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Revisiting the logic in language: The scope of *each* and *every* universal quantifier is alike after *all*

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ABSTRACT

A doubly-quantified sentence like *Every bear approached a tent* is ambiguous: Did every bear approach a different tent, or did they approach the same tent? These two interpretations are assumed to be mentally represented as logical representations, which specify how the different quantifiers are assigned scope with respect to each other. Based on a structural priming study, Feiman and Snedeker (2016) argued that logical representations capture quantifier-specific combinatorial properties (e.g., the specification of *every* differs from the specification of *each* in logical representations). We re-examined this conclusion by testing logical representation priming in Dutch. Across four experiments, we observed that priming of logical representations emerged if the same quantifiers are repeated in prime and target, but also if the prime and target contained different quantifiers. However, logical representation priming between quantifiers emerged less consistently than priming within the same quantifier. More specifically, our results suggest that priming between quantifiers emerges more robustly if the participant is presented with quantifier variation in the prime trials. When priming between quantifiers emerged, however, its strength was comparable to priming within the same quantifier. Therefore, we conclude that logical representations do not specify quantifier-specific biases in the assignment of scope.

Introduction

Sentence comprehension involves the construction of a complex meaning by combining the meaning of the words that make up a sentence. This skill is far from trivial, which becomes clear in the interpretation of quantifier words like *all*, *each*, or *some*. These words do not refer to anything in the surrounding world, but specify abstract information about sets of referents and the relations between such sets and their predicates. This abstract nature of quantifier words can result in ambiguity if multiple quantifiers co-occur within the same sentence. Consider sentence (1), containing the quantifiers *each* and *a*:

(1) Each bear approached a tent.

This sentence allows two interpretations: It can be understood as meaning that each bear approached a (potentially) different tent but also as meaning that each bear approached the same tent.

How do comprehenders disambiguate between these different interpretations? One of the cues that guides this ambiguity resolution is the lexical content of the quantifier words. Compare the sentence in (1) with the sentence in (2):

(2) All the bears approached a tent.

The sentence in (2) is ambiguous in the same way as the sentence in (1): Both an interpretation in which all bears approached a different tent and an interpretation in which all bears approached the same tent is possible. The difference between (1) and (2), however, is the quantifier words that are used: *each* and *a* in (1), and *all* and *a* in (2). These differences in quantifier words lead to differences in interpretation: People prefer the interpretation in which each bear approached a different tent for (1), whereas (2) is typically understood as meaning that all bears approached the same tent (Feiman & Snedeker, 2016; Ioup, 1975).

How are these differences between universal quantifiers represented? Do they instantiate distinct quantifier-specific combinatorial mechanisms in interpretation (Beghelli & Stowell, 1997; Champollion, 2017; cf., May 1985; Szabolcsi, 2015), or do they merely serve as a cue for disambiguation? This question was previously addressed by Feiman

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and Snedeker (2016), who used a structural priming paradigm to experimentally test quantifier representations. *Structural priming* refers to the tendency to re-apply the abstract structure to a sentence if that structure was recently computed in the processing of a previous related sentence. This effect emerges because it is easier to re-use a representation if it is recently used and therefore processing of a sentence facilitates the processing of a subsequent similar sentence (e.g., Bock, 1986; Branigan et al., 2005; for review, see Branigan & Pickering, 2017; Tooley, 2022).

Feiman and Snedeker (2016) showed that the interpretations of sentences like (1) and (2) are susceptible to priming: When participants are forced to assign a specific interpretation to a doubly-quantified sentence like (1) or (2), then they are more likely to re-assign that particular interpretation to a subsequent similar sentence. Importantly, this priming was only observed if the two structures contained the same quantifier words, which suggests that the semantic representations underlying quantifiers like *all* and *each* differ, and thus that quantifier words instantiate distinct mechanisms in semantic interpretation. In the current study, we re-examined Feiman and Snedeker's conclusions.

Quantifiers and logical representations

Quantifier words specify an abstract relation between the different concepts denoted in a sentence (e.g., Champollion, 2017; Szabolcsi, 2010, 2015). Consider the sentence *All the bears are hungry*, which contains the universal quantifier *all*. Such a universal quantifier instantiates a relation between all members of a set and a predicate. In this example, *all* specifies that all things that are a 'bear' are also 'hungry' (that is, anything that is a bear is also a hungry thing).

Quantifiers assign semantic *scope* to define the order of quantifier relations, which causes ambiguity if multiple quantifiers co-occur within the same sentential clause. To illustrate, consider the sentences in (1) and (2) again. In one possible reading, the universal quantifier (*each* in (1) and *all* in (2)) is assigned wide scope over the existential quantifier (*a*). This interpretation, referred to as the *universal-wide* interpretation, denotes the situation in which each bear approached a (potentially) different tent (i.e., the property 'is approaching a tent' is asserted to each individual bear). Using the formal machinery of first-order logic, we can represent this interpretation as follows:

(3a) Universal-wide: $\forall x[\textsc{bear}(x) \rightarrow \exists y[\textsc{tent}(y) \wedge \textsc{approached}(x, y)]]$.
For all x, if x is a bear, there exists a y such that y is a tent, and x approached y

Alternatively, the existential quantifier can be assigned wide scope over the universal quantifier. This interpretation, which we will call the *existential-wide* interpretation, refers to a situation in which all bears approach the same tent (i.e., the property 'every bear is approaching *y*' is asserted to a specific tent, labelled *y*). This existential-wide interpretation can be represented as follows:

(3b) Existential-wide: $\exists y[\textsc{tent}(y) \wedge \forall x[\textsc{bear}(x) \rightarrow \textsc{approached}(x, y)]]$.
There exists a y, such that y is a tent, and for all x, if x is a bear, then x approached y.

The disambiguated interpretations of scopally ambiguous structures such as (1) or (2) are assumed to be represented as *logical representations* (e.g., Chemla & Bott, 2015; Feiman & Snedeker, 2016; Heim & Kratzer, 1998; Raffray & Pickering, 2010).

But which information is exactly specified in mental logical representations? Which mechanisms are involved in the assignment of scope, and how is scope specified in logical representations? Theorists have postulated various approaches to explain how listeners derive unambiguous meanings from scopally ambiguous structures. In one prominent class of theories, it has been argued that the construction of a logical representation predominantly relies on the syntactic ordering of the quantifiers. This hypothesis is based on the observation that people prefer the interpretation in which the highest quantifier in the syntactic structure is assigned wide scope over the quantifier that is lower in the syntactic tree structure (e.g., Conroy et al., 2009; Fox, 2000; Jackendoff, 1972; Lidz & Musolino, 2002; May 1985). In case the lowest quantifier in the grammatical structure is assigned wide scope over the highest quantifier, an additional operation is needed to reverse the order of the scope assignment. Theorists differ in the exact nature of this operation (Hendriks, 1988; May 1985; see for overview Ruys & Winter, 2011; Szabolcsi, 2010), but they share the assumption that this 'scope-reversal operation' is cognitively costly.

However, the ordering of the quantifiers in the sentence is not the sole determiner of the final interpretation of a scopally ambiguous structure. Our comparison of the sentences in (1) and (2) showed that the assignment of scope is also modulated by the lexical content of the quantifier words (Ioup, 1975; Vendler, 2019).[1] More specifically, quantifier words differ from each other in scope-taking behaviour. In English, for instance, the universal quantifier *each* has a stronger tendency to be assigned wide scope than the universal quantifier *all*. Ioup (1975) observed that quantifier words can be placed in a hierarchy, depending on their inherent lexical tendency to be assigned wide scope. This *Quantifier Hierarchy* is presented in (4):

(4) EACH ≻ EVERY ≻ ALL ≻ MOST ≻ MANY ≻ SEVERAL ≻ SOME ≻ A FEW

Ioup constructed the Quantifier Hierarchy based on judgement data from a variety of languages and syntactic constructions (see also Gil, 1995). The existential quantifier *a* was not placed in the original hierarchy, although others have hypothesised that *a* is positioned between *every* and *all* (Filik et al., 2004; Kurtzman & MacDonald, 1993).

Importantly, lexical factors can override—at least to some extent—pragmatic or contextually-driven biases in sentence interpretation. In a sentence-picture matching task, Feiman and Snedeker (2016, Experiment 1) tested how English-speaking participants spontaneously interpret doubly-quantified sentences like *Every hiker climbed a hill*. In this task, the participants read an ambiguous doubly-quantified sentence and paired it with one out of two pictures. These pictures displayed the universal-wide or the existential-wide interpretation of the sentence. The universal quantifier in the test sentences differed between *each*, *every*, or *all*. This manipulation strongly affected the results: Participants who read test sentences with *each* selected the universal-wide picture in over 90% of the cases, whereas participants who read test sentences with *all* selected the universal-wide picture in roughly 20% of the cases. Crucially, the rest of the sentences and visual contexts were the same across conditions, meaning that these large differences in interpretations are solely driven by the lexical properties of the quantifier words.

Some theorists have taken the different patterns of scope behaviour associated with each quantifier word as an indication for quantifier-specific scope-mechanisms. Here, the hypothesis is that distinct scope-taking mechanisms are mapped onto the lexical representations of each quantifier word. It is worth noting that semantic theories are typically concerned with the question which scope assignments are *possible* for a given quantifier, and less with the question of why a particular scope assignment is *preferred* (AnderBois et al., 2012; Higgins & Sadock, 2003; Saba & Corriveau, 2001). Nevertheless, if scope assignment is uniquely operationalised for each quantifier word, then it could follow that quantifier words may differ in their scope behaviour (e.g. Beghelli & Stowell, 1997; Champollion, 2017; Steedman, 2012).

On the other hand, other theories stipulate that scope is assigned with a general scope-taking mechanism that is mapped onto the lexical

[1] Other sources of information that guide scope ambiguity resolution are linear order of the quantifiers (Fodor, 1982; Kurtzman & MacDonald, 1993), language-specific pragmatic constraints (Hemforth & Konieczny, 2019), or contextual information (Saba & Corriveau, 2001). However, studying all these factors goes beyond the scope of the present study, which revolves around the representation of quantifier-specific lexical content in logical representations.

representation of all quantifier words (although there are, again, multiple hypotheses on the exact nature of this scope-taking mechanism; e.g. Hendriks, 1988; May 1985; Montague, 1973). These theories, however, are typically less concerned with the lexical component in scope-taking, and assume that such differences are mostly caused by pragmatic or contextual constraints (an assumption that is difficult to reconcile with Feiman and Snedeker's (2016) findings presented above).

These two classes of theories yield different predictions about the representation of scope in logical representations. In case scope assignment is operationalised distinctly for each quantifier word, then scope is predicted to be represented differently for each quantifier word. This means that the specification of, for example, the scope of *all* differs from the representation of the scope of *each* in logical representations. If, on the other hand, scope is assigned with a quantifier-general mechanism, then the representation of scope is predicted to be the same for all quantifier words.

Structural priming of logical representations

The mental architecture of logical representations can be studied using the *structural priming paradigm* (Chemla & Bott, 2015; Feiman & Snedeker, 2016; Maldonado et al., 2017; Raffray & Pickering, 2010). Recall that structural priming refers to the effect that people tend to re-use previously processed structures, because the re-use of a representation is facilitated by its previous use. The underlying rationale of this effect is that (parts) of the representations used in sentence processing are shared between related sentences (Chang et al., 2006; for reviews, see Branigan et al., 2005; Pickering & Ferreira, 2008; Tooley, 2022; for meta-analysis in production, see Mahowald et al., 2016).

