FACULTY OF PSYCHOLOGY
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Processing and Representation of Quantificational Scope

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Supervisor: Prof. Dr. Robert J. Hartsuiker
Co-supervisor: Prof. Dr. Peter Lauwers

A dissertation submitted to Ghent University in partial fulfilment of the requirements for the degree of Doctor of Psychology

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Contents

1 Introduction

Language allows us to put an infinite number of thoughts into words. To illustrate, consider the sentence in (1).

(1) Every dog is breakdancing.

Most people will have no problems in understanding this sentence, despite having never seen - or thought about - breakdancing dogs before. The relative ease of interpreting (1) can be explained by the expressive power of language: Language allows us to combine the meaning of words into an infinite number of sentences that express complex meanings (Dowty, 2007; Fox, 2000). Thus, we can interpret (1) because (i) we know the meanings of *dog* and *breakdancing*, and (ii) because we know how to put the meanings of these words together. However, this silly example shows that this skill is far from trivial: The words *dog*, and *breakdancing* all refer to things or actions out there in the world, but how do we interpret *every*?

A quantifier word like *every* (but also *each*, *all*, or *some*, among others) has a very abstract meaning. Rather than referring to anything out there in the world, it is typically analysed as specifying a relation between the referring expressions in a sentence (cf., Knowlton et al., 2021). In interpreting (1), *every* specifies that all things that are 'dogs' are also things that are 'breakdancing'. This relation can be expressed using notation from first-order logic, illustrated in (1a).

(1a) $\forall x[\text{DOG}(x) \rightarrow \text{BREAKDANCING}(x)]$ [1]

The logical formula in (1a) can be paraphrased as meaning that "For every *x*, if *x* is a dog, then *x* is breakdancing" – everything that is a dog is also a breakdancing thing. This analysis of the meaning of *every* illustrates that quantifiers instantiate the relation between different content words in a sentence.

[1] The symbols used in these formulae are rooted in classical logic. The symbol $\forall$ represents universal quantification and can be paraphrased as "for all..."; the $\rightarrow$ symbol represents an "if...then" statement.

These logical relations between content words are thought to be mentally represented at a level known as *logical representation*, which can be captured in formulae like (1a). Logical representations therefore provide the structure needed for semantic representation (Fox, 2000; Heim & Kratzer, 1998). This dissertation is concerned with the organisation of these logical representations: To what extent do they abstract away from linguistic structure? Do they only specify the logical relations between the content words, or also the conceptual meaning content of these words? Are logical representations language-specific? This dissertation presents four chapters that report experimental studies onto these questions, which all use the *structural priming* paradigm. Before describing these studies, however, the key notions and some background on mental logical representations will be presented.

1.1 Scope ambiguity and logical representations

The necessity of logical representations is especially clear in cases where there is no one-to-one mapping between semantic and syntactic composition. This is the case in sentences in which multiple quantifiers co-occur in the same sentential clause. Consider the sentence in (2), containing the universal quantifier *every* and the existential quantifier *a*.

(2) Every man bit a dog.

The sentence in (2) can be understood as meaning that every man bit a different dog, but also as meaning that the same (poor) dog was bitten by every man. This ambiguity emerges because the rules of semantic interpretation instantiated by *every* and *a* can interact in two ways. In the first interpretation, the interaction between *every* and *a* is specified as follows:

(2a) $\forall x[\mathsf{MAN}(x) \rightarrow \exists y[\mathsf{DOG}(y) \wedge \mathsf{BIT}(x,y)]]$ [2]

The formula in (2a) can be paraphrased as meaning that “For every *x*, if *x* is a man, then there exists a *y*, such that *y* is a dog, and *x* bit *y*”. In this interpretation, the predicate ‘bit a dog’ is thus asserted to all things that are ‘men’.

The second interpretation can be captured in the following formula:

(2b) $\exists y[\mathsf{DOG}(y) \wedge \forall x[\mathsf{MAN}(x) \rightarrow \mathsf{BIT}(x,y)]]$

[2] The $\exists$ symbol represents existential quantification and can be paraphrased as "there exists at least one…"; and $\wedge$ represents conjunction ("and"). The other symbols used in this example are defined in the previous footnote.

