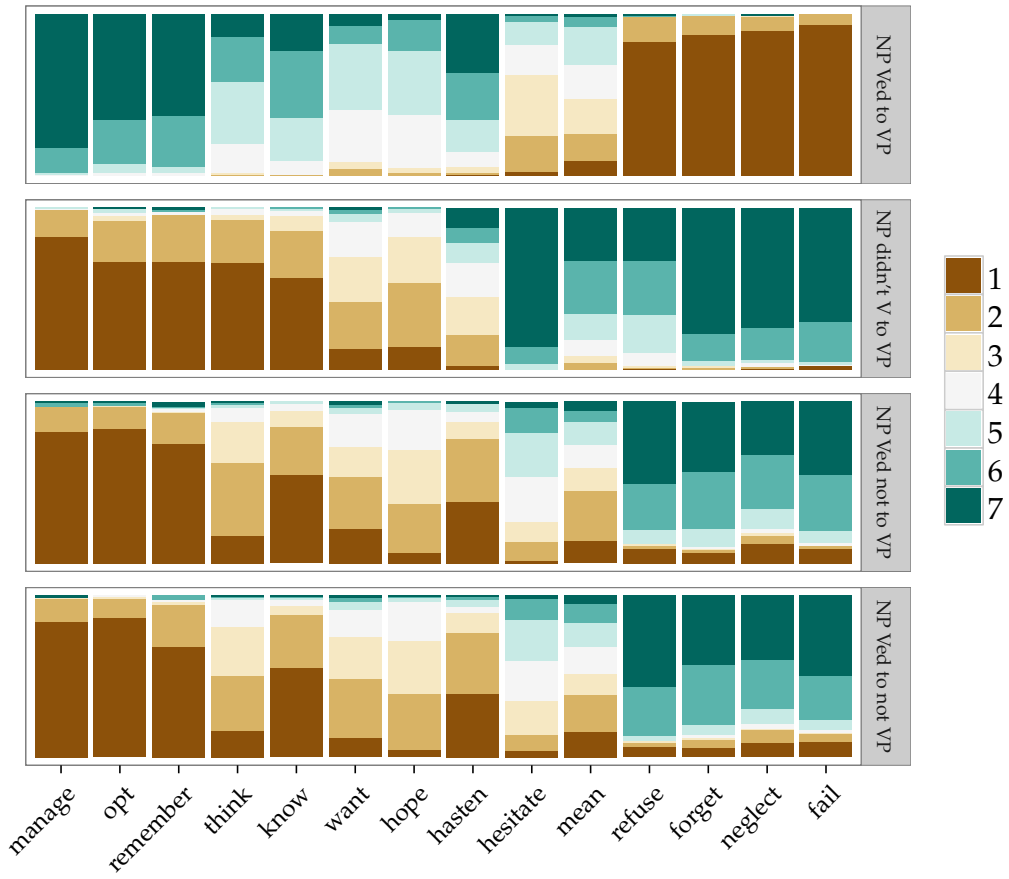

Figure 1: Likelihood experiment response distributions. **1** is *very unlikely* and **7** is *very likely*.

3.6.1 Overview of statistical analyses

All analyses are based on Bayesian model fits with weakly informative priors using the R package `MCMCglmm` (Hadfield, 2010), and so instead of providing frequentist model fits and test statistics, e.g., based on χ^2 distributions, I provide Bayesian credible intervals and posterior probabilities (cf. White & Grano 2014, who employ Bayesian fits on similarly structured experimental data). For those more familiar with frequentist statistics, credible intervals can be interpreted in a way similar to standard confidence intervals, but they have added interpretive benefits—namely, that the credible interval is associated with a distribution over parameter values, and so the probability of the existence of some effect can be assessed directly. To make these probabilities comparable to their frequentist counterparts, I assume a 95% posterior probability cut-off when I state that a result is 'significant', though this assumption is not necessary for interpreting these model fits, and it is often more informative to pay attention to the posterior probability itself.

