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# Balancing the (Horn) Scale: Explaining the Production-Comprehension Asymmetry for Scalar Implicatures

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## Abstract

Preschoolers struggle with Scalar Implicature (SI) generation, showing difficulties in interpreting the scalar element “some” with its upper-bounded meaning “some but not all”. Strikingly, despite the fact that the comprehension of “some” is not adult-like until at least 5 years of age, recent corpus data suggest that children, in production, can use “some” as “not all” already in their third year of life. In this paper, we propose the Asymmetry Account, an account of SI generation formulated in the framework of Bidirectional Optimality Theory (Bi-OT). By taking Bi-OT as a model of language use, we show that the comprehension of “some” requires hearers’ to consider the speaker’s perspective, but not vice versa: to produce “some” with its upper-bounded meaning no mentalizing about other perspectives is needed. In light of this, we predict that the comprehension of weak scalar elements such as “some” is cognitively more demanding than their production and argue that children’s difficulty with the “some”-implicature is to be related to children’s developing of cognitive abilities, in particular, Theory of Mind.

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## 1 Introduction

Grice's seminal work (Grice 1975, 1989) paved the way for the investigation of pragmatic inferences. Among these, Scalar Implicatures (SIs) have attracted much attention both from a theoretical and an experimental point of view. Consider sentence (1), which is typically interpreted as (2).

(1) Some of Van Gogh's paintings are lost.

(2) Some but not all of Van Gogh's paintings are lost.

According to the Gricean perspective (Grice 1975, 1989, Matsumoto 1995), the inference in (2) emerges in connection with the Principle of Cooperativity. Specifically, the SI arises as follows: the Maxim of Quantity invites speakers to always provide as much information as they can in their communicative exchanges; upon hearing sentence (1), hearers easily recognize that there is a non-pronounced alternative sentence that the speaker could have uttered instead of (1), namely (3).

(3) All of Van Gogh's paintings are lost.

The sentence in (3) is informationally stronger than the sentence in (1), because *all* asymmetrically entails *some*. On the assumption that the speaker who uttered (1) is cooperative and follows the Maxim of Quantity, the speaker has no reason not to prefer (1) over (3), unless (3), according to the speaker, does not hold. Thus, upon hearing (1) and reasoning about the non-pronounced stronger alternative (3), *some* can be interpreted as having an upper-bound (SOME BUT NOT ALL) and the SI in (2) is generated (note that in this paper linguistic forms are presented in italics and linguistic meanings in small caps). It is worth remembering here the fundamental role played by the so-called Horn scales (e.g., <*some*, *all*>) for the Gricean account of SIs just sketched. Horn scales are sets of lexical elements ordered by informativeness, such that uttering a weaker term on the scale (e.g., *some*) can trigger the generation of a SI (SOME BUT NOT ALL).

Despite the fact that infants are endowed with an incredible pragmatic sensitivity from an early age (Kovacs, Teglas, and Endress 2010), children have been shown to struggle with the generation of SIs (e.g., Foppolo, Guasti, and Chierchia 2012, Pouscoulous et al. 2007). Preschoolers appear knowledgeable of the lexical semantic meaning of *some*, namely AT LEAST ONE, POSSIBLY ALL (Pouscoulous et al. 2007), but until at least the age of five, unlike adults, accept *some* in situations in which *all* is true. When tested with a Truth Value Judgment Task (TVJT), for instance, they accept a sentence like "some horses jumped over the fence" when in fact all three horses jumped over the fence (Papafragou and Musolino 2003), hence demonstrating that they have not generated an implicature and have not inferred the meaning SOME BUT NOT ALL upon hearing the form *some*.

Children's performance, however, is not consistent across tasks. Certain experimental methods have been shown to enhance children's ability to generate SIs (e.g., the act out task of Pouscoulous et al. 2007), whereas other experimental methods appear to disfavor SI generation even in adults (e.g., the statement evaluation task used in the landmark study Noveck 2001). Strikingly, recent corpus data seem to complicate the picture even further. Eiteljoerge, Pouscoulous, and Lieven (2018) analyzed corpus data of five English children between ages 2;00 and 5;01. Children's utterances containing the quantifier *some* were extracted (as well as six lines of context) and categorized. For instance, the sentence "the puzzle is missing some pieces", uttered by a child playing with a puzzle, was categorized as containing an intended implicature, given that it suggests that the child wanted to communicate SOME BUT NOT ALL. The analysis of Eiteljoerge and colleagues shows that in 19.5% of children's *some* utterances, *some* was indeed used to trigger implicature generation. Hence, shortly after their second birthday children are in fact able to produce *some* with its upper-bounded meaning. This result points to a surprising production-comprehension asymmetry that warrants further consideration: how can children fail to generate SIs in comprehension until the age of 5 or 6 (e.g., Foppolo, Guasti, and Chierchia 2012), if they are able to produce *some* with the upper-bounded meaning already in their third year of life?

