Distributive ignorance implications of inquisitive and epistemic attitudes*

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Abstract

Inquisitive attitude verbs like *wonder* do not just imply that their subject does not know the answer to the embedded question, but a stronger form of ignorance, which has been called *distributive ignorance* (Roelofsen and Uegaki, 2016). Similarly, if an epistemic attitude verb like *believe* takes a disjunctive complement, it implies that its subject considers all disjuncts possible. We present two experiments examining the ignorance implications of *wonder* and *believe*, with different types of complements and different types of quantificational subjects. The results of these experiments suggest that the distributive ignorance implications triggered by the two verbs should be accounted for in a unified way. More specifically, we argue that the data are best explained by an account that involves a strengthening mechanism which is sensitive to the syntactic structure of the complement of the verbs involved and optionally applies locally, as part of the semantic composition process.

1 Introduction

Consider the following sentence:

(1) The detective wonders whether Ann, Bill, or Carol did it.

This sentence implies that the detective doesn't know yet whether Ann did it, that he doesn't know yet whether Bill did it, and that he doesn't know yet whether Carol did it. Roelofsen and Uegaki (2016) call this *distributive ignorance*. Note that distributive ignorance is a stronger form of ignorance than merely not knowing the answer to the embedded question in (1), i.e., the question whether Ann, Bill, or Carol did it. If the detective already knows that Carol didn't do it, but still wonders whether it was Ann or Bill, then he doesn't yet know the answer to the question whether Ann, Bill, or

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Carol did it. Thus, he is still ignorant to some extent. Distributive ignorance, however, requires more than this: the detective should still consider all three options possible. Besides *wonder*, other inquisitive predicates like *investigate* and *be curious* seem to trigger distributive ignorance implications as well.

Roelofsen and Uegaki (2016) show that these implications are not predicted by previous work on the semantics of *wonder* (Ciardelli and Roelofsen, 2015; Uegaki, 2015), even if pragmatic strengthening is taken into account. Based on various further empirical observations, they develop a refined semantic entry for *wonder*, and suggest that similar entries may be given for other inquisitive predicates.

It seems, however, that distributive ignorance implications (henceforth, DIIs) may well constitute a broader phenomenon, not specific to the domain of inquisitive predicates. In particular, *epistemic* predicates like *believe* give rise to similar implications. To see this, consider the sentence in (2):

(2) The detective believes that Ann, Bill, or Carol did it.

Just like (1), this sentence also seems to imply that the detective still considers all of Ann, Bill, and Carol possible culprits.

The goal of the present paper is to investigate experimentally whether the ignorance implications triggered by *wonder* and *believe* indeed call for a unified account, and if so, what the main empirical desiderata for such an account are. More specifically, we will report the results of two experiments, one examining the extent to which DIIs persist when *wonder* and *believe* take different kinds of complements (e.g., ones involving existentials or *wh*-phrases rather than disjunctions), and one examining what kind of ignorance implications arise if the verbs take different kinds of quantificational subjects (upward monotonic, downward monotonic, or non-monotonic) rather than a referential expression like *the detective*.

The results of these experiments indeed suggest that DIIs triggered by *wonder* and *believe* should receive a unified account. Moreover, they also provide some important clues as to what such an account should look like. In particular, the patterns we find suggest that DIIs result from a strengthening mechanism which is sensitive to the syntactic structure of the complement of the verbs involved (cf., Katzir, 2007) and optionally applies locally, as part of the semantic composition process (cf., Chierchia et al., 2012).

The paper is organized as follows. In Section 2 we introduce our baseline lexical entries for *believe* and *wonder* (adopted from Theiler et al. 2017b and Ciardelli and Roelofsen 2015, respectively) and show that these entries by themselves do not account for DIIs. In Section 3 we outline various possible refinements of this baseline account, and discuss how these may be teased apart experimentally. In Sections 4 we present the results of our first experiment, involving different kinds of complements. In Section 5 we turn to our second experiment, involving different kinds of quantificational subjects. Finally, Section 6 provides a general discussion of the results and explicates the theory that they favor in further detail.

2 A baseline account of *believe* and *wonder*

For concreteness, we will fix a specific baseline account of *believe* and *wonder*. For *believe* we will adopt the account proposed in Theiler et al. (2017a,b), which is similar to many other treatments of *believe* but has the additional advantage of capturing the fact that the verb only takes declarative complements (unlike, e.g., *know* and *be certain*).[1] For *wonder* we will adopt the lexical entry proposed in Ciardelli and Roelofsen (2015), which similarly captures the fact that the verb only takes interrogative complements.[2] These entries for *believe* and *wonder* are both formulated in *inquisitive semantics* (Ciardelli et al., 2013, 2015). We will briefly review the relevant features of inquisitive semantics, then spell out the entries for *believe* and *wonder*, and finally show that these entries by themselves fall short of deriving DIIs for sentences like (1) and (2).

2.1 Inquisitive semantics background

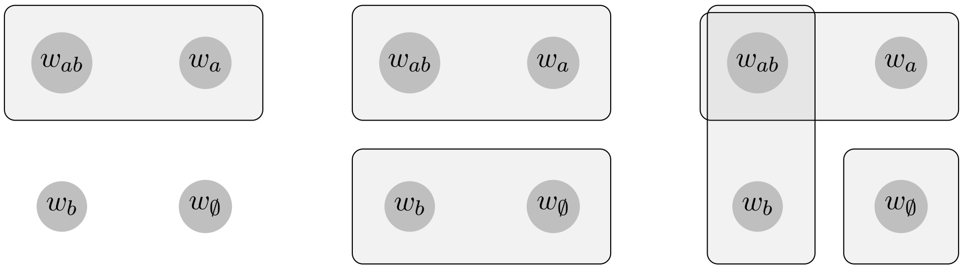
In inquisitive semantics, declarative and interrogative clauses are taken to have the same kind of semantic value, namely a set of propositions. The conceptual motivation behind this uniform notion of sentence meaning is as follows. While traditionally the meaning of a sentence φ is taken to capture just the information conveyed by φ, in inquisitive semantics it is taken to additionally capture the *issue* expressed by φ as well. The information that is conveyed by a sentence is called its *informative content*, and the issue expressed by it its *inquisitive content*. To encode both kinds of content at once, the meaning of a sentence is construed as a set of propositions, no matter whether the sentence is declarative or interrogative.

By uttering a sentence φ with meaning $[\![\varphi]\!]$, a speaker is taken to raise an issue whose resolution requires establishing one of the propositions in $[\![\varphi]\!]$, while simultaneously providing the information that the actual world is contained in the union of these propositions, $\bigcup[\![\varphi]\!]$. $\bigcup[\![\varphi]\!]$ is called the informative content of φ, and is written as $\mathsf{info}(\varphi)$.

Downward-closure, alternatives, and truth Sentence meanings in inquisitive semantics are taken to be *downward closed*: if $p \in [\![\varphi]\!]$ and $q \subset p$, then also $q \in [\![\varphi]\!]$. This captures the intuition that, if a proposition p resolves a given issue, then any stronger proposition $q \subset p$ will also resolve that issue. As a limit case, it is assumed that the inconsistent proposition, $\emptyset$, trivially resolves all issues, and is therefore included in the meaning of every sentence. The maximal elements in $[\![\varphi]\!]$ are referred to as the *alternatives* in $[\![\varphi]\!]$ and the set of these alternatives is denoted as $\textsc{alt}(\varphi)$. Alternatives are those propositions that contain precisely enough information to resolve the issue expressed by φ. Finally, from the meaning of a sentence in inquisitive semantics, its truth-conditions are derived in the following way: φ is true in a world w just in case w is compatible with $\mathsf{info}(\varphi)$, i.e., $w \in \mathsf{info}(\varphi)$.

[1]See Cohen (2017) and Mayr (2017) for closely related proposals, and Theiler et al. (2017a) for comparison.

[2]See Uegaki (2015) for a closely related account, and Theiler et al. (2017a) for comparison. For earlier informal discussions of the semantics of *wonder*, see Karttunen (1977) and Guerzoni and Sharvit (2007).



(a) that Ann left (b) whether Ann left (c) who left

Figure 1: Examples of complement clause meanings in inquisitive semantics.