The first priming studies focussed on linguistic representations in production, looking primarily at the representation of syntactic structure. These studies showed that participants are more likely to produce a passive sentence (e.g., *The church was hit by lightning*) after having processed a similar passive sentence (e.g., *The banker was robbed by a gang of teenagers*) than after having processed and active sentence (e.g., *The gang of teenagers robbed the banker*; Bock, 1986; Bock & Loebell, 1990). Research done over the last decades has shown that semantic structures can also serve as the locus of priming effects (such as thematic structure, animacy ordering, event structure, and information structure; Bock et al., 1992; Chang et al., 2003; Ziegler & Snedeker, 2018, 2019; Ziegler et al., 2018). Moreover, structural priming also emerges in language comprehension, where it is characterised as the re-application of a structure to a comprehended sentence (Arai et al., 2007; Segaert et al., 2013; Thothathiri & Snedeker, 2008; Ziegler & Snedeker, 2019; for review, see Tooley, 2022). Altogether, structural priming is thus a valuable window into the cognitive representations involved in language processing.

Logical representations are also susceptible to priming, which has been shown in several studies in language comprehension (Chemla & Bott, 2015; Feiman & Snedeker, 2016; Maldonado et al., 2017; Raffray & Pickering, 2010; Slim et al., 2021). The first to study priming of logical representations were Raffray and Pickering (2010). They implemented a structural priming paradigm in a sentence-picture matching task in which the participants matched a doubly quantified sentence like *Every kid climbed a tree* with one out of two pictures. These sentences are ambiguous between a universal-wide (as in 3a) and an existential-wide interpretation (as in 3b). In the prime trials of their experiment, one picture corresponded to one possible interpretation of the sentence, whereas the other picture was a foil picture that was no match for either interpretation. Each prime trial was immediately followed by a target trial. This target contained a similar doubly-quantified sentence (e.g., *Every hiker climbed a hill*), but the two response pictures corresponded to both possible interpretations of the sentence. Thus, in the prime trials, the participants were forced to assign one specific interpretation to the prime sentence, whereas in the subsequent target trials, the participants could freely assign either interpretation. Raffray and Pickering observed that participants were more likely to assign the universal-wide interpretation to targets following a universal-wide prime than to targets following an existential-wide prime, showing that participants perseverate in their interpretation of doubly-quantified sentences.

So, Raffray and Pickering's (2010) main finding is that logical representations can be primed in language comprehension, which indicates that comprehenders compute such representations. However, they did not test whether lexical differences in quantifier words were represented in logical representations, because their test sentences only involved the quantifier *every* and *a*. This question, however, was tested by Feiman and Snedeker (2016, Experiment 2), who used a similar sentence-picture matching paradigm as Raffray and Pickering. Like Raffray and Pickering, they tested the interpretation of English sentences like *Every hiker climbed a hill*, but they manipulated the quantifier in the subject of these sentences. Specifically, the subject phrase could contain a universal quantifier like *each*, *every*, or *all* or a numeral quantifier like *three* or *four*. Because the quantifier in the subject position was manipulated in both prime and target trials, Feiman and Snedeker's experiment involved sixteen different prime-target configurations (of which four were within-quantifier conditions: *each-each, every-every, all-all*, numeral-numeral, and the other twelve between-quantifier conditions, such as *each-every*, *every-all*, etc.). Feiman and Snedeker's study showed priming effects for all quantifiers, but only if the prime and the target sentence contained the same quantifiers. For example, there was priming from an *each…a* sentence to a subsequent *each…a* sentence, but not to an *all…a* or an *every…a* sentence. Based on this finding, Feiman and Snedeker concluded that logical representations are differentiated according to quantifier-specific scope-taking properties. This finding supports theoretical accounts that postulate that there is no universal scope-assigning mechanism that is shared by all quantifiers, but that scope is assigned to quantifiers following quantifier-specific mechanisms (e.g., Beghelli & Stowell, 1997; Steedman, 2012).

Moreover, in a follow-up experiment, Feiman and Snedeker observed logical representation priming between different numeral quantifiers (e.g., from *three…a* to *four…a*). Importantly, Feiman and Snedeker assume that numeral quantifiers have identical scope-taking properties even though they are not synonymous. This experiment showed priming between different numbers, and the magnitude of this priming effect was similar to priming within the same number. Therefore, Feiman and Snedeker concluded that logical representation priming is not dependent on phonological or lexical repetition between prime and target (see also Slim et al., 2021, who observed priming from the Dutch quantifier *alle* ('all') onto its French translation equivalent *tous les* ('all')), which can also not be due to repetition of phonology or lexical items). Rather, priming of logical representations depends on the repetition of the abstract combinatorial properties of the quantifiers involved. These combinatorial properties include the scope-taking mechanisms of quantifiers, but not their conceptual meaning content (e.g., the magnitude difference between *three* and *four*).

The present study

As described above, Feiman and Snedeker (2016) argued that logical representations specify quantifier-specific scope-taking properties. In this paper, we present four structural priming experiments in Dutch that evaluate this claim. We re-assessed this claim because we observed logical representation priming between different universal quantifiers in Dutch in an experiment that was originally conducted for a different purpose.[2] The findings of this experiment—reported below as Experiment 1—contradict Feiman and Snedeker's hypothesis that logical representations specify quantifier-specific scope biases, and therefore necessitated a reconsideration of their conclusions.

All experiments below used a similar sentence-picture matching task as the one used by Feiman and Snedeker (2016). The prime and target sentences were always doubly-quantified Dutch sentences like *Elke wandelaar beklom een heuvel* ('Every hiker climbed a hill'). In the prime sentences, we manipulated the quantifier in the subject position between *elke* ('every'), *iedere* (also 'every'), and *alle* ('all'). The target sentences, however, always contained *elke*. In Dutch, the quantifiers *iedere* and *elke* are more-or-less synonymous to each other (Haeseryn et al., 1997). We both gloss them as 'every', but they are not exact translation equivalents. Depending on the context of use, they can also be translated as 'each'. The quantifier *alle*, however, is a very close translation equivalent of English'all' (Gil, 1995).

Based on Feiman and Snedeker's (2016) findings and the differences between the Dutch universal quantifiers, we predicted that priming emerges between *elke* and *elke* (within-quantifier condition) and possibly between *iedere* and *elke* (which, as near-synonyms, likely have similar scope-taking properties), but not between *alle* and *elke* (which we assumed to have different scope-taking properties, similar to *every* and *all* in English).

To foreshadow the results, these predictions were not borne out. In Experiment 1, we manipulated the quantifiers in the prime sentences between-participants (following Feiman & Snedeker, 2016). This experiment revealed priming from *elke* to *elke* but also from *alle* to *elke*. We further tested these findings in Experiment 2, but this time in a full within-participants design. This experiment showed clear priming within and between quantifiers, with no difference in magnitude of priming. Experiments 1 and 2 suggest that logical representations are not quantifier-specific, but the extent of between-quantifier priming seems to vary with design-related factors.

We conducted two further experiments with the aim of pinpointing these design-related factors in between-quantifier priming. In Experiment 3, we tested whether priming between quantifiers is dependent on the presence of a within-quantifier condition (inspired by Muylle et al., 2021, who found an analogous effect in syntactic priming). We manipulated the presence of a within-quantifier condition (in addition to between-quantifier conditions) in this experiment. The results indicated that between-quantifier priming also emerged if the participants are not exposed to a within-quantifier condition. This suggests that priming between quantifiers emerges if the participant is presented with a diversity of prime types regardless of whether these are within- or between-quantifier conditions (see also Savage et al., 2006). We tested the hypothesis that priming between quantifiers depends on diversity in the prime trials in Experiment 4. This experiment varied the number of between-quantifier conditions (one or two) between participants, and revealed between-quantifier priming in both cases.

[2] This experiment was intended as a monolingual control for a cross-language priming experiment involving the Dutch quantifiers *iedere* and *elke* and their approximate English translation equivalents *each* and *every*; pre-registered here: https://osf.io/s84bv/registrations. In this pre-registration, we registered multiple experiments at once, but we ultimately only carried out only one of these (i.e., Experiment 1 in this paper, pre-registered as Experiment 2 in the pre-registration). To maintain transparency about our original study aims, we chose to keep all experiments in the initial pre-registration and created additional pre-registrations for Experiments 2–4.

Experiment 1: Prime quantifier manipulated between participants

Methods

Participants

We recruited 218 native speakers of Dutch to participate in Experiment 1. They were first-year psychology students at Ghent University, and received course credit for their participation. Thirty participants were removed, either because they selected the wrong response in more than 10% of the filler trials (1 participant), suggesting insufficient attention to sentence meaning, or because they guessed the goal of the experiment in a post-experimental debriefing (27 participants; more below). The final analysis therefore included 190 participants.

Materials

The stimuli were adapted from Slim et al. (2021), who in turn adapted some of their stimuli from Raffray and Pickering (2010). The materials from Raffray and Pickerings were also used in Feiman and Snedeker (2016). A list of the critical test sentences is provided in Appendix A in the Supplementary Materials (available at https://osf.io/s84bv/). A full list of sentences and the visual materials are available at https://osf.io/s84bv/. The experiment contained 54 prime trials, 54 target trials, and 162 filler trials. All trials consisted of a Dutch sentence and two pictures. In the prime trials, this sentence was a doubly quantified scopally ambiguous sentence (e.g., *Alle beren naderden een tent*, 'All bears approached a tent'). One of the two response pictures in the prime trials corresponded to one of the possible interpretations of the sentence, whereas the other response picture was a foil picture that matched neither interpretation of the sentence (either because the subject or the object noun mismatched that picture; Fig. 1).

Similar to the prime trials, the target trials contained a scopally ambiguous doubly quantified sentence (e.g., *Elke kat naderde een hut*, 'Every cat approached a shed'). The two response pictures in the targets displayed the two possible interpretations of the sentence: One picture corresponded to the universal-wide interpretation, whereas the other picture corresponded to the existential-wide interpretation of the sentences. Thus, the prime trials forced the participants to assign one of the two interpretations to the sentences, whereas the participants had a free choice between the two interpretations in the target trials. The prime and target trials were organised in sets: Each target trial was directly preceded by a prime trial (Fig. 1).

The prime trials were presented in two prime conditions, which were manipulated within-participants: the *universal-wide* and the *existential-wide* condition. In the universal-wide condition, the matching picture corresponded to the universal-wide interpretation (in which all bears approached different tents) of the sentence. In the existential-wide condition, the matching picture corresponded to the existential-wide interpretation of the sentence (in which all bears approached the same tent; Fig. 1). The prime sentences contained the universal quantifier *alle* ('all'), *elke* ('every'), or *iedere* ('every') in the subject position. The target trials, however, contained *elke* ('every') in all conditions. The prime quantifier was manipulated between-participants (following Feiman & Snedeker, 2016). Analyses included 64, 64, and 62 participants in the *elke*, *iedere*, and *alle* conditions respectively.

Filler trials all contained unambiguous sentences. Half of these filler sentences was transitive (e.g., *The cowboy punched the burglar*), and the other half was intransitive (e.g., *All witches slept*). These filler sentences were paired with one matching picture and one mismatching picture. The intransitive filler sentences contained a quantifier in the subject phrase. This quantifier matched the Prime Quantifier condition in half of the intransitive fillers and the target quantifier *elke* in the other half of the intransitive fillers.