The reading in (2b) can be paraphrased as meaning that "There exists a *y*, such that *y* is a dog, and for all *x*, if *x* is a man, then *x* bit *y*". In this interpretation, the predicate "Every man bit y" is thus asserted to a single dog (that is, *y*).

The logical formulae in (2a) and (2b) illustrate that the interaction between *every* and *a* can be captured in the order in which the two quantifiers influence each other in the logical structure. This ordering is defined as *scope*, and a doubly-quantified sentence like (2) is therefore *scopally ambiguous*. In (2a), the universal quantifier *every* takes widest possible scope. Therefore, this reading will be referred to as the *universal-wide* reading. Likewise, the reading in (2b) will be referred to as the *existential-wide* reading because the existential quantifier *a* takes widest possible scope.

This example shows that a scopally ambiguous sentence corresponds to two possible logical representations. But what information is captured at this level of representation? A prevalent assumption in the semantic literature is that logical representations only specify the structure of semantic interpretation, but not the conceptual meaning content of any of the lexical items in the sentence (Heim & Kratzer, 1998; Hornstein, 1995). Consider the sentence in (1) and its associated logical representation again, repeated below in (3).

(3) Every dog is breakdancing.

(3a) $\forall x[\text{DOG}(x) \rightarrow \text{BREAKDANCING}(x)]]$

The logical representation in (3a) specifies that all things that are 'dogs' are also things that are 'breakdancing' (as specified through a variable *x*), but it does not specify what it means to be a 'dog' or to be 'breakdancing'. This distinction therefore posits that semantic interpretation depends on two cognitive systems: the *combinatorial* system that combines concepts in the construction of complex (sentence) meaning, and the *conceptual* system that stores the meaning content of these concepts (Feiman & Snedeker, 2016; Heim & Kratzer, 1998; Hornstein, 1995).

Moreover, these logical representations are assumed to abstract away, at least to some extent, from the (surface) linguistic structure. This explains why semantic and syntactic composition does not necessarily converge, as shown in the doubly-quantified sentence in (2). But are there aspects of linguistic structure that are specified in logical representation, and how do people map these different logical representations onto linguistic structures? These questions will be discussed in the next subsection.

1.2 The computation of logical representations

Semanticists and psycholinguists have described multiple sources of information that influence the computation of logical representations. Importantly, the resolution of scope relies on both linguistic (i.e., structural and lexical) and non-linguistic (i.e., pragmatic and contextual) cues.

Focusing on structural cues first, the order of the quantifiers in the sentence has a clear effect on the assignment of scope: The quantifier that is first in the sentence is more likely to take wide scope. To illustrate, compare the sentence in (4) (which is a repetition of (2)) to the one in (5).

(4) A dog was bitten by every man.

(5) Every man bit a dog.

Both these sentences allow a universal-wide interpretation in which every man bit any dog and an existential-wide interpretation in which every man bit the same dog. However, the preferred reading differs: The sentence in (4) is typically assigned the universal-wide reading, whereas the sentence in (5) is most often interpreted with the existential-wide reading (Ioup, 1975; Kurtzman MacDonald, 1993), due to the different order of the quantifiers *every* and *a* in the sentence.

This preference can firstly be attributed to the structural order of the quantifiers. In English (among other languages), the quantifier that is presented leftmost in the sentence is also highest in the syntactic tree structure (which is not the case for all languages, cf. Lidz & Musolino, 2002). Therefore, it has been argued that the logical representation in which the scopal order corresponds to the order of the quantifiers in the syntactic structure of the sentence is computed automatically in syntactic parsing (e.g., Kurtzman & MacDonald, 1993; Lidz & Musolino, 2002). Additional operations are required to reverse the scopal order. Theorists debate the exact nature of these operations (with some claiming that they are syntactic and others that they are semantic in nature, e.g. Champollion, 2017; Fox, 2000; Hendriks, 1988; May, 1985; Szabolcsi, 2010; see also Ruys & Winter, 2011), but they share the assumption that these additional operations are cognitively costly.