In this paper, we will propose the Asymmetry Account, a novel account of children's difficulties with SIs. In Section 2, we illustrate Optimality Theory, the framework we adopt for our account. In Section 3, we describe our account in detail and show that the aforementioned production-comprehension asymmetry is predicted to emerge in the acquisition of SIs. In Section 4, we discuss some crucial features and predictions of our account. In Section 5 we present some concluding remarks.

## 2 Gricean Pragmatics in Optimality Theory

Originally developed in phonology by Prince and Smolensky (1993/2004), Optimality Theory (OT) has been adopted to model syntactic, semantic, and pragmatic phenomena (Barbosa et al. 1998, Dekkers et al. 2000, Hendriks et al. 2010, Legendre et al. 2016) in the domains of language acquisition (Hendriks and Spenader 2006) and language change (Holt 2003) as well. In the framework of OT, language production and language comprehension are seen as processes of optimization. In particular, in OT production is considered an optimization from an input meaning to an output form. It consists of the selection of the best form, among a (potentially infinite) number of forms, for the expression of a particular meaning. Likewise, comprehension is considered an optimization from an input form to an output meaning. It consists of the selection of the best meaning, among a (potentially infinite) number of meanings, for a particular form. What counts as best, or optimal, is established on the basis of a set of relevant constraints. Moreover, constraints differ in strength and whenever two constraints are in conflict the weakest can be violated in order to satisfy the strongest.

One of the major advantages of the OT approach is the ability to describe production and comprehension as separate optimization processes. Developing Bidirectional Optimality Theory (Bi-OT), Blutner (1998, 2000, and subsequent work) took a step further, adopting a somewhat more holistic perspective on language. Bi-OT allows us to formalize the idea that what counts as optimal is not just a form *or* a meaning, as in unidirectional optimization, but a form-meaning pair. Specifically, the version of Bi-OT that is relevant here is weak Bi-OT (see Blutner 2000, 2010, and Jäger 2002, for discussion of different forms of Bi-OT). Weak Bi-OT, also called super optimality, can be defined as follows:

(4) A form-meaning pair $<f_1, m_1>$ is weakly bidirectionally optimal iff:
  a. There is no other weakly bidirectionally optimal pair $<f_1, m_2>$ such that $<f_1, m_2>$ better satisfies the constraints than $<f_1, m_1>$;
  b. There is no other weakly bidirectionally optimal pair $<f_2, m_1>$ such that $<f_2, m_1>$ better satisfies the constraints than $<f_1, m_1>$.

Crucially for our purposes, Blutner (1998, 2000, 2006, 2007, 2015) proposed that Gricean implicatures can be seen as reflecting the machinery of Bi-OT and its inherently recursive character (see also Krifka 2009, 2010, 2011). To illustrate, consider the following example:

(5) Aurelio stopped the car.

(6) Aurelio caused the car to stop.

The sentence in (5) suggests that the car has been stopped in the regular way, using brakes. In contrast, upon hearing the sentence in (6) an implicature (specifically, a manner implicature) emerges: the intended meaning of the utterance appears to be that the car has been stopped in a non-stereotypical or indirect way (e.g., by putting something in front of the car) (see McCawley 1978 for a similar example). Bi-OT provides us with a way to describe the process whereby such an inference arises. First, consider the forms *stop* and *cause to stop*, and the meanings that can be possibly associated with them, namely STEREOTYPICAL STOPPING and NON-STEREOTYPICAL STOPPING. Consider then all the possible form-meaning pairs that can be generated combining them:

(7) a. <*stop*, STEREOTYPICAL STOPPING>
b. <*cause to stop*, STEREOTYPICAL STOPPING>
c. <*stop*, NON-STEREOTYPICAL STOPPING>
d. <*cause to stop*, NON-STEREOTYPICAL STOPPING>