Prime and target trials were organised in sets: Each target trial was immediately preceded by a prime trial. The verb in the prime-target sets was held constant, which is similar to Feiman and Snedeker's (2016)

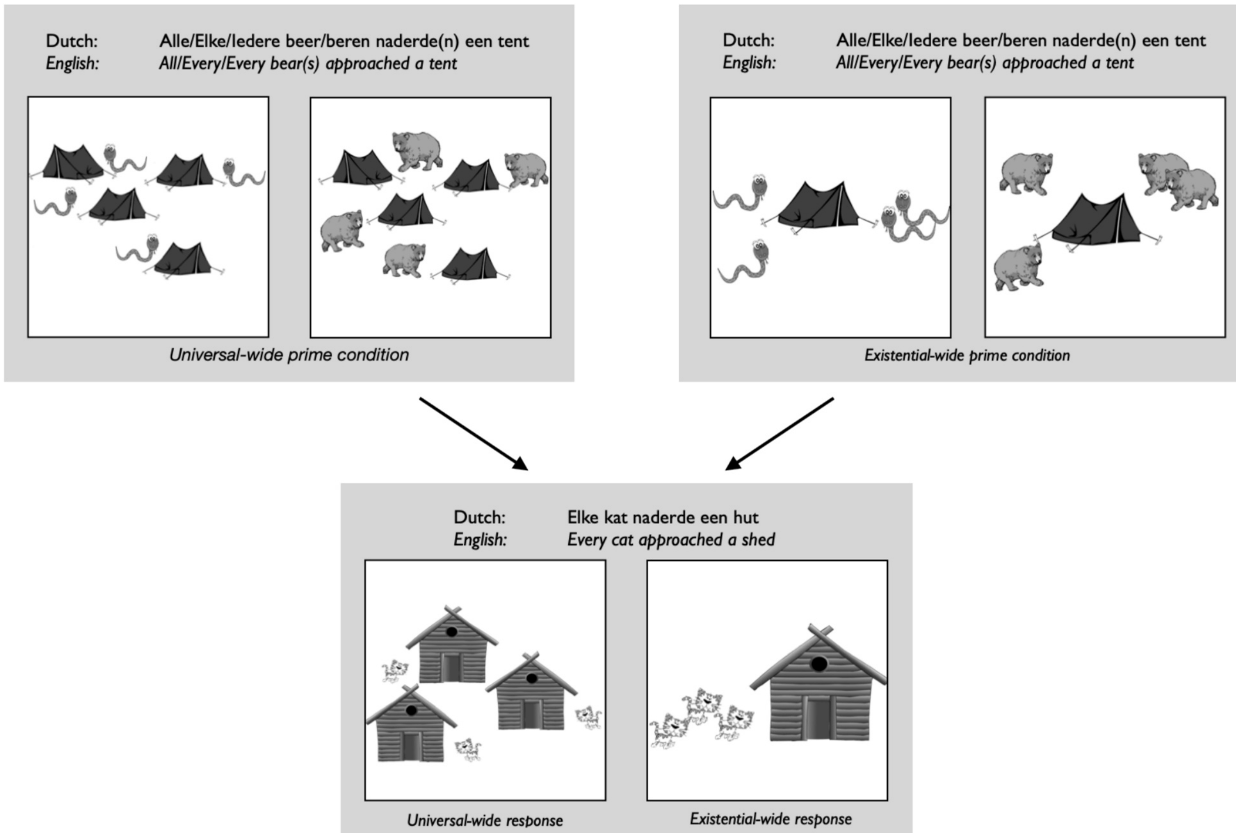

Fig. 1. Example of the prime-target procedure in the experiment. The target trials were always immediately preceded by prime trials. The labels *Universal-wide/Existential-wide prime condition*, and *Universal-wide/Existential-wide response* are added for ease of illustration and were not shown to the participants. We added English translations to the figure for the sake of illustration.

experiment that tested priming within and between quantifiers (and this also follows Raffray & Pickering, 2010). Verb repetition has been shown to increase effects of priming in research on structural priming in language production and comprehension (Branigan et al., 2005; Slim et al., 2023), and repeating the verb may therefore maximise the chances to find priming (but see, Feiman & Snedeker, 2016, Experiment 3, for verb-independent logical representation priming). Prime-target sets were intervened by two to five filler trials (also following Feiman & Snedeker, 2016; Raffray & Pickering, 2010). In all Prime Quantifier conditions, we created two lists of trials in the pseudo-randomised order as described above. Moreover, the prime trials were counterbalanced between prime conditions between participants, and the positions of the two pictures was determined at random in each trial.

Procedure

The experiment was implemented and conducted online using PennController for Ibex (PCIbex), a `javascript`-based library for programming web-based experiments (Zehr & Schwarz, 2018). In all trials, the sentence and two pictures were shown simultaneously on the computer screen. Before the task, participants were instructed to select the picture that best fitted the sentence and to select their spontaneous preference if they thought that both pictures corresponded to the sentence. After selecting one of the two pictures with their computer mouse, the next trial began automatically. Once the sentence-picture matching task was completed, the participants filled in a short questionnaire regarding their language background. Finally, the participants were presented with a question that asked whether the participant had any ideas about the purpose and manipulations of the experiment. This was a single question ("Do you have any ideas what this experiment tried to test? Please try to describe your ideas about the goal of this experiment."), which had to be filled in before the participant could proceed. Those who guessed the goal of the experiment were removed from further analyses: Participants were excluded if they described the pattern of the trials (prime-target), and/or guessed that the experiment examined the possible influence from the preceding trial on the target trials.

Analyses and results

Predictions

Experiment 1 tested the hypothesis that logical representations are differentiated according to quantifier-specific scope-taking mechanisms, which presupposes that scope is represented in a quantifier-specific way at logical representations (Feiman & Snedeker, 2016). If this is correct, then it is predicted that priming emerges if the prime and the target contain the same quantifiers, and no priming if the prime and target sentence contain different quantifiers.

Therefore, we predict at least priming in the *elke-elke* condition that is stronger than priming in the *alle-elke* condition. Like the English quantifiers *every* and *all*, the Dutch quantifiers *elke* and *alle* have different scope-taking tendencies (Ioup, 1975). Based on Feiman and Snedeker's (2016) findings, these quantifiers are therefore assumed to be mapped onto distinct scope-taking mechanisms. In addition, priming in the *elke-elke* condition may be similar to priming in the *iedere-elke* condition, since *iedere* and *elke*—as near-synonyms—likely have similar scope-taking properties. However, this latter prediction is more exploratory.

Data treatment and analyses procedure

Target responses were discarded if the participant selected the incorrect picture in the preceding prime trial (following Raffray & Pickering, 2010), as the participants may not have constructed the logical representation that the prime was meant to elicit. See Appendix B in the Supplementary Materials for an overview of the number of removed trials from this experiment and all further experiments in this paper (available at https://osf.io/s84bv/). The remaining responses were coded as `true` if the universal-wide response was selected, and `false` if the existential-wide response was selected.

The data were analysed by modelling response-type likelihood using logit mixed-effect models (Jaeger, 2008). The model included the binary target response type as the dependent variable and Prime Condition (*universal-wide* and *existential-wide*) and Prime Quantifier (*elke*, *iedere*, and *alle*), and their interaction term as predictor variables.

All predictors were sum coded. The random-effects structure was maximal: It included random intercepts by Participant and Item, and a random slope of Prime Condition by Participant (we did not include a random by-Participant slope for Prime Quantifier, because Prime Quantifier was manipulated between participants; Barr et al., 2013). If this model did not converge, or if we obtained a singular fit, then the random effects structure was simplified by dropping random slopes until the model converged (Bates et al., 2015).

All analyses were carried out in `R` (Version 4.2.3; R Core Team, 2019). First, we constructed an omnibus full model using the `glmer()` function of the `lme4` package (Bates et al., 2014). We obtained *p*-values by conducting Type III Wald χ^2 likelihood ratio tests to compare the full model with models in which the relevant predictor terms were removed (using the `Anova()` function of the car package, Fox et al., 2012). Post-hoc interaction analyses were carried out to test for differences in the effect of Prime Condition between the multiple levels of the Prime Quantifier variable. These pairwise comparisons were χ^2 tests conducted using the `testInteractions()` function from the `phia` package (De Rosario-Martinez, 2015).

Results

As expected based on the inherent biases of *elke* (Ioup, 1975), the results show a strong bias toward the universal-wide reading of the target sentences: 78.10% of all target responses are universal-wide. Moreover, there was a numerical difference between the responses in the universal-wide and those in the existential-wide Prime Condition in all three Prime Quantifier conditions. This difference was in the direction of the predicted priming effect in all cases: The effect was 8.28 % in the *elke-elke* condition, of 2.88% in the *iedere-elke* condition, and of 2.33% in the *alle-elke* condition (Fig. 2).

The analysis revealed a main effect of Prime Condition ($\chi^2(1)$ =

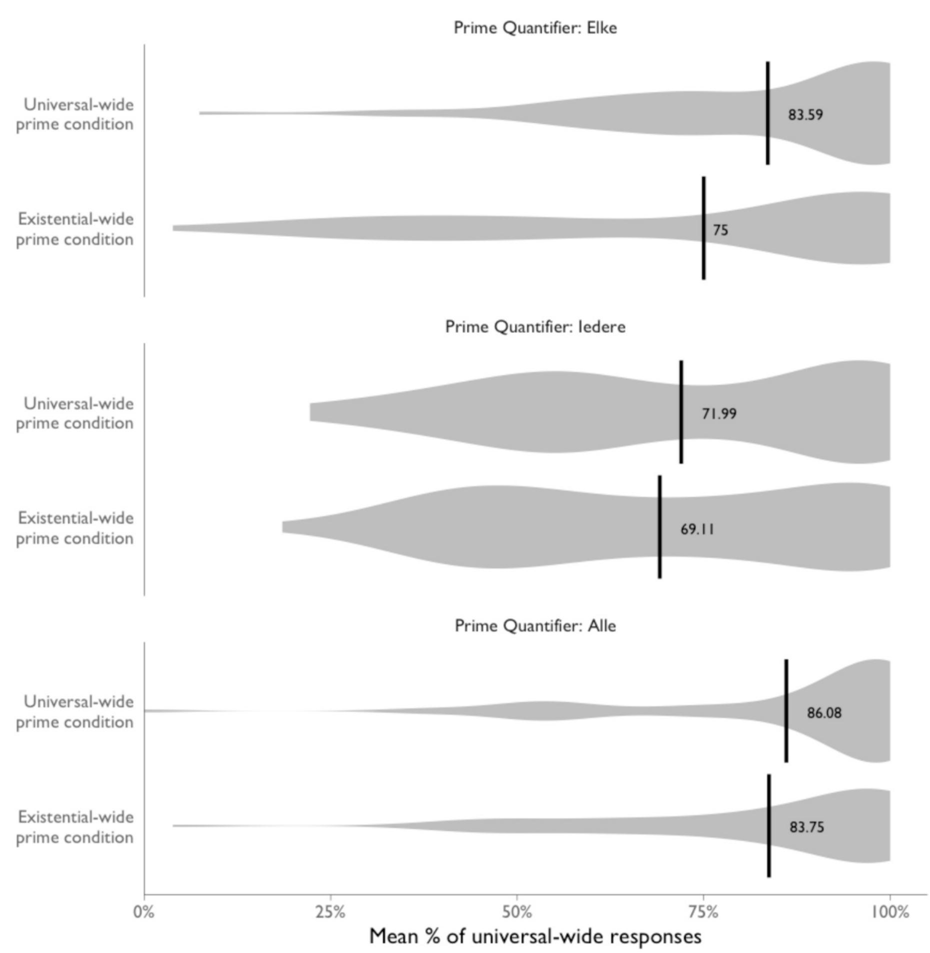

Fig. 2. The participants' mean percentage of universal-wide responses on the target trials in the Experiment 1. Note that the target sentences all contained *elke*. The black vertical lines represent the overall mean response rate, and the width of the outlined area represents the proportion of the data located at that point.