All models employed here are logistic mixed effects models with maximal random effects structure (Barr et al., 2013), which include random intercepts for participants and contexts as well as by-participant random slopes for VERB, ANTECEDENT POLARITY, CONTEXT, and the interaction of ANTECEDENT POLARITY and CONTEXT and by-context random slopes for VERB, ANTECEDENT POLARITY, and their interaction. This structure is maximal because it is not possible to estimate any larger random effects structure from the data at hand. Nothing further is mentioned about the random effects, since I focus mostly on fixed effects (as is standard), but all data and analysis

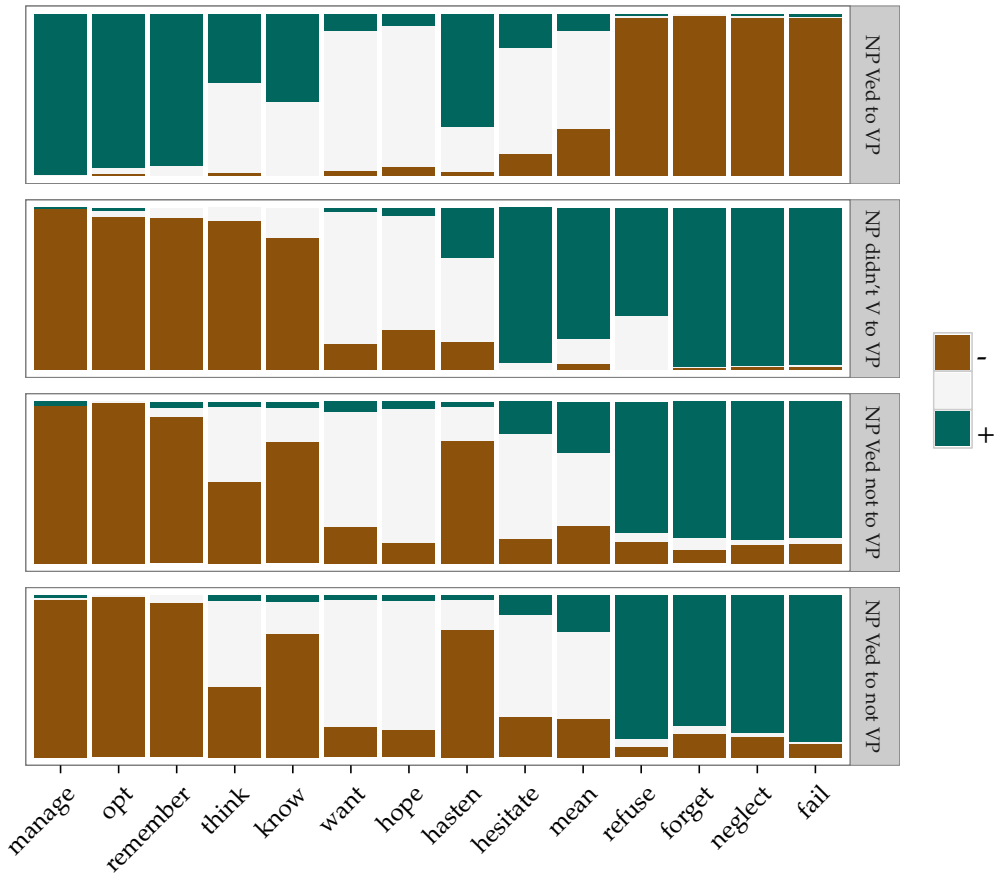

Figure 2: Implicature experiment response distributions

code are available on my github.

3.6.2 Methodological validation

I conduct a methodological validation in two steps. First, I show that participants in the implicature experiment give more *positive* and *negative* responses than in the entailment experiment. Second, I show that participant's responses in the likelihood experiment correlate better with those in implicature experiment than with those in the entailment experiment. These two results are expected if, in the implicature experiment, an implicature is strengthening a nonentailment.

To conduct the first validation, I fit a logistic mixed effects model with IS NOT NULL (*null* v. *positive* or *negative*) as the dependent variable, fixed effects for PROMPT (*entailment* v. *implicature*), VERB, ANTECEDENT POLARITY, and the interaction of VERB and ANTECEDENT POLARITY, and the random effects structure mentioned above. There are two reasons to use IS NOT NULL as the dependent variable, instead of the normalized responses themselves. First, it makes interpreting the relevant effects easier, since the directionality of the inference is straightforwardly computed from Figures 1–3. Second, it helps control for errors that participants make in computing directionality,

