# Monolingual and Bilingual Logical Representations of Quantificational Scope: Evidence from Priming in Language Comprehension

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Abstract

A doubly quantified sentence, such as *All hikers climbed a hill*, allows two interpretations: Did all hikers climb different hills, or did they climb the same hill? Previous work has shown that comprehenders construct disambiguated logical representations of these interpretations (Raffray & Pickering, 2010). We extended this line of research by investigating whether bilingual logical representations are shared between languages or separate per language. We conducted four sentence-picture matching experiments in which we primed interpretations of doubly quantified sentences in Dutch and French monolingual and bilingual language comprehension. These experiments showed that bilinguals have fully shared logical representations and that logical representations constructed in the L1 and the L2 are comparable. Moreover, a control experiment ruled out that the priming effects were driven by visual overlap between prime and target pictures. We discuss these findings in terms of a language-dependent account of logical representations, although these findings can also be reconciled with the idea that logical representations involve conceptual mental models of sentence meaning.

*Keywords*: Logical Representations, Quantifiers, Priming, Semantics, Language comprehension, Bilingualism

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## 1. Introduction

A prominent question in research on bilingualism is to what extent two languages are integrated in the mind of a bilingual: Do bilinguals have separate linguistic representations for each language or shared representations for both languages they know? This question has been studied extensively in research on the linguistic levels of syntax and the lexicon (e.g. Basnight-Brown & Altarriba, 2007; Grainger, Midgley & Holcomb, 2010; Hartsuiker, Beerts, Loncke, Desmet & Bernolet, 2016; Hartsuiker, Pickering & Veltkamp, 2004; for review see Van Gompel & Arai, 2018). These previous studies predominantly support an account by which bilinguals' syntactic and lexical representations are integrated across languages.

Less is known about bilingual representations of semantic structures at the sentence level. In this study, we investigated whether bilingual logical representations, which are representations of a sentence's logico-semantic structure, are shared or separate. We studied this question by using a structural priming paradigm (Raffray & Pickering, 2010). Before discussing the aims and methods of the present study, however, we will first provide some background on logical representations and bilingual linguistic representations.

### 1.1. Quantificational Scope and Logical Representations

Quantifiers, such as *every, all*, or *a*, are used to specify the quantity of individual referents. In order to quantify over the relevant items in a sentence, quantifiers are assigned semantic scope. Ambiguity arises when multiple quantifiers are present in the same clause. In this case, there are multiple ways in which the quantifiers may take scope vis-à-vis each other. This is illustrated in (1):

(1) All hikers climb a hill

One possible interpretation of (1) is that all hikers climb any hill, which is not necessarily the same hill. In this interpretation, the universal quantifier *all* takes wide scope over the existential quantifier *a* (the *universal-wide* interpretation). The universal-wide interpretation of (1) can be represented as follows:

(1a) $\forall x[\text{hiker}(x) \rightarrow \exists y[(\text{hill}(y) \wedge \text{climb}(x, y)]]$
*For every x, if x is a hiker, there exists a y such that y is a hill, and x climbs y*

Another possible interpretation of (1) is that all hikers climbed the same single hill. In this interpretation, the existential quantifier *a* takes wide scope over the universal quantifier *all* (the *existential-wide* interpretation), as represented as follows:

(1b) $\exists y[(\text{hill}(y) \wedge \forall x[\text{hiker}(x) \rightarrow \text{climb}(x, y)]]$

*There exists a y, such that y is a hill, and for all x, if x is a hiker, then x climbs y*

The question arises how the unambiguous interpretations such as (1a) and (1b) are represented in the mind of the language user. Given that the syntactic structure in (1) is unambiguous, it has been proposed that semantic scope configurations are captured at a separate level of linguistic representations: The level of *logical (form) representations* (Chomsky, 1995; Hornstein, 1995; May, 1985). It must be noted that it is still an open question whether such logical representations are distinct from wider semantic representations which, for instance, also contain information about thematic roles and information structure (Branigan & Pickering, 2017; see also Goldberg, 2006).

Logical representations and semantic scope have received much interest in theoretical linguistics (for discussion see Ruys & Winter, 2011). However, psycholinguists only recently started to investigate the architecture of mental logical representations (Feiman & Snedeker, 2016; Maldonado, Chemla & Spector, 2017; Raffray & Pickering, 2010). These studies focused on the mental organisation and construction of logical representations in language comprehension, which was investigated using the structural priming paradigm. *Structural priming* refers to the effect that the processing of a sentence is influenced by previous processing of sentences with a similar structure. More specifically, structural priming is the tendency to repeat the structure of a previously processed related sentence. This effect indicates that parts of the representations are shared between related sentences (Bock, 1986; Branigan, Pickering & McLean, 2005; for reviews, see Branigan & Pickering, 2017; Pickering & Ferreira, 2008; for meta-analysis, see Mahowald, James, Futrell & Gubson, 2016).

Raffray and Pickering (2010) used a structural priming paradigm in language comprehension to investigate the organisation of mental logical representations. They tested whether people construct disambiguated logical representations in the comprehension of scopally ambiguous sentences by using a sentence-picture matching task. In these tasks, the participants read a sentence and were instructed to select one of two pictures that best fitted the sentence (see also Branigan et al., 2005). In the prime and target trials, participants read doubly quantified transitive sentences with the universal quantifier *every* in the subject position and the existential quantifier *a* in the object position (thus of the form *Every noun verbed a noun*). These sentences are ambiguous between a universal-wide interpretation and an existential-wide interpretation in the same way as the doubly quantified sentence in (1). The authors observed that the participants tended to select the universal-wide response picture more often following a universal-wide prime trial than following an existential-wide prime trial, and vice versa for the existential-wide response picture (a priming effect of 8%). This finding indicates that people construct logical representations in language comprehension, which influence future language processing.

Follow-up experiments conducted by Raffray and Pickering (2010) using the same paradigm showed that logical representation priming effects also occur if the prime sentences are presented in the passive voice (*A noun was verbed by every noun*) and the target sentences in the active voice (*Every noun verbed a noun*). Thus, exposure to a universal-wide interpretation of a passive prime trial increased the likelihood that a subsequent active target sentence is interpreted as universal-wide. This finding suggests that participants did not perseverate in assigning wide (or narrow) scope to the quantified phrase in the subject position, but rather in assigning wide (or narrow) scope to the quantified agent in the sentence. This observation indicates that comprehenders map representations of the thematic structure of the sentence onto logical representations. Moreover, this experiment showed that logical representation priming is not affected by changes in word order or a sentence's diathetic structure, which further demonstrates that logical representations are separate from syntactic representations. Finally, the authors did not observe priming in an additional experiment in which the prime sentences were replaced by generic sentences without quantifiers (e.g., *Kids like to climb tree*s). This result indicates that the observed priming effects are due to persistence of logical representations and not due to effects of visual priming.

The critical test sentences in Raffray and Pickering's (2010) study always contained the quantifiers *every* and *a*. However, quantifiers differ from each other with regard to their combinatorial properties: *Each* has a stronger inherent tendency to take wide scope than *every*, and *every* has a stronger tendency to take wide scope than *all* (Cooper, 1990; Fodor, 1982; Ioup, 1975). Feiman and Snedeker (2016) tested whether logical representations are sensitive to these quantifier-specific lexical differences. They used a similar sentence-picture matching task to the one used by Raffray and Pickering. The test sentences in this experiment were doubly quantified active transitive sentences. The object phrase always contained the existential quantifier *a*. The quantifier in the subject position, however, varied between the universal quantifiers *each*, *every*, and *all* and numeral quantifiers such as *three*. The overlap in subject quantifier between prime and target was manipulated: The prime and target sentence contained either the same or a different quantifier in the subject position. This experiment showed that priming of logical representations only emerged when the prime and target sentences contained the same quantifiers, which suggests that different quantifiers have different abstract representations that are included in logical representations. Moreover, a follow-up experiment in which Feiman and Snedeker tested effects of priming between different numeral quantifiers (such as *three* or *four*) showed that logical representation priming really is sensitive to the repetition of the inherent combinatorial properties of the quantifier words, and not necessarily to repetition of the phonological word forms or even the magnitude of the numeral (see also Maldonado et al., 2017).

Finally, the verb in the prime-target sets in the experiments from Raffray and Pickering (2010) and the above-described experiments from Feiman and Snedeker (2016) were repeated. Previous work on structural priming of syntactic representations has shown that verb repetition can enhance the strength of priming, an effect known as the *lexical boost* (e.g. Branigan & Pickering, 2017; Mahowald et al., 2016; Pickering & Ferreira, 2008). In a final follow-up experiment, Feiman and Snedeker tested whether the priming of logical representations is boosted by verb repetition as well. In this experiment, the quantifiers were the same in the prime and target trials (*every...a*), but the verb differed. This experiment yielded a statistically significant effect of priming, though it was numerically smaller (5%) compared to the effect observed in experiment that involved verb overlap between prime and target (7%).

Raffray and Pickering's (2010) and Feiman and Snedeker's (2016) studies indicate that abstract logical representations are not merely a theoretical construct, but they are real mental representations that are constructed in language comprehension. An important question regarding such mental logical representations is to what extent logical representations are linguistic or conceptual in nature. A conceptual account of logical representations was argued by Fodor (1982). In her view, logical representation are conceptual mental models that contain information on the number of participants that are involved in the event denoted in the sentence (Johnson-Laird et al., 1989; Johnson-Laird, 1983). However, this account is difficult to reconcile with Feiman and Snedeker's (2016) finding that logical representations are only susceptible to priming effects if the quantifiers are similar in the prime and target trials. This observation suggests that quantifier-specific lexical, and thus linguistic, information is included in mental logical representations. Moreover, quantifier words are prone to cross-linguistic differences, in the sense that not all languages contain the same set of lexicalised quantifier words (Gil, 1995). This would predict that the construction of logical representations is dependent on language-specific considerations, namely on the properties of the quantifier words available in the language under discussion.

An additional reason to assume that the construction of logical representations is influenced by language-specific dependencies is that there are cross-linguistic differences in the interpretation of scopally ambiguous sentences. This is, for instance, the case for scopally ambiguous sentences with the universal quantifier *all* in subject position and the negation *not* in object position. Such a sentence is ambiguous in a similar way as the doubly quantified sentence in (1), because negation is also a scope-bearing operator. An example of such a sentence, together with its two interpretations, is given below.

(2) All the students are not in class.

(2a) *Universal-wide*: $\forall x[\text{student}(x) \rightarrow \neg \text{in class}(x)]$
*It is the case that for all x, if x is a student, x is not in class*
'None of the students are in class'

(2b) *Negation-wide*: $\neg \forall x[\text{student}(x) \rightarrow \text{in class}(x)]$
*It is the case that for not all x, if x is a student, x is in class*
'Not all of the students are in class'

In English and Dutch, among other languages, the universal-wide interpretation (2a) of *all...not* sentences is preferred. In Estonian, among other languages, the negation-wide interpretation (2b) of such sentences is preferred (Katsos & Slim, 2018; for cross-linguistic differences in interpreting other types of scopally ambiguous sentences, see Beck & Kim, 1997; Szabolcsi, 2002; Szabolcsi & Haddican, 2004). Cross-linguistic differences in interpreting scopally ambiguous sentences further suggest that language-specific properties affect the construction of logical representations. The mapping between the form of a scopally ambiguous sentence and the underlying, conceptual, meaning is thus affected by language-specific dependencies. Based on this observation, we assume that the construction of logical representations is (at least) language-dependent.

**1.2. Bilingual Linguistic Representations and Between-Language Priming**

Given our assumption that the construction of logical representations is language-dependent, the question of whether a bilingual has separate logical representations for each language or shared logical representations that are used in processing both languages they know is relevant. The question of whether certain bilingual representations are shared or separate can also be investigated with the priming paradigm. In such research, the prime and target trials are usually presented in different languages. Thus, these studies test effects of *between-language priming* (as opposed to *within-language priming*). Between-language priming effects indicate that the underlying representations of the stimuli are shared between the languages a bilingual knows (for review, see Van Gompel & Arai, 2018).

A number of studies have investigated the question of whether bilingual syntactic representations are shared. Hartsuiker et al. (2004) observed that Spanish-English bilinguals are more likely to produce a passive sentence in English to describe a picture on a card, after they had heard a similar passive description in Spanish than after they had heard such a description in an active sentence in Spanish. This between-language structural priming effect led to the *shared-syntax* account, which argues that bilingual syntactic representations are shared if both languages allow the syntactic structure that is represented. Support in favour of the shared-syntax account has been observed a number of times, involving different language pairs, such as Dutch-English, Swedish-English, Dutch-French, English-Korean, Mandarin-Cantonese, and different syntactic constructions including transitives, datives, genitives, and noun phrases with pre- or postnominal modification (Bernolet, Hartsuiker & Pickering, 2013; Cai, Pickering, Han & Branigan, 2011; Hartsuiker et al., 2016; Hartsuiker et al., 2004; Kantola & van Gompel, 2011; Loebell & Bock, 2003; Schoonbaert, Hartsuiker & Pickering, 2007; for meta-analysis, see Mahowald et al., 2016; and for review, see Van Gompel & Arai, 2018).

Similar to the organisation of the bilingual syntactic system, studies on lexico-semantic representations have also reported considerable evidence for an integrated account on the organisation of bilingual lexical representations (Basnight-Brown & Altarriba, 2007; Fox, 1996; Francis, 2005; Smith, Walters & Prior, 2019). In this line of research, the main question is whether bilinguals have one integrated mental lexicon that is used in processing of both languages or whether they have separate language-specific mental lexicons. As was the case for bilingual syntactic representations, many studies have investigated this question using a between-language priming paradigm. These studies typically employ *semantic priming*, in which the activation of the semantic representation of a word (e.g., *boy*) is measured in terms of the time needed to recognise a semantically related word (e.g., *girl*) or translation equivalent in the other language of a bilingual (e.g. *jongen* in Dutch; Basnight-Brown & Altarriba, 2007). These studies have indeed demonstrated translation priming (*boy* - *jongen*) and cross-linguistic semantic priming (*girl* - *jongen*; e.g. Schoonbaert et al., 2009; Smith et al., 2019; Wen & Van Heuven, 2017). These findings suggest that lexico-semantic representations are stored in one integrated mental bilingual lexicon (Dijkstra & Van Heuven, 2002; Francis, 2005).