This preference can secondly be attributed to the linear order of the quantifiers in the surface structure of the sentence: The leftmost quantifier in the surface structure of the sentence is more likely to take wide scope. Again, in languages like English, this is difficult to distinguish from syntactic ordering effects. However, the linear order of the quantifiers has been argued to be an independent influence on scope assignment. In this case, the preference is not attributed to syntactic parsing, but to the incremental nature of language processing (e.g., Altmann & Kamide, 1999; Rayner & Clifton Jr, 2009). Comprehenders build up a semantic representation of sentence meaning as the sentence unfolds word-by-word. Therefore, the quantifier that is encountered first is likely given wide scope, because the sentence is not yet ambiguous at this point of processing. Therefore, a revision of the semantic representation that is computed so far is required if the second quantifier in the sentence takes wide scope (which, again, is cognitively costly; Fodor, 1982; Johnson-Laird et al., 1989; Kurtzman & MacDonald, 1993). This revision of the semantic representation built up so far is not necessarily dependent on linguistic operations. Rather, such operations may involve mechanisms of combinatorial thought (e.g., revision of a conceptual mental model of the event described in the sentence computed so far; Fodor, 1982; Kurtzman & MacDonald, 1993).

The studies presented in this dissertation all involve languages and structures in which the structural and linear order align, and therefore, does not seek to distinguish between these two independent influences on scope assignment. However, this brief discussion does highlight an important aspect of logical representation that is pivotal to the work presented in this dissertation: The same underlying logical representation can be mapped onto multiple linguistic structures, although aspects of the linguistic structure can influence the preferred reading (e.g., an existential-wide configuration in which *a* takes wide scope over *every* can be mapped onto the passive structure in (4) as well as onto the active structure in (5)).

The assignment of scope is also guided by lexical information. Compare the sentences in (6) and (7).

(6) All men bit a dog.

(7) Every man bit a dog.

The quantifiers *all* and *every* both instantiate universal quantification: They both asses a property (in this case, 'bit a dog') to all members of a certain set (in this case, the set of things that are 'men'). They differ, however, in their scope-taking dependencies: The sentence in (6)is more likely to be given the existential-wide reading in which all men bit the same dog than the sentence in (7) (Feiman & Snedeker, 2016; Ioup, 1975). This difference is attributed to the different lexical tendencies of *all* and *every*: *every* has a stronger tendency to assign wide scope over other sentence elements than *all*.

Based on these lexical differences in the assignment of scope, Ioup (1975) constructed the *Quantifier Hierarchy*: Quantifiers that are leftmost in this hierarchy have a stronger tendency to assign wide scope over other elements in the sentence. This Quantifier Hierarchy is presented in (8).

(8) EACH $\succ$ EVERY $\succ$ ALL $\succ$ MOST $\succ$ MANY $\succ$ SEVERAL $\succ$ SOME $\succ$ A FEW

Ioup's Quantifier Hierarchy is an observation, rather than a theory that explains why quantifiers differ in their scope-taking tendencies. However, this observation has led to a class of theories that stipulate that quantifier words differ in their scope-taking tendencies because they are mapped onto distinct scope-taking mechanisms. Under this analysis, the differences in scopal tendencies between, say, *each* and *all*, are due to the differences in the scopal mechanisms tied to these two quantifier words (e.g., Beghelli & Stowell, 1997; Champollion, 2017). This suggests that logical representations specify properties of the lexical representation of quantifier words, and not fully abstract conceptual representations of quantificational relations (Feiman & Snedeker, 2016). However, it is worth noting that this class of theories is not universally accepted. Many theories posit that quantifiers do not differ in their scopal mechanisms (e.g., May, 1985; Montague, 1974; Szabolcsi, 2010). Thus, quantifier words assign scope with the same general mechanism, but differ in the degree to which they evoke this mechanism. To our knowledge, these lexical tendencies are not well formalised within this class of theories. However, for the purposes of this dissertation, it is more important that this class of theories posits that scope of quantifiers is represented alike at logical representations, despite different lexical realisations of these quantifiers.