Informative and inquisitive sentences The informative content of φ can be trivial, namely iff the propositions in $[\![\varphi]\!]$ together cover the entire logical space W, i.e., iff $\mathsf{info}(\varphi) = W$. In this case, we call φ *non-informative*. Conversely, φ is called *informative* iff $\mathsf{info}(\varphi) \neq W$. The inquisitive content of a sentence can also be trivial. This is the case iff the issue expressed by φ is already resolved by the information conveyed by φ itself, i.e., iff $\mathsf{info}(\varphi) \in [\![\varphi]\!]$. In this case, φ is called *non-inquisitive*. Conversely, φ is called *inquisitive* iff $\mathsf{info}(\varphi) \notin [\![\varphi]\!]$. If φ is non-inquisitive, $[\![\varphi]\!]$ always contains a unique alternative, namely $\mathsf{info}(\varphi)$. Vice versa, if $[\![\varphi]\!]$ contains multiple alternatives, it is inquisitive.

Declarative and interrogative complements Following Ciardelli et al. (2015) and much earlier work in inquisitive semantics, we assume that a declarative complement or matrix clause φ is never inquisitive.[3] That is, its meaning $[\![\varphi]\!]$ always contains a single alternative, which coincides with its informative content, $\mathsf{info}(\varphi)$. For example:

(3) $\textsc{alt}(\text{that Ann left}) = \{\ \{w \mid \text{Ann left in } w\}\ \}$

Conversely, we assume that an interrogative complement or matrix clause is never informative. This means that the alternatives associated with an interrogative clause always completely cover the set of all possible worlds in which the presuppositions of the clause are satisfied. For example, if the domain of discourse consists of Ann and Bob, we assume the following sets of alternatives for the interrogative complements *whether Ann left* and *who left*.[4]

(4) $\textsc{alt}(\text{whether Ann left}) = \left\{ \begin{array}{l} \{w \mid \text{Ann left in } w\}, \\ \{w \mid \text{Ann didn't leave in } w\} \end{array} \right\}$

[3]There is also work in inquisitive semantics that does not make this assumption (e.g., AnderBois, 2012), but this requires a view under which uttering an inquisitive sentence does not necessarily involve issuing a request for information. See Ciardelli et al. (2012) for discussion.

[4]The alternatives assumed here for *wh*-interrogatives only allow us to derive non-exhaustive (mention-some) readings. The account can be refined to derive strongly and intermediate exhaustive readings too (see Theiler et al., 2016). This refinement doesn't affect any of the results presented here.

(5) $\textsc{alt}(\text{who left}) = \left\{ \begin{array}{l} \{w \mid \text{ Ann left in } w\}, \\ \{w \mid \text{ Bob left in } w\}, \\ \{w \mid \text{ nobody left in } w\} \end{array} \right\}$

The alternative sets in (3)–(5) are also depicted in Figure 1, where w_{ab} is a world where both Ann and Bill left, w_a a world where only Ann left, w_b one in which only Bill left, and $w_\emptyset$ one in which neither Ann nor Bill left.

2.2 Believe

Let us first consider the following preliminary entry for *believe*. In this entry, P is the meaning of the clausal complement, its semantic type $\langle\langle s,t\rangle,t\rangle$ is abbreviated as T, and $\textsc{dox}_x^w$ is the doxastic state of the subject x in world w.[5]

(6) $[\![\text{believe}]\!]^w = \lambda P_T.\lambda x.\, \textsc{dox}_x^w \in P$

This entry corresponds to the canonical treatment of *believe*, rooted in epistemic logic (Hintikka, 1962). However, it fails to capture two important properties of the verb, namely the fact that it is *neg-raising* and the fact that it is incompatible with interrogative complements (unlike other epistemic verbs such as *know* and *be certain*).

The verb is neg-raising because it licenses the following kind of inference:[6]

(7) Mary does **not** believe that Ann left.
∴ Mary believes that Ann did **not** leave.

One prominent account of neg-raising verbs, originally proposed by Bartsch (1973) and further developed by Gajewski (2007), assumes that neg-raising behavior results from a so-called *excluded-middle (EM) presupposition*.[7] For instance, (8) below is taken to presuppose that Mary is opinionated as to whether Ann left: she either believes that Ann left or she believes that Ann didn't leave.

(8) Mary believes that Ann left.
Presupposition: M believes that A left or M believes that A didn't leave.

In (8), the presupposition easily goes unnoticed, since it is weaker than the asserted content. However, if we negate (8), presupposed and asserted content become logically independent. Taken together, they imply that Mary believes that Ann didn't leave—which accounts for the neg-raising effect.

(9) Mary does **not** believe that Ann left.
Presupposition: M believes that A left or M believes that A didn't leave.

[5]For simplicity, we give truth-conditional entries here. For a full-fledged compositional inquisitive semantics, these can easily be transformed into support-conditional entries (see Theiler et al., 2017a).

[6]See, e.g., Horn 1989; Gajewski 2007 for an alternative characterization of neg-raising predicates in terms of strict NPI licensing. This characterization is arguably more reliable but would take us a bit too far afield here.

[7]Besides the presuppositional account of neg-raising, there are also accounts based on implicatures (e.g., Romoli, 2013) or homogeneity (Gajewski, 2005; Križ, 2015); see Križ (2015, Ch.6) for a recent overview and comparison.

$\therefore$ Mary believes that Ann did **not** leave.

Theiler et al. (2017a,b) show that adding an EM presupposition to the preliminary entry in (6) does not only account for the fact that the verb is neg-raising, but also for the fact that it doesn't take interrogative complements. Note that, since the entry in (6) is formulated in inquisitive semantics, the semantic object P that *believe* takes as its argument is not a single proposition but a set of propositions. In formalizing the EM presupposition, the negation of P has to be computed. This is done using the standard negation operation in inquisitive semantics, written as $\neg$. When applied to P this operation returns the set of those propositions that are inconsistent with every member of P:[8]

(10) $\neg P \;:=\; \{p \mid \forall q \in P : p \cap q = \emptyset\}$

Using this inquisitive negation operator, Theiler et al. (2017b) formulate the lexical entry for *believe* in (11).

(11) $[\![\text{believe}]\!]^w = \lambda P_T.\lambda x : \underline{\text{DOX}^w_x \in P \vee \text{DOX}^w_x \in \neg P}\,.\, \text{DOX}^w_x \in P$

Let us first see what the predictions of this treatment are when the verb takes a declarative complement, and then consider the case in which it takes an interrogative complement.

Declarative complements. As discussed above, we assume that declarative complements are never inquisitive. This means that if P is the meaning of a declarative complement, it contains a single alternative p. Then, the first disjunct in the presupposition amounts to $\text{DOX}^w_x \subseteq p$ (x believes p), while the second disjunct amounts to $\text{DOX}^w_x \cap p = \emptyset$ (x believes $\overline{p}$). Hence, for declarative complements, the inquisitive rendering of the EM presupposition boils down to its ordinary rendering in a truth-conditional setting. This accounts for neg-raising effects.

Interrogative complements. On the other hand, we assume that interrogative complements are never informative, and typically inquisitive. This means that the alternatives in the meaning of an interrogative complement, taken together, always cover the set of all possible worlds in which the presuppositions of the clause are satisfied. Let us restrict our attention here to non-presuppositional interrogative complements.[9] The alternatives in the meaning of such complements together cover the entire logical space. As a consequence, the inquisitive negation of an interrogative complement meaning P is always $\neg P = \{\emptyset\}$, since there can be no non-empty proposition that is inconsistent with every alternative in P. This means that the second disjunct of the presupposition can only be satisfied if $\text{DOX}^w_x = \emptyset$. Under the standard assumption that doxastic states are consistent, this is impossible. Moreover, even if we want to allow for inconsistent doxastic states, the second disjunct of the presupposition can only be satisfied if the first disjunct is satisfied as well, since $\emptyset$ is contained in any complement meaning P. Thus, with or without the

[8] There is both conceptual and empirical support for this way of treating negation in inquisitive semantics. Conceptually, it can be characterized in terms of exactly the same algebraic properties as the standard truth-conditional negation operator (Roelofsen, 2013). Empirical support comes, for instance, from sluicing constructions (AnderBois, 2014).

[9] See Theiler et al. (2017a) for discussion of presuppositional interrogative complements.

assumption that doxastic states are consistent, the second disjunct in the presupposition turns out redundant. That is, if *believe* takes an interrogative complement, its lexical entry reduces to (12).