However, it must be noted that bilinguals form a very heterogeneous group. Bilinguals differ from each other in terms of language dominance, proficiency, age of L2 acquisition, multilingualism, amount of exposure to each language, to name just a few aspects of bilingualism (e.g. De Groot, 2011). These factors may in turn influence the organisation of bilingual linguistic representations and thus modulate effects of cross-linguistic priming. A first factor that is known to modulate cross-linguistic priming is language dominance. Cai et al. (2011) hypothesised that fairly balanced bilinguals are very skilled at inhibiting the non-selected language. Therefore, cross-linguistic syntactic priming is expected to be stronger within one language than between two languages when the participants are fairly balanced bilinguals (see also Green, 1998; Kootstra & Doedens, 2016). When the participants are less balanced bilinguals, priming within and between languages is predicted to be more comparable (as observed by Hartsuiker et al., 2016; Kantola & Van Gompel, 2011; Schoonbaert et al., 2007). Similarly, language dominance has been argued to influence the organisation of bilingual lexico-semantic representations. Dijkstra and Van Heuven (2002) hypothesised that word forms in the L2 have a lower resting level of activation than those in the L1 in unbalanced bilinguals, because L2 words are less-frequently used by this group of bilinguals. Therefore, word forms in the L1 are typically processed more efficiently than those in the L2 for unbalanced bilinguals.

A second aspect of bilingualism that should be elaborated is L2 proficiency. Hartsuiker and Bernolet (2017) proposed the following development trajectory for L2 syntactic representations: First, there is an initial stage in which the learner relies on L1-transfer and imitation to process the L2. Then, a stage follows in which syntactic representations are language- and item-specific. As this stage proceeds, the syntactic representations in the L2 become more and more abstract, until the final stage of L2 syntactic acquisition is reached. In this final stage, syntactic representations have become sufficiently abstract to be shared between the L1 and the L2 (see also Bernolet et al., 2013; Hwang et al., 2018). A similar influence of L2 proficiency has been argued to play a role in the organisation of bilingual lexico-semantic representations. Grainger et al. (2010) argued that in the early stages of lexical acquisition in the L2, a new L2 word is processed through its translation equivalence in the L1. In this phase, word forms in the L2 are only connected to their L1 translation equivalents, and not yet to the underlying conceptual meaning representations. As the proficiency in the L2 increases, a direct connection between the word form and the underlying conceptual meaning representation starts to develop. In this final stage of L2 acquisition, the bilingual has an integrated lexicon that contains information of word forms in both languages they know (following Dijkstra & Van Heuven, 2002).

Thus, the organisation of both the bilingual mental lexicon and the bilingual syntactic system seems to depend on language dominance and proficiency. It must be emphasised that there are many other aspects of bilingualism that may influence the organisation of bilingual linguistic representations, as listed in the beginning of this section. Discussing all these possible factors goes beyond the scope of this paper. Furthermore, not only bilingual-specific characteristics may influence the organisation of bilingual representations. Item-specific features also influence the sharedness of bilingual representations. Above, we already mentioned that bilingual syntactic representations are only shared between languages if both languages allow the syntactic structure that is represented (Bernolet et al., 2007; Hartsuiker et al., 2004). Semantic features of the lexical item have also been argued to be an important influence in the organisation of the mental representation of that item. Duyck and Brysbaert (2004) argued that if there is strong or complete meaning overlap between a word in the L1 and in the L2, that L2 word is not acquired through connections with its L1 equivalent. Rather, that L2 world will be acquired by rapid mapping of the word form in the L2 on the underlying conceptual meaning representations (see also Brysbaert & Duyck, 2010; De Brauwer, Duyck & Brysbaert, 2008; Duyck & Brysbaert, 2008). This latter observation thus indicates that there is an influence of lexical overlap between languages in bilingual lexico-semantic processing. With regard to logical representations, it may therefore be the case that quantifier-specific lexical information needed in the construction of logical representations (Feiman & Snedeker, 2016) may be shared between languages if these quantifiers are direct translation equivalents.

To summarise, there is considerable evidence that bilingual syntactic representations are shared across languages. Similarly, bilingual lexico-semantic representations are assumed to be stored in one integrated bilingual mental lexicon. These observations indicate that the two languages are not completely separate entities in a bilingual's mind. However, the organisation of both bilingual syntactic representations and the bilingual mental lexicon depends on bilingual-specific factors (such as language dominance and L2 proficiency) and linguistic item-specific factors (whether both languages allow the syntactic structure under consideratuon or whether there is full meaning overlap for a word form between both languages).

### 1.3. The Present Study

Studies on both bilingual syntactic and lexico-semantic representations have indicated that these representations are, at least to some extent, shared between the languages a bilingual knows. These observations raise the issue of whether logical representations are also shared between the languages a bilingual knows. There is a well-established tradition of studying bilingual representations of syntactic and lexico-semantic information, but research on bilingual representations of more complex semantic structures, such as logical representations, is limited. However, given that the construction of logical representations most likely involves a language-specific mapping of form to meaning, it is an important question whether logical representations are shared among languages or separately constructed per language. Insight in this question will firstly provide a better understanding on how bilinguals assign meaning to a sentence, and in which ways bilinguals may perform differently than monolinguals with regard to this matter. Secondly, insight in this question will also elucidate the architecture of mental logical representations in general, because it will provide insight in the question of whether logical representations are language-specific (in which case they may be separate in bilingual language processing) or not (in which case they are shared by default in bilingual language processing).

The main goal of this study is to investigate to what extent bilingual logical representations are shared between the languages a bilingual knows or separate for each language. We answer this question in terms of priming effects on the level of logical representations in language comprehension. We used a series of sentence-picture matching tasks that are designed to elicit effects of priming in comprehension of doubly quantified sentences (of the form *All nouns verb a noun*) in Dutch and French. We recruited Dutch-French bilinguals for the experiments that involved bilingual participants. The bilingual participants displayed much variability in terms of their L2 proficiency in French. In Flanders, where this study was conducted and where the bilingual participants were recruited, French is a mandatory subject in the final two years of primary education and in all six years of secondary education. Therefore, people in Flanders usually know French as a second language[1]. However, most people in Flanders are not much exposed to French outside this educational setting (especially in comparison to English, which is widely used in popular media and higher education). In our study, we recruited both participants who study French as a second language at university level and participants who are not much exposed to French in daily live (i.e. first-year psychology students). Given this variability among our participants, we also explored the possible influence of L2 proficiency on the sharing of bilingual logical representations.

The experiments below used a sentence-picture matching task, similar to Raffray and Pickering (2010) and Feiman and Snedeker (2016), in which we presented doubly quantified sentences that contained Dutch and French equivalents of the quantifiers *all* and *a* (*alle...een* and *tout(es) les...un(e)* respectively; Table 1). If the priming of logical representations observed in English can be generalised to other languages, we expect to replicate these priming effects in Dutch (Experiment 2a) and French (Experiment 2b). If bilinguals share logical representations across languages, we further expect such priming between L1 Dutch and L2 French (Experiment 3) and within L2 French (Experiment 4). Finally, we tested effects of possible visual priming in Experiment 5. But first, we will describe two baseline experiments that measured the spontaneous preference for the universal-wide or existential-wide interpretation of our target sentences in native Dutch and native French speakers.

## 2. Experiment 1: Baselines

The goal of Experiment 1 was to determine the spontaneous interpretation of the doubly quantified test sentences in Dutch and French. Specifically, we conducted this experiment to test for possible cross-linguistic differences in the spontaneous interpretation of these sentences in Dutch and French. We chose to investigate these baseline responses in separate experiments, rather than include baseline trials in our priming experiments (e.g. Maldonado et al., 2017), in order to reduce effects of priming on our baseline measures (Hartsuiker & Westenberg, 2000).

### 2.1. Method

#### *2.1.1. Participants*

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[1] With *second language*, we refer to any language that is not the native language. Thus, in this study, we do not discriminate a second language, a third language, and so on

*Experiment 1a: Dutch.* In the Dutch version of Experiment 1, 69 native speakers of Dutch participated (mean age: 25 years, SD: 8 years, range: 18-62[2] years). They were recruited online (via social media and Ghent University's participant recruitment platform) and received a small payment for their participation (€5). All of these participants resided in a Dutch-speaking country at the time of participation. Most of the participants reported to be speakers of Flemish Dutch (*n* = 57), though some reported to be speakers of Netherlandic Dutch (*n* = 12). For more information on the participant characteristics of this (sub-)experiment and the following experiments, please see https://osf.io/ysgx4/.

*Experiment 1b: French.* In the French version of Experiment 1, 62 native speakers of French were recruited online via Prolific Academic (mean age: 26 years, SD: 7 years, range: 16-46 years). They received a small payment for their participation (€5). All of the participants resided in a French-speaking country at the time of participation. Two of the participants were removed because they reported that French was not their native language. Of the remaining 60 participants, most reported to be speakers of Hexagonal French (*n* = 40), but some reported to speak Canadian French (*n* = 13), Belgian French (*n* = 4), or Swiss French (*n* = 3).

#### *2.1.2. Materials*

Each trial consisted of a sentence and a pair of pictures. The target trials always contained a doubly quantified sentence with the universal quantifier *all* in the subject position (Dutch: 'alle', French 'tou(te)s (les)'), and *a* in the object position (Dutch: 'een', French: 'un(e)'). The two response pictures displayed both possible interpretations of the doubly quantified target sentence (Figure 1; all visual materials are available at https://osf.io/v2w3a/.). Thus, the participants had a real choice between the two possible interpretations of the test sentence in the target trials.

We chose the quantifier *all* (unlike Raffray & Pickering, 2010 who used *every* in their stimuli) because we needed quantifiers that are close translation equivalents. It has been claimed that meaning equivalents of *all* are less prone to cross-linguistic variation than those of *every* (Gil, 1995). This is important in light of Feiman and Snedeker's (2016) observation that logical representations are sensitive to quantifier-specific meaning differences.

[2] Kemtes and Kemper (1999) observed that older adults (aged 65 years old and over) differ from younger adults in the preferred interpretation of scopally ambiguous sentences. Only 2 of the participants of Experiment 1a were above 50 years of age. Therefore, we do not expect that the large age range of the participants have influenced the results.

| Language | Sentence and gloss |
| --- | --- |
| Dutch | Alle wandelaar-s klimmen op een heuvel<br>all hiker-PL climb.3PL on a hill.SG |
| French | Tous les randonneur-s montent sur une colline<br>all.M the.PL hiker-PL climb.3PL on a.F hill.SG |
| English translation | All hikers climb a hill |

*Table 1. Example of the test sentences and their glosses in both Dutch and French.*

Table 1 provides an example of a target sentence in both Dutch and French. A list of the English translations of the stimuli is provided in Appendix D and the original Dutch and French sentences are available at https://osf.io/ysgx4/. Note that there are several differences between these languages in the structure of such sentences. First, in French, the plural determiner *les* is added before the subject noun. In French, the quantifier *tou(te)s* does not select a noun phrase (NP), but a determiner phrase (DP) (e.g. Doetjes, 1997). Therefore, the addition of the determiner *les* is obligatory. There is also a Dutch universal quantifier that selects a DP rather than an NP: *al*. However, *al* is not a direct translation equivalent of *tou(te)s.* For instance, *al* cannot be used in generic statements, whereas *tou(te)s* can be used in such contexts. When there is a clear restricted set of referents in the discourse context (as in our materials), however, *al* and *alle* may be used interchangeably. In order to determine whether we would use *al* or *alle* in our test sentences, we conducted a brief pre-experimental survey in which we contrasted *alle* with *al*. Native speakers of Dutch ($n$ = 55) were asked to compare their preference for *alle* and *al* in our test sentences. The results showed a strong preference for the version with *alle* in all test sentences (a mean preference of 81% for *alle*). Therefore, we chose to use *alle* instead of *al*.

We constructed and adapted 108 target items and 162 filler items. The 108 target trials involved 12 different verbs. The subject nouns were always animate and the object nouns varied between animate and inanimate. The pictures of 48 of the target trials were constructed by Raffray and Pickering (2010), and we constructed 60 additional target trials. The 162 filler trials involved 28 different verbs. We borrowed the materials of 85 filler trials from Raffray and Pickering and constructed 77 additional filler trials ourselves. In the filler trials, the participants read an unambiguous transitive sentence (such as *The cowboy punches the burglar*). One of the response pictures corresponded to the sentence, whereas the other response picture mismatched the sentence. This foil picture always showed the same event as denoted in the sentence, but not the same agent or patient.

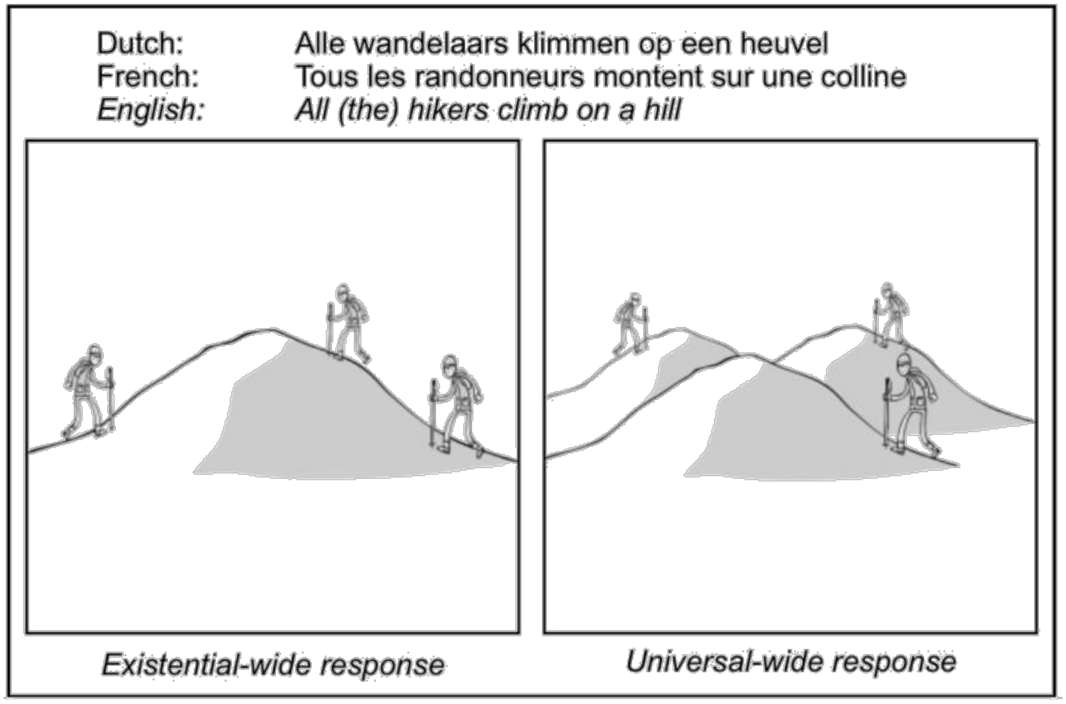


*Figure 1.* *Sample target trial from Experiment 1. For the ease of illustration, we included the target sentence in both Dutch and French, together with an English translation, in this figure. Moreover, we added the labels 'existential-wide response' and 'universal-wide response' for the same reason. In the experiment, these labels were not presented to the participants and the sentence was only shown in one language.*

To keep the experiment within bounds, we distributed the 108 target items over two lists of trials in each language. Each list contained 54 unique target items and all 162 filler items. The participants were randomly directed to one of these two versions. The items were pseudo-randomly organised: Each target item was intervened by two to five filler items. The experiment always started with four filler items, so that the participants could familiarise themselves with the forced-choice task. Moreover, the order of the items differed in both lists of the experiment. Additionally, we counterbalanced the side on which the universal-wide and existential-wide response pictures was presented in the target trials within participants. Similarly, the position of the correct and incorrect pictures in the filler trials was also counterbalanced within participants.

