Revealing abstract semantic mechanisms through priming

Revealing abstract semantic mechanisms through priming: the distributive/collective contrast

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Abstract

Sentences such as *The bags are light* allow both collective (they are light *together*) and distributive interpretations (empheach bag is light). We report the results of two experiments showing that this collective/distributive contrast gives rise to priming effects. These findings suggest that collective and distributive readings involve different interpretative mechanisms, which are at play during real comprehension and can be targeted by priming, independently of the specific verification strategy associated with each interpretation.

Keywords: priming; plurals; distributivity; semantics; gradable adjectives; ambiguity

1. Introduction

In the last thirty years, priming has served to identify the abstract representations that people construct when producing or comprehending language (Pickering & Ferreira, 2008; Branigan & Pickering, 2017, for reviews). This type of priming is known as *structural priming* and it occurs when the processing of a structure is facilitated after the same structure has been recently processed. While structural priming has often been associated with *syntactic priming*, recent studies have revealed that priming methods also serve to tap into abstract semantic mechanisms at play during the interpretative process (Raffray & Pickering, 2010; Bott & Chemla, 2016; Feiman & Snedeker, 2016; Maldonado et al., 2017b).

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Semantic theories have proposed the existence of invisible operations to derive specific sentence interpretations. For example, a silent distributivity operator (D operator) has been proposed to explain why sentences such as "Two boys hold three bags" can have not only a basic *cumulative* reading (e.g., Two boys hold three bags *in total*) but also a distributive interpretation (e.g., Two boys hold three bags *each*). Its meaning roughly corresponds to that of *each* in English (Link, 1998; Champollion, 2016; Roberts, 1987). When modified by the D operator, the VP 'hold three bags' applies to each atomic member of the plural subject, so each boy is allowed to hold three bags (i.e. the bags can *covary* with each boy). Distributive readings are thus explained by postulating the presence of this D operator in the semantic representation. Using a priming paradigm, Maldonado et al. (2017a) have recently shown that this cumulative/distributive contrast gives rise to priming effects. Specifically, they found evidence for an asymmetric distributive priming, suggesting that an abstract mechanism such as the one proposed by semanticists is at play during the comprehension of these ambiguities and can be primed.

Importantly, the optional insertion of the D operator has been proposed to account not only for the cumulative/distributive contrast but also for every sentence that can optionally have a distributive interpretation. Our goal here is to extend these results to what is thought to be another instantiation of the same operator: the collective/distributive ambiguity illustrated in (1) and (2):

(1)   The bags are heavy.

      a.   Collective reading
          The bags together are heavy, without each bag necessarily being heavy.

      b.   Distributive reading
          Each bag is heavy (and the bags are heavy in total as well).

(2)   The bags are light.

      a.   Collective reading
          The bags together are light (and each bag is light as well).

      b.   Distributive reading
          Each bag is light, without the bags necessarily being light together.

In their collective reading, (1) and (2) are true as long as the predicate can denote a property of the plural subject as a whole, without necessarily being true of each individual member. Distributive readings, instead, entail that the predicate is true of each atomic member of the plural subject. VPs that present this ambiguity, such as 'heavy' or 'light', are called 'mixed' predicates (Link, 1983; Scha, 1984; Schwarzschild, 1996, 2011)[1].

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[1]There is a question in plural semantics of whether or not all gradable adjectives give rise to the collective/distributive ambiguity. Some gradable adjectives have been traditionally considered to be "stubbornly-distributive" in that they do not seem to admit collective interpretations (Schwarzschild, 1996, 2011; Syrett, 2015; Glass, 2018). Recent evidence, however, has challenged this hypothesis (Scontras & Goodman, 2017). Given that the predicates used

Note that collective and distributive readings of (1) and (2) are not logically independent: one reading entails the other. A scenario that makes the distributive reading of (1) true (i.e. each bag is heavy) also makes the collective reading true. The distributive interpretation *entails* the collective interpretation. This entailment is asymmetric: the collective reading of (1) can be true while the distributive reading is false. Changing the polarity of the adjective switches the direction of the entailment (see Table 1).

Collective interpretations of (1) and (2) seem to be the result of just applying the plural subject to the predicate, whereas distributive readings are thought to arise by inserting the covert D operator. That is, the collective/distributive ambiguity of adjectival predicates is explained analogously to the distributive/cumulative contrast tested by Maldonado et al. (2017a). If the same mechanism is required to derive optional distributive readings across different sentences and predicates, we would expect to see priming effects at play for sentences such as (1)/(2) as well as in the cases discussed in the previous study.