13.02, $p < 0.001$) and of Prime Quantifier ($\chi^2(2) = 12.31$, $p = 0.002$). Moreover, the interaction between Prime Condition and Prime Quantifier was significant ($\chi^2(2) = 10.68$, $p = 0.005$). The planned post-hoc pairwise comparisons on the interaction term revealed a significant effect of Prime Condition in the *elke-elke* condition ($\chi^2(1) = 18.55$, $p < 0.001$) and in the *alle-elke* condition ($\chi^2(1) = 6.10$, $p = 0.027$), but the effect in the *iedere-elke* condition did not reach the conventional level of significance ($\chi^2(1) = 1.34$, $p = 0.247$).

Additional pairwise comparisons revealed that the effect of Prime Condition was stronger in the *elke-elke* condition compared to the *iedere-elke* condition ($\chi^2(1) = 10.58$, $p = 0.003$), but not in the *elke-elke* condition compared to the *alle-elke* condition ($\chi^2(1) = 2.86$, $p = 0.181$) or in the *iedere-elke* condition compared to the *alle-elke* condition ($\chi^2(1) = 1.43$, $p = 0.232$). Thus, these analyses only revealed that priming was stronger in the *elke-elke* condition compared to the *iedere-elke* condition and no differences in strength of priming in the other conditions.

Discussion

Descriptively, the results of Experiment 1 were comparable to those of Feiman and Snedeker (2016, Experiment 2). The numerical effect was larger in the within-quantifier *elke-elke* condition than in the between-quantifier *iedere-elke* and *alle-elke* conditions: In the *elke-elke* condition, the differences between the universal-wide response choice in both prime conditions was roughly 8% (which is very similar to the effects observed by Feiman and Snedeker (2016) and other studies that showed logical representation priming (Raffray & Pickering, 2010; Slim et al., 2021)), whereas this difference was closer to 2.5% in the *iedere-elke* and *alle-elke* conditions. This descriptive pattern does not suggest considerable priming from *iedere* to *elke*, in contrast to our expectations, which were based on the semantic similarities between these two quantifiers. Possibly, there is a larger difference in the scope-taking properties of *elke* and *iedere* than we initially assumed.

However, the statistical analyses revealed that the descriptive pattern of results was not reliable: Our analysis showed that priming in the *elke-elke* condition was stronger than priming in the *iedere-elke* condition, but the analysis did not give evidence that priming in the *elke-elke* condition was stronger than priming in the *alle-elke* condition. This was unexpected based on our pre-defined hypothesis that distinct scope-taking mechanisms are mapped onto different quantifier words, because *elke* and *alle* have different scope behaviours (Ioup, 1975). Moreover, this finding seems still open to doubt: The significant priming effect in the *alle* condition was small and descriptively similar to the non-significant effect in the *iedere* condition

In addition, our analyses also revealed an effect of Prime Quantifier on the target response choice. We did not predefine any predictions about this effect. However, the effect suggests that the quantifiers in the prime trials influenced the overall target response choices (independent of the scope assignment in the preceding prime trial). Specifically, participants in the *alle* condition selected most universal-wide responses, followed by the participants in the *elke* and *iedere* conditions. This finding can perhaps be explained in terms of *adaptive learning*: The quantifiers *elke* and *iedere* are both biased to the universal-wide interpretation. In the prime sentences, however, they are forced to alternate between the universal-wide and the existential-wide interpretations. This exposure to the non-preferred interpretation of the prime sentences may have weakened the universal-wide bias of the prime sentences because people adapt their expectations (Jaeger & Snider, 2013; Myslín & Levy, 2016; Yildirim et al., 2016). This weakening of the bias, in turn, could have affected the responses on the targets (independent from the trial-by-trial priming effects). In the case of *iedere*, this effect might generalise to the interpretation of *elke* (again, independent from trial-by-trial priming; see the supplementary materials from Feiman &Snedeker, 2016, for similar findings in the interpretation of *each* and *every* in English). The quantifier *alle*, however, is not as strongly biased towards the universal-wide or existential-wide reading (see Slim et al., 2021). Therefore, people do not have any strong biases to adjust in the prime sentences of the *alle* condition, which is why the overall responses on the targets are closer to baseline.

The effect of Prime Quantifier is complementary to our research purposes: Most important to our present purposes is that the results regarding priming between quantifiers of Experiment 1 do not paint a clear picture about the role of quantifier overlap in logical representation priming. We observed the predicted within-quantifier priming from *elke* to *elke*, but our analysis also showed a between-quantifier priming effect from *alle* to *elke* and no between-quantifier priming effect from *iedere* to *elke*. In Experiment 2, we further tested priming between quantifiers by conducting a conceptual replication of Experiment 1. This experiment contained the same manipulations of Prime Condition and Prime Quantifier but now manipulated both variables within participants. This way, we aimed to increase the statistical power of this experiment (e.g., Bellemare et al., 2014).

Experiment 2: Prime quantifier manipulated within participants

Method

Participants

Participants were 216 further native speakers of Dutch. Of these participants, 194 were recruited among the first-year psychology students at Ghent University, and received course credit for their participation. The other 22 participants were recruited via the Prolific platform and received compensation for their participation (£4.50). Both groups of participants were directed to the same online experiment. We excluded 6 participants because they answered more than 10% of the filler trials incorrectly and 30 participants because they guessed the goal of the experiment. Thus, 180 participants were included in the final analyses.

Materials

The materials were similar to those of Experiment 1. Now, however, both Prime Condition and Prime Quantifier were manipulated within participants. In order to counterbalance Prime Condition and Prime Quantifier across trials in this within-participants design, we constructed six lists of trials. The trials were differently ordered in each list, following the same randomisation restrictions as in Experiment 1. Another deviation from Experiment 1 is that the intransitive filler sentences contained the quantifier *elke* (in 1/3rd of the intransitive fillers), *iedere* (in 1/3rd of the intransitive fillers), and *alle* (in 1/3rd of the intransitive fillers) in all six lists. This way, the participants were exposed to the quantifiers *elke*, *iedere*, and *alle* equally often.

Procedure

The procedure was identical to that of Experiment 1. Like Experiment 1, this experiment was carried out online using PCIbex. Participants were distributed over the six lists based on their order of participation: The first list was presented to the first participant, the second list to the second participant, and so on.

Analyses and results

Predictions

Experiment 2 tested the same hypothesis and predictions as Experiment 1, but now in a more sensitive within-participants design. Based on

Feiman and Snedeker's (2016) findings, we assumed that quantifier words instantiate quantifier-specific scope-taking mechanisms that are represented in logical representations. Based on this hypothesis, we predicted priming in the *elke-elke* condition but not in the *iedere-elke* or *alle-elke* conditions.

However, Experiment 1 showed that priming may emerge between quantifiers. This contradicts Feiman and Snedeker's (2016) description of logical representations, and suggests that scope assignment is represented in a non-quantifier-specific way. If this hypothesis is correct, then priming is predicted to emerge in the *elke-elke, iedere-elke* and *alle-elke* conditions with no differences in the size of the effect.

Note that we have relaxed our predictions about priming from *iedere* onto *elke*. In Experiment 1, we predicted that priming from *iedere* onto *elke* may emerge because these quantifiers may share their scope-taking properties (e.g., Haeseryn et al., 1997). However, Experiment 1 did not provide any evidence for such an effect. Therefore, we now formulate our predictions more general in terms of whether priming emerges between quantifiers.

Data treatment and analysis procedure

The data treatment and analysis procedure were similar to those in Experiment 1. The only difference is that our full model also contained a random slope of Prime Quantifier by participants, because Prime Quantifier was now manipulated within participants (Barr et al., 2013).

Results

Like in Experiment 1, the participants mostly selected the universal-wide response picture in target sentences (i.e., in 75.62% of the target trials). Moreover, across the three Prime Quantifier conditions, the universal-wide response was selected more often following a universal-wide prime trial than following an existential-wide prime trial (Fig. 3; this difference was 7.78% in the *elke-elke* condition; 6.35% in the *iedere-elke* condition, and 7.23% in the *alle-elke* condition).

The analysis revealed a main effect of Prime Condition ($\chi^2(1) = 34.39$, $p < 0.001$) but not of Prime Quantifier ($\chi^2(2) = 0.01$, $p = 0.995$). There was no interaction ($\chi^2(2) = 0.44$, $p = 0.803$). Planned post-hoc analyses revealed that this main effect of Prime Condition was significant in all three Prime Quantifier conditions (*elke-elke*: $\chi^2(1) = 18.55$, $p < 0.001$, *iedere-elke*: $\chi^2(1) = 22.79$, $p < 0.001$, *alle-elke*: $\chi^2(1) = 11.57$, p

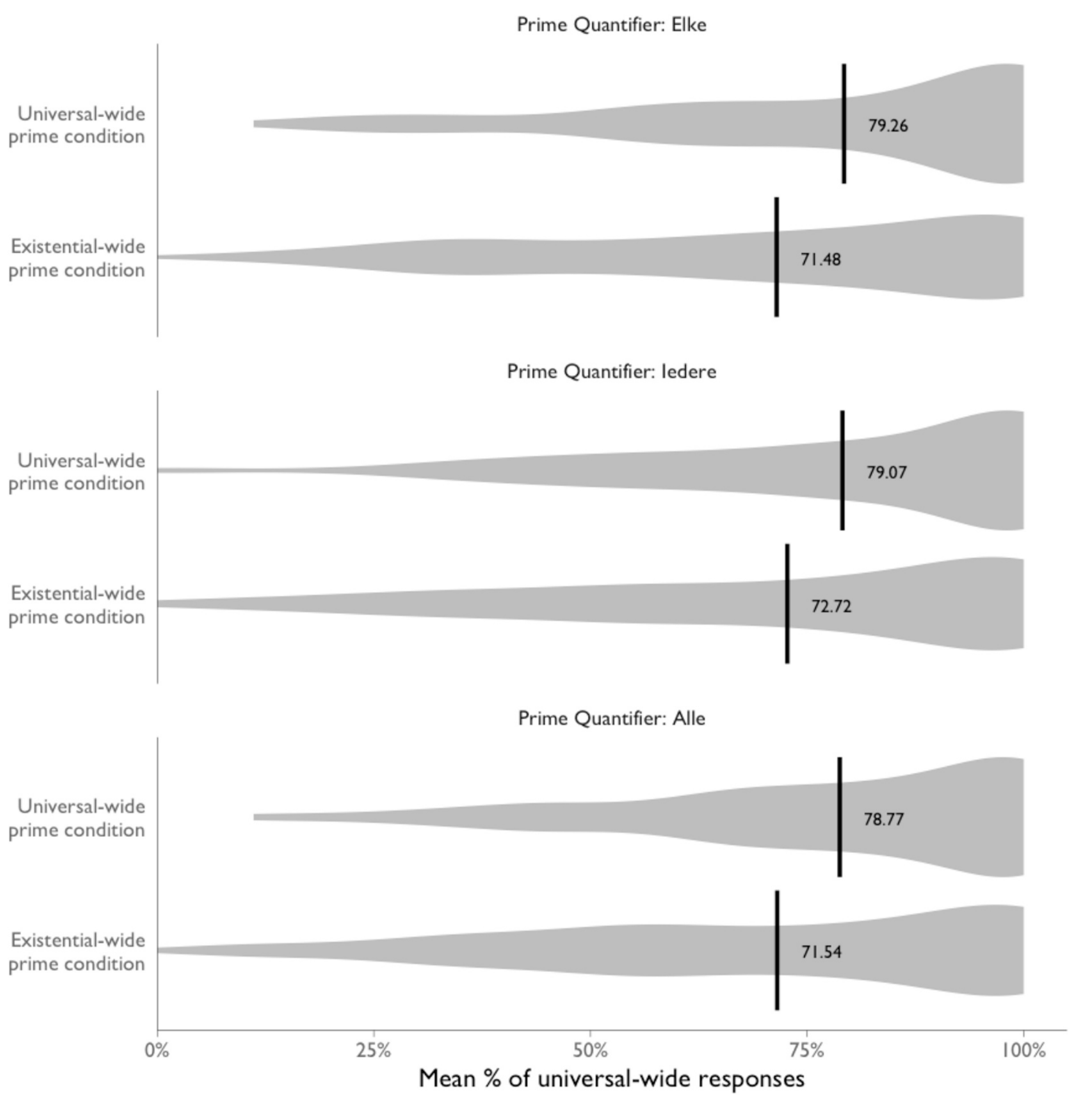

Fig. 3. The participants' mean percentage of universal-wide responses on the target trials in Experiment 2. The black vertical lines represent the overall mean response rate, and the width of the outlined area represents the proportion of the data located at that point.