#### *2.1.3. Procedure*

The experiment consisted of a sentence-picture matching task that was administered over the internet using LimeSurvey. On LimeSurvey, the participants were redirected to one of the two versions of the task. They first saw an instruction and consent screen that explained the procedure. They could begin the first trial by clicking a 'start' button.

In all trials, the sentence and two pictures were shown simultaneously on a screen (as illustrated in Figure 1). The participant was instructed to select the picture that corresponded to the sentence, by clicking on the chosen picture on the screen with their mouse. Prior to the task, the participants were instructed to select their spontaneous preference if they thought that both pictures matched the sentence. After selecting one of the two pictures, the next trial began automatically. After completion of the sentence-picture matching task, the participants filled in a short questionnaire regarding their language background.

#### *2.1.4. Data treatment and analyses procedure*

One target trial was discarded from the French version of the experiment due to a programming error. The remaining responses were coded as TRUE if the response was universal-wide, and FALSE if the response was existential-wide.

We analysed the results by modelling response-type likelihood with logit mixed-effect models (Jaeger, 2008) as a function of the between-subject factor Language (i.e., sub-experiment). This model included Target Response as the binomial dependent variable and Language as the (deviation coded) predictor variable. The random-effects structure of this model was maximal, as recommended by Barr et al. (2013): It included random intercepts for Item and Subject, and a random slope of Language per Item. We did not include a random slope of Language per Subject, as Language was a between-subject variable. We obtained a *p*-value by running a Wald $\chi^2$-test on the fitted model. All analyses were carried out in the *R* programming language (version 3.6.0, R Core Team, 2019), using the *lme4* (Bates et al., 2015) and *car* (Fox & Weisberg, 2019) packages. The analysis script and data of this experiment and the subsequent experiments are freely available online at https://osf.io/ysgx4/.

### 2.2. Results and discussion

Figure 2 shows the percentage of universal-wide target response choices in both versions of the experiment. The Dutch-speakers of Experiment 1a selected the universal-wide response 38.4% of the time in all target trials on average. The French-speakers of Experiment 1b selected the universal-wide response in 37.3% of all target trials. The statistical analysis showed no main effect of Language ($\chi^2(1) = 0.36$, $p = 0.547$). The output of this model (and of those constructed in the subsequent experiments) is reported in Appendix A.

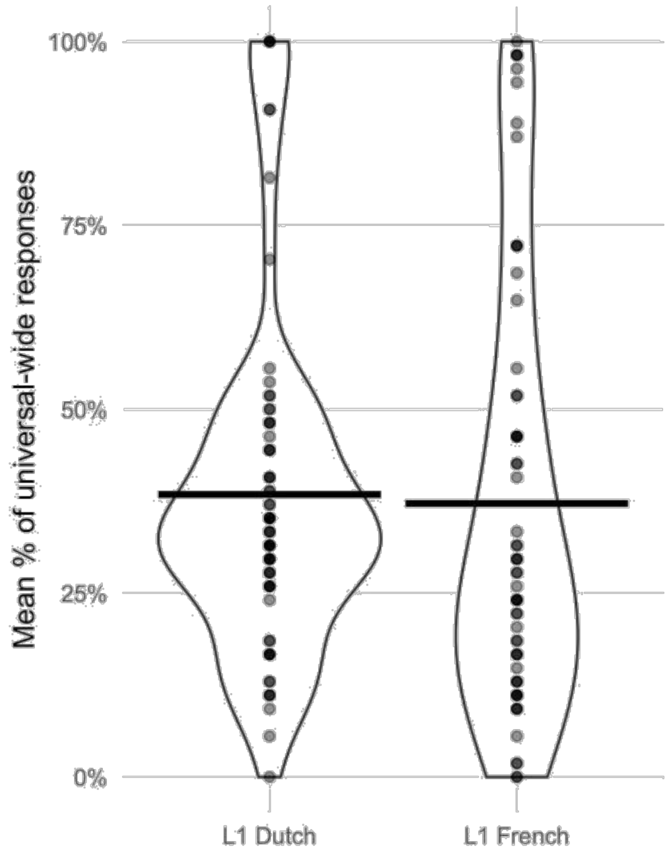


*Figure 2. The participants' mean percentage of universal-wide responses on the target trials in Experiment 1. The dots in this plot denote the overall mean response rate of the individual participants and the black horizontal lines represent the overall mean response rate. The outlines of the violin plots indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. For ease of interpretation, we chose to display these results in percentages rather than in logit space.*

These results show that there does not seem to be a cross-linguistic difference between French and Dutch in the interpretation of doubly quantified *all…a* sentences. Moreover, these results further suggest that *alle* and *tou(te)s (les)* are very close (if not direct) translations of each other, as they display very similar combinatorial patterns.

## 3. Experiment 2: L1-L1 priming in Dutch and French

In the following experiments, we manipulated the response choice in the target trials by priming one of the two possible interpretations of the doubly quantified *all…a* sentences. These experiments will provide insight in whether comprehenders construct logical representations that bias towards the same interpretation in subsequent processing of similar scopally ambiguous sentences. In Experiment 2, we tested priming of logical representations within L1

Dutch and L1 French. This experiment will show whether Raffray and Pickering's (2010) findings that people compute logical representations in the comprehension of doubly quantified sentences replicate in Dutch and French L1 comprehension.

In this experiment and in the subsequent priming experiments, we repeated the verb in each prime and target trial (following Raffray & Pickering, 2010). As discussed in the Introduction, verb repetition has been shown to enhance effects of structural priming (predominantly tested within the priming of syntactic representations, see Branigan & Pickering, 2017; Mahowald et al., 2016; Pickering & Ferreira, 2008). By repeating the verb, we hoped to increase our chances of finding effects of priming, especially because Feiman and Snedeker (2016) observed descriptively larger effects when verbs were repeated in prime and target compared to when the verb differed.

## 3.1. Method

### *3.1.1. Participants*

*Experiment 2a: Dutch.* We tested 84 further native Dutch speakers (mean age: 22 years, SD: 6 years, range: 18-48 years). Thirty-eight of them were recruited via Prolific Academic; they received a small payment for their participation (€7.50). The other 46 participants were first-year psychology students at Ghent University who received course credits for their participation. Of all participants, 49 reported to speak Flemish Dutch, and 34 to speak Netherlandic Dutch. We removed one participant from further analyses because they reported that Dutch was not their native language. Additionally, 16 participants were excluded from further analysis because they correctly guessed the purpose of the experiment (which was assessed in a post-experimental debriefing). Fifteen of the latter participants were psychology students, who may have been familiar with priming paradigms. Thus, 66 participants were included in the data analyses.

*Experiment 2b: French.* We recruited 68 further native French speakers online via Prolific Academic (27 years, SD: 8 years, range: 18-56 years[3]). Of all participants, 49 reported to speak Hexagonal French, 15 to speak Canadian French, 3 to speak Belgian French, and one to speak Swiss French. The participants received a small payment for their participation (€7.50). One participant was removed from further analyses because they reported that French was not their first language. Moreover, six participants were removed because they had guessed the purpose of the experiment. Thus, 59 participants were included in the data analyses.

[3] Of these participants, only 3 were above 50 years of age.

#### *3.1.2. Materials*

The materials were similar to those of Experiment 1, except that half of the previous target trials now served as prime trials. The sentences in the prime trials were identical to those in the target trials, but the two response pictures differed. 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 (because either the subject or the object noun mismatched the picture). This way, the participants were forced to assign a particular interpretation to the prime sentence.

The prime trials were presented in two conditions that were manipulated within-subjects: The *universal-wide* and the *existential-wide* condition. In the universal-wide condition, the matching picture corresponded to the universal-wide interpretation of the test sentence. In the existential-wide condition, the matching picture corresponded to the existential-wide interpretation of the test sentence. The prime trials were constructed by altering the response pictures of half of the target trials of Experiment 1. We randomly selected which of the target items of Experiment 1 would serve as prime trials in this experiment, though we ensured that the prime and target trials were equally spread out over the verbs. Prime trials were immediately followed by target trials. These target trials were identical to those in Experiment 1. The prime-target ordering is illustrated in Figure 3.

We presented 54 prime-target sets (27 in each prime condition) to all participants, together with the same 162 filler trials as Experiment 1. Prime and target trials were now organised in sets: Target trials immediately followed prime trials and these prime-target sets always contained the same verb (following Raffray & Pickering, 2010). Two to five filler trials intervened between each prime-target set (also following Raffray & Pickering, 2010). As in Experiment 1, we made two lists of trials, organised following these restrictions. Participants were randomly directed to one of these two lists. The counterbalancing procedure was similar to that of Experiment 1, with the addition that the prime condition of each prime trial was also counterbalanced between subjects.

#### *3.1.3. Procedure*

The procedure was similar to that of Experiment 1. Importantly, this experiment was also administered over the internet using LimeSurvey. Moreover, the participants filled in the same short questionnaire regarding their language background. A difference with the procedure of Experiment 1 is that the present experiment ended with a page on which we explicitly asked whether the participant had any ideas about the purpose and manipulations of the experiment. Those who guessed the goal of the experiment were removed from further analyses: Participants were excluded if they noticed the prime-target pattern in the trials and/or guessed that there may have been an influence from the preceding trial on the target trials.

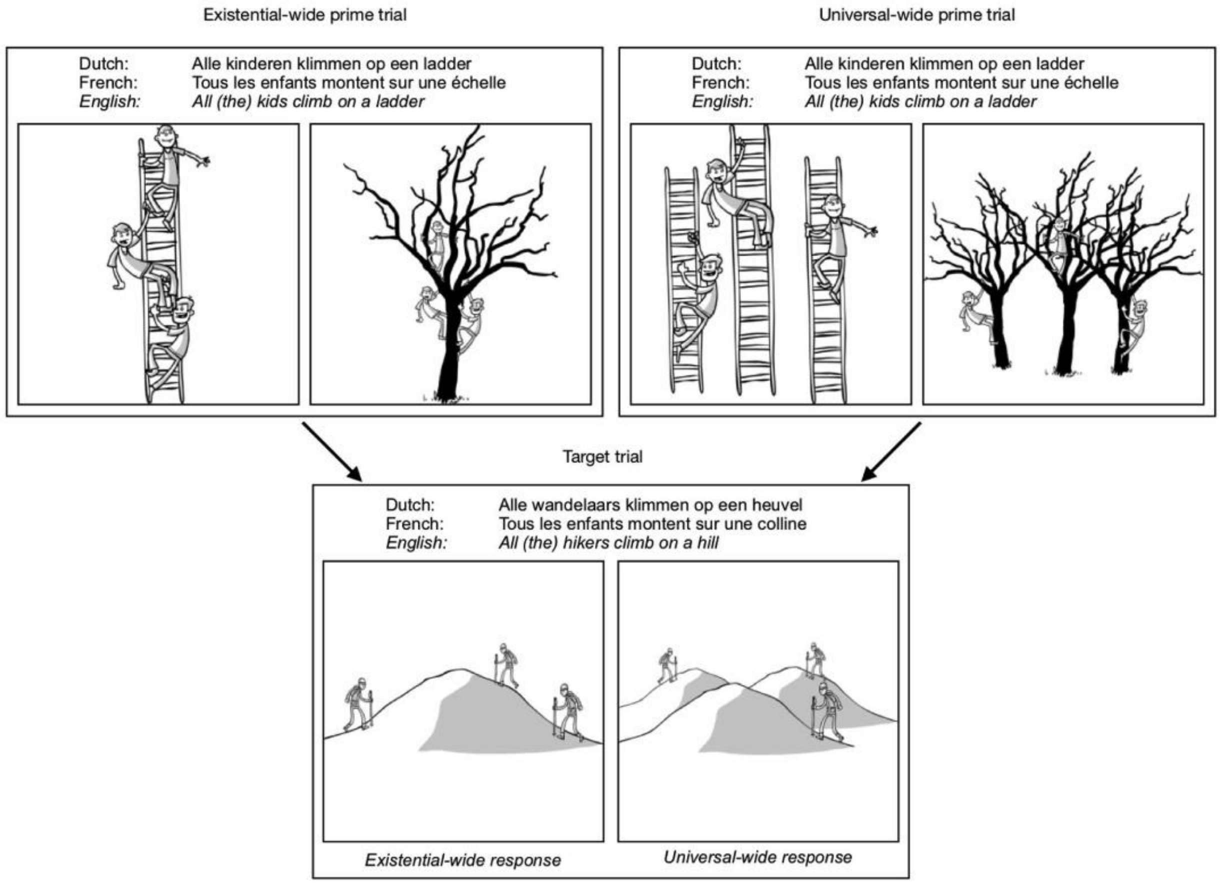


*Figure 3. Example of the prime-target procedure in Experiments 2-4. The target trials were always immediately preceded by prime trials.*

#### *3.1.4. Data treatment and analyses procedure*

The data treatment was similar to that in Experiment 1. However, as noted above, all responses of a participant were removed from further analyses if the participant guessed the aim of the experiment correctly. Moreover, following Raffray and Pickering (2010), target responses were discarded if the participant selected the incorrect picture in the preceding prime trial. The statistical analyses were carried out by modelling response-type likelihood using logit mixed-effect models. These analyses were first carried out over the combined dataset of both Experiment 2a and 2b. In this model, Target Response was included as the binomial dependent variable, and Language and Prime Condition as (deviation coded) predictor variables. In the analyses, we thus tested for main effects of Language and Prime Condition and for a possible interaction between these two predictors. Next, we constructed logit mixed-effects models that tested the effect of Prime Condition in the separate datasets of Experiment 2a and Experiment 2b. These models only contained Prime Condition as a predictor variable. As in Experiment 1, the random effects structure in all models was maximal.

### 3.2. Results and discussion

In Experiment 2a, 14 target responses in the existential-wide condition (0.79% of all target responses in the existential-wide condition) and 26 target responses in the universal-wide condition (1.46% of all target responses in the universal-wide condition) were excluded from the analyses due to incorrect answers in the preceding prime trials. For the same reason, 33 target responses in the existential-wide condition (2.07% of all target responses in the existential-wide condition) and 43 of the target responses from the universal-wide condition (2.70% of all target responses in the universal-wide condition) were discarded in Experiment 2b.