Finding priming effects related to the collective/distributive ambiguity would provide further evidence for the existence of an abstract mechanism to derive distributive readings. Moreover, the use of adjectival predicates brings two important advantages. First, as observed, distributive and collective interpretations can be weak or strong depending on the polarity of the adjective (cf. Table 1). Consequently, 'mixed' adjectival predicates allow us to test, for the first time, priming of specific readings independently of logical strength (i.e. *weak* distributive readings might prime *strong* distributive readings, while before strong distributive could only be related to strong distributive readings). We can thereby dissociate priming effects revealing some aspects of semantic representations and those due to logical strength during parsing.

Furthermore, sentences such as (1) and (2) allow us to dissociate the processing of distributive readings from verification strategies that are not inherent to distributivity. In psycholinguistics, the collective/distributive ambiguity has been mostly investigated by testing transitive sentences such as "The boys are painting a castle" (Frazier et al., 1999; Syrett & Musolino, 2013; Brasoveanu & Dotlačil, 2015, among others). Distributive interpretations were isolated here by presenting participants with scenarios where the object co-varies with each member of the plural subject. In the example above then, the distributive scenario would involve a different castle per boy. Participants may use a verification strategy specific to distributive interpretations, based on checking for covariation of the object with respect to the subject. The processing pattern attributed to distributivity therefore confounds verification strategy with semantic interpretation. Mixed adjectival predicates allow us to isolate distributivity from covariation, and therefore to remove this confound.

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in these experiments are undoubtfully ambiguous, we will not address this discussion here.

	Collective reading		**Distributive reading**
POSITIVE ADJECTIVE: *The bags are heavy*	The bags are heavy together	⇐	Each bag is heavy
NEGATIVE ADJECTIVE: *The bags are light*	The bags are light together	⇒	Each bag is light

Table 1: Entailment relation between readings. Distributive readings asymmetrically entail collective readings of positive adjectives (e.g., 'heavy'). The reverse pattern is attested for negative adjectives (i.e. 'light'). The distributive interpretation is the *strong* reading for sentences involving positive adjectives, and the *weak* interpretation for sentences involving negative adjectives (and the other way around for collective readings). This entailment pattern arises for most *adjectival* mixed predicates (e.g., expensive/cheap; noisy/quiet).
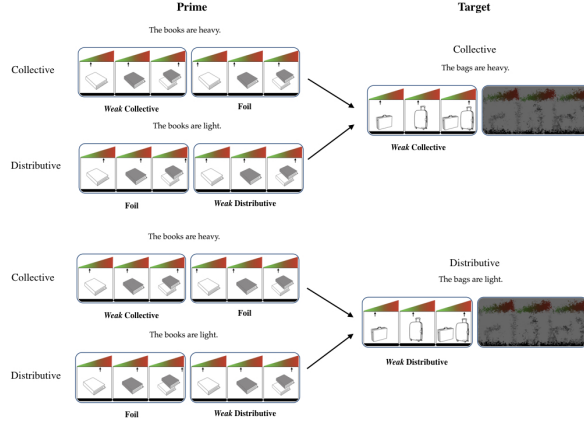
2. Experiment 1

### 2.1. Methods and materials

We used a sentence-picture matching task where participants had to read a sentence and match it with one of two pictures (Raffray & Pickering, 2010; Maldonado et al., 2017a, among others). In experimental trials, the sentence involved adjectival predicates and was ambiguous between a collective and a distributive reading. Each sentence was presented with two out of three possible pictures: (a) a **foil** picture, that made both readings of the sentence false, (b) a **weak** picture, that made only one reading of the sentence true (whether this reading is the collective or the distributive one depends on the adjective polarity, Table 1), and (c) a **'blur'** picture, where the relevant information was blurred so participants could not see it. Specific arrangements between pictures and sentences gave rise to two experimental items: primes and targets (see Figure 1).

Primes were designed to force one specific sentence interpretation. There were two types of primes: *Collective primes* displayed a foil and a weak *collective* picture, so participants would click on the collective picture and access the collective reading of the sentence. *Distributive primes* displayed a foil and a weak *distributive* picture, forcing participants to access the distributive reading. **Targets** could also be either *collective* or *distributive*. They displayed a weak picture, compatible with the collective or the distributive reading depending on the condition, and a 'blur' picture. Participants were instructed to select the 'blur' option if they felt that the overt picture was not a sufficient match for the sentence (modeled from the "covered picture" method, Huang et al., 2013). Table 2 illustrates how target responses are indicative of a choice between a collective and a distributive interpretation.