(12) $[\![\text{believe}]\!]^w = \lambda P_T.\lambda x : \underline{\textsc{dox}^w_x \in P}.\ \textsc{dox}^w_x \in P$

The presupposed and the asserted content in (12) are exactly the same. This means that when *believe* combines with an interrogative complement, its assertive component is trivial relative to its presupposition. Theiler et al. (2017a,b) show that this triviality is a case of *logical analyticity* in the sense of Gajewski (2002) and can thus be taken to explain the fact that sentences in which *believe* takes an interrogative complement are perceived as ungrammatical sentences. More generally, the proposal accounts for the observation, first made by Zuber (1982), that combining a neg-raising verb with an interrogative complement always leads to ungrammaticality.

2.3 Wonder

To model what it means for an individual to *wonder*, we do not only need a formal representation of her information state, but also a representation of the issues that she entertains, i.e., of her *inquisitive state*. In *inquisitive epistemic logic* (Ciardelli and Roelofsen, 2015), an individual's inquisitive state in a world w, which we will denote as $\textsc{inq}^w_x$, is formally modeled as a downward closed set of propositions which together cover her doxastic state, i.e., $\bigcup \textsc{inq}^w_x = \textsc{dox}^w_x$. The propositions in $\textsc{inq}^w_x$ are those that are informative enough to resolve the issues that x entertains. They correspond to extensions of her current doxastic state in which all her questions are settled one way or another.

Intuitively, x wonders about a question, e.g., about *who left*, just in case (i) x isn't certain yet who left, and (ii) she wants to find out who did. This is the case exactly if (i) x's current doxastic state does not resolve the question; and (ii) every doxastic state in x's inquisitive state is one that does resolve the question. Thus, Ciardelli and Roelofsen (2015) propose the following formal treatment of the verb:

(13) $[\![\text{wonder}]\!]^w = \lambda P_T.\lambda x.\ \underbrace{\textsc{dox}^w_x \notin P}_{x\text{ isn't certain yet...}} \wedge \underbrace{\textsc{inq}^w_x \subseteq P}_{\text{but wants to find out}}$

This entry yields the expected results when the verb takes an interrogative complement. To see this consider the following example:

(14) John wonders whether Ann left.

The meaning of the complement, $[\![$*whether Ann left*$]\!]$, is the set of all propositions p such that either (i) all worlds in p are ones where Ann left, or (ii) all worlds in p are ones where Ann didn't leave, as was depicted in Figure 1(b). For (14) to be true in a world w it has to be the case that $\textsc{dox}^w_j \notin [\![\text{whether Ann left}]\!]$ and $\textsc{inq}^w_j \subseteq [\![\text{whether Ann left}]\!]$. The first requirement is satisfied just in case $\textsc{dox}^w_j$ contains at least one world in which Ann left and at least one world in which she didn't leave, i.e., in case John doesn't know yet whether Ann left. The second requirement is satisfied just in case every extension of John's current information state in which the issues that he entertains are resolved is one in which he has come to know whether Ann left. This seems to be precisely what is expressed by (14).

Now let us consider what happens when *wonder* takes a declarative complement:

(15) *John wonders that Ann left.

Recall that if P is the meaning of a declarative complement it always contains a single alternative p. Since complement meanings are downward closed, this means that P amounts to the powerset of p, $\wp(p)$. Now suppose that the first conjunct in (14) holds: $\text{DOX}_x^w \notin P$. Then it must be that $\text{DOX}_x^w \not\subseteq p$. But then, since $\bigcup \text{INQ}_x^w = \text{DOX}_x^w$, it must also be that $\bigcup \text{INQ}_x^w \not\subseteq p$. It follows that there is at least one $s \in \text{INQ}_x^w$ such that $s \not\subseteq p$. But if $s \not\subseteq p$, then since p is the unique alternative in P, we have that $s \notin P$. So the second conjunct in the lexical entry must be false. Hence, whenever *wonder* takes a declarative complement, it yields a contradiction. This systematic contradictoriness can be taken to explain the fact that sentences in which *wonder* takes a declarative complement are perceived as ungrammatical sentences. With small modifications, the account could be extended to other inquisitive verbs such as *be curious* and *investigate* as well.

2.4 Distributive ignorance is not captured

The baseline entries for *believe* and *wonder* given above do not predict DIIs. To see this consider the following scenario.

(16) **Scenario** A crime has been committed, and there are three suspects: Ann, Bill and Carol. Detective Jones is on the case, and has already ruled out that Carol did it. However, he has not determined yet whether Ann or Bill did it.

In this scenario, consider sentences (1) and (2) from the introduction, repeated in (17) and (18) below:

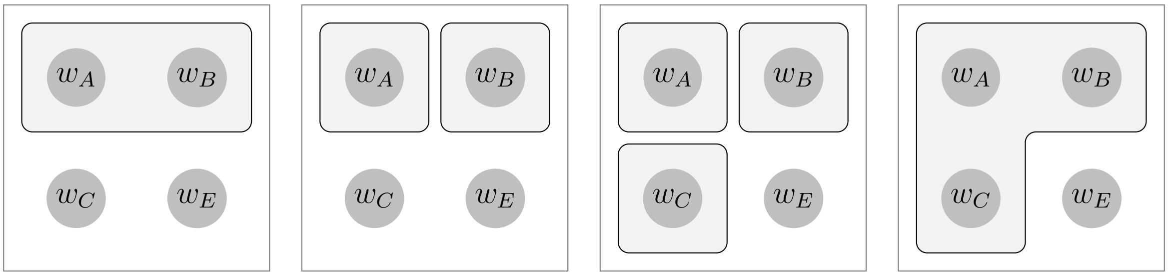
(17) The detective wonders whether Ann, Bill, or Carol did it.

(18) The detective believes that Ann, Bill, or Carol did it.

These sentences seem false in the given scenario, because Jones has already ruled out the possibility that Carol did it (the experiments presented in Sections 4 and 5 show that this is indeed the majority judgment). However, our baseline entries for *believe* and *wonder* predict the sentences to be true.

To see this, let us first explicate what Jones' information state and inquisitive state are in the described scenario. For simplicity, let us assume that our logical space consists of just four possible worlds, w_A, w_B, w_C, and w_E. In w_A, Ann committed the crime, in w_B Bill did it, in w_C Carol did it, and in w_E the crime was not committed by any of the current suspects but rather by someone else.

Jones' information state, DOX_j^w, consists of those worlds in which either Ann or Bill did it, i.e., $\text{DOX}_j^w = \{w_A, w_B\}$. This is depicted in Figure 2(a). On the other hand, John's inquisitive state, INQ_j^w, consists of all extensions of his current information state in which the issue that he entertains is resolved. These are the states $\{w_A\}$, $\{w_B\}$, and $\emptyset$ (recall that it is assumed that the inconsistent information state, $\emptyset$, trivially resolves all issues).



(a) DOX_j^w (b) INQ_j^w (c) ⟦*whether A, B, or C*⟧ (d) ⟦*that A, B, or C*⟧

Figure 2: Jones' information state and inquisitive state in the scenario in (16), and the meaning of the complements in (17) and (18). Recall that inquisitive states and complement meanings are downward closed; only their maximal elements are depicted.

INQ_j^w is depicted in Figure 2(b).

Let us now turn to the meaning of the complements in (17) and (18). We assume that the interrogative complement in (17), just like the corresponding matrix interrogative, expresses an issue whose resolution requires establishing which of Ann, Bill, and Carol did it. Thus, as depicted in Figure 2(c) its meaning contains three alternatives, each corresponding to one of the three disjuncts.[10] On the other hand, we assume that the declarative complement in (18), just like the corresponding matrix declarative, carries the information that one of Ann, Bill, and Carol did it, and does not express an issue requesting any further information. Thus, as depicted in Figure 2(d) its meaning contains a single alternative consisting of all worlds in which Ann, Bill, or Carol did it.[11]

Now that we spelled out the meaning of the complement clauses in (17) and (18), as well as the detective's information state and inquisitive state in the given scenario, we can turn to the predictions made by our baseline entries for *wonder* and *believe*. The entry for *wonder* predicts that (17) is true if and only if the following two requirements are met:

(19) a. $\text{DOX}_j^w \notin [\![\textit{whether } A, B, \textit{or } C]\!]$
b. $\text{INQ}_j^w \subseteq [\![\textit{whether } A, B, \textit{or } C]\!]$

By inspecting Figures 2(a)-2(c), it can be seen that these requirements are indeed met. So the sentence is incorrectly predicted to be true.