Assume also that syntactically simpler forms are preferred to more complex forms (constraint F), and simpler meanings are preferred to more complex meanings (constraint M). On the basis of the two constraints, *stop* is to be preferred to *cause to stop*, whereas STEREOTYPICAL STOPPING is preferred to NON-STEREOTYPICAL STOPPING. The form-meaning pair 7a includes a simple form and a simple meaning, thus satisfying both F and M, and can unequivocally be considered bidirectionally optimal. What about the other pairs? 7b incorporates the meaning STEREOTYPICAL STOPPING, which has already been incorporated in a bidirectionally optimal pair (7a). Hence, regardless of any other consideration, it is immediately blocked: the existence of 7a prevents 7b from being bidirectionally optimal (see 4a). By the same token, 7c is blocked by 7a: 7c incorporates the form *stop*, but the form *stop* has already been incorporated in 7a, which is bidirectionally optimal. Thus, 7c is also blocked and can never be bidirectionally optimal (see 4b). Lastly, 7d violates the two constraints, because it includes a complex form (*cause to stop*) and a complex meaning (NON-STEREOTYPICAL STOPPING). However, it proves to be bidirectionally optimal. As the reader can verify, 7a cannot block 7d: the two pairs do not have form nor meaning in common; hence, the existence of 7a does not affect 7d. The other pairs 7b and 7c cannot block 7d either, because they have been discharged as non-bidirectionally optimal. Consequently, they can be ignored when evaluating 7d. In conclusion, the pair <*cause to stop*, NON-STEREOTYPICAL STOPPING> appears to be bidirectionally optimal as well. Evaluating all the alternatives, there is not a better form than *cause to stop* to express NON-STEREOTYPICAL STOPPING and there is not a better meaning than NON-STEREOTYPICAL STOPPING to interpret the form *cause to stop*. This accounts for the inference linked to the interpretation of the sentence in (6). Broadly speaking, the Bi-OT process just described is the reason why, in everyday natural language, periphrastic constructions of the form *cause* + infinitive are associated with more complex interpretations.

As this example shows, Bi-OT can model linguistic phenomena that require integration between the effect of the constraints in production (speaker's perspective) and the effect of the constraints in comprehension (hearer's perspective). In developing our Asymmetry Account of SIs, we will follow Blutner's (1998, 2000, and subsequent work) insights. Contrary to Blutner (2010), however, we maintain that bidirectional optimization, and not just unidirectional optimization, is a cognitively plausible mechanism of online sentence interpretation. In the next section, we present our account, focusing in particular on the *some*-implicature – although we believe that, with the appropriate modifications, our analysis can also be extended to other SIs. In Section 3.1, we introduce two specific constraints, which will be shown to regulate the semantics of the terms *some* and *all* of the <*some*, *all*>-scale. We then illustrate the interaction between these two constraints, which gives rise, thanks to the bidirectional optimization mechanism, to SIs (Section 3.2 and 3.3).

## 3 The Asymmetry Account

### 3.1 Semantic Constraints on the Scalar Elements *Some* and *All*

We argue that the production and comprehension processes related to the scalar items *some* and *all* are modulated by the interaction between two constraints of a different type. The first one is a faithfulness constraint. In OT, faithfulness constraints are constraints that evaluate the link between input and output. Specifically, in OT syntax and in OT semantics, faithfulness constraints promote maximal transparency between forms and meanings (Hendriks 2014).

The faithfulness constraint we introduce as relevant for the production and comprehension of scalar elements originates from an essential feature of Horn scales, namely the fact that these scales are always polarized towards an upper or lower bound. In other words, Horn scales convey a certain dimension, which is maximal at a culmination point. We introduce the term *apex* to refer to such a culmination point. For instance, the dimension of the scale <*warm*, *hot*> culminates with an apex that we could name HEAT; whereas the scale <*possible, certain*> has NECESSITY as its apex. It is worth mentioning that even scales that give rise to particularized or ad hoc implicatures (linked to so-called Hirschberg scales, after Hirschberg 1985) have apices, though it may be more difficult to attribute a specific name to those apices. Consider the following example:

(8) a. The deadline for the manuscript submission is tomorrow. How is it going?
b. I've proofread it.

The answer in (8b) suggests that the manuscript has not been submitted yet. Clearly, the scale <*proofread*, *submit*> is pragmatically defined; the inference from *proofread* to NOT SUBMITTED is highly context-dependent (and perhaps easily derived by academics, but probably less so by people with a different profession). The dimension conveyed by the scale corresponds to the submission procedure, which culminates and has its apex in the submission itself.