Targets immediately followed prime trials. After being biased towards one specific sentence interpretation in primes, participants were expected to select more often a picture compatible with this same interpretation in targets, independently of the target condition. For example, collective primes should lead

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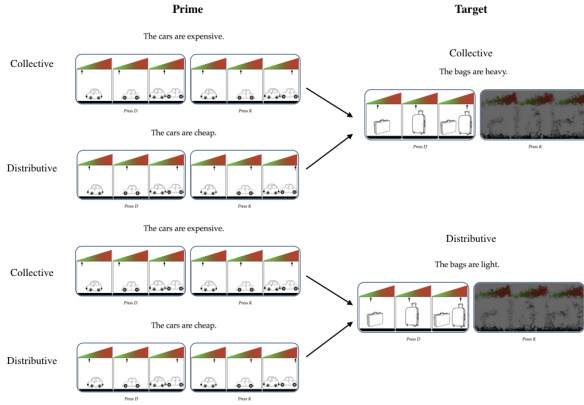
(b) Mismatching predicates

Figure 1: Illustration of experimental trials. Each experimental trial involved an ambiguous sentence presented with two pictures. In both primes and targets, sentences were constructed using the frame *The* [plural exemplar] *are* [predicate]. Predicates were selected among three possible predicate pairs, depending on the scale dimension: light/heavy, cheap/expensive and noisy/quiet. Exemplars varied depending on the predicate pair. Collective primes and targets always displayed sentences involving positive adjectives; distributive primes and targets involved negative adjectives. Prime trials combined the ambiguous sentence with two overt pictures; whereas targets presented an overt *weak* picture and a 'blur' picture. Pictures displayed three scales, which could measure degrees of various dimensions (weight, price or sound intensity). Values at the green portion of the scale represented low degrees; values at the red portion represented high degrees.

to a greater proportion of overt responses in collective targets and of 'blur' responses in distributive targets. Priming of semantic interpretation would then

	COLLECTIVE TARGET (Positive adjective) *e.g., The bags are heavy*	DISTRIBUTIVE TARGET (Negative adjective) *e.g., The bags are light*
Collective reading	Overt weak, collective picture	'Blur' picture
Distributive reading	'Blur' picture	Overt weak, distributive picture

Table 2: **Pictures compatible with each reading in target conditions.** Image selection in targets is an indicator of the reading participants have accessed. In collective targets, the collective reading is made true by the overt *weak* picture, whereas the distributive reading is only compatible with the 'blur' option. Distributive targets display the reverse pattern: the distributive reading is made true by the overt option, and the collective reading is only compatible with the 'blur' scenario. Since participants were instructed to select the 'blur' option only when the overt (weak) picture was not satisfying (as a last resort), the selection of the 'blur' option was taken to be an indicator of strong interpretations (participants were unsatisfied with a choice that would be compatible with the weak interpretation).

be observed as a main effect of Prime condition in target responses. Given that the picture compatible with the primed reading is not the same across target conditions, we control for visual priming.

The four possible prime-target combinations were present in the experiment. There were two primes of the same condition preceding each target (cf. Maldonado et al., 2017a), forming experimental *triplets*. Primes and target within one experimental triplet could use predicates from the same or different degree dimension (i.e. height, price, volume), resulting in matching or mismatching predicate conditions. The left/right position of the 'weak' image was counterbalanced.

The experimental design consisted of four fully-crossed factors to obtain 16 prime-target triplets (48 trials): 2 (PRIME CONDITION) × 2 (TARGET CONDITION) × 2 (PREDICATE CONDITION) × 2 (WEAK IMAGE POSITION). A further 64 controls trials were randomly inserted between triplets. These controls were designed to highlight both 'blur' and overt pictures as possible correct responses (see Supplementary Materials).

We recruited 54 English speakers using Mechanical Turk. Participants were paid for their participation (approx. 10 minutes). After application of a predetermined exclusion criterion of 75% accuracy on True and Foil controls, 33 participants were considered for the analyses. Further details about the experimental procedure and the control items are provided in the Supplementary Materials.