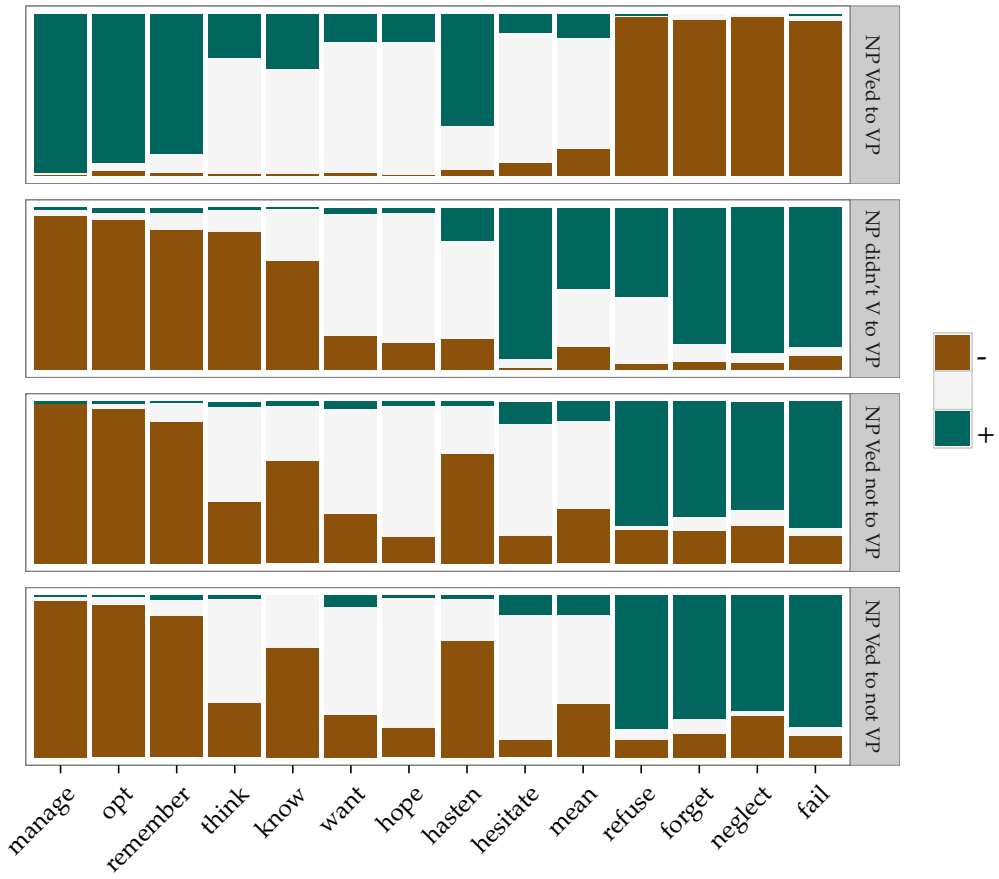

Figure 3: Entailment experiment normalized response distributions

which can be seen particularly in the embedded negation conditions.

With *entailment* as the reference level for PROMPT in a dummy coding, I find a significant positive effect of PROMPT (posterior mean=0.69, 95% CI=[0.36, 0.99], $p > 99\%$). This result means that participants give more non-null—i.e. *positive* or *negative*—responses in the implicature experiment compared to the entailment experiment.

To conduct the second validation, I first compute the mean normalized likelihood rating from the likelihood experiment by item. Mean likelihood values closer to 0 or closer to 1 are predicted to raise the probability of IS NOT NULL, and so prior to entering likelihood into the model, I apply an inverse logistic transform to the mean normalized likelihood rating and then take the absolute value. This means that the more extreme (close to 0 or 1) a normalized likelihood value is, the more positive it is. I thus refer to the resulting variable as LIKELIHOOD EXTREMENESS.

I then fit a logistic mixed effects model that is identical to the first except for the fixed effects structure. In this second model, I remove the VERB and ANTECEDENT POLARITY effects but retain the simple effect of PROMPT and add an effect of LIKELIHOOD EXTREMENESS and its interaction with PROMPT. I again use *implicature* as the reference level in a dummy coding of PROMPT. I find a significant positive simple effect of LIKELIHOOD EXTREMENESS (posterior mean=3.77, 95% CI=[3.46, 4.12], $p > 99\%$), and a significant positive interaction between PROMPT and LIKELIHOOD EXTREMENESS (posterior mean=0.76, 95% CI=[0.49, 1.03], $p > 99\%$), but no simple effect of PROMPT (posterior mean=0.01, 95% CI=[-0.33, 0.34], $p \approx 50\%$).