Finally, pragmatic biases and real-world knowledge also affect the assignment of scope. These biases have been less studied by (semantic) theorists. Crucially, semantic theory has mostly been concerned with describing the *possible* scopal readings of a sentence, and less with describing the *preferred* reading of a scopally ambiguous sentence (e.g., AnderBois et al., 2012). Nevertheless, pragmatic biases driven by our real-world knowledge of events undoubtedly affect processing of scopally ambiguous sentences, as shown in (9).

(9) A dog lives in every doghouse.

Here, the existential-wide reading in which the same dog occupies every doghouse is dispreferred, because we know that a dog usually lives in just one doghouse (even though this reading does not follow the surface scope order; e.g., Saba & Corriveau, 2001). Likewise, a sentence like (10) typically receives a universal-wide reading, whereas this is not the case for (11).

(10) Every kid climbed a tree.

(11) Every kid carried a boat.

Note that the sentence structure and quantifiers are the same in both (10) and (11). Rather, these biases seem to be be evoked by lexico-pragmatic biases of the event type denoted by the verb: The *climbing* event in (10) is more likely to be done individually (on different trees), whereas the *carrying* event in (11) is more likely to be done collectively by a group of people (e.g., Dowty, 1987; Dwivedi, 2013; Dwivedi et al., 2010).

Summing up, the assignment of scope is regulated by an interaction of multiple factors, such as the (i) structural and linear order of the quantifiers in a sentence, (ii) lexical properties of the quantifier words involved, and (iii) pragmatic biases evoked by world knowledge. Note that the structural and lexical influences on the computation of logical representation discussed in this section can be driven by preferences in the abstract combinatorial patterns of a language. This is not the case for the pragmatic biases, which are driven by knowledge of the conceptual meaning content of the lexical items in a sentence. If we assume that the combinatorial and the conceptual system are distinct in semantic interpretation (as described in Section 1.1.), then conceptual knowledge somehow interacts with the combinatorial processes in semantic interpretation (see also Dwivedi, 2013).

1.3 Language-specific logical representations?

The previous subsection discussed that the computation of logical representation is dependent on linguistic and non-linguistic cues that guide the assignment of scope. The computation of logical representations is therefore language-dependent, and possibly even specify lexical features (e.g., Beghelli & Stowell, 1997; Feiman & Snedeker, 2016). This gives rise to the question of whether logical representations are language-specific (e.g., Jackendoff, 1992), especially because there are cross-linguistic differences in the assignment of scope. To illustrate this point, consider the sentence in (12).

(12) All dogs are not in the boxes.

This sentence contains the quantifier *all* and the negator *not*. Like quantifiers, negative terms like *not* are scope-taking elements that specify an abstract relation between different concepts in a sentence (e.g., Horn, 1989). Therefore, sentences with a quantifier word and a negative term are also scopally ambiguous. First, *all* can take scope over *not* (the universal-wide reading, represented in (12a)). In this interpretation, the property 'is not in the boxes' is assigned to everything that is a 'dog', meaning that no dog is in the boxes.

(12a) $\forall x[\text{DOG}(x) \rightarrow \neg\text{IN-BOXES}(x)]$
It is the case that for all *x*, if *x* is a dog, *x* is in the boxes.

Second, *not* can take scope over *all* (the negation-wide reading, given in (12b)). In this interpretation, the property 'is not in the boxes' is assigned to not everything that is a 'dog': Not all, but possibly some, dogs are in the boxes.

(12b) $\neg\forall x[\text{DOG}(x) \rightarrow \text{IN-BOXES}(x)]$
It is not the case that for all *x*, if *x* is a dog, *x* is in the boxes

The preferred interpretation of these sentences differs across languages. In English and Dutch, for instance, the universal-wide interpretation is preferred, whereas the negation-wide interpretation is preferred in French and Estonian (among other languages; Amiraz, 2021; Hemforth & Konieczny, 2019).