2.2. Results and discussion

The responses were analyzed by modeling response-type likelihood using logit mixed-effect models (Jaeger, 2008), keeping the random structure maximal

when possible; p-values were obtained by a χ^2 likelihood ratio test comparing each model with a simpler one in which the relevant predictor was removed (Barr et al., 2013). The dependent measure was the log-odds of choosing a distributive over a collective response on target trials, after each type of prime (see Table 2 for reading-picture correspondences). Target responses that were not preceded by two correct prime responses ($\sim$10%) were excluded from the analyses.

Figure 2a illustrates the mean percentage of distributive responses after accurate primes. Figure 2b separates the results depending on the PREDICATE CONDITION (matching or mismatching between primes and targets). A first analysis reveals a significant effect of PRIME CONDITION ($\chi^2 = 36.146$; $p < .001$), such that the rate of distributive responses was overall higher after distributive primes than after collective primes. No interaction was detected between PRIME and PREDICATE conditions ($\chi^2 < 1$; $p = .85$), suggesting that the priming effect is partly independent from whether sentences in primes and targets used the same predicates. Indeed, the main effect of PRIME CONDITION was still significant when the analysis was restricted to mismatching cases ($\chi^2 = 16.028$; $p < .001$). We also note that these effects could not be explained by visual priming: as visible in Figure 1, the correct picture in the different prime conditions are the same (only the sentence changes).

These findings suggest that priming of interpretation is at play: participants' choices in targets appear to be influenced by the reading that was forced in prime trials. So far, however, one cannot tell whether the priming was triggered by all types of primes, or by solely, say, distributive primes. Maldonado et al. (2017a), for instance, found an asymmetry between distributive and cumulative priming, such that distributive primes influenced target selection, whereas cumulative primes behaved just like baselines (i.e. targets after no prime). Such inquiries require a baseline rate of responses in targets in the absence of primes, absent here.

Finally, we should note an alternative explanation of the results in terms of a 'verification strategy priming'. To illustrate (cf. Figure 1), in distributive primes, participants may note that only the values of the first two first scales (those concerning single objects) matter. If so, participants may be biased to decide on the basis of only these two scales in subsequent targets (i.e. 'check-two-scales' strategy), effectively leading to an increase of distributive responses. Similarly, collective primes may lead participants to focus on the third scales (concerning all objects together), which would lead to accept the collective image without even noticing that it makes the distributive reading false (i.e. 'check-one-scale' strategy). In short, readings may trigger specific verification strategies, which may lead to shallow acceptance in Targets, mimicking the effect of priming of readings we are interested in. Experiment 2 was designed to rule out this alternative explanation and to determine from which of the prime(s) condition(s) the effect follows.
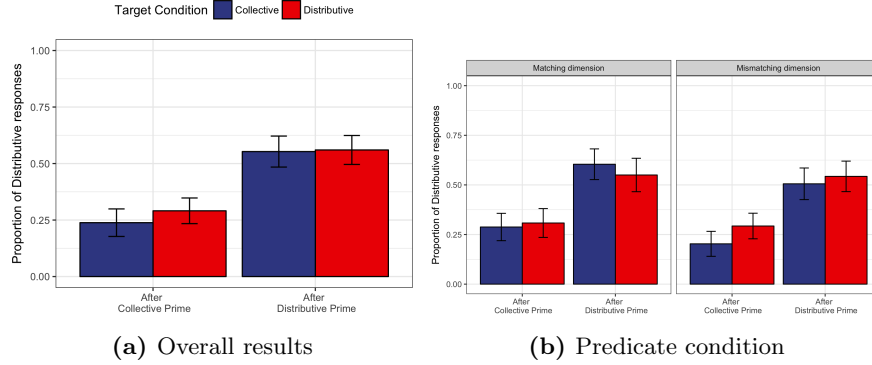
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(a) Overall results   **(b)** Predicate condition

Figure 2: Target results in Experiment 1. (a) Mean proportion of distributive responses in collective and distributive targets after each prime condition. Distributive responses correspond to the selection of the overt picture in distributive targets (red) and of the 'blur' picture in collective targets (blue). (b) Mean proportion of distributive responses per predicate dimension. In the matching dimension, primes and targets instantiate predicates of the same dimension (e.g., heavy/light); in the mismatching dimension, predicates in primes and target belong to different dimensions (e.g., expensive/light).