< 0.001), and that the effect of Prime Condition was comparable in all three Prime Quantifier conditions (*elke* vs. *iedere*: $\chi^2(1) = 0.48$, $p = 0.999$, *elke* vs. *alle*: $\chi^2(1) = 0.47$, $p = 0.999$, *iedere* vs. *alle*: $\chi^2(1) = 0.51$, $p = 0.999$).

Discussion

Experiment 2 revealed priming in the *elke-elke, iedere-elke*, and the *alle-elke* conditions, with no significant difference in the size of priming across these three conditions. These results indicate that priming within the same quantifier is comparable to priming between quantifiers. This finding does not support the hypothesis that logical representations capture quantifier-specific lexical properties that specify scope assignment. In addition, these results differed from those of Experiment 1, which did show differences in priming across the three Prime Quantifier conditions. Experiments 1 and 2 only differed in design: Both Prime Quantifier and Prime Condition were manipulated within participants in Experiment 2, whereas Prime Quantifier was manipulated between participants in Experiment 1 (following Feiman & Snedeker, 2016).

We did not expect any influence of experimental design on the pattern of priming, given our predefined hypotheses. One possibility is that between-quantifier priming is modulated by the presence or absence of a within-quantifier condition. In a within-quantifier condition, like the *elke-elke* condition in our experiments, the participants are explicitly exposed to both possible interpretations of the target sentence in the prime trials. In these prime trials, the participants can (implicitly) learn that both possible interpretations of the target sentences are acceptable. This could lower the threshold to compute the dispreferred interpretation of the target sentences, leading participants to alternate between both target interpretations. Once this bias for a particular interpretation of the target sentence is lowered sufficiently, priming may emerge both within and between quantifiers (as previously hypothesised in a study on syntactic priming, Muylle et al., 2021).

This hypothesis explains the discrepancy between Experiment 1 and Experiment 2. In the between-participants design of Experiment 1, only a third of the participants were explicitly exposed to the dispreferred interpretation of the target sentence (*viz*. those in the *elke-elke* condition). In Experiment 2, however, all participants were explicitly exposed to the dispreferred interpretation of the target sentences in a sixth of the prime trials (in existential-wide prime condition of the *elke-elke* trials). We tested the hypothesis that priming between quantifiers only emerges if the participant is also presented with a within-quantifier condition in Experiment 3. In this experiment, we manipulated the presence of a within-quantifier condition (*elke-elke*) between experimental blocks.

Experiment 3: Prime quantifier manipulated between blocks

Method

Participants

We recruited 274 further native speakers of Dutch via Prolific to participate in Experiment 3. All participants were paid £4.50 for their participation. We removed 5 participants because they answered more than 10% of the filler trials incorrectly, and 14 further participants because they guessed the goal of the experiment in the post-experimental debriefing question. So, a total of 255 participants were included in the analyses, which was our predefined sample size, so that each cell in our design would have a similar number of observations as in Experiments 1 and 2.

Materials

The materials were similar to those used in Experiments 1 and 2. Like in the previous experiments, the target sentence always contained the universal quantifier *elke*, whereas the universal quantifier in the prime sentence differed across *elke*, *iedere*, and *alle*. Unlike the previous experiments, however, Experiment 3 was divided into two blocks: the *exclusive-elke* and the *inclusive-elke* block. In the *exclusive-elke* block, the prime trials were only presented in the *iedere* and in the *alle* prime quantifier conditions. This block contained 20 prime-target sets, which were evenly distributed among the prime quantifier conditions (*iedere* and alle) and prime conditions (*existential-wide* and *universal-wide*). In the *inclusive-elke* block, the prime trials were presented in all three prime quantifier conditions (*elke*, *iedere*, and *alle*). This block contained 30 prime-target pairs, which were again evenly distributed among the prime quantifier conditions and prime conditions. We varied the order of these two blocks across participants.

A minor difference between this experiment and the previous two experiments is that this experiment contained four prime-target sets fewer than the previous two experiments (50 instead of 54). This number of trials allows for an even distribution of the trials among the conditions in this experiment. Consequently, Experiment 3 also contained fewer filler items than Experiments 1–2, namely 150 instead of 162. This way, the ratio of prime-targets and fillers remained equal across the experiments. We raised the number of participants of Experiment 3 compared to Experiments 1–2, in order to keep the number of collected observations similar across experiments.

We constructed 10 lists in which Prime Condition, Prime Quantifier, and Block were counterbalanced across trials. The trials were organised in the same pseudo-randomised fashion as in the previous experiments, and the trials were uniquely randomised in each list. Prime Quantifier, Prime Condition, and Block were manipulated within participants. The order of the two blocks, however, was manipulated between participants ($n = 127$ in the *inclusive-elke first* and $n = 128$ *inclusive-elke second* conditions).

Procedure

The procedure was similar to Experiments 1–2. Participants were evenly distributed between both block order conditions based on their order of participation. There was no pause or any other type of obvious transition from the first block onto the second block. The rest of the procedure of Experiment 3 was identical to that of Experiments 1–2.

Analyses and results

Predictions

This experiment tested the hypothesis that priming between quantifiers only emerges if the participant is presented with between-quantifier conditions and a within-quantifier condition. Based on this hypothesis, we firstly predict that priming emerges in the *inclusive-elke* block regardless of the order in which the blocks are presented, because the participants are presented with both between-quantifier and within-quantifier conditions (similar to Experiment 2).

Secondly, we predict that priming in the *exclusive-elke* block is modulated by the order in which the two blocks are presented to the participant. If the participant is presented with the *exclusive-elke* block first, then we do not predict priming in this block because the participant has not been presented with a within-quantifier condition yet. If, however, the *exclusive-elke* block is presented second, then we do expect to find priming here, because the participant has been presented with within-quantifier condition in the first part of the experiment in this case (and therefore the bias towards the dispreferred interpretation of the target sentence has already been weakened sufficiently to elicit priming between quantifiers; Fig. 4).

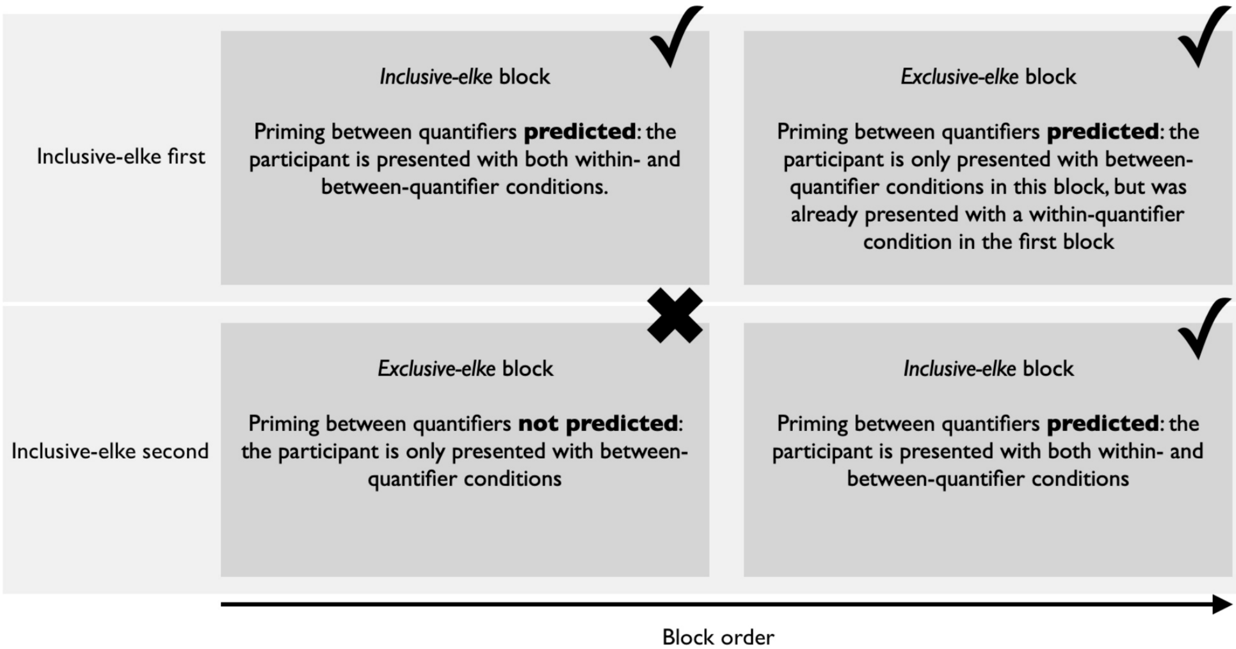

Fig. 4. Schematic overview of the predictions in Experiment 3. The two rows represent both possible orderings of the blocks, and the two columns represent those blocks. The check marks and cross indicate where priming between quantifiers is predicted.

Data treatment and analyses procedure

Like in Experiments 1–2, we modelled response-type likelihood using logit mixed-effect models. Unlike Experiments 1–2, we are not only interested in the effects of Prime Condition and the interaction between Prime Condition and Prime Quantifier, but also in the effects and interactions of the Block (*exclusive-elke* and *inclusive-elke*) and Block Order (*exclusive-elke first* or *exclusive-elke second*) variables.

The addition of these variables complicated the design of this experiment relative to those of Experiments 1–2. This led to two issues in our analyses. First, the levels of the Prime Quantifier variable were not the same between the two levels of the Block variable (the *inclusive-elke* block contained three Prime Quantifier levels, whereas the *exclusive-elke* block only contained two Prime Quantifier levels). Second, we were interested in interactions among four predictor variables (Prime Condition, Prime Quantifier, Block, and Block Order), which makes the omnibus model that includes all these variables very complex.

To tackle these issues, we carried out our analyses in two parts. First, we analysed whether the effect of Prime Condition was modulated by Block and an interaction between Block and Block Order. We conducted this analysis by constructing a logit mixed-effect model with Prime Condition, Block, and Block Order as (sum-coded) predictor variables (together with their interaction terms). We excluded the data from the *elke-elke* condition, so the design of both blocks was balanced. Second, we tested whether Prime Quantifier and Block Order modulated the effect of Prime Condition. We therefore constructed another model that contained Prime Condition, Prime Quantifier, and Block Order as predictor variables (again, together with their interaction terms). This model was run on the data of each Block separately.

Finally, similar to the previous two experiments reported in this paper, we calculated *p*-values by running Wald χ^2 tests on the model, in which the full model was compared to reduced models in which the predictors and interaction terms were omitted.

Results

Descriptively, priming seemed to emerge in all conditions of Experiment 3 (Fig. 5): The universal-wide response was selected more often after a universal-wide prime than after an existential-wide prime in all Prime Quantifier, Block, and Block Order configurations.

Our first analysis tested the main effects of Prime Condition, Block, and Block order, as well as their interaction terms. This analysis showed a main effect of Prime Condition ($\chi^2(1) = 22.99$, $p < 0.001$) and no main effects of Block Order ($\chi^2(1) = 0.95$, $p = 0.330$), or Block ($\chi^2(1) = 0.86$, $p = 0.354$). The only significant interaction was the two-way interaction between Block and Block Order ($\chi^2(1) = 21.83$, $p < 0.001$; more in the following subsection). No other interactions were significant (Prime Condition x Block ($\chi^2(1) = 1.08$, $p = 0.301$); Prime Condition x Block Order ($\chi^2(1) = 0.47$, $p = 0.492$); Prime Condition x Block x Block Order ($\chi^2(1) = 0.36$, $p = 0.547$).