Do such cross-linguistic differences in the assignment of scope also affect the organisation of scope? If logical representations are non-linguistic representations that capture the abstract (conceptual) relations between different concepts in semantic interpretation, it is expected that logical representations do not capture such language-specific properties of scope assignment. On the other hand, if logical representations are linguistic representations that capture lexical properties of quantifiers (Beghelli & Stowell, 1997; Feiman & Snedeker, 2016), then logical representation may be differentiated according to language-specific properties (especially because the lexical realisation of quantifier words differ across languages; e.g., Gil, 1995). In this dissertation, this question – which again relates to the overarching question of how abstract logical representations are – will be tested by focusing on *bilingual* logical representations. If logical representations are not language-specific, it is expected that bilinguals rely on the same logical representations in the processing of both languages they know. On the other hand, if logical representations are language-specific, then bilinguals compute separate logical representations in the processing of both languages they know.

1.4 Priming logical representations

The previous subsections summarised the different factors that guide the computation of logical representations, and briefly discussed that languages differ in scopal preferences. This dissertation is concerned with the organisation of such logical representations: Do they abstract away from linguistic structure? Do they specify quantifier- and/or language-specific properties in the assignment of scope? Do they only specify abstract logical relations between the content words in semantic interpretation, or do they also specify conceptual meaning content of these lexical items? These questions can be studies using the structural priming paradigm. *Structural priming* refers to the often-observed effect that people tend to repeat structures that they encountered in recent processing. This effect was first observed in research on the representation of syntactic structure: People are more likely to utter a passive structure (like *The church was hit by lightning*) after exposure to another passive structure (like *The referee was punched by one of the fans*) than after exposure to an active structure (like *One of the fans punched the referee*; Bock, 1986). Priming effects are assumed to arise because it is easier to re-use a representation in the processing of a sentence if it was involved in the processing of a previous sentence. Therefore, the emergence of priming reveals that two sentences have representational overlap (see e.g., Branigan & Pickering, 2017; Pickering & Ferreira, 2008, for reviews).

There are different theoretical descriptions of structural priming, of which the *residual activation* model and the *implicit learning* theory are the most influential (e.g., Branigan & Pickering, 2017; Pickering & Ferreira, 2008). The residual activation model posits that structural priming emerges because the use of a certain structure increases the activation of the representation of that structure. This activation facilitates further processing of that structure (although it rapidly decays; Hartsuiker et al., 2008). This class of theories puts emphasis on the role of lexical overlap between the prime and the target structures: Priming of syntactic structures is usually enhanced if the verb is repeated (the so-called *lexical boost* effect; e.g., Pickering & Branigan, 1998; see also Mahowald et al., 2016, for meta-analysis). According to the residual-activation model, this enhancing effect emerges because in such cases, there is not only residual activation of the representation of a content-free syntactic phrase structure, but also of the combinatorial nodes that specify the possible structures in which a specific verb can occur (e.g., Pickering & Branigan, 1998; but cf. Scheepers et al., 2017).

On the other hand, the implicit-learning account stipulates that processing of a certain structure leads to the implicit learning of the representation underlying that structure. This implicit learning increases the likelihood that the representation of that specific structure is used in subsequent processing (Bock & Griffin, 2000; Chang et al., 2006; see also Jaeger & Snider, 2013). In this account, the lexical boost is typically understood as a lexical memory cue: In case the verb is repeated, a explicit memory trace to the previous use of this verb is activated, leading to stronger learning (e.g., Bock & Griffin, 2000; Hartsuiker et al., 2008; Segaert et al., 2013).

Structural priming has been observed in production (e.g., Bock, 1986; Pickering & Branigan, 1998; see Mahowald et al., 2016, for meta-analysis), comprehension (Branigan et al., 2005; Segaert et al., 2013; Thothathiri & Snedeker, 2008; Ziegler & Snedeker, 2019), and in multiple levels of (linguistic) representation, such as thematic structure (Chang et al., 2003; Ziegler & Snedeker, 2018), information structure (Bernolet et al., 2009; Fleischer et al., 2012; Ziegler & Snedeker, 2019), pragmatic mechanisms (Bott & Chemla, 2016; Meyer & Feiman, 2021), and - germane to this dissertation - logical representations. It therefore should be noted that the theoretical accounts on priming root from research of syntactic priming in production, and it is an open question to what extent they apply to other types of structural priming data.