3. Experiment 2: Baseline inclusion

3.1. Methods and materials

Experiment 2 was similar to Experiment 1 except that baseline experimental triplets were added, in which two *pseudo-primes* replaced the two primes (see Figure 3). Pseudo-primes displayed one picture that made the sentence true (correct picture), and one that made it false (foil picture), and they involved sentences that do not instantiate the collective/distributive ambiguity. Instead, pseudo-primes were associated with distributive/collective conditions through the verification strategies mentioned above: decisions could be based on one or on more than one scale (see Table 3).

There were then two types of pseudo-primes. In *pseudo-collective primes*, the sentence involved a singular definite description (e.g. "The book is light"). Correct and foil pictures only differed on one scale (i.e. the scale containing the relevant exemplar). As in collective primes (cf. Experiment 1), participants could make an accurate decision by verifying a single scale. Collective and pseudo-collective primes shared a "check-one-scale" strategy. In contrast, in *pseudo-distributive primes*, the sentence included the focus-sensitive operator *only*, which enriches the meaning of the expression by negating its alternatives. A sentence such as *Only the book is light* implies that nothing but the book is light. Indeed, the foil image for these trials made the sentence false by satisfying the predicate not only for the exemplar but also for its alternatives. Since foil and correct images differed on more than one scale, participants are required to
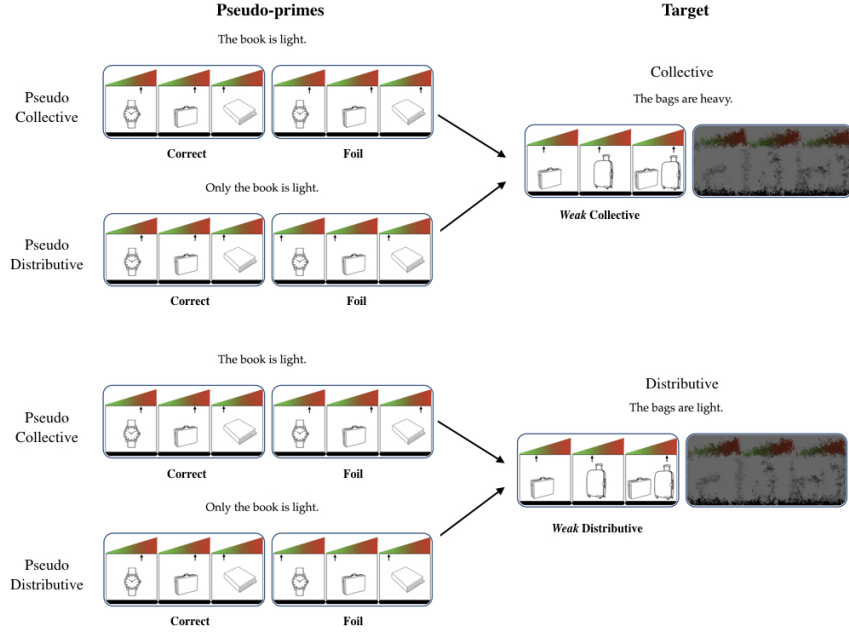
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Figure 3: Pseudo-prime–Target combinations in Experiment 2. On top of the four prime-target combinations of Experiment 1 (see Figure 1), Experiment 2 included four *pseudo-prime*–target combinations. All pseudo-primes involved unambiguous sentences and forced the selection of a picture with 'mismatching' scales. Participants had to choose the same type of image as in primes, but, since the sentence was not ambiguous, they were no biased towards one specific interpretation. Differences between pseudo-collective and pseudo-distributive primes correspond to differences in the verification strategies that could be developed to make an accurate choice.

check at least two scales in each image. Consequently, distributive and pseudo-distributive primes give rise to a common verification strategy.

If the effect found in Experiment 1 was due to verification strategy priming only, we would expect both pseudo-primes and primes that instantiate the same verification strategy to behave similarly. Instead, semantic priming should lead to an effect for targets specifically after *true* primes, and not after *pseudo-*primes. Then, using pseudo-primes as baselines, the potential difference between primes and pseudo-primes within one condition, say distributive, could be used as a measure of the priming force of distributive primes, and we could look for asymmetries between distributive and collective priming.

The experimental design was the same as in Experiment 1 except that there was an additional PRE-TARGET TYPE factor (prime, pseudo-prime). The PRIME CONDITION is defined here by the verification strategy (see Table 3). We obtained 32 experimental triplets (96 trials) by crossing the factors. A further 64 controls were randomly inserted between triplets. A group of 55 fresh En-

glish speakers was recruited using Mechanical Turk. Participants were paid for their participation (approx. 14 minutes). After exclusion (cf. Experiment 1), 41 participants were included in the analyses. Responses were analyzed as in Experiment 1.