This means, first, that the probability of IS NOT NULL is positively correlated with LIKELIHOOD

EXTREMENESS. Second, it means that, as LIKELIHOOD EXTREMENESS grows, the probability of IS NOT NULL grows more quickly in the implicature experiment than in the entailment experiment, suggesting that responses in the implicature experiment are locked more tightly with likelihood than in those in the entailment experiment. And finally, it means that when likelihood is close to complete uncertainty (4 on the ordinal scale), there is not much difference between the probability of IS NOT NULL in the implicature and entailment experiments.

The first of these results is unsurprising, since it is expected that likelihood responses to correlate with both entailment and implicature. The second and third results are interesting because in combination, they suggest that the entailment and implicature experiments are tapping the intended phenomena.[7]

3.6.3 Verb analysis

I now turn to an analysis of particular subsets of verbs. This analysis is based on a logistic mixed effects model of the implicature and entailment experiments. As in the last section, I use IS NOT NULL as the dependent variable and the random effects structure described at the beginning of the section, but in this case, I use fixed effects for PROMPT, VERB, and ANTECEDENT POLARITY as well as all possible two- and three-way interactions.

All effects are reported assuming a dummy coding with *entailment* as the reference level for PROMPT, *hope* as the reference level for VERB, and *positive* (*NP Ved to VP*) as the reference level for ANTECEDENT POLARITY. Thus, the simple effects of VERB and ANTECEDENT POLARITY as well as their interaction give estimates for the entailment experiment directly, and the remaining simple effect and interactions tell us how the implicature prompt affects these estimates.

Analytic v. synthetic negation *Manage* and *remember* are a minimal pair with respect to the actional-attitudinal distinction mentioned in Section 2. Both are two-way implicatives, but *manage* is actional while *remember* is attitudinal. *Fail* and *forget*, which both involve synthetic negation, are the analogous minimal pair among inverted two-way implicatives.

In Figure 3, *manage* can be seen to nearly always elicit *positive* (normalized) responses with positive matrix polarity, and *negative* responses with analytic matrix or embedded negation. In contrast, *remember* appears to elicit slightly fewer non-null responses with both positive matrix polarity and analytic matrix or embedded negation. This is borne out statistically. The simple effect of *remember* is significantly smaller (posterior $p > 99\%$) than the simple effect of *manage*, and the simple effect of *remember* plus the interaction of *remember* with the three types of negation is significantly less (posterior ps $> 95\%$) than the simple effect of *manage* plus the interaction of *manage* with the three types of negation.

This pattern contrasts with the one found for *fail* and *forget*. The response distributions for *fail* and *forget* appear fairly well matched. This is borne out statistically, with the posterior probability that either is greater than other at between 50–90%—specifically, there is a 58% posterior probability that *fail* has more non-null responses than *forget* with positive polarity and between 80% and 90% posterior probability that *fail* has more non-null responses with negative polarity. Further, *forget* has significantly more non-null responses than *remember* with positive polarity (posterior $p > 95\%$), though the probability that it has more with negative polarity is between 50% and 65%.

[7] Caution is still warranted in interpreting the entailment experiment as capturing bare entailment, as opposed to entailment plus some subset of the implicated content measured in the implicature experiment. I return to this question below.

A similar pattern carries over to other pairs of two-way attitudinal implicatives. *Refuse* shows significantly more non-null responses than *opt* with positive polarity (posterior $p > 95\%$), but it does not show similar behavior with negative polarity (posterior ps $< 90\%$).

This may suggest an interaction between the actional-attitudinal distinction and whether negation is introduced analytically—e.g. via *not*—or synthetically—e.g. via the lexical semantics of *fail* or *forget*. Specifically, it appears that, with positive matrix polarity, attitudinal implicatives like *remember* and *opt*, which do not encode synthetic negation, do not have the relevant entailment in the positive direction under some circumstances. But with analytic negation, they always have the entailment, regardless of where in the sentence that negation sits. This contrasts with attitudinal implicatives like *forget* and *neglect*, which show no such modulation.

One question that arises here is whether two-way implicatives like *remember* and *opt* are misclassified one-way implicatives (cf. van Leusen, 2012), some of which are known to trigger quite strong inferences in their non-implicative direction. This is a potential interpretation of this pattern, but it seems to miss the fact that *opt* and *remember* show clear differences with comparable one-way implicatives like *think* and *know*. For instance, *know*, which one might expect to pattern very much like *remember*, yields significantly fewer non-null responses than *remember* with all polarities (posterior ps $> 95\%$). *Remember* also shows significantly more non-null responses in the positive direction than *think* (posterior $p > 99\%$), even though the two are matched with matrix negative polarity, with only a 61% posterior probability that *remember* receives more non-null responses than *think*.