Figure 4 displays the mean percentage of universal-wide target responses as a function of Language and Prime Condition. The Dutch-speaking participants selected the universal-wide response on average in 47% of all target trials in the universal-wide prime condition and in 38% of the target trials in the existential-wide prime condition, a priming effect of 9%. The French-speaking participants selected the universal-wide response on average in 31% of all target trials in the universal-wide prime condition and in 25% of all target trials in the existential-wide prime condition, a priming effect of 6%. There was a significant main effect of Prime Condition ($\chi^2(1) = 31.04$, $p < 0.001$) and Language ($\chi^2(1) = 7.93$, $p < 0.001$), but no significant interaction between Prime Condition and Language ($\chi^2(1) = 1.47$, $p = 0.226$). The analyses on the separate data of Experiment 2a and 2b showed a significant main effect of Prime Condition in both the Dutch version ($\chi^2(1) = 28.02$, $p < 0.001$) and in the French version ($\chi^2(1) = 4.29$, $p = 0.038$) of the experiment. These analyses show that there is priming of logical representations in both Dutch and French, and that there is no statistical evidence that the language of the experiment influences the strength of priming.

The combined analysis revealed a significant effect of Language: The Dutch-speaking participants in Experiment 2a selected the universal-wide response more often than the French-speaking participants in Experiment 2b. This finding differs from the baseline measures in Experiment 1. For now, we note that Experiment 1 had a comparable number of participants as Experiment 2 but twice as many items. Therefore, Experiment 1 had more statistical power. On the other hand, the results of Experiment 1 show that, numerically, French-speakers in Experiment 1b selected the existential-wide response more often than the Dutch-speakers in Experiment 1a (see Figure 2). We will return to this unexpected result in the General Discussion.

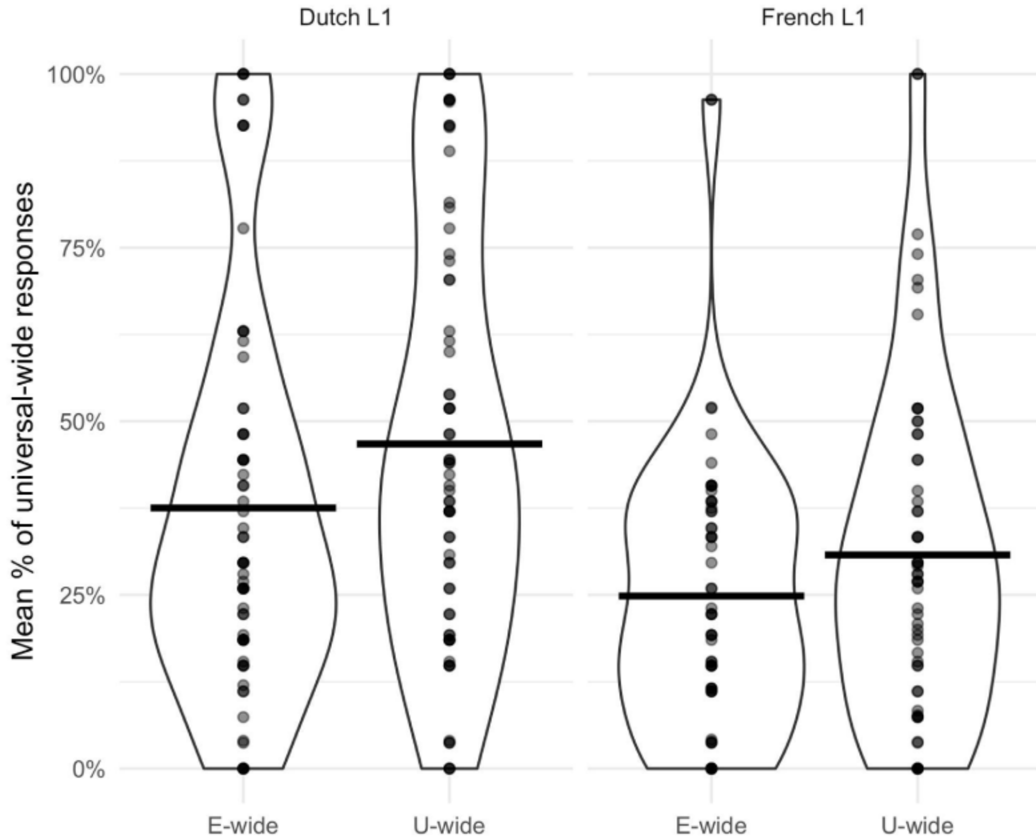


*Figure 4.* *The participants' mean rate of universal-wide responses on the target trials in Experiment 2. The labels E-wide and U-wide denote the two prime conditions (existential-wide and universal-wide). The dots in this plot denote the overall mean response rate of the individual participants and the black horizontal lines represent the overall mean response rate. The width of the outlined area represents the proportion of the data located at that point.*

More important with regard to our research objectives is that Experiment 2 shows that logical representations can be primed in both L1 Dutch and in L1 French. Thus, Raffray and Pickering's (2010) and Feiman and Snedeker's (2016) finding that comprehenders construct logical representations of doubly quantified sentences can be generalised to other languages than English. Do note that the priming effect in the French version of the experiments is numerically smaller than in the Dutch version of the experiment (6% vs. 9%). However, we did not observe a significant interaction between Language and Prime Condition. Therefore, this numerical difference might be due to chance.

## 4. Experiment 3: L1-Dutch to L2-French priming

Experiment 3 tested whether priming of logical representations persists between languages. Here, the prime trials were presented in the participants' L1 and the target trials in the participants' L2. This experiment will therefore provide further insight in whether bilinguals have shared or separate logical representations. The participants of this experiment varied in terms of their L2 proficiency: Some participants were students of French linguistics, while others were students in other domains. This latter group of participants is presumably less proficient in French than the first. Participation was open for both simultaneous and late bilinguals.

### 4.1. Method

#### *4.1.1. Participants*

We recruited 90 further native Dutch speakers, who received a small payment (€10) or course credit for their participation. These participants were required to be L1 speakers of Dutch and L2 speakers of French. However, four participants were excluded from further analyses because they reported that Dutch was not their L1. Moreover, seven participants answered more than 10% of the filler trials incorrectly and 18 participants guessed the goal of the experiment during the post-experimental debriefing. Thus, 61 participants were included in the analyses.

Table 2 provides information about the participant characteristics. For more detailed information of the participants, see Appendix B. Moreover, the (anonymous) individual participant characteristics are available at https://osf.io/ysgx4/. The mean age of French L2 acquisition of these 61 included participants was 9 years old (SD: 3.2, range: 0-15). Three participants reported to have acquired French from birth. Moreover, 28 of the included participants are studying or have studied French at university level and 8 have taken a course in French as part of a higher vocational training programme. The other 35 participants have not studied French as part of a higher education course.

#### *4.1.2. Materials*

The materials were similar to those in Experiment 2. In this experiment, however, the prime sentences were always given in Dutch (the participants' L1) and the target sentences in French (the participants' L2). Moreover, half of the filler trials were presented in Dutch and the other half in French.

| | Experiment 3: L1-L2 | Experiment 4: L2-L2 |
|---|---|---|
| Age | 21 (3.11) | 20 (4.8) |
| Age of French acquisition | 9 (3.22) | 10 (2.00) |
| Self-rating Dutch (L1) | | |
| Speaking | 9.5 (0.70) | 9.6 (0.67) |
| Listening | 9.7 (0.53) | 9.5 (0.85) |
| Reading | 9.6 (0.63) | 9.7 (0.71) |
| Writing | 9.3 (0.86) | 9.1 (0.96) |
| Overall | 9.5 (0.60) | 9.5 (0.66) |
| Self-rating French (L2) | | |
| Speaking | 6.8 (1.4) | 6.0 (1.48) |
| Listening | 7.1 (1.36) | 6.6 (1.47) |
| Reading | 7.8 (1.26) | 7.3 (1.60) |
| Writing | 6.7 (1.6) | 6.2 (1.67) |
| Overall | 7.1 (1.6) | 6.5 (1.3) |
| LexTale-FR | 66% (13%) | 56% (10%) |
| Estimated daily use: | | |
| Dutch (L1) | 78% (16%) | 81% (14%) |
| French (L2) | 13% (12%) | 13% (19%) |
| Other L2s | 10% (13%) | 14% (17%) |

*Table 2. Information on the participants of Experiment 3 and 4 that were included in the data analyses. Mean values are reported, with standard deviations indicated in parentheses. The self-ratings were scored on a scale from 1-10.*

#### *4.1.3. Procedure*

The procedure was similar to that of Experiment 2, with the addition that the participants now filled in a test of proficiency in French (the LexTale-FR test; Brysbaert, 2013) after completing the sentence-picture matching task and before the language background questionnaire. In this test, participants read 84 letter strings. Of these stimuli, 56 are existing French words, whereas the other 28 stimuli are French-looking nonwords. These tests have been shown to be good predictors of not only L2 vocabulary size but also of general language proficiency (Lemhöfer & Broersma, 2012). The instructions of this LexTale-FR test were provided in Dutch, as were the questions of the language background questionnaire. The language background questionnaire differed slightly from those used in Experiment 1 and 2, because it included some questions specifically related to French as the L2 (such as age of acquisition, daily use, and self-rated proficiency; see Table 2, Appendix B, and the individual participant characteristics available at https://osf.io/ysgx4/)

#### *4.1.4. Data treatment and analyses procedure*

The data treatment and analysis procedure were similar to those in Experiment 2. However, we added an exploratory analysis that tested the possible influence of L2 proficiency on the organisation of bilingual logical representations. Therefore, the logit mixed-effects model fitted for this experiment included the LexTale-FR test scores as an additional continuous predictor variable[4]. These LexTale-FR scores were centred around the mean (following Bernolet et al., 2013).

### 4.2 Results and discussion

We excluded 36 target responses in the existential-wide condition (2.19% of all target responses in the existential-wide condition) and 20 target responses in the universal-wide condition (1.21% of all target responses in the universal-wide condition) from the analyses due to incorrect responses in the preceding prime trials.

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[4] We collected two measures of L2 proficiency: the scores on the LexTale-FR test, and self-rated proficiency scores. A Kendall's rank correlation test revealed a positive correlation between LexTale-FR score and the self-ratings on French proficiency: The participants that reported higher self-ratings on French proficiency were more likely to obtain a higher score on the LexTale-FR test ($\tau = 0.409$, $p < 0.001$). Given this correlation and because self-rated proficiency is argued to be a less valid predictor of L2 proficiency than LexTale scores (Lemhöfer & Broersma, 2011), we decided to only include LexTale-FR in the analyses.

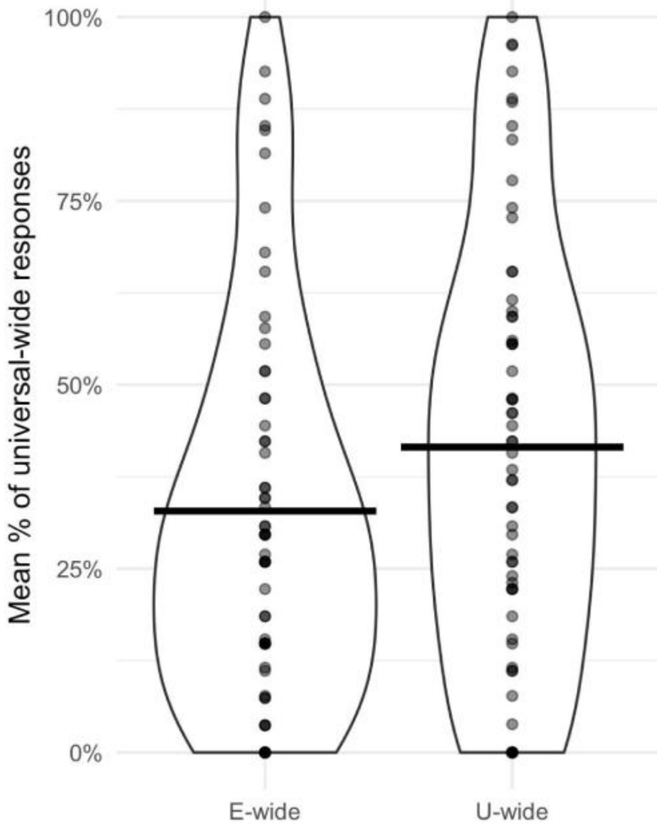


*Figure 5.* *The participants' mean percentage of universal-wide responses on the target trials in Experiment 3. The labels E-wide and U-wide denote the two prime conditions (existential-wide and universal-wide). The dots in this plot denote the overall mean response rate of the individual participants and the black horizontal lines represent the overall mean response rate. The width of the outlined area represents the proportion of the data located at that point.*

Figure 5 displays the percentage of universal-wide responses in each prime condition. The participants selected the universal-wide response in 41% of the target trials in the universal-wide condition and in 33% of the target trials in the existential-wide condition, a priming effect of 8%. Our analyses showed that this main effect of Prime Condition was statistically significant ($\chi^2(1) = 21.99$, $p < 0.001$).

In our models, we also included the participant's LexTale-FR scores as a predictor variable, in order to explore the possible role of L2 proficiency in between-language priming of logical representations. As shown in Table 2, the mean score on the LexTale-FR test was 66% of all stimuli correct (SD: 13.38%, range: 37% - 89%). The statistical analyses showed no significant main effect of LexTale-FR score ($\chi^2$ (1) = 3.43, $p = 0.064$), although we note that the *p*-value of this test was close to the conventional alpha level of 0.05. This result is plotted in the left panel of Figure 6. This numerical trend suggests that participants with higher LexTale-FR scores selected the universal-wide response somewhat less often than those with lower scores. Possibly, more advanced learners of French are more likely to exhibit the bias for the existential-wide interpretation that native speakers of French also seem to show (as observed in Experiment 2b, but not Experiment 1b). Finally, there was no significant interaction between Prime Condition and LexTale-FR score ($\chi^2(1) = 0.12$, $p = 0.718$). These results are plotted in the right panel of Figure 6. This finding suggests that there was no observable influence from L2 proficiency on the strength of the priming effects.