PRIMING SOURCE	Prime	Pseudo-Prime
Reading Priming	YES	NO
Verification Strategy Priming	YES	YES

Table 3: Items in Experiment 2. Primes and pseudo-primes in Experiment 2 differed on whether they could serve to prime both a verification strategy and a semantic interpretation or only a verification strategy. While pseudo-primes do not force collective or distributive interpretations, they share the verification strategy with the prime from the same condition.

3.2. Results and discussion

Figure 4a illustrates the proportion of distributive responses after pseudo-primes and primes. First, results from Experiment 1 were replicated: when restricted to targets after *prime* trials (Figure 4a, right panel), the proportion of distributive choices is significantly higher after distributive primes than after collective primes (main effect of PRIME CONDITION: $p < .001$, $\chi^2 = 62.2$). Moreover, among *prime* trials, no interaction PRIME $\times$ PREDICATE condition was found ($p = .47$, $\chi^2 < 1$).

A second analysis performed on the entire data set reveals that the difference between collective and distributive primes (i.e. Experiment 1 replication) is significantly different from the one between pseudo-primes, as it is revealed by a significant interaction PRIME CONDITION (collective/distributive) $\times$ PRE-TARGET TYPE (prime/pseudo-prime) ($p < .001$, $\chi^2 = 17.1$). This result suggests that the priming effect is not entirely driven by verification strategy priming, or else primes and pseudo-primes would have had the same effect in targets. Therefore, priming of semantic interpretation must be at play.

To assess whether the priming effect was asymmetric, we analyzed the proportion of responses compatible with priming within each condition (see Figure 4c); namely, the responses compatible with distributive readings in the distributive condition, and the ones compatible with the collective reading in the collective condition. If, e.g., distributive priming were stronger than collective priming (cf. Maldonado et al., 2017a), the difference between pseudo-primes and primes in the distributive condition should be bigger than in the collective one. The interaction PRIME CONDITION $\times$ PRE-TARGET TYPE, however, was not significant ($p = .49$, $\chi^2 < 1$), indicating no evidence of an asymmetry in distributive and collective priming. Finally, a *posthoc* analysis revealed a baseline preference for collective interpretations, expressed as a main effect of PRIME

CONDITION in the proportion of 'priming' responses ($p < .001$, $\chi^2 = 85.4$; see Figure 4c) . [2]

These results suggest that the collective/distributive contrast gives rise to priming of semantic interpretation, independently of verification strategy priming (which may be at play on top of the semantic effect). Despite the numeric difference between the two effects, there was no evidence of an asymmetry of priming from distributive or collective primes. Unlike previous experiments (cf. Maldonado et al., 2017a), our findings cannot be straightforwardly explained by saying that priming targets the mechanism responsible for distributive interpretations (i.e. distributivity operator). Instead, some part of the abstract representations underlying *each* of the readings seem to be the locus of the priming effect.

The absence of evidence for an asymmetry could be related to the use of different contrasts (cumulative/distributive vs. collective/distributive), different predicate types (transitive vs. adjectival) or some aspect of our experimental set-up. For instance, as suggested by a reviewer, the derivation of collective readings might also involve some additional semantic mechanism, analogous to the distributivity operator. Something along these lines has been indeed proposed by Winter (2001). If both collective and distributive readings are derived, one might expect priming to arise for both readings to a similar degree: priming would be targeting each specific semantic mechanism (e.g. distributivity/collectivizer operators). This would not be expected for more basic cumulative readings, explaining the contrast with Maldonado et al.'s (2017a) study.

4. Conclusions

Several experimental studies have focussed on the ambiguity between distributive and non-distributive construals of sentences involving transitive verbs. Instead, we investigated the distributive-collective ambiguity in the interpretation of adjectives (see also Syrett, 2015; Scontras & Goodman, 2017). Our results establish that the distributive/collective ambiguity gives rise to priming effects, independently of considerations of visual priming, object covariation, logical strength and verification strategies. This shows that the abstract properties of distributivity and collectivity are accessed in on-line comprehension.

Assuming that distributive readings require a specific distributivity mechanism that is not present in collective construals, we might have expected the effect of distributive primes to be stronger that that of non-distributive primes.