On the basis of the very existence of apices, a faithfulness constraint can be spelled out. In general, faithfulness constraints "can be viewed as a relation of association" (Hendriks et al. 2010). The constraint we propose and call FaithHorn encourages a strict mapping between the strongest element on a Horn scale and the apex of the same Horn scale (its culmination point).

(9) FaithHorn: The strongest element on a Horn scale maps onto the apex of the scale.

Clearly, this constraint is applicable to Horn scales in general. If we apply it to the particular case of the scale <*some*, *all*> we obtain a more specific constraint, which we call FaithAll.

(10) FaithAll: *All* maps onto an exhaustive meaning.

This constraint promotes the association between the form *all* and an exhaustive meaning. Conversely, it is violated whenever *all* is interpreted as mapping onto a non-exhaustive meaning. More informally, it can be said that when *all* is not used to denote complete sets, FaithAll is violated.

We now introduce our second constraint. Unlike FaithAll, this constraint is a markedness constraint. In contrast with faithfulness constraints, OT markedness constraints do not pertain to the connection between input and output; rather, they are output-oriented and express a preference for or suggest avoidance of particular outputs, irrespective of the input (Hendriks et al. 2010). Importantly, because of the fact that in OT semantics the outputs of the production process are forms whereas the outputs of the comprehension process are meanings, a markedness constraint can have an effect in one direction but not in the other (Hendriks 2014, Hendriks and van Rij 2011, Hendriks et al. 2010).

Our markedness constraint is based on the Principle of Cooperativity and, more specifically, on the first Maxim of Quantity. This maxim (here in the formalization of Matsumoto 1995) is widely accepted as a fundamental premise of SIs (e.g, Grice 1975, Hirschberg, 1985):

(11) Quantity-1 Maxim: Make your contribution as informative (strong) as possible.

We attempt to translate this maxim into a constraint that pertains to scalar terms. This can be done by operationalizing the tendency towards informativeness as a preference for the strongest term on the scale. The result is a markedness constraint that we call Strength (cf. similar constraints introduced by Hogeweg 2009 and Zeevat 2000):

(12) Strength: Use the strongest element on the Horn scale.

It is worth noticing that this constraint, as typically happens with markedness constraints, reflects a tendency towards economy (Hendriks et al. 2010) on the side of the hearer. The more informative the form (where informativeness is its ability to reduce hearer's uncertainty; Shannon 1948), the more easily it can be interpreted. Having introduced the two constraints, FaithAll and Strength, we now show how they interact for the production and comprehension of the scalar terms *some* and *all*.

### 3.2 Unidirectional Optimization: Production and Comprehension of *Some* and *All*

As mentioned, in OT production and comprehension can be seen as optimization processes in which given an input, the possible outputs are evaluated on the basis of the constraints of the grammar. The evaluation process ends with the selection of the best (optimal) output. When the production process and the comprehension process are considered independently, we talk about unidirectional optimization. In production, unidirectional optimization takes a meaning as input, and gives a form as output. In comprehension, unidirectional optimization takes a form as input, and gives a meaning as output.

Let us take the concrete case of a speaker who wants to refer to a complete set of elements. In this situation, the input of the unidirectional optimization is an exhaustive meaning. How does the selection of the optimal form for this meaning proceed? We can illustrate the process of evaluation using a constraint tableau (Prince and Smolensky 1993).

| INPUT: EXHAUSTIVE | OUTPUT | FaithAll | Strength |
|---|---|---|---|
| | ☞ *all* | | |
| | *some* | | *! |

Table 1 (production): Unidirectional optimization of EXHAUSTIVE.

The first column introduces the input and the second one some of the possible outputs. The first possible output, the form *all*, complies with FaithAll because this constraint promotes precisely the mapping between *all* and exhaustive meanings. The constraint Strength is not violated by *all* either, because *all* is the strongest element of the scale at hand. Consider now the other possible output listed in Table 1, the form *some*. Like *all*, the form *some* does not violate FaithAll, but for a different reason. FaithAll constrains just the mapping from *all* to a meaning, and hence does not pertain to the form *some*. Thus, FaithAll is vacuously satisfied by *some*. On the other hand, *some* violates Strength because *some* is not the strongest element of the scale to which it belongs. This violation is marked in the tableau with an asterisk. This violation is fatal (as indicated by the presence of an exclamation mark), because due to this constraint violation *some* is a suboptimal output. Consequently, *all* is chosen as the best candidate to express EXHAUSTIVE, as indicated in the tableau by the presence of the pointing finger.