In our second analysis, we tested per block whether the results were modulated by Prime Condition, Prime Quantifier, and Block Order for each block separately. The analysis of the *inclusive-elke* block showed a significant main effect of Prime Condition ($\chi^2(1) = 24.40$, $p < 0.001$). No other main effects were significant (Prime Quantifier: $\chi^2(2) = 0.02$, $p = 0.989$; Block Order: $\chi^2(1) = 1.91$, $p = 0.167$), and neither were any of the interaction terms (two-way: Prime Quantifier x Block Order: $\chi^2(2) = 1.41$, $p = 0.495$; Prime Condition x Block Order: $\chi^2(1) = 0.27$, $p = 0.601$; Prime Condition x Prime Quantifier: $\chi^2(2) = 0.58$, $p = 0.749$; three-way: Prime Condition x Prime Quantifier x Block Order: $\chi^2(2) = 0.35$, $p = 0.838$).

The analysis of the *exclusive-elke* block showed a similar pattern: There was a main effect of Prime Condition ($\chi^2(1) = 24.40$, $p < 0.001$), but no main effects of Block Order ($\chi^2(1) = 1.91$, $p = 0.167$) or Prime Quantifier ($\chi^2(1) = 0.02$, $p = 0.989$). In addition, none of the possible interactions between Prime Condition, Prime Quantifier, or Block Order significantly improved the model (three-way: $\chi^2(2) = 0.35$, $p = 0.838$; two-way Prime Quantifier x Block Order: $\chi^2(2) = 1.41$, $p = 0.495$; two-

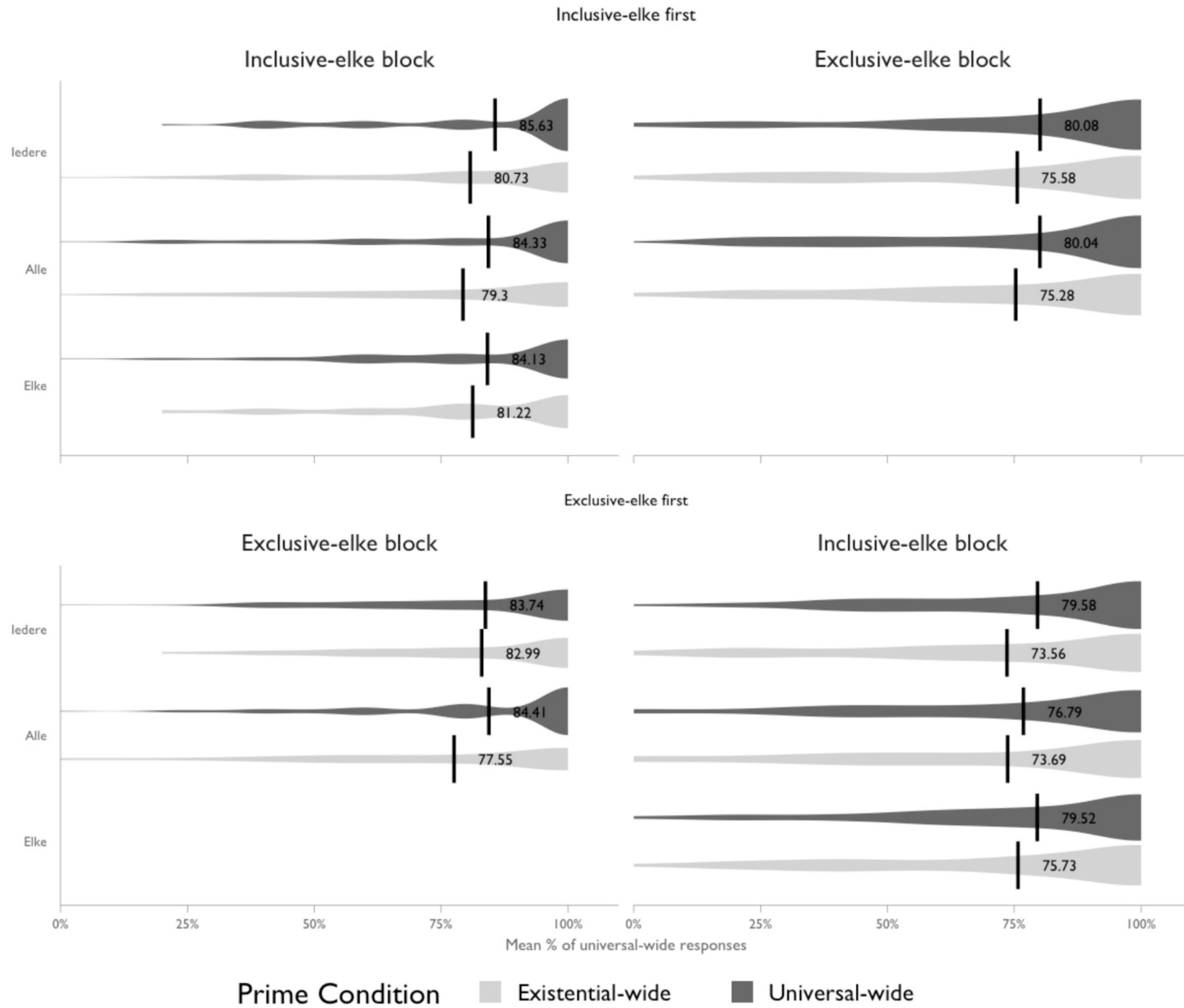

Fig. 5. The participants' mean percentage of universal-wide responses on the target trials in all conditions of Experiment 3. The black vertical lines represent the overall mean response rate. The width of the outlined area represents the proportion of the data located at that point.

way Prime Condition x Block Order: $\chi^2(1) = 0.27$, $p = 0.601$; two-way Prime Condition x Prime Quantifier: $\chi^2(2) = 0.58$, $p = 0.750$).

Discussion

Experiment 3 tested whether priming between quantifiers depends on the presence of a within-quantifier condition. This was not the case. Firstly, there was priming both between and within quantifiers (with no difference in the strength of priming), and between-quantifier priming was not modulated by the Block or Block Order variables. These null effects show that priming between quantifiers emerged regardless of whether the participant had been exposed to a within-quantifier condition. Secondly, our analyses also revealed that priming was not modulated by effects of Prime Quantifier or Block Order.

The analyses of Experiment 3 also revealed an interaction between Block and Block Order: Participants selected the universal-wide response more often in the *exclusive-elke* block if the *exclusive-elke* block was presented first and in the *inclusive-elke* block if the *exclusive-elke* block was presented second. In other words, the participants selected the universal-wide response more often in the first than in the second block of the experiment, regardless of whether that second block was the *exclusive-elke* or *inclusive-elke* block. This latter finding can be explained in terms of *adaptive learning*, as also mentioned in the Discussion of Experiment 1: Throughout the experiment, the participants are exposed to both the universal-wide and the existential-wide interpretations in the prime sentences. This may weaken the bias for the universal-wide reading of the target sentences as well, leading to more alternations in the target responses in the second half than in the first half of the experiment (e.g., Jaeger & Snider, 2013; Yildirim et al., 2016; see also Feiman & Snedeker, 2016, supplement materials).

Taken together, Experiment 3 showed priming of logical representations across the board: Both within- and between quantifiers, regardless of whether the participant was also exposed to a within-quantifier condition. In light of the full set of experiments reported here, it seems that between-quantifier priming emerges if the participants are exposed to multiple quantifiers in the prime trials (also if those are multiple between-quantifier conditions, like in the *exclusive-elke* block of this experiment). This suggests that diversity in the prime trials aids participants to generalise over quantifiers in the construction of logical representations, perhaps because the lexical variation across prime types facilitates the detection of the common logical structure underlying different universal quantifiers (a point we will return to in the General Discussion; for similar effects in children, see Savage et al., 2006).

We tested this hypothesis in Experiment 4. In Experiment 4, we only tested between quantifier priming. Half of the participants was only presented with the *iedere-elke* condition (which is essentially a replication of the *iedere-elke* condition of Experiment 1). The other half of the participants, however, was presented with both the *iedere-elke* and the *alle-elke* conditions. If priming between quantifiers depends on the presentation of multiple prime quantifier conditions, then priming is expected to be stronger for participants that are presented with both the *iedere-elke* and *alle-elke* conditions than for the participants that are only presented the *iedere-elke* condition.

Experiment 4: The role of diversity in the primes

Method

Participants

We recruited 154 native speakers of Dutch to participate in Experiment 4 on Prolific. They were paid for their participation (£4.50). Six of these participants were excluded because they gave the incorrect response to more than 10% of the filler trials, and seven further participants were removed because they guessed the aim of the experiment in a post-experimental debriefing question. So, a total of 140 participants were included in the analysis. This was our predefined sample size, so we collected a similar number of observations in each cell in the design as in the previous experiments.

Materials

The materials of Experiment 4 were similar to those used in Experiments 1–3. The target sentences were doubly-quantified sentences with *elke* in subject position and *een* in object position. The universal quantifier in the prime sentence varied between *iedere* and *alle*. Unlike the previous experiments, however, the number of prime quantifiers presented to the participants varied: In the single-quantifier condition, the participants ($n = 70$) were only presented with prime sentences that contained the universal quantifier *iedere* in the subject position. In the multiple-quantifier condition, the participants ($n = 70$) were presented with prime sentences that contained *iedere* and with prime sentences that contained *alle*. In both conditions, the prime trials were evenly distributed between the two Prime Conditions (*universal-wide* vs *existential-wide*). Note that this experiment did not contain a within-quantifier priming condition; any observed priming is thus priming between different quantifiers.

Experiment 4 contained 48 prime-target sets. This is fewer than in Experiments 1–3, but this number of trials allowed for an even distribution of trials across the experimental conditions. In addition, this experiment contained 144 filler trials, so that the ratio of fillers and prime/targets was alike in all experiments. The filler trials were identical to the ones used in Experiments 1–3: Half of them involved unambiguous transitive sentences and half of them involved unambiguous, quantified, intransitive sentences. In the single-quantifier condition, half of the intransitive filler sentences contained *iedere* and the other half contained *elke*. In the multiple-quantifier condition, 1/3rd of the intransitive filler sentences contained *iedere*, 1/3rd contained *alle*, and 1/3rd contained *elke*.

We created six lists with all the trials. Two of these lists contained the trials of the single-quantifier condition. Prime Condition was counterbalanced between these two lists. The other four lists contained the trials of the Multiple-Quantifier condition. Both Prime Condition and Prime Quantifier (*iedere* vs *alle*) was counterbalanced across these four lists. The trials are presented in a pseudorandomised order: Each prime was directly followed by a target trial (which involves the same verb as the preceding prime), and two to five fillers interspersed each prime/target set.

Procedure

The procedure of Experiment 4 was similar to Experiments 1–3. The participants were evenly distributed across the experimental conditions based on their order of participation. Then, per condition, they were evenly distributed across the different lists of trial orders.

Analyses and results

Predictions

Experiment 3 showed that priming between quantifiers emerges if the participant is presented with multiple prime quantifier conditions, also if those are between-quantifier conditions. In Experiment 4, we directly tested whether between-quantifier priming is dependent on variation in the prime types.