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[2]This result reveals that, in the experimental context, collective interpretations are *more frequent* than distributive ones (i.e. baseline preference rates). This difference in frequency between the readings, however, does not seem to give rise to an inverse-preference effect, whereby less preferred or less frequent constructions exhibit stronger priming effects than more preferred ones (see Ferreira & Bock, 2006; Pickering & Ferreira, 2008 for reviews): no evidence for an asymmetry in priming strength is observed in our results.
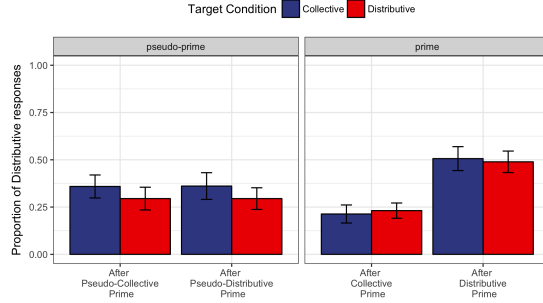
(a) Distributive responses in Targets: Overall results
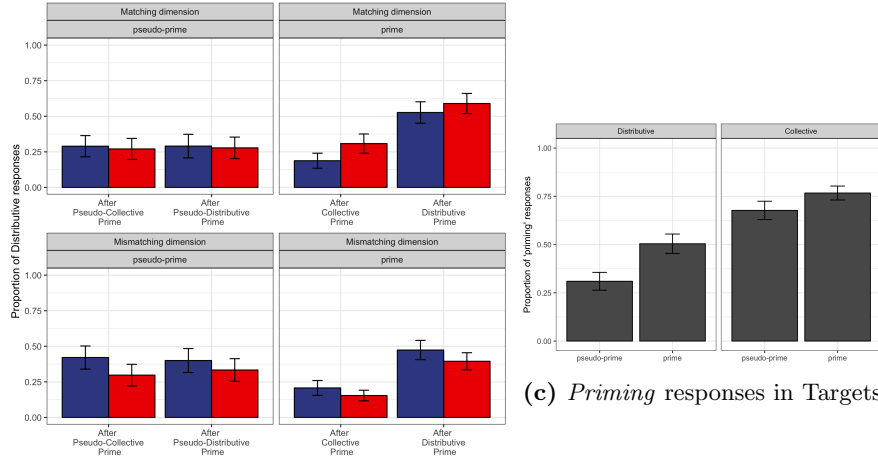
(c) *Priming* responses in Targets

(b) Distributive responses in Targets: Predicate condition

Figure 4: Target results in Experiment 2. (a) Mean proportion of responses compatible with the distributive reading on targets trials. (b) Mean proportion of distributive responses per predicate dimension. (c) Proportion of responses compatible with *priming* within each prime condition. Responses are coded depending on whether or not they are compatible with distributive readings (left panel) or collective readings (right panel). Target condition is aggregated for simplification.

Such an asymmetry was found in Maldonado et al. (2017a), but it was not replicated here. Although the current study contrasts distributivity with collectivity (rather than with cumulativity), this discrepancy calls for further investigation which should inform us both about distributivity and about the mechanisms by which priming operates in semantics.

Acknowledgements

Supplementary materials

Experimental procedure. In both experiments, participants were instructed to choose between two cards or pictures the one that "best illustrates the sentence". They were given two simple examples, which involved singular items and therefore did not display the relevant ambiguity (e.g. *Only the bag is light*). While in the first example the two cards were fully visible, the second example involved a 'blur' picture. Participants were told that they should go for the blur option only when the visible card was not a "good enough description" of the sentence. No further specifications about how to perform the task (e.g. speed) were given to participants. Note that these instructions are similar to the ones used in previous 'covered box' and priming paradigms (Huang et al., 2013; Bott & Chemla, 2016).

The two experiments were implemented using the Ibex Farm online platform. Experimental triplets and individual fillers were administered in random order to each participants. The presentation paradigm is exemplified in Figure 5. An online version of Experiment 1 can be found here, and all materials, data and analyses for both experiments are provided here.
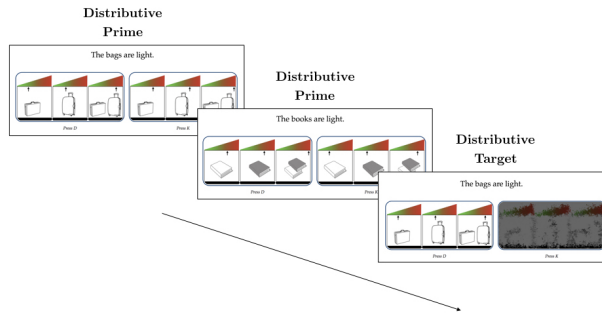

Figure 5: Experimental procedure (Distributive-Distributive triplet). Immediately after a response to given trial, the next trial would appear on the screen.