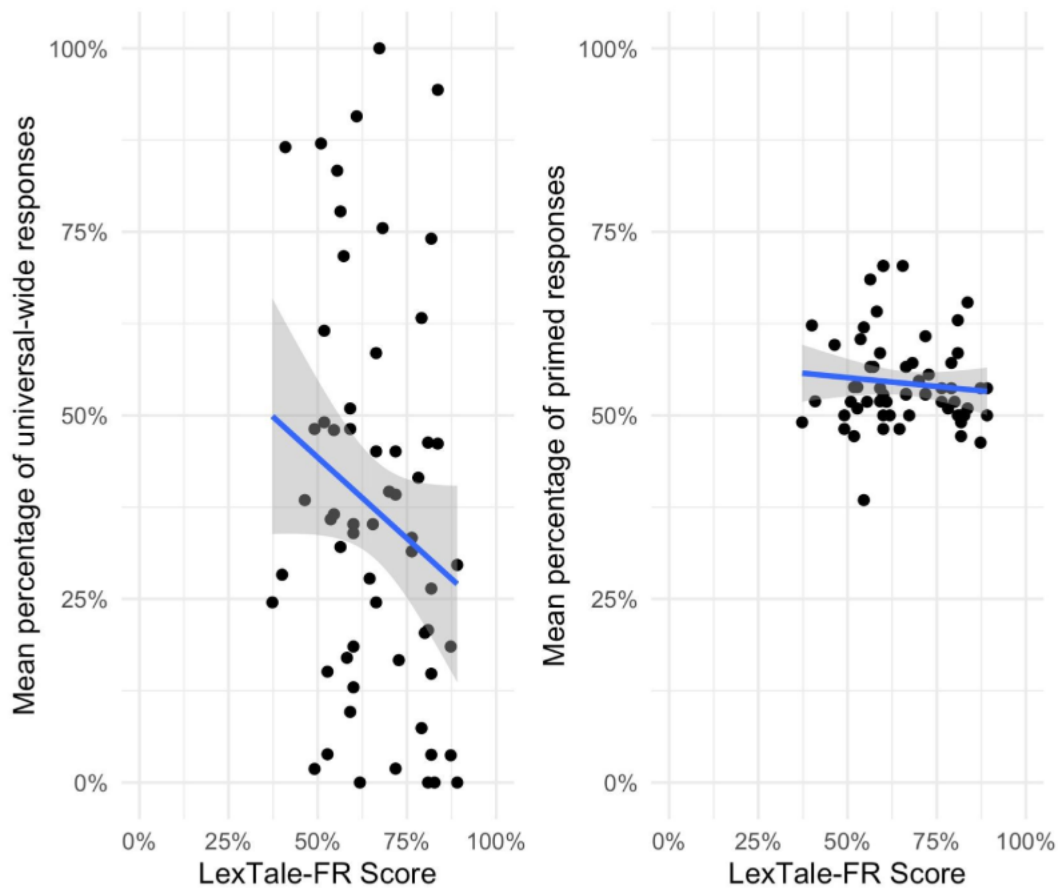


*Figure 6. The participants' mean rate of universal-wide target responses (left panel) and of primed target responses (universal-wide in the universal-wide prime condition and existential-wide in the existential-wide prime condition; right panel) in function of LexTale-FR scores in Experiment 3.*

Thus, the results of Experiment 3 showed that priming of logical representations persists from the L1 onto the L2. This indicates that bilinguals make use of shared logical representations if the logical representation is constructed in the L1. Moreover, the strength of the between-language logical representation priming effects in this experiment was not influenced by L2 proficiency. This finding suggests that the L2 proficiency of the bilingual does not modulate the sharedness of bilingual logical representations (at least when these logical representations involve quantifiers that have much semantic overlap in the two languages involved). However, it should be emphasised that the results regarding L2 proficiency should be considered as exploratory, as a sample of 60 participants may be too small for an analysis on the level of individual differences.

## 5. Experiment 4: L2-L2 priming

In Experiment 3, the prime trials were presented in the participants' L1. Therefore, this experiment does not show whether logical representations that are constructed in the L1 are comparably strong as those constructed in the L2. We addressed this question in Experiment 4, where we investigated priming within the L2.

### 5.1. Method

#### *5.1.1. Participants*

As in Experiment 3, the participants were required to be L1 speakers of Dutch who speak French as an L2. Eighty-eight further participants took part in the experiment and received a small payment (€10) or course credit for their participation. Of these 88 participants, 13 were removed because they answered more than 10% of the unambiguous filler trials incorrectly, 5 were removed because they guessed the goal of the experiment and 6 because they reported that Dutch was not their L1. Thus, the data of 64 participants are included in the final analyses.

The mean age of L2 French acquisition of the included 64 participants was 10 years old (SD = 2.0, range: 0-14). One participant reported to have acquired French from birth. Moreover, of the included participants, 15 studied French at university level, and 10 took a course in French as part of a higher vocational training course. The other 39 participants have not studied French in higher education. Table 2 reports information on the participants' age of French L2 acquisition, proficiency in L2 French, and daily use of each language. For more detailed information on the participant characteristics of Experiment 4, see Appendix C or the participant characteristics data available at https://osf.io/ysgx4/)

#### *5.1.2. Materials*

The materials were identical to those of Experiment 2b.

#### *5.1.3. Procedure*

The procedure was identical to Experiment 3: The participants completed the sentence-picture matching task first, then filled in the LexTale-FR test, and finally completed the short language background questionnaire. The instructions of the sentence-picture matching task and of the LexTale-FR test were given in Dutch, as were the questions of the language background questionnaire.

### *5.1.4. Data treatment and analyses procedure*

The data treatment and analyses procedure were identical to those in Experiment 3.

## 5.2. Results and discussion

We excluded 60 target responses in the existential-wide condition (3.47% of all target responses in the existential-wide condition) and 89 target responses in the universal-wide condition (5.15% of all target responses in the universal-wide condition) from the analyses due to incorrect answers in the preceding prime trials.

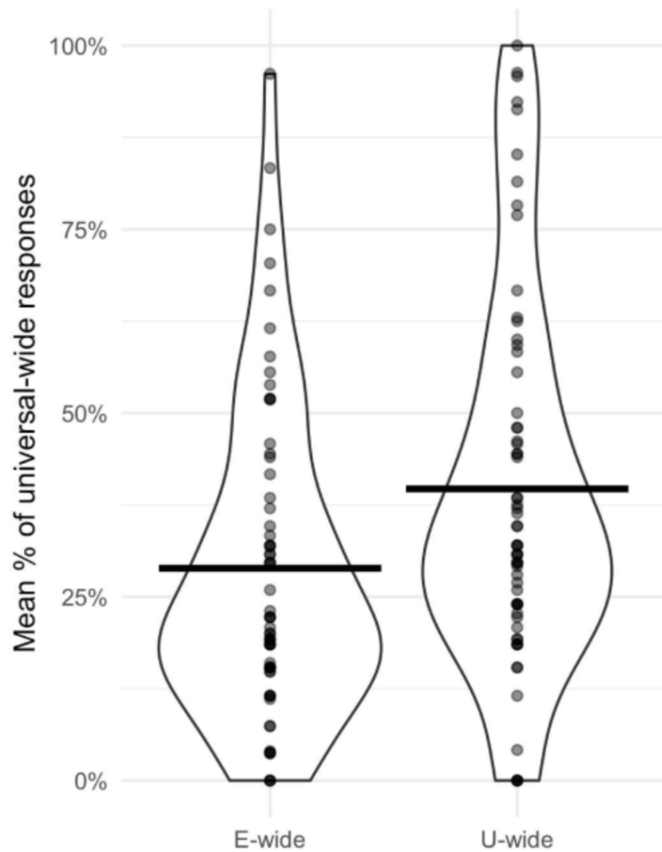


*Figure 7. The participants' mean percentage of universal-wide responses on the target trials in Experiment 4. The labels* E-wide *and* U-wide *denote the two prime conditions (existential-wide and universal-wide). The dots in this plot denote the overall mean response rate of the individual participants and the black horizontal lines represent the overall mean response rate. The width of the outlined area represents the proportion of the data located at that point.*

Figure 7 shows the percentage of universal-wide responses in each Prime Condition. The participants selected the universal-wide response more often after a universal-wide prime trial than after an existential-wide prime trial, a priming effect of 11%. The analyses showed that the effect of Prime Condition was significant ($\chi^2(1) = 18.88$, $p < 0.001$).

Regarding L2 proficiency, Table 2 shows that the mean score on the LexTale-FR test was 56% of the stimuli correct (SD: 9.81%, range: 18% - 75%)[5]. The bilingual participants that participated in Experiment 4 seemed to be less proficient in L2 French than those who participated in Experiment 3. A Kruskall-Wallis test showed that this difference was significant, both when L2 proficiency is measured in terms of LexTale-FR scores ($\chi^2(1) = 961.1$ $p < 0.001$) and in terms of self-ratings ($\chi^2(1) = 339.6$, $p < 0.001$). This difference in L2 proficiency between the participants of Experiment 3 and 4 may result from the fact that more people who studied French at a university level participated in Experiment 3 than in Experiment 4 (28 in Experiment 3 vs. 15 in Experiment 4). The analyses revealed no effect of LexTale-FR score on Target Response ($\chi2(1) = 0.262$, $p = 0.609$). This result is plotted in the left panel of Figure 8. Moreover, there was no significant interaction between LexTale-FR scores and Prime Condition ($\chi2(1) = 0.452$, $p = 0.501$). These results are plotted in the right panel of Figure 8.

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[5] As in Experiment 3, a Kendall's rank correlation test revealed a significant positive correlation between LexTale-FR score and the self-ratings on French proficiency ($\tau = 0.252$, $p < 0.001$)

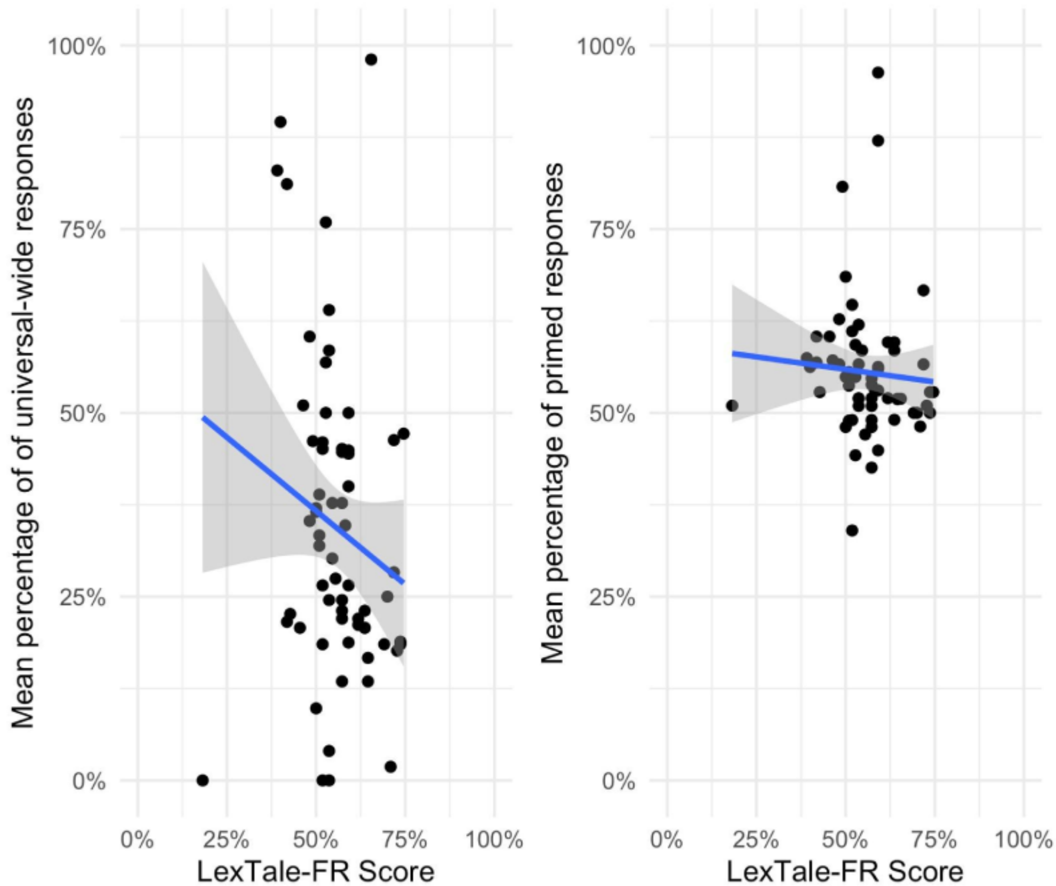


*Figure 8.* *The participants' mean rate of universal-wide target responses (left panel) and of primed target responses (universal-wide in the universal-wide prime condition and existential-wide in the existential-wide prime condition; right panel) in function of LexTale-FR scores in Experiment 4.*

Thus, the exploratory results on L2 proficiency suggest that the strength of logical representation priming within the L2 observed in this experiment is not dependent on L2 proficiency. More important, however, is the observation that there is priming of logical representations in L2 comprehension. This finding indicates that logical representations constructed in the L2 are strong enough to affect subsequent language processing in the L2, which mirrors the results observed in L1 language comprehension (Feiman & Snedeker, 2016; Raffray & Pickering, 2010).

## 6. Combined analyses of experiments 2-4: Prime Direction

Our experiments have shown priming of logical representations within the L1 (9% in Dutch, 6% in French), from the L1 onto the L2 (8%), and within the L2 (11%). In order to investigate whether the strength of priming is similar across these experiments, we conducted analyses on the combined data of the priming experiments (Experiment 2-4). For this analysis, we constructed a logit mixed-effects model on the combined dataset of Experiments 2-4. This model included Target Response as the binomial dependent variable, and Prime Condition and Prime Direction as the predictor variables. As in the previous analyses, Prime Condition was a two-level factor (*universal-wide* and *existential-wide*). Prime Direction was a three-level factor (*L1-L1 priming*, *L1-L2 priming*, and *L2-L2 priming*). Similar to all previous described analyses in this paper, the random effects structure was maximal following Barr et al. (2013). The two categorical predictor variables were deviation coded. Subsequent post-hoc pairwise comparisons to contrast the different levels of Prime Direction were carried out using the *phia* package in *R* (Rosario-Martinez, 2015)

A Type III Wald $\chi^2$ test on the fitted model showed a significant main effect of Prime Condition, ($\chi^2(1) = 24.81$, $p < 0.001$) but no main effect of Prime Direction ($\chi^2(2) = 0.19$, $p = 0.912$). Importantly, there was no significant interaction between Prime Condition and Prime Direction ($\chi^2(2) = 1.23$, $p = 0.540$). These findings suggest that the strength of logical representation priming was comparable in all our experiments. Thus, the direction of priming does not seem to substantially affect the strength of the priming effect. This finding suggests that bilingual logical representations are shared, and not merely connected, as within-language priming (both in the L1 and in the L2) is similar to between-language priming of logical representations (as observed by Kantola & van Gompel, 2011 for bilingual syntactic representations). If bilingual logical representations were merely connected between languages, between-language priming would be caused indirectly. Such an account would predict smaller between-language priming than within-language priming, which is not observed in our results.

However, there may be an alternative account for these priming effects in terms of *visual priming*. On that account, participants are more likely to select a particular picture because it visually resembles the picture selected in the preceding prime trial. This account was addressed in Experiment 4 of the study by Raffray and Pickering (2010). In their experiment, doubly quantified prime sentences were replaced by non-ambiguous generic statements that did not contain quantifiers (e.g., *Kids like to climb trees*). This experiment revealed no effect of visual priming. As we constructed additional stimulus materials, the next experiment addresses this issue again. We decided to test the influence of visual priming using a non-linguistic visual search task, as reported below.