On the other hand, the entry for *believe* predicts that (18) is true if and only if the following requirement is met:

(20) $\text{DOX}_j^w \in [\![\textit{that } A, B, \textit{or } C]\!]$

By inspecting Figures 2(a) and 2(d), it can be seen that this requirement is met as well.

[10] For simplicity, we leave the presupposition of the complement, namely that one of Ann, Bill, and Carol did it, out of consideration here. As far as we can see this simplification does not affect the arguments made in this paper. For treatments of alternative questions in inquisitive semantics that do take presuppositions into account and are compatible with our present assumptions, see AnderBois (2012) and Roelofsen (2015).

[11] Spelling out how the clause meanings in Figure 2(c) and 2(d) could be derived compositionally would take us too far afield here; see Ciardelli et al. (2015) and Roelofsen (2015).

So this sentence is also incorrectly predicted to be true.

3 Toward a refined account: two parameters

There are various ways to refine the assumed baseline account of *believe* and *wonder* so as to derive DIIs. Of course, the choice between these various options cannot be made merely on the basis of the two simple example sentences we have considered so far. Rather, to provide a richer testbed, we should investigate variants of these basic cases as well. Before turning to this empirical investigation, however, we should determine which kinds of constructions to look at exactly. This requires a preliminary exploration of the various theoretical options. Thus, our aim in this section will not be to spell out any particular theory in full detail, but rather to discuss the main parameters that set the various approaches apart.

There are, as far as we can see, two main parameters, which we will label *structure-sensitivity* and *locality*, respectively. We will discuss each in turn.

3.1 Structure-sensitivity

Compare the following two pairs of sentences.

(21) a. The detective wonders whether Ann, Bill, or Carol did it.
b. The detective wonders which of the (three) suspects did it.

(22) a. The detective believes that Ann, Bill, or Carol did it.
b. The detective believes that one of the (three) suspects did it.

Note that (21a) is a repetition of our initial example (1), and that (21b) is a variant of it in which the verb takes a *wh*-question as its complement rather than an alternative question. Similarly, (22a) is a repetition of our earlier example (2), and (22b) is a variant of it in which the complement involves an existential quantifier rather than a disjunction.

In the scenario under consideration, where the suspects are Ann, Bill, and Carol, the two interrogative complements in (21a) and (21b) are semantically equivalent, assuming that there is no implicit domain restriction in the (b)-examples.

The assumption that the (b)-examples do not involve implicit domain restriction is plausible at least in the versions with the numeral *three*, given experimental evidence showing that implicit domain restriction is very unlikely in a partitive structure with a numeral (Geurts and van Tiel, 2016).[12]

The various possible refinements of our baseline account can be divided into ones that are sensitive to such structural differences and ones that are not. Note that the baseline account itself is not sensitive to the structure of the clauses that *wonder* and *believe* take as their complement. According to the given entries, the verbs only operate on the semantic content of their complement. Thus, in the absence of any further stipulations, it is predicted that (21a) and (21b) are equivalent, and similarly for (22a) and (22b).

[12] In our experiment investigating the structure sensitivity of DIIs, we use this fact to control for the possibility of implicit domain restrictions. That is, we test both partitive structures with a numeral and those without, as different conditions, and see if the presence of the numeral makes any difference.

Importantly, this does not only hold for the baseline account itself, but also for any variant of it that remains insensitive to the structure of the clauses that the verbs take as their complement. This includes any account which derives DIIs as pragmatic implicatures and which assumes that the formal alternatives that play a role in the computation of such implicatures are fully dictated by the semantic content of the sentence under consideration and contextual factors such as the question under discussion.

An example of a structure-sensitive account would be one that derives DIIs as pragmatic implicatures but does *not* assume that the relevant formal alternatives are fully determined by semantic content and contextual factors such as the question under discussion, but also depend on the structure of the sentence involved. A general argument for such a structure-sensitive approach to computing implicatures has been made by Katzir (2007). In particular, he proposes that the formal alternatives of a sentence φ that are taken into account when computing implicatures are only those sentences that can be obtained from φ either (i) by deleting elements in φ, or (ii) by substituting elements in φ with other elements from an appropriately defined source. Such an account would be able to derive a difference in interpretation between (22a) and (22b) as follows. In the case of (22a), pragmatic reasoning would involve the formal alternatives in (23) below, which can all be obtained from (22a) by deleting parts of it:

(23) a. The detective believes that Ann or Bill did it.
b. The detective believes that Ann or Carol did it.
c. The detective believes that Bill or Carol did it.
d. The detective believes that Ann did it.
e. The detective believes that Bill did it.
f. The detective believes that Carol did it.

These formal alternatives all entail (22a) itself. Thus, routine pragmatic reasoning leads to the conclusion that, if a speaker utters (22a), he does not have enough information to support any of the alternatives in (23), and if we further assume that the speaker is knowledgeable about what the detective believes, we end up deriving that the alternatives in (23) are all false. This, in turn, implies that the detective must still consider all of Ann, Bill, and Carol possible culprits. Thus, the DII is accounted for.

In the case of (22b), on the other hand, this derivation does not get of the ground, because the formal alternatives in (23) cannot be obtained from (22b) by deletion and are therefore not taken into account when computing implicatures. Thus, it would be predicted that (22b) does not imply distributive ignorance.

Roelofsen and Uegaki (2016) argue for such a structure-sensitive account of DIIs under *wonder*. According to them, the structure-sensitivity of DIIs is evidenced by the contrast in (24):[13]

(24) (Judgments reported in Roelofsen and Uegaki 2016)
a. The detective wonders whether Ann, Bill, or Carol did it.(=(21a)) $\rightsquigarrow$ DII

[13]More precisely, Roelofsen and Uegaki (2016) claim that the version of (24c) with numerals induces DIIs more strongly than the one without. They explore ways to account for this reported contrast in a structure-sensitive account as well as in a structure-insensitive account of DIIs, in view of the fact that numerals prevent implicit domain restriction (Geurts and van Tiel, 2016). Testing the role of numerals in DIIs will be among the goals of our Experiment 1.

b. The detective wonders which of Ann, Bill, and Carol did it. ⇝ DII
c. The detective wonders which of the (three) suspects did it.(=(21b)) $\not\rightsquigarrow$ DII

In addition to the disjunctive complement in (24a) and the *wh*-complement in (24c), this paradigm also includes the complement in (24b) involving a partitive *wh*-phrase whose domain of quantification is explicitly listed by means of a conjunction over individuals. Roelofsen and Uegaki report that (24b) gives rise to DIIs, just like (24a). This is indeed predicted by a structure-sensitive account since formal alternatives involving complements with smaller domains (e.g., *The detective wonders which of Ann and Bill did it*) can be obtained as Katzir-style alternatives of (24b). In our Experiment 1, to be discussed below, we tested the structural sensitivity of DIIs by comparing four types of complements: disjunctive complements (e.g., (24a)), partitive complements with a listed conjunctive domain (e.g., (24b)), partitive complements with a (non-listed) NP domain without a numeral (e.g., (24c) without *three*), and partitive complements with a (non-listed) NP domain with a numeral (e.g., (24c) with *three*).

3.2 Locality

We now turn to the second important parameter on which the various possible refinements of the assumed baseline account would differ. To see what this amounts to, consider the following scenario:[14]

(25) There is a crime with three suspects, Ann, Bill, and Carol. There are three detectives investigating the case.

- Detective 1 still considers Bill and Carol possible culprits, but not Ann.
- Detective 2 still considers Ann and Carol possible culprits, but not Bill.
- Detective 3 still considers Ann and Bill possible culprits, but not Carol.

In this scenario, consider the following two sentences:

(26) Every detective is wondering whether Ann, Bill, or Carol did it.

(27) Every detective believes that Ann, Bill, or Carol did it.