On the other hand, *remember* does show pragmatic strengthening that is comparable to *think* and *know* with positive polarity in the implicature experiment. All three are significantly more likely to elicit non-null responses (posterior ps $> 99\%$). It is unclear whether this indicates that *remember* is truly one-way, however, since *opt* does not show similar significant strengthening—though it does trend in the right direction (posterior $p \approx 92\%$).

A potential explanation for these facts, which retains *remember* and *opt* as two-way implicatives, might come from White's (2014) account of attitudinal implicatives, which suggests that *remember* is two-way in virtue of the structures it enters into. Specifically, if *remember* takes an infinitive and semantically restructures, it gives rise to implicative entailments. Thus, one possible explanation for the pattern laid out above is that *remember*, *opt*, and potential any 'positive' attitudinal two-way has the option of occurring in a non-restructuring infinitival contexts, and thus the pattern might be explained via a structural ambiguity that tends to get resolved in the direction of restructuring. In this case, one would still need to say why negation neutralizes this ambiguity's effect on entailments, but it may be a reasonable start.

Indeed, in light of the middling proportions of non-null responses seen in the entailment experiment—e.g. for *think*, *know*, and *refuse*—some explanation beyond a single kind of implicature—e.g. one based in an exhaustification-like mechanism—seems necessary. It may well be that the entailment experiment does not succeed in capturing bare entailments, but the existence of strenghtening in the implicature experiment still needs an explanation.

Position of analytic negation As noted in Section 2, it has been known since as least Karttunen 1971a that actional and attitudinal implicatives gives rise to presuppositions that seem to involve some sort of modalized version of their embedded content—though the modality appears to differ between actional and attitudinal implicatives. Some authors have even suggested that this modality is a component of the embedded clause content (White 2014; see also Kratzer 2006; Moulton 2009; Bogal-Allbritten 2016). This raises the question whether, e.g., negation can scopally interact with the modal, which under accounts such as White's (2014) would yield differences in implica-

tive entailments.

This does not appear to be borne out by the implicative entailment behavior of two-way implicatives such as *manage*, *fail*, *remember*, or *forget*. But the behavior of *think* and *know* gives some evidence that the syntactic position of analytic negation matters for at least some one-way implicatives. Specifically, with *know*, both kinds of embedded negation pattern with matrix negation—positive matrix polarity with *know* shows significantly fewer non-null responses compared to embedded negative polarity (posterior ps $> 95\%$)—while with *think*, both kinds of embedded negation pattern with matrix positive polarity in terms of strength—negative matrix polarity with *think* shows significantly greater non-null responses compared to embedded negative polarity (posterior ps $> 95\%$). *Know* is thus like *remember* and *opt* in the sense that embedded negation patterns with matrix negation for those verbs as well.

But *think* is not an outlier. At least *refuse*, *hasten*, and *hesitate* show a similar pattern. Interestingly, *refuse* and *hasten* are also verbs that are not covered by Nadathur's (2016) proposal, since that proposal predicts that one-way implicatives only entail in the negative, but not the positive direction. *Refuse* is particularly interesting, since it also falls under the prior section's generalization regarding synthetic negation—namely, when a verb that contains synthetic negation has an implicative entailment, evidence for that entailment is never weakened in the way it is for, e.g., *remember* and *opt*.

A potential explanation for these facts may lie in the kind of modality that is encoded in a particular infinitival structure (cf. Bhatt, 1999), though whatever is said here cannot allow the embedded modal to interact scopally with negation inside the embedded clause (cf. Hackl & Nissenbaum, 2012), since there does not appear to be a distinction between the different positions of embedded negation in terms of (non-presuppositional) entailments. This approach may be quite reasonable in light of the fact that the presuppositions of *know to* and *think to* differ in previously unexplored ways.

(27) a. John didn't know to get hummus.
b. John didn't think to get hummus.

For instance, whereas the presuppositions of (27a) are like the analogous sentence with *remember*—i.e. (27a) presupposes that John had a (weak) obligation to get hummus—the presuppositions of (27b) involve a weaker modality—i.e. (27b) presupposes that John has the option of getting hummus. This might furthermore explain the behavior of *refuse*, which seems to have a related presupposition involving existential modality.

(28) John didn't refuse to get hummus.