## 7. Experiment 5: Visual priming

Experiments 2–4 showed effects of priming in the target response choice. However, not only linguistic representations are susceptible to priming. Visual stimuli are also processed with more ease after exposure to a similar stimulus. Therefore, our findings from the previously reported experiments can alternatively be interpreted in terms of visual priming. According to this explanation, the similarities between the response pictures that corresponded to the same interpretation of the test sentence in the prime and target trials triggered the observed priming effect. Thus, the participants tended to select the (for instance) universal-wide response picture after a universal-wide prime trial because that picture was visually similar to the picture they had just selected in the preceding prime trial. This alternative explanation is considered in Experiment 5, which had the form of a non-linguistic visual search task.

## 7.1. Method

### *7.1.1. Participants*

Because we wished to ensure the experiment had enough power to detect even a relatively small effect of visual priming, we increased the number of participants. We recruited 105 further participants who were all first-year psychology students at Ghent University (mean age: 19 years, range: 17 – 29 years), and received course credits for their participation. Of these 105 participants, 6 were removed from further analysis because they guessed the purpose of the experiment in the post-experimental debriefing. Thus, 99 participants were included in the further analysis.

### *7.1.2. Materials and procedure*

Experiment 5 used similar materials as Experiments 2-4, but all sentences were replaced by small visual figures (e.g., of a ladder, see Figure 9). The task was to select the response picture that contained this small figure. The to-be-searched-for figure was present in only one of the two response pictures in the prime trials. This way, the participants were forced to select the same picture on the prime trials as in Experiment 2-4. In the subsequent target trials, however, the figure was present in both response pictures. Here, the figure always showed the referent of the subject noun of the test sentences in Experiments 2-4. Thus, similar to Experiments 2-4, the participants were forced to choose one of the two response pictures in the prime trials, but they could freely choose between the two possible response pictures in the target trials. The prime trials were again presented in two prime conditions: the *existential-wide* condition and the *universal-wide* condition. In the universal-wide prime trials, the two response pictures were the same as those in the universal-wide prime trials in Experiments 2-4. Likewise, the two response pictures in the existential-wide condition were the same as those in the existential-wide prime trials in Experiments 2-4. It must be noted that this experiment was non-linguistic. Nevertheless, we still refer to the two prime conditions as universal-wide and existential-wide, as the use of these labels allows for clearer comparison with the previous experiments.

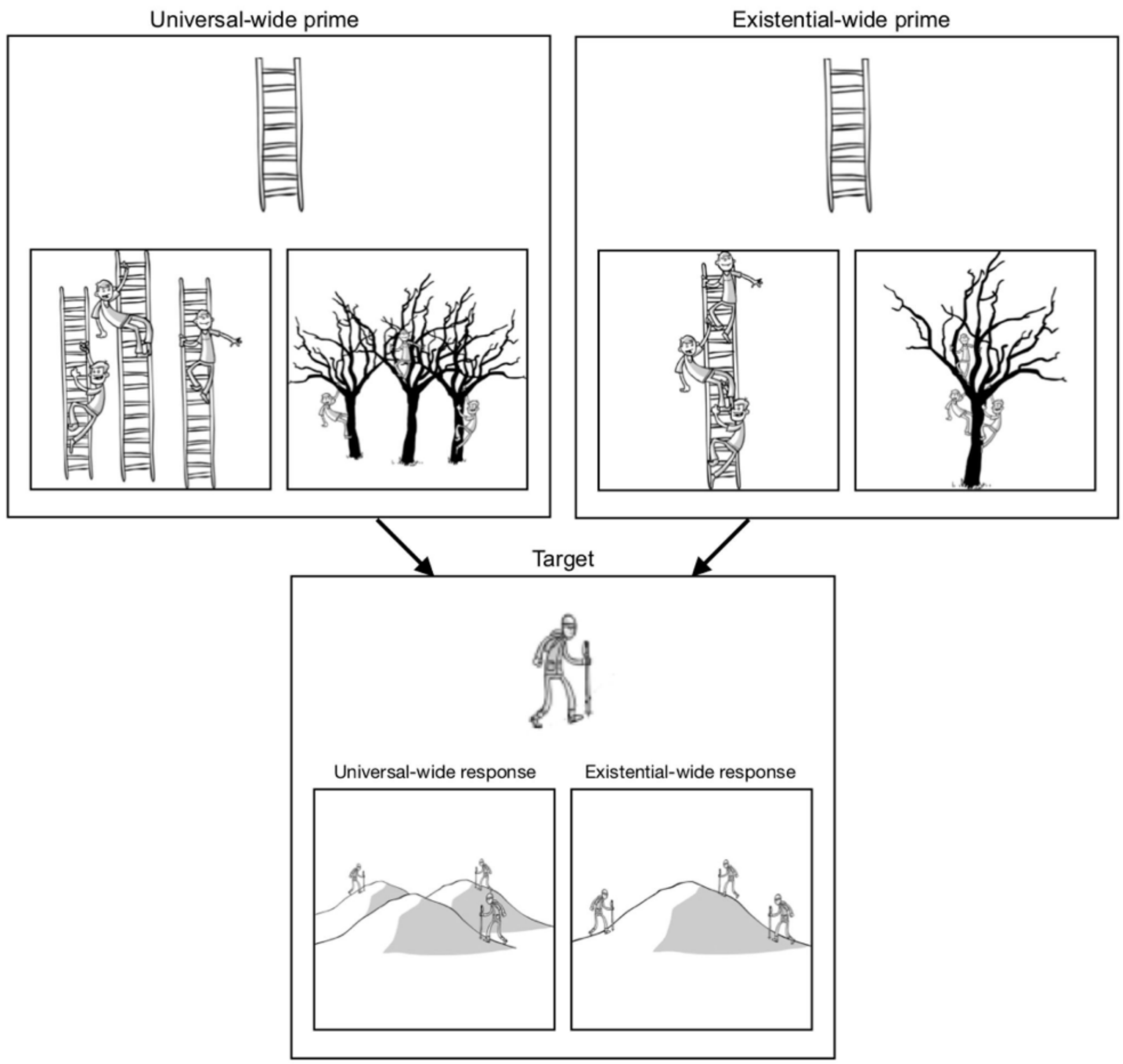


*Figure 9. Sample prime and target trials in the two prime conditions of Experiment 5. The participant needed to search the small visual item in the two response pictures and select the response picture that contained this item. The labels 'Universal-wide response' and 'Existential-wide response' were not shown to the participants but were added to this figure for the ease of illustration.*

The task in the filler trials was similar. The participants searched for a visual figure in two response pictures and select the response picture that contained this figure. The response pictures in these filler trials were the same as those in the filler trials in Experiment 2-4. The target for visual search was present in only one of those two response pictures. The rest of the procedure was identical to Experiment 2-4

#### *7.1.3. Data treatment and analyses procedure*

The data treatment and analysis procedure were similar to those in Experiment 2, with the exception that there was no predictor variable of Language.

### 7.2. Results and discussion

As in the previous experiments, a target response was discarded if the participant did not select the intended picture in the previous prime trial. Seventeen target responses were discarded in the universal-wide condition (0.61% of all responses in the universal-wide condition) and fifteen target responses were discarded in the existential-wide condition (0.54% of all responses in the existential-wide condition) for this reason.

The results of Experiment 5 are shown in Figure 10. The participants selected a universal-wide response slightly more often after a universal-wide prime trial than after an existential-wide prime trial (a numerical difference of 1%). There was no significant effect of Prime Condition ($\chi^2(1) = 0.12$, $p = 0.733$). It thus seems that participants were not (or at least not considerably) guided by visual similarities between prime and target pictures in their target response choice.

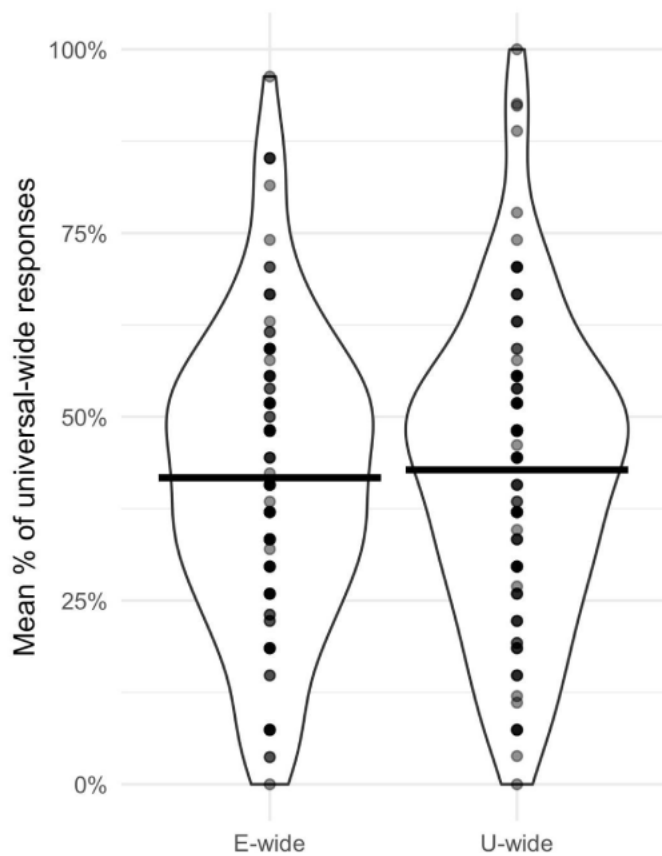


*Figure 10. The participants' mean percentage of universal-wide responses on the target trials in Experiment 5. The labels* E-wide *and* U-wide *denote the two prime conditions (existential-wide and universal-wide). The dots in this*

*plot denote the overall mean response rate of the individual participants and the black horizontal lines represent the overall mean response rate. The width of the outlined area represents the proportion of the data located at that point.*

To test whether the strength of logical representation priming observed in Experiment 2 and 4 differs from the strength of visual priming observed in the current experiment, we conducted analyses on the combined data of Experiments 2-5. These analyses were carried out following the procedure we previously used to compare the priming effects of Experiments 2-4. In this analysis, however, Prime Direction was a four-level factor (*L1-L1, L1-L2, L2-L2*, and *visual*). This combined analysis showed a significant main effect of Prime Condition ($\chi^2(1) = 35.40$, $p < 0.001$), Prime Direction ($\chi^2(1) = 11.71$, $p < 0.01$) and a significant interaction between Prime Condition and Prime Direction ($\chi^2(3) = 31.38$, $p < 0.001$). Planned post-hoc pairwise comparisons using the *testInteractions* command from the *phia* package (Rosario-Martinez, 2015) showed that priming was greater in L1-L1 priming than in visual priming ($\chi^2(1) = 18.20$, $p < 0.001$), in L1-L2 priming than in visual priming ($\chi^2(1) = 13.60$, $p < 0.001$), and finally also in L2-L2 priming than in visual priming ($\chi^2(1) = 22.93$, $p < 0.001$). These results thus indicate that the observed priming effects were stronger in Experiments 2-4 than in Experiment 5, which further suggests that the logical representation priming observed in Experiments 2-4 is not driven by visual priming.

## 8. General discussion

We have shown across multiple experiments that people tend to perseverate in their interpretation of Dutch or French *all...a* sentences, both within one language and between two languages. Experiment 1 showed no difference between Dutch and French in the spontaneous interpretation of such sentences by native speakers. Experiment 2 showed that Dutch and French native speakers tend to perseverate in their interpretation of doubly quantified sentences in their native language when we influence their response choice by including prime trials. This finding provides further evidence for the hypothesis that people construct logical representations containing semantic scope assignment in language comprehension (Feiman & Snedeker, 2016; Raffray & Pickering, 2010) and also shows that priming of logical representations can be generalised to other languages. In Experiment 3, we observed that bilinguals persisted in their interpretation of doubly quantified sentences from the L1 onto the L2. This finding indicates that bilinguals have shared logical representations in language comprehension. Experiment 4 showed that bilinguals also tended to perseverate in their interpretation of the test sentences when both prime and target trials were given in the L2. Moreover, this priming effect was similar in strength to those observed in Experiments 2 and 3, which suggests that logical representations constructed in the L2 are comparable to those constructed in the L1. Our results show that priming of logical representations is comparable within the L1, from the L1 onto the L2, and within the L2. This finding suggests that bilingual logical representations are fully shared between two languages. (e.g. Kantola & van Gompel, 2011). If bilingual logical representations were merely connected across different languages, we would expect priming between languages to be weaker that priming within one language (e.g. Van

Gompel & Arai, 2018). Finally, Experiment 5 indicated that an alternative explanation in terms of visual priming is not applicable to the above-mentioned priming effects (as previously observed by Maldonado et al., 2017 and Raffray & Pickering, 2010).

Thus, the findings listed above indicate firstly that bilingual logical representations are fully shared between languages in language comprehension, at least if the scopally ambiguous sentence under discussion has a similar surface structure in both languages and involves quantifier words that are close or direct translation equivalents of each other. We will elaborate this finding in Section 8.1. Secondly, we will discuss whether French and Dutch may exhibit cross-linguistic differences in interpreting *all...a* sentences in Section 8.2. Thirdly, our results are also relevant to our understanding of representations of sentence meaning in general. Most notably, our results suggest that logical representations are not language-specific. This observation can be reconciled with an account that assumes that logical representations are not linguistic but conceptual in nature (as discussed in the Introduction). We will discuss the implications of our results with respect to our general understanding of logical representations in sections 8.3 and 8.4.

**8.1. Bilingual logical representations are shared**

Let us first consider the main finding of the study reported in this paper: Bilingual logical representations seem to be fully shared between languages (again, at least if the sentence under discussion has a similar surface structure in both languages and contains quantifier words that are close or direct translation equivalents). A similar organisation of bilingual linguistic representations has been hypothesised with regard to syntactic representations and lexico-semantic representations. An explanation for the shared nature of bilingual linguistic representations is in terms of *cognitive economy*: If bilingual representations are shared, they only need to be represented once (Hartsuiker et al., 2004). Our findings extend this hypothesis on cognitive economy in bilingual representations to logical representations.

A possible alternative to our interpretation in terms of shared bilingual logical representations would be an explanation in terms of *translation*. According to that explanation, our bilingual participants translated the prime and/or target sentences from their L2 into their L1 and therefore processed the sentences in the L2 through translation equivalents in the L1. If this were the case, logical representations are in fact constructed in the L1, and not in the L2, in L2 comprehension. Although we cannot rule out such an explanation, there is good reason to believe that this explanation does not bear out, based on previous studies on bilingual processing. As will be discussed below, these studies have shown that (I) translation is cognitively effortful and therefore unlikely to replace reading for comprehension in the L2, (II) *all* is one of the earliest quantifiers learnt and therefore unlikely to rely on translation to be understood, and (III) a translation account is inconsistent with results from structural priming studies in production.