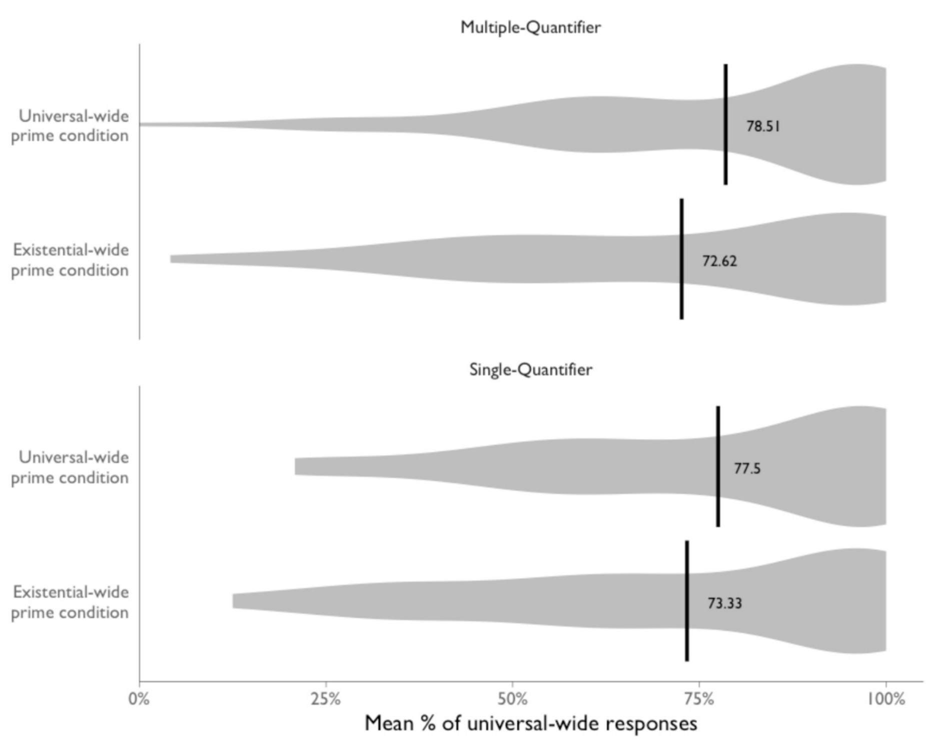

Fig. 6. The participants' mean percentage of universal-wide responses on the target trials in all conditions of Experiment 4. The black vertical lines represent the overall mean response rate. The width of the outlined area represents the proportion of the data located at that point.

In the multiple-quantifier condition, the participant is presented with two between-quantifier conditions: *iedere-elke* and *alle-elke*. Based on our hypothesis that between-quantifier priming depends on variation in the prime quantifiers, priming is predicted in this condition.

In the single-quantifier condition, on the other hand, the participant is only presented with one between-quantifier priming condition (i.e., *iedere-elke*). Here, the participant is not presented with a varied prime set. Therefore, we predict no priming in this condition. Also, note that this condition is essentially a replication of the *iedere-elke* condition in Experiment 1 and we also did not observe priming there.

Note that we did not test any differences in priming between the *iedere-elke* and *alle-elke* conditions, because the previous experiments have not shown any systematic differences in priming between these two conditions. Rather, we conflate these two conditions as general *between-quantifier* priming.

Data treatment and analyses procedure

The data treatment is identical to that of Experiments 1–3. The analyses procedure was also similar to that of Experiments 1–3: The responses were analysed using logit mixed-effect modelling. The full model contained response type as the binomial dependent variable, and Prime Condition (*universal-wide* vs. *existential-wide*) and Prime Quantifier Number (*single-quantifier* vs. *multiple-quantifier*), and their interaction term as the predictor variables. The rest of the analysis procedure was similar to that of Experiments 1–3.

Results

The participants in Experiment 4 selected the universal-wide response more often following a universal-wide prime trial than following an existential-wide prime, both in the Multiple-Quantifier and in the Single-Quantifier condition (Fig. 6). Numerically, this difference was slightly smaller in the Single-Quantifier condition (4.57%) than in the Multiple-Quantifier condition (5.64%) The analyses revealed a main effect of Prime Condition ($\chi^2(1) = 10.14$, $p = 0.001$) and no main effect of Quantifier Number ($\chi^2(1) = 0.03$, $p = 0.874$). Importantly, the analyses also revealed no interaction between Prime Condition and Quantifier Number ($\chi^2(1) = 0.50$, $p = 0.478$).

Discussion

Experiment 4 showed that logical representations can be primed between quantifiers, and the strength of priming was not affected by variation in the prime trials. This was not predicted by our predefined hypothesis that between-quantifier priming is dependent on variation in the prime types. Note that the Single-Quantifier condition, in which we only tested priming from *iedere* onto *elke*, is essentially a replication of the *iedere-elke* condition in Experiment 1, where we did not observe priming. This suggests that logical representation priming between quantifiers can emerge, also if the participants are not presented with multiple types of prime quantifiers. We will return to this finding in the General Discussion.

General Discussion

We reported four structural priming experiments that examined the representation of quantifier scope in logical representations. The central question in these experiments was whether scope is uniquely specified per quantifier, or whether scope is represented uniformly for all universal quantifiers. We tested this question by measuring effects of structural priming: If structural priming of logical representations only emerges when the prime and the target sentence contain the same universal quantifiers, then we can infer that logical representations capture scope in a quantifier-specific way (e.g., Branigan & Pickering, 2017; Feiman & Snedeker, 2016). Experiment 1 showed within-quantifier priming (that is, priming when the same quantifiers were repeated in the prime and the target) and inconsistent between-quantifier priming (that is, priming when the prime and the target contained different quantifiers). To further assess these inconclusive results, we conducted a conceptual replication of Experiment 1 in Experiment 2. In Experiment 2, we manipulated the quantifier in the prime trials within participants rather than between participants (which is what we did in Experiment 1; following Feiman & Snedeker, 2016). Importantly, Experiment 2 showed clear priming effects that were comparable within and between quantifiers.

Together, the results of Experiment 1 and 2 suggest that priming is not dependent on quantifier overlap, although both experiments revealed different patterns of priming. The only difference between these experiments was whether the prime quantifier was manipulated between (Experiment 1) or within (Experiment 2) participants. Therefore, experimental design seems to affect between-quantifier priming. Although the present study was not a priori set up to test the influence of experimental design in logical representation priming, we conducted Experiments 3 and 4 to identify the influence of experimental design post-hoc. Experiment 3 tested whether priming between quantifiers depends on the presence of a within-quantifier condition (inspired by Muylle et al., 2021). This experiment showed that priming between quantifiers emerges in experimental contexts in which multiple between-quantifier conditions are presented to the same participant, without the presence of an additional within-quantifier priming condition. Experiment 4 tested whether variation in the prime types is required for priming between quantifiers. This experiment showed priming between quantifiers, even if the participant was only presented with one universal quantifier in all prime trials (cf., Feiman & Snedeker, 2016).

Altogether, these findings suggest that between-quantifier priming is not dependent on variation in the prime trials, although such variation does seem to influence between-quantifier priming. When the participants were presented with only one between-quantifier prime condition (like in Experiment 1, the Single-Quantifier condition in Experiment 4, and in Feiman and Snedeker's (2016) study), between-priming emerged in some cases but not consistently across all conditions and experiments. In contrast, when the participants were presented with multiple between-quantifier prime conditions (like in Experiments 2 and 3, and the Multiple-Quantifier condition in Experiment 4), between-quantifier priming consistently emerged. Most important for our purposes, the observation that between-quantifier priming is less consistent compared to within-quantifier priming does not imply that between-quantifier priming is *weaker* than within-quantifier priming: When between-quantifier priming emerges, its size is comparable to that of within-quantifier priming (something we further examined statistically in a small meta-analysis, reported in Appendix C in the Supplementary Materials, available at https://osf.io/s84bv/). As we will describe in this General Discussion, this finding supports an account of logical representations that posits a quantifier-general mechanism in scope assignment (Fodor, 1982; May 1985; Montague, 1973).

Alternative explanations for between-quantifier priming

The main finding of our study is that logical representations can be primed both within and between quantifiers, and when between-quantifier priming emerged, its size is comparable to within-quantifier priming. Recall that structural priming effects indicate that parts of the underlying representations of the prime and the target sentence are shared, with larger effects indicating more representational overlap (e.g., Ziegler & Snedeker, 2018). Therefore, the finding that the size of between-quantifier priming is comparable to within-quantifier priming indicates that the representation of scope assignment underlying different universal quantifiers is alike (e.g., Hendriks, 1988; May 1985; Montague, 1973). These findings contradict earlier results from Feiman and Snedeker (2016), who observed that the scope of universal quantifiers was only susceptible to priming in within-quantifier conditions. How can we explain the discrepancy between Feiman and Snedeker's findings and the present results?

A first possibility is that this discrepancy is due to differences in the languages studied: Feiman and Snedeker's (2016) experiments were in English, whereas our experiments were in Dutch. However, we can rule out an explanation in terms of differences between these two languages. Although English and Dutch universal quantifiers are not direct translations of each other (e.g., the distinction between *each* and *every* in English is not lexicalised in Dutch, Dik, 1975; Haeseryn et al., 1997), Dutch universal quantifiers nevertheless differ in scope-taking behaviour with respect to each other. In particular, *elke* and *iedere* are more likely to take wide scope than *alle* (Ioup, 1975). If logical representations are differentiated according to quantifier-specific scope-taking properties, then between-quantifier priming is therefore also not predicted in Dutch. Thus, it seems unlikely that the presence of between-quantifier priming in the present study is caused by some unique language-specific properties of Dutch.

A second alternative explanation of our results is in terms of *visual* priming. Priming is a domain-general effect that cannot only facilitate language processing, but also visual processing (e.g., Tulving & Schacter, 1990). Therefore, the participants could also be more likely to choose the target picture that depicted the primed interpretation because this picture shared more visual commonalities with the selected picture in the preceding prime. However, several studies that directly tested the influence of visual priming in the context of a sentence-picture matching task showed no evidence for such visual priming. Raffray and Pickering (2010), who were the first to test logical representation priming in a sentence-picture matching task, conducted a control experiment in which visual priming was isolated. In this experiment, the prime sentences were not doubly-quantified sentences, but unambiguous generic sentences like *Kids like to climb trees*. Crucially, they used the same response pictures from their logical representation priming experiments, and the target sentences were doubly-quantified sentences like *Every hiker climbed a hill*. Here priming cannot be driven by perseverance of scope assignment, because the prime and target sentences do not have the same logical structure. Any priming effects can therefore be best explained in terms of visual priming, but effects were not observed (see also Maldonado et al., 2017, for similar findings).

Slim et al. (2021) further tested for visual priming and corroborated this null evidence using a visual search experiment. On each trial of this task, the participant searched a visual object in two response pictures. Crucially, these two response pictures were identical to those used in the trials of their logical representation priming experiments. In the prime trials, this object was only present in one of these response pictures. In the subsequent target trials, however, this object was present in both response pictures. Note that the general logic of the task is similar to that of sentence-picture matching tasks that test logical representation priming: The participant is forced to select a specific picture in the prime, but has a free choice between either picture in the target trials. If the priming is driven by visual similarities, then it is predicted that participants select the picture that bears most similarities to the preceding picture selected in the preceding prime. However, there was no effect of visual priming: Participants selected a picture at the target trial at chance. We used exactly the same response pictures in our prime and target sentences as Slim et al. Therefore, an explanation of the current results in terms of visual priming seems unlikely, and the results of our study are thus best described in terms of persistence at the level of logical representations. Moreover, our materials included the set of response pictures constructed by Raffray and Pickering (2010), which were also used by Feiman and Snedeker (2016). Therefore, it also seems unlikely that the discrepancy between the current study and that of Feiman and Snedeker is due to differences in the materials used.