Such an account would, however, need to explain why *opt* is two-way and why predicates like *intend* and *decide*, which seem to involve similar embedded modality (cf. Stowell, 1982; Grano, 2012; Wurmbrand, 2014; White & Rawlins, 2016), are not implicative at all.

4 General discussion

Using three experiments, I have established two findings in this squib. First, I showed that implicative entailments are sensitive to whether negation is introduced analytically or synthetically (e.g., *not remember to*) or synthetically (e.g., *forget to*) and that this interaction is furthermore modulated with whether the predicate is actional or attitudinal. Second, I showed that implicative entailments are sensitive to the placement of analytic negation within the sentence (e.g., *not know*

to v. *know not to*).

These findings raise two major questions for theories of implicativity moving forward. First, why should the actional-attitudinal distinction interact with synthetic and analytic negation in the way it does? And in particular, why should only verbs like *remember* and *opt* show weakened implicative entailments with only positive polarity? Even if an explanation based in causal sufficiency and necessity is viable for, e.g., *forget*, it is unclear how such an explanation could handle cases such as *remember* and *opt* while ensuring that *forget* is not incorrectly predicted.

Second, supposing one knows the behavior of an implicative predicate with positive and negative matrix polarity, what more needs to be known about the predicate to predict its implicative entailments with embedded negation? In Section 3, I suggested that a fruitful approach might base its explanation on differences in modal force, but how does modal force relate to other properties of the predicate? Further, how do these properties interact with the complement clause, and is there a connection between this modal force and causal explanations of actional implicatives?

5 Conclusion

This squib has focused almost entirely on implicative verbs. There are, however, a wealth of other predicates—e.g. adjectives and idiomatic constructions—that have been classed with implicative verbs (Karttunen, 2012; Karttunen et al., 2014; Karttunen, 2016). A question for future work is whether the findings described here carry over to these predicates; and if they do, what form do they take? In light of preliminary evidence that the form of syntactosemantic composition that combines a predicate with its complement may matter for implicativity (White, 2014), such a comparative study may prove illuminating.

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A Appendix 1

A.1 Likelihood prompt

> When people are speaking, they often imply things beyond what their words strictly mean. In this experiment, you'll be given statements and asked to judge what someone making those statements is likely to be implying (if anything).
>
> One instance of implying something beyond the strict meaning can be seen in (i).
>
> 1. John was able to hit the bullseye three times in a row.
> 2. John hit the bullseye three times in a row.
>
> Strictly speaking, (i) just says something about John's ability to hit the bullseye three times in a row, not necessarily whether he did it or not. In general, though, if someone says (i), they are probably implying that (ii) is also true. In fact, in most cases, it would be pretty deceptive to say (i) if (ii) weren't true.

In this experiment, you will make judgments about what a trustworthy person is likely to be implying in making a particular statement. On each trial, you will be given a statement and a question about how likely something is to be true assuming that the statement is true. You'll indicate your response on a 1 to 7 scale, where 1 means *very unlikely* and 7 means *very likely*.

A.2 Implicature prompt

The implicature prompt was exactly the same as the likelihood prompt, except that the last paragraph was changed to the following.

In this experiment, you will make judgments about what a trustworthy person is likely to be implying in making a particular statement. On each trial, you will be given a statement and a question related to that statement. Your task will be to respond *yes*, *maybe or maybe not*, or *no* based on what someone is likely to be implying by making the statement.

A.3 Entailment prompt

Some sentences must be true at the same time. For instance, if (i) is true, (ii) *must also be true*; if John hates that Mary is sick, Mary must be sick. Other sentences cannot be true at the same time. If (i) is true, (iii) *must be false*; that is, if John hates that Mary is sick, then she must not be healthy.

1. John hates that Mary is sick.
2. Mary is sick.
3. Mary is healthy.
4. John believes that Mary is sick.

Some sentences don't have either relationship. For instance, if (iv) is true, (ii) *could be true or false*; if John believes that Mary is sick, Mary very well could be healthy. Similarly, if (iv) is true, (iii) *could be true or false*; if John believes that Mary is sick, Mary very well could be sick.

In this experiment, you will make judgments about these sorts of relationships. On each trial, you will be given two sentences. Your job will be to say whether, if the first sentence is true, the second *must be true*, *must be false*, or *could be true or false*. To respond, you will press **1** for *must be true*, **2** for *could be true or false*, or **3** for *must be false*. Please make a response as quickly as possible.

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