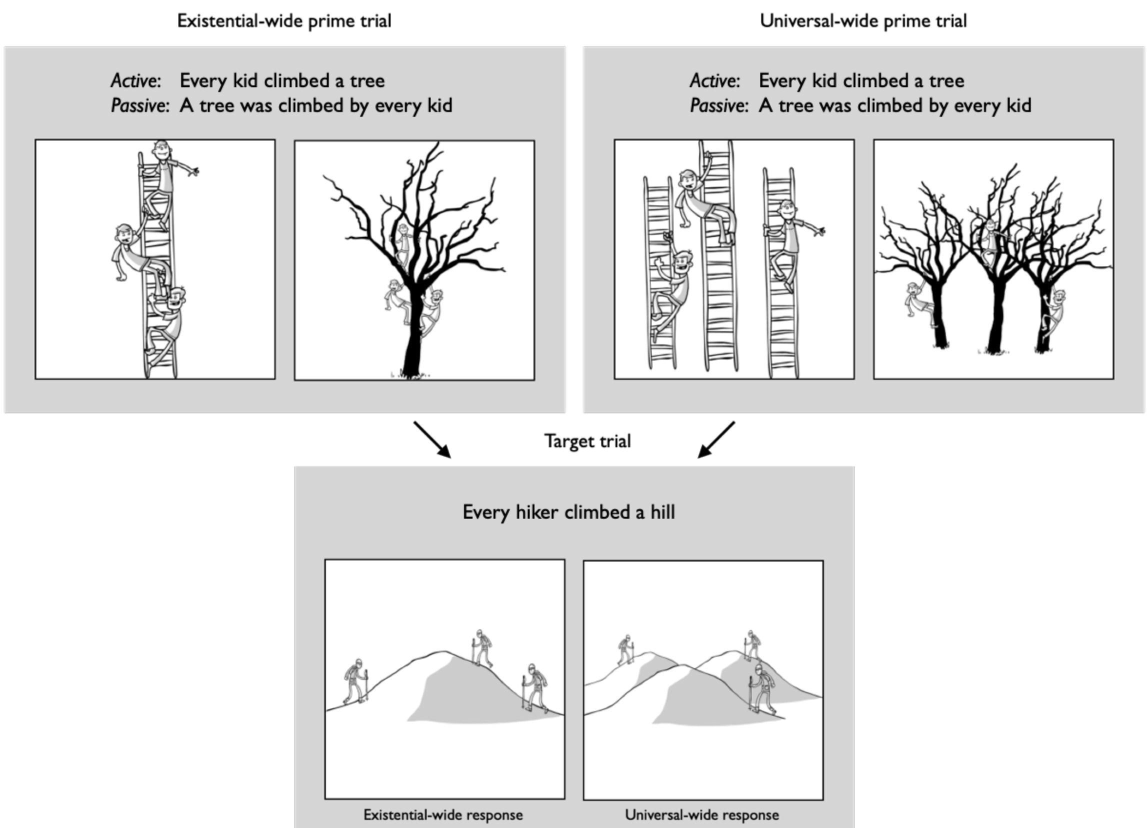


Figure 1.1: Example of a prime-target set in Raffray and Pickering's (2010) experiments.

The first to demonstrate priming of logical representation were Raffray and Pickering (2010). On each trial of their experiments, participants read a transitive sentence and paired that sentence with one out of two pictures. In the prime trials, participants read a doubly-quantified sentence like *Every kid climbed a tree*. One of the pictures matched the sentence, whereas the other picture did not (for instance, because the kids are not climbing a tree but a ladder). The matching picture always depicted either the universal-wide reading or the existential-wide reading. This way, the participants were forced to assign a specific logical analysis to the sentence. Each prime trial was followed by a target trial. In the target trials, participants again read a doubly-quantified sentence (e.g., *Every hiker climbed a hill*), but on these trials they could choose between a picture that displayed the universal-wide reading and a picture that displayed the existential-wide reading. Thus, participants were forced to assign one of the two readings to the prime sentences, but they could freely assign either interpretation to the target sentences (Figure 1.1).