Note that these are variants of our initial examples (1) and (2) in which the subject is a universal quantifier rather than a referential expression. Consider the structure-sensitive account of DIIs as pragmatic implicatures outlined above. When we apply this account to (27), the following implicatures are derived:

(28) It is not the case that every detective believes…
a. …that Ann or Bill did it.
b. …that Ann or Carol did it.
c. …that Bill or Carol did it.
d. …that Ann did it.
e. …that Bill did it.
f. …that Carol did it.

[14]We thank Benjamin Spector for drawing our attention to this type of scenarios.

These implicatures are all true in the given scenario, and the same holds for the literal meaning of the sentence according to our baseline entry. Thus, the sentence is predicted to be true, even though in the given scenario all the detectives have already ruled out one of the suspects, so none of them is distributively ignorant.

Besides pragmatic theories which predict that the literal interpretation of an utterance may be strengthened through reasoning about formal alternatives of the uttered sentence as a whole, there are also theories which predict that the meaning of any *part* of a given sentence may be strengthened through comparison with formal alternatives, and that this strengthened meaning may then serve as input to operators that apply to this part of the sentence, all within the process of composing the semantic content of the sentence, before pragmatic reasoning enters the stage (see, e.g., Chierchia et al., 2012). This process of strengthening through comparison with formal alternatives is referred to as *exhaustification*.

Thus, while pragmatic reasoning can only have a 'global' effect on the interpretation of a sentence as a whole, exhaustification as conceived by Chierchia et al. (2012) and others can also have a 'local' effect, on parts of a sentence. For instance, if exhaustification is applied to the verb phrase in (27), before the universal quantifier in subject position is composed with it, we derive the following implications:

(29) Every detective is such that it is not the case that she believes...

a. ...that Ann or Bill did it.
b. ...that Ann or Carol did it.
c. ...that Bill or Carol did it.
d. ...that Ann did it.
e. ...that Bill did it.
f. ...that Carol did it.

Notice that the first three implications are false in the given scenario. Thus, on an account which assumes that the meaning of the verb phrase in (27) is *obligatorily* strengthened through exhaustification, the sentence is predicted to be false, unlike on the pragmatic account considered above. More specifically, under the assumption that local exhaustification is obligatory, (27) is only true in situations in which every detective is distributively ignorant. On the other hand, if exhaustification of the verb phrase is only considered *optional*, then (27) is predicted to have two readings: one under which it is true in the given scenario (without local exhaustification), and one under which it is false (with local exhaustification).

Which of these two readings is preferred could then be taken to depend on pragmatic factors (Chierchia et al., 2012; Potts et al., 2016). In particular, Chierchia et al. (2012) suggest that Dalrymple et al.'s (1998) Strongest Meaning Hypothesis plays an important role in determining such preferences. According to this suggestion, other things being equal, a reading involving local exhaustification is preferred if it is stronger than the reading obtained without local exhaustification, and dispreferred if it is weaker than that reading. Thus, in the case of (27) for instance, the reading with local exhaustification would be preferred, since it is stronger than the one without. However, if the quantifier in subject position were downward entailing rather than upward entailing (e.g., *no detective* rather than *every detective*) the reading without local exhaustification would

	Structure-sensitive	Not structure-sensitive
Only global strengthening	Approach 1	Approach 4
Optional local strengthening	Approach 2	Approach 5
Obligatory local strengthening	Approach 3	Approach 6

Table 1: Overview of possible theoretical approaches.

in principle be preferred. Finally, if the quantifier is non-monotonic (e.g., *exactly two detectives*), local exhaustification makes the reading neither stronger nor weaker. This means that Strongest Meaning Hypothesis does not constrain local exhaustification under non-monotonic quantifiers.

Let us now take a step back. Given the considerations above, the various possible refinements of our baseline account that derive the DIIs of (1) and (2) through comparison with formal alternatives can be of three types: they could assume that such comparison (i) only happens globally, (ii) optionally happens locally as well, or (iii) obligatorily happens locally. The latter type of theory can be implemented, for instance, by incorporating an exhaustification operator in the lexical semantics of the relevant verbs, as is done for *wonder* (though not *believe*) in Roelofsen and Uegaki (2016).

Combining the two parameters we have considered, structure-sensitivity and locality, we can distinguish six general theoretical approaches, as indicated in Table 1. In the following two sections, we will report the results of two experiments that were aimed to determine which of these general approaches is most adequate. This is done by considering variants of our basic examples in which the structure of the complement clause is different (Experiment 1), and ones involving different kinds of quantificational subjects (Experiment 2). The former should allow us to tease apart structure-sensitive approaches from structure-insensitive ones. The latter should allow us to distinguish between approaches that assume only global strengthening, and ones that assume optional or obligatory local strengthening through comparison with formal alternatives.

We should note that we are not presupposing at this point that one and the same approach is most fitting to account for DIIs of both *wonder* and *believe*. In fact, in Roelofsen and Uegaki (2016, footnote 5) it was explicitly suggested that Approach 3 in Table 1 is most appropriate for *wonder*, while Approach 1 is most suitable for *believe*. Anticipating what is to come, the results of our experiments refute this hypothesis and suggest instead that Approach 2 is most adequate for both *wonder* and *believe*.

4 First experiment: complements

4.1 Goal

The goal of our first experiment was to compare the DIIs with *wonder* and *believe*, and to investigate the contrast presented in (21) and (22). In particular, we wanted to test the claim made by Roelofsen and Uegaki (2016) that there is a contrast between, on the one hand, disjunctive complements ('whether/that A, B, or C') and complements whose domain is explicitly listed by means of a conjunction over individuals ('which/one of A, B, and C') and, on the other hand, complements whose domain is not explicitly listed ('which/one of the suspects'). Another case of interest discussed in §3.1 is that of numerals. Since it is known that numerals in the domain phrase ('which/one of the *three* suspects') block implicit domain restriction (Geurts and van Tiel, 2016), we wanted to see whether the presence of numerals would affect the judgments concerning DIIs.

4.2 Design

Participants were recruited on Amazon's Mechanical Turk and took a survey directly on the platform. The survey consisted of the context in (30) and three sentences they had to judge. Each sentence was followed by the sentences "In this context, would you say that this sentence is true or false?" and a 7-point scale, the extreme points of which were labeled 'Clearly false' and 'Clearly true'. These three sentences were followed by two demographic questions, asking for participants' age and native language. The whole survey was presented on a single page.

(30) **Context:** Sue has three children, Sophie, Bill, and Mary, who all live on their own. Sue is impatiently waiting for all of them to arrive at her place for Thanksgiving dinner. Someone rings the bell. Sue isn't sure who it is, but she knows that it can't be Bill, because he just texted her that he would be late.

Eight different surveys were designed, corresponding to the eight possible target sentences obtained by combinations of the following two factors: embedding VERB ('wonder' or 'believe') and COMPLEMENT type (disjunction, conjunction, NP, NumP). Each survey version had 3 SENTENCES (a Target, a True control, and a False control), which were presented in random order. Target sentences were literally true, but falsified the DII. This way, we could test whether a participant had derived the inference by measuring how unacceptable the target was for them. The target sentences for each combination are listed in Table 2. The True sentences were derived by dropping Bill from the disjunction and conjunction, and replacing 'children' or 'three children' with 'daughters' (this way, the DII was satisfied). The False sentence was the same across all four complement types, and involved 'whether Bill arrived' and 'that Bill arrived' for *wonder* and *believe* respectively.

4.3 Participants

For each survey version, we recruited eight participants for each of the six possible orders for the Target, True and False sentences (hence a total of 384 HIT were posted on Mechanical Turk, paid 27ct each). Despite requesting that participants take the survey only once (and enforcing this with the UniqueTurker script), a few participants took multiple surveys. Three participants who took the survey 5 or more times were not paid for their retakes and their HITs were offered to new participants. Any retakes were discarded from the analyses, as well as the data from 10 participants who reported native languages other than English.

In all, after removing all retakes and non-native speakers, we had data from 326 unique native English speakers (age range: 19–70).

COMPLEMENT	VERB	Target sentence
Disjunction	*wonder*	Sue wonders whether Sophie, Bill, or Mary arrived.
	believe	Sue believes that Sophie, Bill, or Mary arrived.
Conjunction	*wonder*	Sue wonders which of Sophie, Bill, and Mary arrived.
	believe	Sue believes that one of Sophie, Bill, and Mary arrived.
NP	*wonder*	Sue wonders which of her children arrived.
	believe	Sue believes that one of her children arrived.
NumP	*wonder*	Sue wonders which of her three children arrived.
	believe	Sue believes that one of her three children arrived.