Consider now the case of a speaker who wants to refer to a proper subset of elements. The production process is described by the following tableau.

| INPUT: NON-EXHAUSTIVE | OUTPUT | FaithAll | Strength |
|---|---|---|---|
| | *all* | *! | |
| | ☞ *some* | | * |

Table 2 (production): Unidirectional optimization of NON-EXHAUSTIVE.

As can be seen, the form *all* again complies with Strength. Indeed, irrespective of the meaning with which it is associated, *all* never violates Strength because it is always the strongest element of the scale. However, in this tableau *all* does violate FaithAll because in the pair <*all*, NON-EXHAUSTIVE>, the form *all* is associated with a meaning that is not EXHAUSTIVE. The other possible output, the form *some*, violates Strength because it is not the strongest term of the scale. However, it does not violate FaithAll. As said above, this constraint is always vacuously satisfied by *some* in production because FaithAll is not relevant for the use of *some*. Thus, in this tableau the two possible outputs, *some* and *all*, both violate a constraint. However, FaithAll is ranked higher than Strength (as the position in the tableaux indicates). Consequently, the form *some* turns out to be the optimal output for the meaning NON-EXHAUSTIVE.

The unidirectional mechanism just described models the online production process of the scalar elements *some* and *all* both in adults and in children. Assuming the constraints FaithAll and Strength, we predict that an exhaustive meaning will be expressed by the form *all*, whereas a non-exhaustive meaning will be expressed by the form *some*.

We now consider the comprehension of the forms *some* and *all*. The same constraints are at the basis of the evaluation and appear in the tableaux, but in this case the inputs are the forms *some* and *all*.

Table 3 and Table 4 show the optimization involved in the comprehension of the forms *all* and *some*, respectively. It immediately becomes clear that Strength is vacuously satisfied in both tableaux. To see why, recall that Strength regulates the choice of form and does not concern the choice of meaning. Consequently, because of the fact that in comprehension what needs to be chosen is the optimal meaning, whereas the input form is already given, Strength cannot be violated. Therefore, in comprehension, Strength does not have any effect.

| INPUT: | OUTPUT | FaithAll | Strength |
|---|---|---|---|
| *all* | ☞ EXHAUSTIVE | | |
| | NON-EXHAUSTIVE | *! | |

Table 3 (comprehension): Unidirectional optimization of *all*.

| INPUT: | OUTPUT | FaithAll | Strength |
|---|---|---|---|
| *some* | ☞ EXHAUSTIVE | | |
| | ☞ NON-EXHAUSTIVE | | |

Table 4 (comprehension): Unidirectional optimization of *some*.

Consider now the possible outputs in Table 3. The first meaning, EXHAUSTIVE, does not violate FaithAll. Conversely, NON-EXHAUSTIVE does violate FaithAll: if the form-meaning pair <*all*, NON-EXHAUSTIVE> is created, *all* becomes associated with a meaning that is different from EXHAUSTIVE and this is against FaithAll. This violation is fatal and the optimal meaning to be associated with *all* in comprehension is EXHAUSTIVE.

What about the comprehension of the form *some* (Table 4)? Strength is vacuously satisfied. Moreover, as already mentioned, FaithAll constrains the mapping from *all* to a specific meaning (EXHAUSTIVE), hence it is not relevant when the form under scrutiny is *some*. So the constraint FaithAll is vacuously satisfied too. The conclusion is that *some* in comprehension admits two potential meanings: as the presence of two pointing fingers indicates, EXHAUSTIVE and NON-EXHAUSTIVE are both optimal solutions for the interpretation of the form *some*. Because of this predicted ambiguity, we expect listeners to allow *some* to be interpreted as expressing also a non-exhaustive meaning. Notably, this prediction seems to be confirmed by children's pattern of behavior in comprehension experiments. However, this still leaves us with the question how the adult-like comprehension of *some* emerges. We argue that in order to unambiguously interpret *some* as NON-EXHAUSTIVE, bidirectional optimization is necessary.