So, an explanation for the between-quantifier priming observed in our experiments cannot be explained in terms of Dutch-specific combinatorial tendencies or in terms of visual priming. Rather, our experiments suggest that (lexical) variation in the prime trials influenced the likelihood of whether between-quantifier priming emerges, which suggests a larger role of experimental design than we expected. We will speculate on the nature of this role in the next section.

Between-quantifier priming and experimental design

Across our experiments, we observed that between-quantifier priming—when it emerged—was comparable in size to within-quantifier priming. However, our results also suggest that between-quantifier priming did not emerge consistently. Experiments 2–4 showed consistent between-quantifier priming, but the effect did not consistently emerge across conditions in Experiment 1 and in Feiman and Snedeker's (2016) study. In contrast, within-quantifier priming consistently emerges across experiments (both those reported in this paper and in Feiman and Snedeker's study). Why is within-quantifier priming more robust than between-quantifier priming? Crucially, the focus of our study was to test the nature of logical representations, and not a priori set up to examine mechanisms underlying structural priming. Therefore, we can only provide a speculative answer to this question.

To reiterate, our results indicate that experimental design plays a role in the robustness of between-quantifier priming. Experiment 1, in which the quantifier in the primes was manipulated between participants (similar to Feiman & Snedeker, 2016), we observed robust within-quantifier priming but no consistent between-quantifier priming. In Experiment 2, however, we observed robust within- and between-quantifier priming in a fully within-participant design. To identify why experimental design unexpectedly affected between-quantifier priming, we tested two post-hoc hypotheses in Experiments 3 and 4. In Experiment 3, we tested whether between-quantifier priming depends on the presence of a within-quantifier priming condition. In Experiment 4, we tested whether between-quantifier priming depends on variation in the primes. The results of both experiments did not clearly confirm any of these hypotheses.

Altogether, our experiments suggest that between-quantifier priming robustly emerges if the participant is presented with multiple universal quantifiers in the primes (as in Experiments 2–4). When the participant is only presented with the same between-quantifier priming in the prime trials, however, the effect can emerge, but it does not do so consistently. Why could variation in the prime types influence the robustness of between-quantifier priming? To gain insight in this question, we should consider why structural priming emerges in the first place. Recall that structural priming emerges because it is easier to re-use representations that are shared with some recently processed structure (e.g., Branigan & Pickering, 2017). This effect is often explained in terms of *implicit learning*: Every time we process a structure, the parsing of that structure is entrenched — an effect that emerges across the lifespan (e.g., Chang et al., 2006). Crucially, the implicit learning of structures is affected by lexical diversity: When some structure combines with a diverse range of lexical items, it is possible to detect the abstract representation of the structure that generalises to novel exemplars (e.g., Bybee, 1995; Savage et al., 2006; Suttle & Goldberg, 2011; see also Braithwaite & Goldstone, 2015, for analogous effects in reasoning).

So, assuming that implicit learning drives structural priming, and that lexical diversity facilitates the detection and construal of abstract structural representations, we can now consider how these two factors could interact in our experiments. In a within-quantifier condition, the repetition of the quantifiers in the prime and target sentence accentuates the common logical representation underlying both sentences. This surface-level overlap can facilitate the (implicit) detection of the common underlying logical structure, making within-quantifier priming a robust effect (e.g., Gentner & Smith, 2012; Holyoak, 2012; see also Bock & Griffin, 2000, for an explanation of facilitating effect of lexical repetition on structural priming in terms of an explicit memory cue). In a between-quantifier condition, the shared logical structure underlying the prime and target is less apparent in the surface level of the test sentences. Therefore, this effect hinges on the (implicit) recognition of the common logical structure instantiated by multiple universal quantifiers. Variation in the universal quantifiers in the prime trials, could promote the detection of the common abstract logical representation (see also Savage et al., 2006): In the within-participant designs in Experiments 2–4, the participants were forced to assign the same two interpretations to prime sentences with different universal quantifiers. Thus, in this case, the prime trials showed that different types of prime sentences are ambiguous between the same two interpretations. This variation could therefore highlight the abstract logical representation underlying the different prime trials, leading to more entrenched abstract representations and robust between-priming effects.

Again, this explanation is post-hoc, speculative and warrants future investigation. We should also note that the effect of lexical repetition on structural priming in comprehension is piecemeal in general, also in the domain of syntactic representation (Tooley, 2022). Therefore, future work is encouraged to test whether effects of experimental design also emerge in priming of other levels of linguistic structure. Turning to the main purpose of the present study, the central finding is that logical representation priming is not limited to within-quantifier conditions. We will discuss the implications of this finding in the next section.

Scope-taking is not quantifier-specific

Scope assignment has been well-studied in formal semantics. Some of these investigations have led to semantic theories that posit that scope-taking is uniquely operationalised per quantifier. Although these theories differ in the nature of these scope-taking operations, they share the overall assumption that quantifier words differ in their combinatorial structure. Therefore, some or all quantifier words may call upon distinct scope-taking operations in the computation of complex sentence meaning (e.g., Beghelli & Stowell, 1997; Champollion, 2017; Steedman, 2012). Feiman and Snedeker (2016) previously argued for a quantifier-specific mechanism of scope-taking, based on their finding that logical representation priming only emerged in within-quantifier conditions.

Our results, however, show that the scope assignment can be primed between quantifiers, and the size of between-quantifier priming is comparable to within-quantifier priming. This finding indicates that the assignment of scope is represented alike for all universal quantifiers in logical representation, and is therefore unexpected under the hypothesis that scope is uniquely operationalised per quantifier. Rather, our results suggest that universal quantifiers instantiate the same abstract, non-lexicalised scope-taking operation in the computation of complex sentence meaning. Such a uniform, abstract mechanism has been proposed in multiple theoretical frameworks (e.g., Fodor, 1982; Hendriks, 1988; May 1985; Montague, 1973), but our interpretation of the results is not committed to any specific formalisation of scope-taking.

Semantic theories, however, do not seem to account for the quantifier-specific biases in the assignment of scope, which is typically considered a pragmatic phenomenon (AnderBois et al., 2012; Saba & Corriveau, 2001). Nevertheless, any theory on the online processing and representation of quantifier scope should incorporate why certain quantifiers are more likely to take wide scope over others. Previous work has shown that these biases cannot be solely attributed to contextually-driven constraints — the differences in scope-taking between universal quantifiers are also observed when the discourse context and lexical items in a sentence are equal and only the universal quantifier varies (Feiman & Snedeker, 2016; Ioup, 1975; Kurtzman & MacDonald, 1993). The findings of our current study also rule out the possibility that these quantifier-specific biases are somehow caused by differences in the scope-taking operation specified in the lexical entry of a quantifier (although do note that a hypothesis in terms of quantifier-specific scope-taking mechanisms only locates a possible source of these biases, and additional hypotheses would be required to explain why such biases emerge in a principled manner; Feiman & Snedeker, 2016). Here, we will consider that these biases can be attributed to the different patterns of use associated with each quantifier.

We know from research on the processing of verbs that distributional patterns of lexical items can influence online combinatorial processing (e.g., Jaeger & Snider, 2013; Thothathiri et al., 2017). Verbs are biased towards particular argument structures. Dative verbs, like *give*, for example, can occur in both a double-object (*The man gave the boy a ball*) and a prepositional-object (*The man gave a ball to the boy*) structure. However, verbs typically occur more often in one structure than in the other (*give*, for example, occurs more often in a double-object than in a prepositional-object structure Gries & Stefanowitsch, 2004). Some verbs are so strongly biased towards a particular structure that the sentence seems ill-formed when they occur in the other structure. This is the case for a verb like *cost* (*This course cost me £300* v.*??This course cost £300 to me*; Gries, 2005).

Studies on language development have shown that these verb biases emerge gradually over the course of language development (e.g., Peter et al., 2015; Rowland et al., 2012). This suggests that such combinatorial biases develop with the cumulative exposure to a particular verb in naturalistic input, rather than by learning of distinct verb-specific combinatorial mechanisms (in which case a more abrupt developmental course is predicted). Although the combinatorial processing of verbs is typically taken to be a matter of syntactic, rather than semantic, analysis (but cf. Goldberg, 2006), distributional patterns of quantifiers could also be at the root of the quantifier-specific combinatorial biases. However, there is an unsatisfying circularity in the hypothesis that quantifiers differ in scope-taking biases because they appear in different scope-taking contexts — *why* do certain quantifiers appear more often in wide-scope-taking contexts in the first place?

Universal quantifiers not only differ in their scope-taking behaviour, but also in other semantic properties. Particularly relevant is the feature of *distributivity*. Some universal quantifiers, like *each* and *every* in English or *elke* and *iedere* in Dutch, bear this feature. These quantifiers force the assertion of a predicate to each individual member that make up the quantified set (Champollion, 2016; Dowty, 1987; Link, 1987). Therefore, a sentence is ill-formed when these quantifiers are paired with a predicate that is necessarily collective (e.g., **Each/*Every child did an assignment together*). The quantifier *all* (or *alle* in Dutch), on the other hand, is non-distributive, and can also assert a predicate to the quantified set collectively (e.g., *All children did an assignment together*). There seems to be a link between scope biases and distributivity, with distributive quantifiers having a stronger tendency to take wide scope than non-distributive quantifiers (Ioup, 1975). Although future research is needed to investigate this link in a more principled way, it may be that this link is mediated by usage patterns. Distributive quantifiers like *each* highlight the individual members of the quantified set (see also Knowlton et al., 2023). Therefore, a wide-scope reading is a natural, but not a required, fit (as previously also noted by Feiman & Snedeker, 2016). For example, the distributivity of the sentence *Each child made a painting* (in which each child separately made their own painting) forces a universal-wide configuration of quantifier scope. Therefore, distributive quantifiers appear more often in wide-scope contexts than non-distributive quantifiers. Conversely, non-distributive quantifiers like *all* allow pairing with collective predicates, which force a narrow-scope reading of the universal quantifier (as in *All students made a painting together*). Therefore, non-distributive quantifiers are more likely to occur in interpretations in which the quantifier receives narrow scope (AnderBois et al., 2012).

Summing up, our results indicate that universal quantifiers instantiate a uniform scope-taking operation. Therefore, differences in scope-taking biases between quantifiers cannot be attributed to differences in the operation. Here we speculated that these different biases may be attributed to the distinct patterns of use associated with each quantifier, which is likely mediated by the semantic content of each quantifier (in particular by distributivity). Future research on the nature of these biases is required: how exactly are they processed in the online computation of complex sentence meaning, and how are they learnt? Do they gradually develop over the course of development (see Brooks & Braine, 1996, for tentative evidence)? Inquiry into such questions is a promising avenue for future research on the processing and representation of complex sentence meaning.

Conclusion

Across four experiments, we observed that logical representations can be primed if the prime and target contain the same (universal) quantifier word and if the prime and target contain different universal quantifier words. This indicates that the scope of universal quantifiers is represented alike for all universal quantifier words, which supports theoretical accounts that posit a general-scope assignment mechanism (e.g., Hendriks, 1988; May 1985). In addition, our results showed an unexpected effect of experimental design on the robustness of priming between different quantifiers: It robustly emerged if the participant is presented with multiple quantifiers in the prime sentences, but not if they are presented with only one prime quantifier. We speculated that this pattern can be explained in terms of prime variation: The detection of a common underlying logical structure is facilitated by diversity in the prime sentences.

Note: All experiments conducted in this study are preregistered on the Open Science Framework: https://osf.io/s84bv/registrations. All data and analyses scripts are freely available on the Open Science Framework: https://osf.io/s84bv/.

CRediT authorship contribution statement

Mieke Sarah Slim: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Peter Lauwers:** Writing – review & editing, Supervision, Conceptualization. **Robert J. Hartsuiker:** Writing – review & editing, Supervision, Resources, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data are freely available on OSF: https://osf.io/s84bv.

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