Control trials in Experiments 1 and 2. Four types of **control trials** (see Figure 6) were included in both experiments. *Foil* controls involved an unambiguous sentence (e.g., 'The bag is heavy') together with a picture that made the sentence false and a 'blur' picture. Participants were thus forced to select the 'blur' option. *True* controls were the counterpart of foil cases. They also involved an unambiguous sentence but they displayed one picture that made the sentence true and a 'blur', leading participants to choose the overt picture.

Strong-Distributive and *Strong-Collective* controls involved the same ambiguous sentences as in primes and targets (e.g., 'The bags are heavy'), but displayed a weak picture and a *strong* picture, which made both readings of the sentence true. The idea behind these controls was to make participants noticing that the 'blur' picture in targets could correspond to a scenario than makes both readings true (strong picture). In the same way as prime trials raise the likelihood of the 'blur' option being a foil picture, these *strong* controls raise the likelihood of the 'blur' picture being a situation that makes both reading true. On top of elevating the overall proportion of 'blur' responses in targets, these controls should give us the baseline preference pattern between collective and distributive readings.

Four repetitions of these four control items were included in each of the experiments, for a total of 64 trials. Foil and True controls were used to fix the exclusion criteria of participants. In particular, participants who had accuracy rates below 75% in these control items were not considered for the analyses. Instead, Strong-Distributive and Strong-Collective controls were informative of the reading participants would access under normal circumstances. Figure 7 illustrates the results for these control items.

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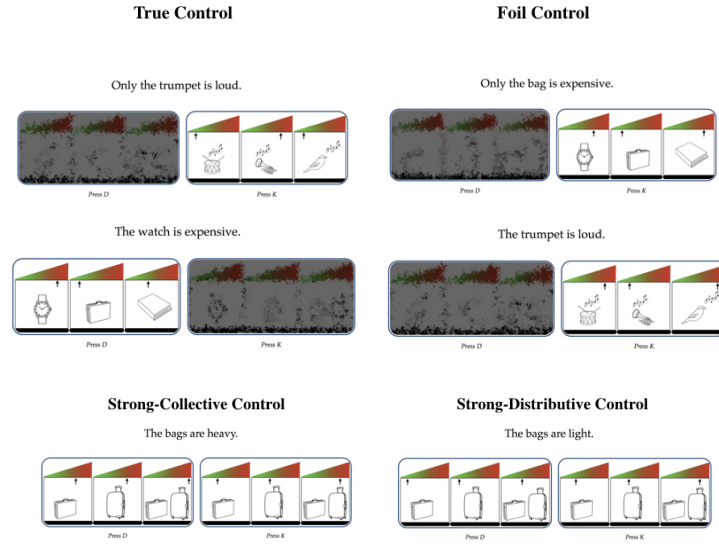
Figure 6: Illustration control trials. Both Experiments 1 and 2 included four types of control trials.
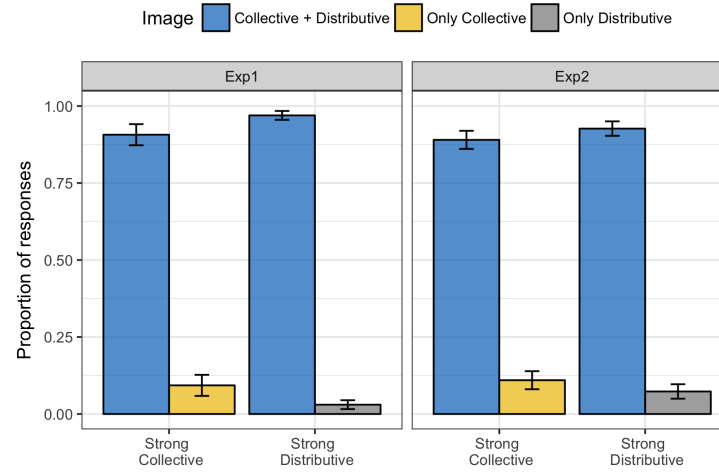

Figure 7: Control results for both experiments.

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