### 3.3 Bidirectional Optimization: The Emergence of the *Some*-Implicature

In bidirectional optimization, forms and meanings are evaluated as pairs (Table 5). The evaluation proceeds as follows. The pair <*all*, EXHAUSTIVE> can immediately be considered bidirectionally optimal, given that it does not violate any constraint. Recall that in Bi-OT forms and meanings that are already part of a bidirectionally optimal form-meaning pair cannot be included in another bidirectionally optimal form-meaning pair (following 4a and 4b). Consequently, given that *all* has already been incorporated in the bidirectionally optimal pair <*all*, EXHAUSTIVE>, the pair <*all*, NON-EXHAUSTIVE> is blocked and can never be considered bidirectionally optimal. Likewise, given that EXHAUSTIVE has already been incorporated in the bidirectionally optimal pair <*all*, EXHAUSTIVE>, the pair <*some*, EXHAUSTIVE> cannot be considered bidirectionally optimal either. The remaining pair in the competition, <*some*, NON-EXHAUSTIVE>, is evaluated as the second bidirectionally optimal pair. Albeit violating Strength, it is the best solution for the comprehension of the form *some* and the expression of the meaning NON-EXHAUSTIVE.

Thus, bidirectional optimization is the mechanism whereby the *some*-implicature emerges. As shown in Table 5, in bidirectional optimization <*some*, EXHAUSTIVE> is blocked and the meaning that comes to be associated with the form *some* is NON-EXHAUSTIVE. Bidirectional optimization hence exemplifies the adult-like comprehension of the scalar element *some*.

Returning to children's pattern of behavior, this pattern can be accounted for by assuming that children are not yet able to apply bidirectional optimization and can only optimize unidirectionally. As shown in Table 1 and Table 2, in production unidirectional optimization suffices. When the speaker wants to refer to a proper subset of elements, the best form that can be used salva veritate and that complies with FaithAll is *some*. This form-meaning association in production does not require speakers to reason about alternatives and carry out complex mentalizing operations. Consequently, given the two constraints FaithAll and Strength, even very young children are expected to associate non-exhaustive meanings (SOME BUT NOT ALL) with the form *some*. This can explain the corpus findings of Eiteljoerge, Pouscoulous, and Lieven (2018).

| Form-meaning pairs | | FaithAll | Strength |
|---|---|---|---|
| ✌ | <*all*, EXHAUSTIVE> | | |
| | <*all*, NON-EXHAUSTIVE> | * | |
| | <*some*, EXHAUSTIVE> | | * |
| ✌ | <*some*, NON-EXHAUSTIVE> | | * |

Table 5: Bidirectional optimization: the second optimal pair represents the *some*-implicature.

In contrast, in comprehension unidirectional optimization gives rise to an ambiguity (Table 4), which children's language system is not yet able to resolve. In order to unambiguously associate *some* with its upper-bounded reading (SOME BUT NOT ALL), bidirectional optimization is necessary (Table 5): in addition to the effects of the constraints in comprehension, hearers also need to take into account the effect of the constraints in production. In other words, hearers also need to take into account the speaker's perspective.

It is important to emphasize that this means that generating the implicature (the strengthened meaning SOME BUT NOT ALL from the lexical meaning AT LEAST ONE, POSSIBLY ALL of the form *some*) is the hearer's task. Following our analysis, in contrast to what is implicitly or, more rarely, explicitly (Hirschberg 1985, Horn 2006) assumed in the literature, it can be argued that implicature generation takes place in comprehension. In fact, the *some*-implicature emerges as an epiphenomenon of the comprehension process. Speakers can use *some* in a way that triggers SI generation, but they do not need to generate the *some*-implicature themselves. In light of this, we predict that the comprehension of *some* requires more cognitive resources than the production of *some*.

## 4 Discussion

In the present paper, we aimed to explain the production-comprehension asymmetry that emerges in the acquisition of SIs. Specifically, we aimed to reconcile the rather surprising finding that children can already use *some* as SOME BUT NOT ALL in production in their third year of life (Eiteljoerge, Pouscoulous, and Lieven 2018) with children's well-attested difficulty in inferring SOME BUT NOT ALL from the form *some* in comprehension (Foppolo, Guasti, and Chierchia 2012). Building upon Blutner's work (Blutner 2000, and subsequent work), we proposed the Asymmetry Account in the framework of constraint-based Bi-OT. We argued that two specific constraints, FaithAll and Strength, are at the basis of both the production and the comprehension of the scalar elements *some* and *all*. Children's mastery of these constraints is what allows them to produce the forms *all* and *some* in an adult-like manner from an early age. Our analysis also predicts that the form *some* is ambiguous in comprehension if comprehension proceeds unidirectionally. The adult-like comprehension of *some* is due to bidirectional optimization, however, which requires additional cognitive resources compared to unidirectional optimization.