Table 2: Target sentences by COMPLEMENT and VERB.

4.4 Results

The results are presented in Figure 3. We can immediately notice that the DIIs are most visible with Disjunction and Conjunction COMPLEMENTS (as indicated by maximal difference between Targets and True controls), and seem to be completely absent with NP and NumP under *believe*.

We ran a mixed-effects ordinal logistic regression on the responses to the True and Target sentences with VERB (sum-coded), COMPLEMENT (baseline: Disjunctive), SENTENCE (baseline: True) and all their interactions as fixed effects, and a random Subject intercept (in `R`, using package `ordinal`, R Core Team, 2014; Christensen, 2015). The full results are presented in Table 3. The highly significant effect of SENTENCE confirms that Disjunctive complements give rise to DIIs, and the absence of a SENTENCE×VERB interaction indicated that this effect is similar for *wonder* and *believe*. That SENTENCE interacts with COMPLEMENT on its NP and NumP levels shows that the DIIs have a very reduced effect with these two complements, although there is a triple interaction with VERB, indicating that unlike *believe*, *wonder* still gives rise to DIIs in these cases.

Model comparisons showed that there was no significant difference between the NP and NumP COMPLEMENTS ($\chi^2(4) = 4.2, p = .38$).

4.5 Discussion

First, we observed clear differences between the various complements. More specifically, the two complement which mentioned each alternative (Disjunction and Conjunction) showed much stronger DIIs. This is in line with the hypothesis that structural alternatives play an important role (Katzir, 2007; Fox and Katzir, 2011), and that mentioned alternatives are more strongly activated, as argued in various empirical domains (see e.g., Onea and Steinbach 2012; Starr 2014 for the role of mentioned alternatives in conditionals; Roelofsen et al. 2016 in embedded questions; Coppock and Brochhagen 2013 in modified numerals, and Csipak and Zobel 2014; Rojas-Esponda 2014 in discourse particles.)

Second, we found relatively small differences between *wonder* and *believe*, and no

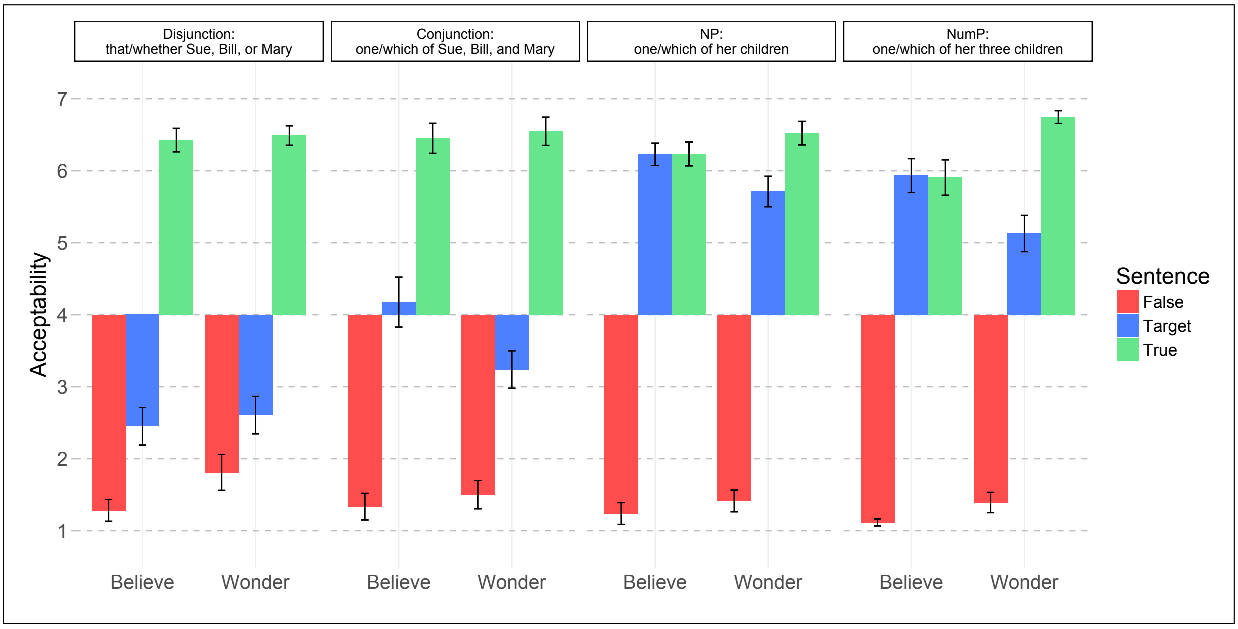


Figure 3: Experiment 1: Mean acceptability for each Verb, Complement, and Sentence (error bars represent standard error).

difference at all with the Disjunction complement, where the strongest DIIs were observed. We would like to point out that the three other complements do not offer as minimal a comparison as Disjunction, because they involve 'which of $X\ldots$' with *wonder* but 'that one of $X\ldots$' with *believe*. This could have affected the results in two ways. First, it opens the possibility of a specific reading with *believe* if 'one' somehow gets wide scope. When designing the experiment, we tried to block this reading as much as possible by making clear that Sue doesn't know which of her daughters will arrive first, but the fact that true controls received a slightly lower rating with *believe* than with *wonder* could indicated that some participants still had the specific reading. Second, it may be that *which* activates domain alternatives in a way that *one* does not. This would lead to stronger DIIs with 'wonders which of' than with 'believes that one of'.

Finally, the addition of a numeral did not have much of an effect (it had no effect with *believe* and if anything, only slightly strengthened DIIs with *wonder*). This is important in view of the role of implicit domain restriction. Although the contrast between Disjunction/Conjunction and NP could in principle be explained in terms of the possibility of implicit domain restriction in the latter, the fact that NumP and NP exhibit the same amount of DII effects suggests that this explanation is implausible, given that implicit domain restriction is highly unlikely in NumP (Geurts and van Tiel, 2016).

At this point, the results clearly favor an approach that is structure-sensitive (§3.1), but they do not tell us anything yet about locality (§3.2) since all sentences had non-quantificational subjects. In the next experiment, we will focus on the disjunctive complements, which offer both the most minimal comparison between *believe* and *wonder* and exhibit the strongest DII effects, and we will test how DIIs project from the scope of various quantified subjects.

	β	z-value	p	
Sentence	-4.51	-11.8	0.000	***
Verb	0.05	0.1	0.925	
[Comp:Conjunction]	0.52	1.4	0.153	
[Comp:NP]	-0.07	-0.2	0.825	
[Comp:NumP]	-0.004	-0.01	0.990	
Sentence×Verb	0.17	0.3	0.787	
Sentence×[Comp:Conjunction]	0.70	1.5	0.130	
Sentence×[Comp:NP]	3.66	7.8	0.000	***
Sentence×[Comp:NumP]	3.17	6.7	0.000	***
Verb×[Comp:Conjunction]	0.32	0.4	0.665	
Verb×[Comp:NP]	0.78	1.2	0.245	
Verb×[Comp:NumP]	1.51	2.2	0.028	*
Sentence×Verb×[Comp:Conjunction]	-1.45	-1.6	0.112	
Sentence×Verb×[Comp:NP]	-1.69	-2.0	0.049	*
Sentence×Verb×[Comp:NumP]	-2.84	-3.2	0.001	**

Table 3: Experiment 1: Results of the model applied to True and Target sentences.

5 Second experiment: quantified subjects

5.1 Goal

The goal of the second experiment was to investigate the projection of DIIs under quantified subjects. In principle, DIIs could always be computed globally, always locally, or optionally locally or globally. In the latter case, we expect to see effects of the type of quantified subject (see Chemla and Spector, 2011; Potts et al., 2016, a.o.), and in particular, we expect less local DIIs in downward-entailing environments.

Note that the DIIs of *wonder* and *believe* could in principle give rise to different projection patterns in quantified cases. This would suggest that the DIIs of the two verbs are of a different nature and require separate treatment, as suggested in Roelofsen and Uegaki (2016).