First, previous studies have shown that processing of the L2 through translation in the L1 requires more effort than processing a L2 sentence directly through the L2. For instance, Macizo and Bajo (2004) observed that online language comprehension of sentences in the L2 was slower (measured with a self-paced reading task) if the sentences needed to be translated in the L1 compared to when such translation was not required (see also Ruiz, Paredes, Macizo & Bajo, 2008). Second, the quantifier *all* has been argued to be the most primitive form of universal quantification (Gil, 1995). Therefore, it is likely that *all* is acquired relatively early in language acquisition (see for instance Brooks & Braine, 1996 for the acquisition of quantifiers in the L1). As many of our participants were fairly proficient in French, we consider it unlikely that they relied on translation into the L2 in the comprehension of the stimuli. Third, Bernolet et al. (2007) tested for structural priming of adjectival modifications of nouns in Dutch, English, and German (e.g., ‘the blue shark’ vs. ‘the shark that is blue’). Such priming occurred between Dutch and German, which both have verb-final word order in the post-nominal construction (‘de haai die blauw is’, ‘der Hai der blau ist’, *lit.* ’the shark that blue is’) but not between Dutch and English or vice versa, which have different word orders. It thus seems that word order matters for cross-linguistic priming, in contrast to what a translation account would predict (as translation would lead effectively to Dutch-Dutch priming, hence with realigned word order). For all of these reasons, we believe that an account in terms of translation is not compelling.

We thus interpret our findings in terms of an account in which logical representations are shared across languages. However, we reiterate that bilinguals form a very heterogeneous group. Therefore, we acknowledge there may be limitations to the extent with which we can generalise our conclusions to all bilinguals. Previous studies have shown that certain aspects of bilingualism can influence the organisation of bilingual linguistic representations (such as language dominance and L2 proficiency, e.g. Cai et al., 2011; Hartsuiker & Bernolet, 2017; Kootstra & Doedens, 2016). Future research may investigate whether these aspects of bilingualism influence the organisation of bilingual logical representations as well. In our study, we explored possible influences of L2 proficiency on the organisation of bilingual logical representations. These analyses suggest that the sharedness of bilingual logical representations is not influenced by L2 proficiency. Though it should be kept in mind that this finding is only exploratory, it is interesting that our results regarding the influence of L2 proficiency seem to be in contrast with previous studies of both syntactic and lexico-semantic representations. With respect to such representations, L2 proficiency has been identified as an important influence on whether bilingual representations are shared (Grainger et al., 2010; Hartsuiker & Bernolet, 2017). It must be noted, however, that the studies that focused on the role of L2 proficiency in cross-linguistic priming cited above predominantly studied this question in language production, whereas we studied cross-linguistic priming in language comprehension.

An important difference between language comprehension and production is that people can often bypass deep processing of the sentence in comprehension but not in production (Tooley & Bock, 2014; Segaert, Kempen, Petersson & Hagoort, 2013). This is also the case in the sentence-matching tasks reported in this paper. In the prime trials, the non-matching pictures either displayed the wrong agent or the wrong theme. Participants therefore only needed to match the noun content of the sentence to the pictures. Crucially, the incorrect picture never displayed another event than the one denoted by the verb in the prime sentences. Full parsing of verb information was thus not required to complete the task. As the participants could bypass deep processing of the sentences, L2 proficiency may not have been an important moderator of cross-linguistic priming in this study.

Summing up, our results indicate that bilingual logical representations are fully shared between languages. Moreover, our results do not indicate that proficiency in the L2 influences the organisation of bilingual logical representations. However, further research is required to see whether this null relationship replicates.

### 8.2. Cross-linguistic differences in interpreting *all...a* in Dutch and French

As noted in the Introduction, the construction of logical representations depends on the mapping of the sentence's form onto its underlying conceptual representation of the sentence's meaning. This mapping seems language-specific, as there may be cross-linguistic differences in the interpretation of scopally ambiguous sentences (Beck & Kim, 1997; Katsos & Slim, 2018; Szabolcsi, 2002; Szabolcsi & Haddican, 2004).

Our experiments provided mixed results with regard to possible cross-linguistic differences in the preferred interpretation of *all...a* sentences between Dutch and French. In the baseline measures collected in Experiment 1, native speakers of both Dutch and French showed a bias towards the existential-wide interpretation of *all...a* sentences. Importantly, there was no evidence for a strong difference in interpretation of these sentences between Dutch and French, although this bias was numerically slightly stronger in French than in Dutch. In Experiment 2, on the other hand, this bias towards the existential-wide interpretation was considerably stronger in French than in Dutch. This observation was unexpected, because we predicted no cross-linguistic differences in the interpretation of these sentences, given the large meaning similarities between the quantifiers involved (Gil, 1995).

A speculative explanation for such a possible bias toward the existential-wide reading of the test sentences in French is that the existential quantifier *un(e)* is a homonym with the numeral quantifier *one*. Possibly, some French-speaking participants therefore interpreted *un(e)* as *one* in the test sentences, which may result in a stronger preference for the object phrase to refer to a single referent (as in the existential-wide reading of the test sentences; e.g. Kurtzman & MacDonald, 1993). In Dutch, the existential quantifier *een* (pronounced as [ən]) is a near-homonym and homograph of the numeral one (*één* in Dutch, pronounced as [e:n]). Thus, the translations of *a* and *one* in French are completely homonymous, which is not the case in Dutch. Therefore, there might be a stronger tendency to interpret the French *un(e)* as referring to a single entity than the Dutch *een*.

However, it must be emphasised again that our experiments did not reveal conclusive results on the preferred interpretation of *all...a* sentences in French: We observed a difference in interpreting *all...a* sentences between Dutch and French in Experiment 2, whereas we did not observe such a difference in Experiment 1. Therefore, future research is needed to investigate whether this cross-linguistic difference between Dutch and French in interpreting *all…a* sentences can be replicated

### 8.3. Scope or Distributivity?

So far, we have interpreted our results in terms of semantic scope assignment. However, we note that one may alternatively posit an explanation in terms of *quantifier distributivity*, which is a property that quantifiers may or may not have. Quantifiers that are *distributive* typically assign a predicate to each individual member of the set it quantifies over (e.g. Champollion, 2017; Dowty, 1987). In English, the quantifiers *each* and *every* are distributive quantifiers. These quantifiers are ungrammatical when paired with a collective predicate (which must necessarily be assigned to a set as a whole), such as *to gather* (e.g., *Each/Every child slept,* but **Each/Every businessman gathered in the meeting room*). A *non-distributive* quantifier like *all*, on the other hand, can be paired with both a distributive and a collective predicate (e.g., *All children slept*, and *All businessmen gathered in the meeting room*).

As motivated in the description of Experiment 1, we chose to use translation equivalents of the non-distributive quantifier *all* in the experiments reported in this paper. Before describing the possible implications of this choice with respect to the interpretations of our findings, let us first elaborate this motivation in more detail. Recall that Feiman and Snedeker (2016) observed that priming of logical representations only emerges if the prime and target trials contain quantifiers with the same combinatorial (i.e. scope-taking) properties. Our interest was not only in priming of logical representations within one language but also between two languages (Dutch and French). Therefore, it was important to consider possible cross-linguistic differences between quantifiers in Dutch and French and use quantifiers that were direct (or at least very close) meaning equivalents of each other.

Distributive quantifiers do not form one uniform group of quantifiers in terms of their semantic properties. As noted, English has two distributive quantifiers: *each* and *every*. Of these two quantifiers, *each* is more strongly distributive than *every* (as *every* may also assign a predicate to multiple subgroups of the quantified set; Tunstall, 1998). Moreover, *each* also has a stronger tendency to take wide scope than *every* (Feiman & Snedeker, 2016; Ioup, 1975). There are also two distributive universal quantifiers in Dutch: *elke* and *iedere*. However, it is not clear whether these two quantifiers are more-or-less synonymous to each other, or whether they may also display differences in their combinatorial semantics (Dik, 1975; Haeseryn, 1997). French also contains two distributive universal quantifiers, *chaque* and *tout*, but their meaning and distribution are completely different compared to Dutch and English. For instance, while *chaque* is used with closed, predefined classes of items, *tout* is constructed with open-ended classes, as shown in *Chaque/??Tout élève de la classe* ('Every student of the class') (Kleiber & Martin, 1977; for a recent update in the framework of formal semantics, see Corblin, 2018). This gives rise to the question of how these different English, Dutch and French distributive quantifiers might map onto each other with respect to their combinatorial properties. Because of the variation between different distributive quantifiers (which may give rise to cross-linguistic variation as well), we chose not to use distributive quantifiers in our experiment. Instead, we used (translations) of *all*, as this non-distributive universal quantifier seems to exist in many languages (Gil, 1995).

However, a pitfall of our choice to use the non-distributive quantifier *all* with respect to the purposes of our study is that these quantifiers thus allow a collective reading of the quantified set. Therefore, it may be the case that the interpretation which we referred to as the existential-wide interpretation does not necessarily involve the scope configuration in which *a* takes wide scope over *all.* Rather, this interpretation may involve a collective reading of the universally-quantified noun phrase. Following this explanation, the observed effects of priming are not due to perseverance of scope assignment between prime and target but to perseverance of a collective or distributive reading of the universally-quantifier subject phrase.

Our results cannot rule out such an interpretation in terms of distributivity rather than scope, but there are reasons to assume that the interpretation in terms of semantic scope configurations should be preferred. The first relates to the visual materials in our experiments. Feiman and Snedeker (2016), who used similar response pictures in their sentence-picture matching tasks as we did (those from Raffray & Pickering, 2010), argued that the response pictures in the prime and target trials most often displayed situations in which the sentence's agents (denoted in the universally-quantified subject phrase) act independently on the sentence's theme (denoted in the existentially-quantified object phrase). For instance, in the picture that displays the existential-wide interpretation of *All hikers climb a hill* (see Figure 1), each hiker is climbing the hill independently from the other hikers. Importantly, they are not displayed as a group that engages in a joint activity (i.e. they are not climbing the hill together). In such a case, the existential-wide analysis of the sentence is more obvious than the 'collective version' of the universal-wide interpretation. In the case of an existential-wide interpretation, there is one theme on which all agents act independently, which corresponds to the picture. In the case of a collective interpretation, however, there is a group of agents that act on one theme collectively, which is not the situation depicted in the picture. Closer inspection of our stimuli showed that 10 of the 54 prime-target sets involve response pictures that show a collective group of agents (e.g., *All boys ride an elephant*; see Appendix D and the stimuli materials available at https://osf.io/ysgx4/). However, descriptively, the items that involved such pictures did not seem to behave differently.

Secondly, many of the verbs that we used in our experiments do not denote actions that are performed by a group as a whole (e.g., *watch, shot, scold, tickle, hit, prod, point to, saw*). In case one of these verbs is interpreted as describing a group action (e.g., multiple soldiers prodding the same sailor together), the event described in the verb involves multiple independent (sub-)events (e.g., multiple soldiers are prodding the same sailor at the same time, but independent from each other). Thus, these types of verbs do imply a certain level of distributivity in the events these verbs describe (and therefore, distributive quantifiers may even be used to describe such group actions; see De Koster, Spenader, Dotlačil & Hendriks, 2020). Again, this makes an interpretation of our results purely in terms of quantifier distributivity less likely. However, 2 of the 12 verbs that we used can refer to events that may involve joint action: *carry* and *push*. In case these verbs are interpreted as denoting an action that is performed by a group as a whole, the event does not involve multiple completely independent (sub-)events. Rather, the group of agents denoted in the subject noun do not act independently from each other but work together in order to perform the action denoted by the verb. Thus, the agents involved in the event denoted by these verbs can be interpreted as completely collective. Descriptively, there was no noticeable difference in behaviour of these different types of verbs. Moreover, given that the vast majority of the verbs that we used do not describe such collective events, an interpretation purely in terms of distributivity does not seem to hold.

Thus, although we cannot fully rule out an explanation in terms of distributivity rather than scope, most of our stimuli do correspond better to an existential-wide analysis of the sentence than to a 'collective' universal-wide one. A final note on the distinction between semantic scope and distributivity with respect to our results is that both phenomena are assumed to be (I) inter-correlated and (II) represented at the level of logical representations. With regard to the first point, quantifier words differ in their inherent tendencies to take wide scope: Distributive quantifiers such as *each* and *every* have a stronger tendency to take wide scope than non-distributive quantifiers such as *all* (Feiman & Snedeker, 2016; Ioup, 1975). This explains why our results showed a greater overall preference for the existential-wide reading than for the universal-wide reading of our test sentences, as these sentences contained translations of *all*.

With regard to the second point: Both semantic scope and distributivity deal with the way the meaning of a quantifier may be combined with other elements in the sentence in order to construct complex meaning representations. Therefore, distributivity, like the configuration of semantic scope, is assumed to be represented at the level of logical representations (Champollion, 2017; Link, 1987; Maldonado et al., 2017). Thus, our main finding that bilingual logical representations are shared still holds under the alternative explanation in terms of quantifier distributivity.

### 8.4. Logical representation as part of wider semantic or conceptual representations?

Thus, the previous section describes that our results cannot disambiguate possible different sources of information that are represented in logical representations. Given this point, it is important to bear in mind that we know relatively little about the architecture of mental logical representations: It is not clear whether logical representations are a distinct level of representations or whether these representations are integrated with other representations of sentence meaning (e.g., those that involve event structure representations or information structure representations; Branigan & Pickering, 2017), and it is even unclear whether these logical representations are linguistic at all.

It is important to note that we repeated the verb in the prime and target sentences, in order to increase our chances to observe effects of priming (following Raffray & Pickering, 2010). However, this does mean that not just the quantifier content was shared between prime and target, but also the verb semantics. Therefore, the priming effects we observed may have been enhanced by overlap in the verb event semantics between prime and target, meaning that we cannot disambiguate between effects of priming of logical representations from priming of more general (verb) event representations (Ziegler, Snedeker & Wittenberg., 2018). Feiman and Snedeker (2016), however, did test the effect of verb repetition in one of their experiments. They observed effects of logical representation priming both when the verb was repeated between prime and target and when the verb was different between prime and target. This observation suggests that priming of logical representations does not seem to be dependent on verb repetition. Nevertheless, the effects of logical representation priming observed by Feiman and Snedeker descriptively decreased when the verb in prime and target differed. Thus, effects of logical representation priming might be somewhat boosted by verb repetition.

Thus, it is unclear whether logical representations are distinct from other levels of semantic representations. Moreover, as already stated in the Introduction, the jury is also still out on whether these logical representations are linguistic or conceptual in nature (e.g. in the form of mental models; Fodor, 1982; Johnson-Laird et al., 1989; Johnson-Laird, 1983). Our results can be reconciled with both accounts on the nature of logical representations. In case logical representations are conceptual representations of the sentence meaning, they are per definition language-non-specific and thus used in the processing of both languages a bilingual knows. Moreover, the tentative result that the organisation of logical representations is not influenced by L2 proficiency also fits such an account of logical representations: If logical representations are conceptual representations, then linguistic factors such as L2 proficiency would not influence the architecture of bilingual logical representations.