As mentioned, this view of bidirectional optimization as modeling online sentence comprehension contrasts starkly with Blutner's view. According to Blutner (in particular, Blutner 2010), weak Bi-OT cannot be taken to describe online processes. Rather, bidirectional optimization emerges offline on the time-scale of language evolution and can be seen as expressing the process of language change (see also Dekker and van Rooy 2000, Van Rooij and De Jager 2012, van Rooy 2004). The results of bidirectional optimization (for instance, the association between *cause to stop* and NON-STEREOTYPICAL STOPPING) become "fossilized" in diachrony and need to be learned in language acquisition. In Blutner's view, bidirectional optimization is not required, or better, does not occur in everyday language exchanges. Accordingly, children's difficulties with implicatures can be seen as reflecting a still incomplete learning process (see Blutner 2010, for a discussion of the acquisition of *some*).

In contrast with this view, we maintain that bidirectional optimization should be seen as a mechanism that is reflected in online sentence processing (Hendriks and Spenader 2006, van Rij et al. 2013, cf. Beaver and Lee, 2004, Zeevat, 2000). Importantly, language acquisition data support this approach (Hendriks and Spenader 2006, Hendriks and van Rij 2011, see Hendriks et al. 2010, for discussion). At the cognitive level in particular, processing speed and Theory of Mind (ToM) have been shown to play a fundamental role in bidirectional optimization, as shown in the computational cognitive modeling study of van Rij et al. (2010) and the psycholinguistic study of Kuijper (2016), respectively.

For our Asymmetry Account, considering the role of ToM seems particularly relevant. As a cognitive ability, ToM (also referred to as mentalizing or mindreading) develops gradually in children (Peterson and Wellman 2019). Children acquire first-order ToM, which is the ability to represent the mental states of others, around the age of 4 or 5 (Wellman, Cross, and Watson 2001). As discussed by Hendriks (2014), first-order ToM seems a prerequisite for bidirectionalization as a process of linguistic perspective-taking.

In light of this, the production-comprehension asymmetry emerging in the acquisition of the *some*-implicature seems to find a natural explanation. We need to acknowledge that hearers, when processing a sentence, need to consider the speaker's perspective in order to correctly interpret the meaning of *some*. The opposite, however, does not hold. In other words, ToM is indispensable to optimize bidirectionally and to interpret *some* in an adult-like manner. On the other hand, in production unidirectional optimization suffices and ToM is not needed.

It is important to stress that, contrary to Blutner's offline perspective on Bi-OT, our online perspective on Bi-OT is compatible with bidirectional optimization as a two-step mechanism (Hendriks 2014, van Rij et al. 2010). That is, optimization proceeds first in one direction (in comprehension: the hearer's perspective) and then, recursively, in the other. Notably, a great deal of experimental evidence supports accounts of SI generation according to which implicatures are calculated in two steps. In this sense, online measures seem particularly revealing: eye-tracking studies (Huang and Snedeker 2009, 2018, cf. Grodner et al. 2010), mouse-tracking studies (Tomlinson, Bailey, and Bott 2013), and reaction time studies (Bott and Noveck, 2004, but see van Tiel et al. 2019) all suggest that adult participants calculate the literal meaning of *some* first, and only later infer SOME BUT NOT ALL. Thus, these data speak in favor of an account of *some*-inferences as an online bidirectional optimization process.

## 5 Conclusions

In this paper, we proposed a novel account of children's generation of SIs in the framework of Bi-OT. The striking finding that children master the upper-bounded meaning of *some* in production 2 or 3 years before showing an adult-like comprehension of the same scalar element was accounted for in terms of their difficulty with bidirectional optimization. Specifically, we showed that to produce *some* in an adult-like manner (with its upper-bounded meaning), no complex inferential process is needed because unidirectional optimization suffices. Conversely, in comprehension bidirectional optimization is necessary in order to resolve the ambiguity that emerges, assign an adult-like interpretation, and thus generate the SI. Importantly, we argued that ToM skills play a crucial role for bidirectional optimization in general and for implicature generation in particular. Thus, our analysis sheds new light on the complex relationship between the development of children's cognitive abilities and children's inferential abilities.

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