5.2 Design

We focused on disjunctive complements, which made DIIs easiest to detect, and tested three quantifiers for the subject: *every* (upward-entailing), *no* (downward-entailing), and *exactly two* (non-monotonic). Six different surveys were designed, corresponding to the six combinations of Verb (*wonder* or *believe*) and subject Quantifier (*every*, *no*, *exactly two*). As in Experiment 1, each survey involved a context, followed by a Target sentence, a True control sentence, and a False control sentence which were presented in random order.

We designed contexts which would make local and global DIIs come apart for each of the quantifiers. The context used in Experiment 1 would not have translated very well with quantified subjects, so we moved to contexts with detectives, which also happened to be closer to the examples of Roelofsen and Uegaki (2016). Context (31) below was used for *every* and *no*, while context (32) was used for *exactly two*. Since the contexts became more complex, we made a few changes to help participants process the information given to them. First, we used colors to identify each suspect. Second, we did not give all suspects a name (which would be difficult for participants to keep track of) but rather identified them in terms of their occupations (the butler, the gardener, et cetera).

(31) ***Every/no* Context:** The rich lord Edgware has been murdered, and three detectives are investigating the case independently. The suspects are four people working for the lord: his butler, his gardener, his maid, and his cook. Every detective quickly established that the gardener is innocent. The first detective further established that the maid cannot be the culprit, while the two other detectives gathered evidence showing that it cannot be the cook. No detective is aware of the others' discoveries, so the first detective still considers the cook as a suspect, and the two others still consider the maid as a suspect.

(32) ***Exactly two* Context:** The rich lord Edgware has been murdered, and three detectives are investigating the case independently. The suspects are four people working for the lord: his butler, his gardener, his maid, and his cook. Every detective quickly established that the gardener is innocent. The first detective further established that the maid cannot be the culprit. No detective is aware of the others' discoveries, so two of them still consider the maid as a suspect.

The crucial information in the two contexts is summarized in Table 4. Note that we did not use the context (25) because we wanted to make sure that the different detectives' beliefs would not contradict each other (there is at least one suspect that could be the murderer according to all of them), and that there was one suspect that had been cleared by all (which was useful for control items).

The Target, True, and False test sentences for *wonder* are presented in (33-35a), (33-35b), and (33-35c) respectively.

		butler	gardener	maid	cook
(31)	D1	suspect	innocent	innocent	suspect
	D2	suspect	innocent	suspect	innocent
	D3	suspect	innocent	suspect	innocent
(32)	D1	suspect	innocent	innocent	suspect
	D2	suspect	innocent	suspect	suspect
	D3	suspect	innocent	suspect	suspect

Table 4: Summary of the situation in the two contexts. For each detective, it is indicated who they consider innocent and who they still consider to be a possible culprit.

(33) *Every-wonder* sentences:

a. Every detective wonders whether the maid, the cook, or the butler committed the crime.

b. Every detective wonders whether or not the butler committed the crime.

c. Every detective wonders whether or not the cook committed the crime.

(34) *No-wonder* sentences:

a. No detective wonders whether the maid, the cook, or the butler committed the crime.
b. No detective wonders whether or not the gardener committed the crime.
c. No detective wonders whether or not the maid committed the crime.

(35) *Exactly two-wonder* sentences:
a. Exactly two detectives wonder whether the maid, the cook, or the butler committed the crime.
b. Exactly two detectives wonder whether or not the maid committed the crime.
c. Exactly two detectives wonder whether or not the gardener committed the crime.

The judgment for each target item in its respective context depended on whether a DII was derived locally, globally, or not derived at all. However, the exact mapping varied: the *every* target (33a) was true with a global or no DII, and false with a local DII, while the *no* and the *exactly two* targets (34a, 35a) were false with a global or no DII, and true with a local DII. Note that this means the experiment will not be able to differentiate between a global DII and no DII at all.

The target *believe* sentences were identical to the target *wonder* sentences, except that *wonders whether* was replaced by *believes that.* True and False controls involved a few more replacements. Examples are given in (36).

(36) Example of *believe* sentences. Differences with *wonder* highlighted in boldface.
a. *Every-believe*; Target: Every detective **believes that** the maid, the cook, or the butler committed the crime.
b. *No-believe*; True: No detective **believes that** the gardener **may have** committed the crime.
c. *Exactly two-believe*; False: Exactly two detective **believe that** the gardener **may have** committed the crime.

5.3 Participants

For each survey version, we recruited 16 participants for each of the six possible orders for the Target, True and False sentences (hence a total of 576 HIT were posted on Mechanical Turk, paid 30ct each). Again, a few participants managed to take multiple surveys. Two participants who took the survey 5 or more times were not paid for their retakes and their HITs were offered to new participants. Any retakes were discarded, as well as the data from 9 participants who reported native languages other than English.

In all, after removing all retakes and non-native speakers, we had data from 543 unique native English speakers (age range: 19–74).

5.4 Results

The results are presented in Figure 4. Since local DIIs had a different effect for the different Target sentences, we could not simply compare True and Target sentences across conditions. Instead of SENTENCE, we defined two factors which had a consistent meaning with all Quantifiers. BASELINE represented the maximum acceptability, so it had value

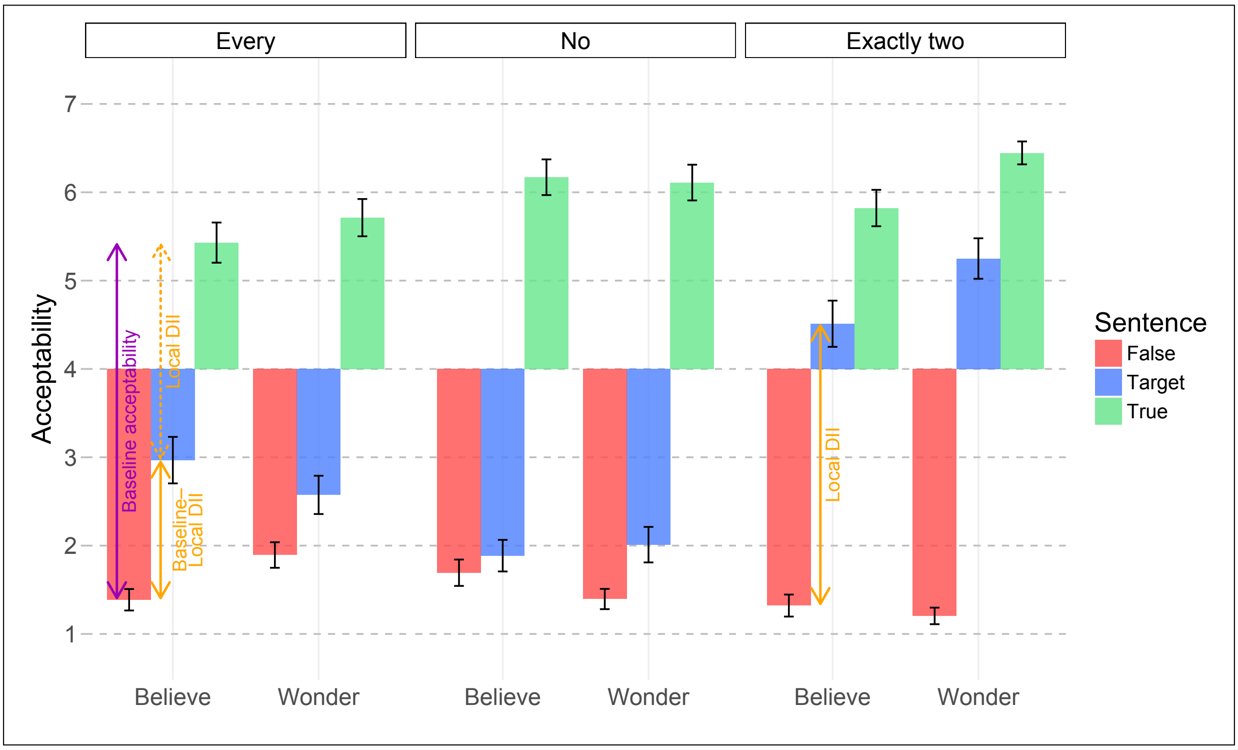


Figure 4: Experiment 2: Mean acceptability for each Verb, Quantifier, and Sentence (error bars represent standard error). With *every*, only the local DII falsifies the Target (as in Experiment 1). With the two other quantifier, it's the opposite: the Target sentences are false, except under a local DII reading.