However, we argued in the Introduction that the construction of logical representations is (at least) language-dependent because the construction of logical representations is influenced by language-specific dependencies. Recall that logical representations are sensitive to subtle lexical differences between different quantifiers (Feiman & Snedeker, 2016). This observation suggests that logical representations are constructed on the basis of quantifier-specific lexical information and that logical representations contain linguistic information. Moreover, cross-linguistic differences in interpreting scopally ambiguous sentences further indicate that the construction of logical representations is dependent on language-specific grammatical or lexical properties (e.g. Beck & Kim, 1997; Katsos & Slim, 2018; Szabolcsi, 2002).

Given these language-specific dependencies in the construction of logical representations, an interesting avenue for future research is whether cross-linguistic differences affect the organisation of bilingual logical representations. These investigations could further elucidate the organisation of bilingual logical representations, but possibly also unravel to what extent logical representations are language-dependent. First, cross-linguistic differences in the construction of logical representation may arise due to cross-linguistic lexical differences. Feiman and Snedeker (2016) observed that logical representations constructed in L1 English are sensitive to meaning differences between different universal quantifiers (*each, every,* and *all*). As we discussed in the previous subsection, the meaning differences between these English quantifiers are not necessarily lexically encoded in other languages in the exact same way (Gil, 1995). Therefore, it is an interesting question whether second language speakers are as sensitive to the lexical differences between quantifier words as native speakers in constructing logical representations. Alternatively, they may experience L1 transfer in the construction of logical representations if there are lexical differences between quantifiers in their L1 and L2 (Grüter, Lieberman & Gualmini, 2010; Marsden, 2009). Such a study would give more insight into the nature of bilingual logical representations and whether bilingual logical representations differ from monolingual logical representations. Moreover, evidence for such cross-linguistic transfer in the construction of logical representations could elucidate the hypothesis that logical representations are language-dependent.

Second, cross-linguistic differences in the construction of logical representation may be due to cross-linguistic grammatical differences. In our experiments, the critical test sentences roughly shared the same syntactic structure in the two languages involved (Dutch and French). Though it is assumed that logical representations are separate from syntactic representations (Raffray & Pickering, 2010), the grammatical structure of a sentence can influence scope assignment in some cases. In Japanese and Korean, for instance, doubly quantified sentences are only ambiguous if the sentence involves the scrambled OSV word order. Such sentences are not ambiguous in the canonical SOV word order, because the object phrase cannot be assigned wide scope (Beck & Kim, 1997; see also Szabolcsi, 1997 for a discussion on grammatical restrictions on scope assignment in Hungarian). Future research may investigate whether such grammatical properties that influence scope assignment also influence the construction of logical representations and whether such cross-linguistic grammatical differences influence the shared nature of bilingual logical representations. Again, such an investigation provides further insight into possible cross-linguistic transfer in bilingual logical representations and the influence of language-specific grammatical dependencies in the construction of logical representations. Thus, studying the organisation of bilingual logical representations can elucidate the (language-specific) construction of logical representations, which enriches our understanding of logical representations in general.

## 9. Conclusion

The study reported in this paper showed that bilinguals have shared logical representations of doubly quantified sentences, at least if the structure of the sentence is similar, if the quantifier words involved are close or direct translation equivalents across the two languages, and if the sentence displays the same ambiguity across the languages under discussion. We explained these findings in terms of a language-dependent account of logical representations, though these findings can also be reconciled with an account of logical representations as non-linguistic.

## Acknowledgements

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**Appendix A: Summary of the output of all logit mixed-model analyses**

| Predictor | Coefficient | SE | Wald Z | *p*-value |
|---|---|---|---|---|
| Experiment 1: Baselines | | | | |
| (Intercept) | -0.581 | 0.285 | -2.042 | 0.041 |
| Language = French | -0.223 | 0.377 | -0.591 | 0.554 |
| Experiment 2: L1-L1 Priming | | | | |
| (Intercept) | -0.776 | 0.297 | -2.615 | 0.009 |
| Prime Condition = Universal-wide | 0.639 | 0.125 | 5.104 | < 0.001 |
| Language = French | -1.083 | 0.385 | -2.815 | 0.005 |
| Universal-wide : French | -0.229 | 0.189 | -1.212 | 0.226 |
| Experiment 2a: L1-L1 Priming in Dutch | | | | |
| (Intercept) | -0.791 | 0.312 | -2.534 | 0.011 |
| Prime Condition = Universal-wide | 0.646 | 0.122 | 5.294 | < 0.001 |

| | | | | |
|---|---|---|---|---|
| Experiment 2b: L1-L1 Priming in French | | | | |
| (Intercept) | -1.825 | 0.316 | -5.770 | < 0.001 |
| Prime Condition = Universal-wide | 0.352 | 0.170 | 2.071 | 0.038 |
| Experiment 3: L1-L2 Priming: Model with LexTale-FR score as predictor | | | | |
| (Intercept) | -1.189 | 0.281 | -4.239 | < 0.001 |
| Prime Condition = Universal-wide | 0.580 | 0.124 | 4.689 | < 0.001 |
| LexTale (centred score) | -3.492 | 1.885 | -1.852 | 0.065 |
| Universal-wide : LexTale-FR | -0.306 | 0.845 | -0.362 | 0.718 |
| Experiment 4: L2-L2 Priming: Model with LexTale-FR score as predictor | | | | |
| (Intercept) | -1.282 | 0.217 | -5.897 | < 0.001 |
| Prime Condition = Universal-wide | 0.669 | 0.154 | 4.345 | < 0.001 |
| LexTale (centred score) | -0.982 | 1.918 | -0.512 | 0.609 |
| Universal-wide : LexTale-FR | -1.083 | 1.611 | -0.672 | 0.501 |
| Comparison: Experiment 2-4 | | | | |
| (Intercept) | -1.242 | 0.183 | -6.801 | < 0.001 |
| Prime Condition = Universal-wide | 0.585 | 0.081 | 7.209 | < 0.001 |
| Type of Priming = L1-L2 | -0.005 | 0.167 | -0.029 | 0.977 |
| Type of Priming = L2-L2 | 0.077 | 0.194 | 0.396 | 0.692 |
| Universal-wide : L1-L2 | -0.066 | 0.088 | -0.754 | 0.451 |
| Universal-wide : L2-L2 | -0.039 | 0.103 | -0.383 | 0.702 |
| Experiment 5: Visual priming | | | | |
| (Intercept) | -0.400 | 0.132 | -3.036 | 0.002 |
| Prime Condition = Uwide | 0.025 | 0.072 | 0.342 | 0.733 |
| Comparison: Experiment 2-5 | | | | |
| (Intercept) | -1.015 | 0.139 | -7.301 | < 0.001 |
| Prime Condition = Universal-wide | 0.445 | 0.056 | 7.937 | < 0.001 |
| Type of Priming = L1-L2 | -0.205 | 0.154 | -1.335 | 0.182 |
| Type of Priming = L2-L2 | -0.122 | 0.182 | -0.674 | 0.500 |
| Type of Priming = Visual | -0.273 | 0.178 | -1.535 | 0.125 |
| Universal-wide : L1-L2 | 0.078 | 0.077 | 1.012 | 0.311 |
| Universal-wide : L2-L2 | 0.104 | 0.096 | 1.088 | 0.277 |
| Universal-wide : Visual | 0.239 | 0.093 | 2.583 | 0.010 |

**Appendix B: Participant characteristics Experiment 3 (priming from Dutch L1 to French L2)**

*Only the participants that were included in the final analyses of Experiment 3 are included in the table reported below.*

| | | |
|---|---|---|
| **Age** | mean: 21 years<br>SD: 3 years<br>range: 16 - 36 | 1 participant reported to be younger than 18; 5 participants reported to be older than 25 |
| **Age of French L2 Acquisition** | mean: 9<br>SD: 3.22<br>range: 0 - 15 | 10 participants reported an Age of Acquisition of L2 French below 9 years old. Of these 9 participants, 5 reported an Age of Acquisition of 0 or 1. One participant reported an Age of Acquisition older than 11 years old. |
| **Mean number of other L2s (besides French)** | 1.8 (0.91)[6] | |
| **Setting of French Acquisition** | Home/family: *n =6*<br>Education (Dutch-speaking school): *n =53*<br>Interaction with friends: *n* =2 | |
| **Primary setting of French use** | Education: *n* =44<br>Holiday: *n =2*<br>Interaction with friends/family: *n =1*<br>Home: *n =10*<br>Work: *n =2*<br>Never: *n =2* | |
| **Participants that have lived in a French-speaking country** | *n* =7 | Mean duration of stay: 6.7 months (SD: 3.5 months, range: 4 – 18 months) |
| **Mean estimated daily use** | | |
| Dutch (L1): | mean: 78%<br>SD: 16%<br>range: 25% - 100% | 8 participants reported to use Dutch less than 60% of the time in everyday life. 12 participants reported to use Dutch more than 90% of the time in everyday life. |

[6] The range of number of other L2s was 0-5; however, the participants could fill in a maximum of 5 other L2s, and therefore, the range may have been constricted by the questionnaire.

| | | |
|---|---|---|
| French (L2): | mean: 13%<br>SD: 12%<br>range: 0 % - 50% | 20 participants reported to use French less than 5% of the time in everyday life; 7 participants reported to use French more than 25% of the time in everyday life. |
| Other L2s: | Mean: 10%<br>SD: 13%<br>Range: 0% - 50% | |

**Appendix C: Participant characteristics Experiment 4 (priming within French L2)**

*Only the participants that were included in the final analyses of Experiment 4 are included in the table reported below.*

| | | |
|---|---|---|
| **Age** | mean: 20 years<br>SD: 4.8 years<br>range: 17 - 46 | 1 participant reported to be younger than 18; 2 participants reported to be older than 25 |
| **Age of Acquisition** | mean: 10 years<br>SD: 2 years<br>range: 0 – 14 | 5 participants reported an Age of Acquisition of L2 French below 9 years old. Of these participants, 2 reported an Age of Acquisition of 0 or 1; 6 participants reported an Age of Acquisition above 11 years old. |
| **Mean number of other L2s (besides French)** | Mean: 2<br>SD: 1[7] | |
| **Setting of French Acquisition** | Home/family: *n* =1,<br>Education (Dutch-speaking school): *n* =62,<br>Education (Dutch-French-speaking school): *n* = 1 | |
| **Primary setting of French use** | Education: *n* = 32,<br>Holiday: *n* = 1,<br>Interaction with friends/family: *n* = 1,<br>Home: *n* = 7, | |

[7] As in Appendix B; The range of number of other L2s was 0-5; however, the participants could fill in a maximum of 5 other L2s, and therefore, the range may have been constricted by the questionnaire.

| | | |
|---|---|---|
| | Work: $n$ = 6,<br>Never: $n$ = 17 | |
| **Participants that have lived in a French-speaking country** | $n$ = 4 | Mean duration of stay: 4.3 months (SD: 1 month, range: 3 - 5 months) |
| **Estimated daily use** | | |
| Dutch (L1): | mean: 80%<br>SD: 14%<br>range: 40% - 100% | 5 participants reported to use Dutch less than 60% of the time in everyday life; 17 participants reported to use Dutch more than 90% of the time in everyday life. |
| French (L2): | mean: 7%<br>SD: 9%<br>range: 0 % - 37.5% | 31 participants reported to use French less than 5% of the time in everyday life; 4 participants reported to use French more than 25% of the time in everyday life. |
| Other L2s: | Mean: 14%<br>Sd: 14%<br>Range: 0% - 50% | |

**Appendix D: Prime-target sets used in Experiment 2 – 4**

This appendix contains English translations of the prime-target sets used in Experiment 2 – 4. The Dutch and French stimuli sentences that are used in the experiments are available at https://osf.io/ysgx4/. The sentences are presented in the simple present tense (rather than in the present continuous tense), because this tense was also used in the Dutch and French stimuli.

Trials that include response pictures that show an obvious collective group of agents (as discussed in Section 8.3) are marked with an asterisk (*). Here, a collective group is also considered to be spatially close together. The picture that displays the existential-wide interpretation of the sentence *All waitresses watch a customer*, for instance, displays multiple waitresses looking at the same customer from different positions and angles. Therefore, these waitresses are not considered as a 'collective group', as the picture shows multiple agents acting independently from each other. Trials that include a verb that can denote a joint action (also discussed in Section 8.3) are marked with an obelisk (†). The visual materials are also available at https://osf.io/ysgx4/.

| **Prime**[8] | **Target** |
|---|---|
| *All dwarfs chase a clown | *All lions chase a zookeeper |
| All artists touch a ballerina | All pixies touch a zebra |
| All foxes see a cake | All gardeners see a spade |
| All tourists see a statue | All guests see a cake |
| All toddlers prod a vicar | All housewives prod a salesman |
| All ballerinas recognise a cake | All protesters recognise a flag |
| All pharaohs beat a slave | All cowboys beat a swimmer |
| All nuns kiss a clown | All professors kiss a monk |
| All skiers descend a mountain | All mountaineers descend a cliff |
| All politicians smell a cake | All angles smell a pizza |
| * All handymen paint a billboard | * All boys paint a wall |
| All ballerinas descend a staircase | All cyclists descend a road |
| All children ride an elephant | All pilgrims ride a donkey |
| All vampires knife a saxophonist | All cowboys knife a doctor |
| † All bees carry a strawberry | † All chefs carry a suitcase |
| All children climb a ladder | All hikers climb a hill |
| All lifeguards point to a witch | All doctors point to a waitress |
| All professors punch a teenager | All hippies punch a traveller |
| All professors punish a sailor | All scientists punish a student |
| * All porters grab a suitcase | * All chefs grab a plate |
| All cowboys punch a farmed | All bodyguards punch a fan |
| All bears approach a tent | All cats approach a shed |
| * All schoolboys ride a unicorn | * All witches ride a cow |
| * All knights follow a monk | * All monkeys follow a cat |
| All matadors tickle a detective | All monks tickle a mechanic |
| All artists kiss a boxer | All waitresses kiss a soldier |
| † All ants carry a bread | † All movers carry a box |
| All aristocrats smell an ice cream | All detectives smell a muffin |
| † All rabbits paint a painting | † All wizards paint a door |
| * All fish follow an orca | * All elephants follow a raccoon |

[8] In Experiment 1 (in which we collected baseline preferences in the L1), these prime sentences were given as additional target sentences.

| | |
|---|---|
| All maids punch a plumber | All footballers punch a policeman |
| All Mexicans shoot a jug | All hunters shoot a ball |
| All nuns knife a troll | All knights knife a queen |
| * All businesswomen push a troll | * All nuns push a clown |
| * All chefs push a swimmer | * All swimmers push a ballerina |
| * All dogs chase a squirrel | * All bouncers chase a cleaner |
| All waitresses point to a handyman | All gnomes point to a plumber |
| All boys watch a golfer | All waitresses watch a customer |
| All artists tickle a sailor | All thieves tickle a doctor |
| * All thieves grab a bag | * All knights grab a sword |
| Alle the guards watch a prisoner | All schoolgirls watch a bird |
| All sharks attack a surfer | All students attack a professor |

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