0 on all False sentences and 1 on all True sentences. The second factor, LOCAL, encoded the effect of local DIIs on acceptability. It had value 0 on all True and False sentences, where the truth of the local DII reading matched the truth of the literal and global DII readings, and its value on Targets depended on the quantifier. The *Every* Target was true under a global DII reading or in the absence of a DII, and false under a local DII reading. Therefore, the effect of local DIIs here was to reduce the acceptability compared to the True sentence, so the two factors were fixed at BASELINE $= 1$ and LOCAL $= -1$. *No* and *Exactly two* Targets were false under a global DII reading or in the absence of DII, and true under a local DII reading. Therefore, the effect of local DIIs was to increase acceptability compared to the False sentence. The values of the factors were thus fixed at BASELINE $= 0$ and LOCAL $= +1$. To sum up, the factor BASELINE always encoded the difference between True and False sentences, while LOCAL encoded the difference between True and Target for *every*, and the difference between Target and False for *no* and *exactly two*. Using these factors, we fitted a mixed-effects ordinal logistic regression to all responses, the details and results of which are described in Table 5.

We observed that LOCAL had a significant effect with baseline quantifier *every*, and that its effect was stronger with *exactly two* and weaker with *no*. Crucially, LOCAL did not interact with Verb at all (model comparison: $\chi^2(3) = 4.6, p = .21$). As a post-hoc analysis we fitted a model to *No* items only, and confirmed that LOCAL had a significant there as well, although numerically small ($\chi^2(2) = 8.7, p = .013$).

	β	z-value	p	
BASELINE	3.6	13.1	0.000	***
LOCAL	2.4	10.6	0.000	***
VERB	1.3	3.5	0.000	***
[QUANT:*no*]	-0.2	-0.9	0.390	
[QUANT:*exactly*]	-1.2	-3.7	0.000	***
BASELINE×VERB	-1.0	-2.2	0.030	*
LOCAL×VERB	0.4	1.1	0.280	
BASELINE×[QUANT:*no*]	1.2	3.5	0.001	***
BASELINE×[QUANT:*exactly*]	1.8	4.5	0.000	***
LOCAL×[QUANT:*no*]	-1.9	-5.6	0.000	***
LOCAL×[QUANT:*exactly*]	1.8	4.7	0.000	***
VERB×[QUANT:*no*]	-1.8	-3.4	0.001	***
VERB×[QUANT:*exactly*]	-1.7	-2.6	0.010	**
BASELINE×VERB×[QUANT:*no*]	1.4	2.0	0.049	*
BASELINE×VERB×[QUANT:*exactly*]	2.2	2.8	0.005	**
LOCAL×VERB×[QUANT:*no*]	.002	.003	0.998	
LOCAL×VERB×[QUANT:*exactly*]	0.5	0.7	0.467	

Table 5: Experiment 2: Full results of the statistical model. Factors of theoretical interest are highlighted for readability. Model structure: `Answer∼(Baseline+Local)*Verb*Quantifier+(1+Baseline|Subject)`

5.5 Discussion

In this experiment, we investigated the projection behavior of DIIs in quantified sentences. We observed three things: first, DIIs are sometimes computed locally in the scope of quantified subjects. Second, there was variability across quantifiers; in particular DIIs do not seem to be computed locally in the scope of *no*. Finally, there was no observable difference between *wonder* and *believe* in the amount of local DIIs they give rise to.

Going back to Table 1, the first result tells us that we can rule out the first line (only global strengthening), while the second result eliminates the last line (only local strengthening). Finally, the third result indicates that we should aim for a unified account of the DIIs of *believe* and *wonder*.[15]

The pattern we observed with the various quantifiers is surprisingly similar to what has been observed in previous experimental work on local strengthening (in particular Chemla and Spector, 2011; Potts et al., 2016). For instance, the scalar item *some* is sometimes locally strengthened into 'some but not all' in the scope of *every*, even more so in the scope of *exactly n*, but less so in the scope of *no*.

6 General discussion

The two experiments discussed in the previous sections were conducted with the goal to investigate the nature of DIIs with respect to two parameters: structure-sensitivity and locality. More specifically, Experiment 1 tested the strength of DIIs with different kinds of complements. Experiment 2, on the other hand, investigated the interaction between DIIs and quantifiers with different monotonicity properties. Furthermore, since both experiments tested DIIs under *believe* and *wonder*, the results inform us as to whether we should aim for a unified account of DIIs under *believe* and *wonder*, or rather for a lexically-specific account.

The results of Experiment 1 indicate that DIIs depend on the structure of the complement. Concretely, DIIs are significantly stronger with Disjunction/Conjunction complements (e.g., *whether/that Sophie, Bill, or Mary arrived* and *which/one of Sophie, Bill, and Mary arrived*) than with NP/NumP complements (e.g., *which/one of her (three) children arrived*). Since the former types of complements give rise to structural alternatives in the sense of Katzir (2007) while the latter types of complements don't, these results demonstrate that the strengthening mechanism that gives rise to DIIs is structure-sensitive. In this regard, we concur with Roelofsen and Uegaki (2016), who arrive at the same conclusion based on introspective judgments by native speakers (although our results did not replicate the contrast between NP and NumP complements reported by Roelofsen and Uegaki 2016).

The results of Experiment 2 indicate that DIIs can arise locally in the scope of subject quantifiers, and furthermore that the presence of local DIIs depends on the monotonicity properties of the quantifier. Specifically, local DIIs are observed under *every*, even more strongly under *exactly two* but less so under *no*, a pattern that has also been found in

[15] Recall that we did find some (relatively small) differences between *believe*-cases and *wonder*-cases in Experiment 1, but these could be attributed to factors other than the verb itself. For instance, as discussed above, it may be that *which* activates domain alternatives in a way that *one* does not.

previous experimental work on the local strengthening of scalar items like *some* and *or* (Chemla and Spector, 2011; Potts et al., 2016). These results point to the conclusion that DIIs arise from a strengthening mechanism that is *optionally* local. Obligatory global strengthening would not capture the DII effects under *every* and *exactly two* while obligatory local strengthening would not capture the reduced effect of DIIs under *no*. These results are incompatible with Roelofsen and Uegaki's (2016) analysis of DIIs, which incorporates an exhaustification operator in the lexical semantics of *wonder* (predicting obligatory local strengthening).

Also, the general similarity between *wonder* and *believe* in our results suggests that there is a single strengthening mechanism that is responsible for DIIs with both *wonder* and *believe*. It is worth noting that we did find a difference between *wonder* and *believe* with NP/numNP complements in Experiment 1. However, as discussed in §4.5, it is possible that this was caused by differences between the complements involved (i.e., *which of...* vs. *that one of...*), and not by the verbs themselves.

Taken together, the results of our experiments point to the conclusion that the best approach to DII is one based on the *structure-sensitive* strengthening mechanism that *optionally applies locally* (i.e. Approach 2 in Table 1). Furthermore, the results suggest that this mechanism applies uniformly to sentences with *wonder* and ones with *believe*.

Looking beyond the domain of DIIs with *wonder* and *believe*, our experimental results make a contribution to the experimental investigation of local strengthening more generally. Of particular interest is the finding that the extent to which DIIs arise locally, i.e., in the scope of quantifiers with different monotonicity properties, is very similar to the extent to which scalar items like *some* and *or* are strengthened locally. An interesting avenue for future research would be to consider whether this finding, as well as further experimental work on DIIs, may be able to tease apart different theoretical accounts of local strengthening (Chierchia et al., 2012; Geurts and van Tiel, 2013; Potts et al., 2016). In particular, while the approach of Chierchia et al. (2012), which derives local strengthening by postulating covert exhaustivity operators, seems to be able to derive DIIs quite straightforwardly, this is less clear for the approach of Geurts and van Tiel (2013), which relies on typicality effects in the interpretation of specific lexical items, and for the approach of Potts et al. (2016), which relies on probabilistic pragmatic reasoning to resolve lexical underspecification. For the latter two approaches, it is, at least at first sight, not so clear how the account of scalar items like *some* and *or* could be extended to the kind of inferences discussed here, which do not seem to arise from any specific lexical item, but rather from the interplay between several elements. However, a careful discussion of this issue must be left for another occasion.

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