Using this paradigm, Raffray and Pickering (2010) found effects of priming of logical representation (a finding that was later replicated by Chemla & Bott, 2015; but cf. Feiman et al., 2020): Participants were more likely to assign the universal-wide interpretation to the target sentences following primes that forced a universal-wide interpretation than following primes that forced an existential-wide interpretation. This indicates that people compute logical representations in comprehension. This effect also emerged if the prime sentences were given in the passive voice (*A tree was climbed by every kid*) and targets in the active voice (*Every hiker climbed a hill*); and the size of the effect was not affected by this change in syntactic structure. This latter finding shows that logical representations abstract away from surface structure: Comprehenders map similar logical representation onto different structural realisations of a sentence. Even though the preferred reading differs from a sentence like *A tree was climbed by every kid* and *Every kid climbed a tree* (Ioup, 1975; Kurtzman & MacDonald, 1993), this difference in syntactic structure and scopal preferences does not cause a differentiation in logical representation. Moreover, this finding also indicates that the assignment of scope is mapped onto thematic, and not grammatical, relations in the semantic analysis of a sentence (see also Branigan & Pickering, 2017).

Raffray and Pickering's (2010) study showed a distinction between logical representation and the representation of a sentence's surface structure. However, their results do not elucidate whether logical representations abstract away from quantifier-specific properties or conceptual meaning content. Although their results showed priming between different nouns, suggesting that logical representations do abstract away from the conceptual meaning content of the sentence to some extent, the quantifiers and the verb were always repeated between prime and target. Therefore, the priming observed in their study may (partly) be driven by this lexical overlap.

The question of whether logical representation is dependent on lexical overlap was tested in a study from Feiman and Snedeker (2016). In one of their experiments, they tested whether priming of logical representations is driven by overlap in the quantifiers between prime and target. Recall that quantifier words differ in their combinatorial properties: *each*, for instance, has a stronger tendency to take wide scope than *every*, even though they both specify a similar relation between concepts (Ioup, 1975). Therefore, it is a relevant question whether different quantifier words are associated with different scope-taking mechanisms, which may cause a differentiation at logical representation according to these quantifier-specific mechanisms (e.g., Beghelli & Stowell, 1997; Champollion, 2017). Feiman and Snedeker tested this question by using the same paradigm as Raffray and Pickering (2010), but they varied the quantifier in the subject phrase. This quantifier could either be one of the three English universal quantifiers (*each*, *every* or *all*) or a numeral quantifier like *three*, *four* or *five* (which would always specify the total number of referents depicted on the pictures). The quantifier varied in both the prime and the target sentences, which led to a total of sixteen prime-target quantifier configurations (which was manipulated between subjects). Of these configurations, four tested priming within the same quantifier (*each-each*, *every-every*, *all-all* and numeral-numeral), and the other twelve tested priming between different quantifiers (e.g., *each-every*, *all-each*, *every*-numeral, and so on). The results showed priming in the interpretation of all tested quantifiers, but only if the prime and the target contained the same quantifier: Priming consistently emerged from *each* onto *each*, from *every* onto *every*, from *all* onto *all*, and from numeral onto numeral, but priming was weaker from, say, *every* onto *all*. This was supported by an interaction analysis: Priming within the same quantifier was significantly stronger than priming between different quantifiers. Feiman and Snedeker interpreted this pattern of data as evidence for a quantifier-specific representation of scope: Quantifier words are associated with different scope-taking mechanisms, which makes logical representations are quantifier-specific (e.g., Beghelli & Stowell, 1997).

In separate experiments, Feiman and Snedeker (2016) also tested the question of whether conceptual meaning content of the sentence meaning is represented at logical representation. Again, using the same structural priming paradigm as described above, they firstly observed that priming of logical representations persisted between different numeral quantifiers (e.g., from *three* to *five* or from *four* to *three*; see also Maldonado et al., 2017a). This finding is relevant, because Feiman and Snedeker assumed that the interpretation of different numeral quantifiers relies on the same scopal mechanisms, although they are not synonymous in meaning (i.e., numerals differ in the magnitude of the specified set). Therefore, this finding can be interpreted as evidence for the distinction between the representation of the combinatorial properties and the conceptual meaning of quantifiers: Although the conceptual semantics differ between numeral words, their representation is alike at the level of logical representation. Moreover, these results also suggest that priming is not driven by phonological or lexical overlap between prime and target, but by overlap of an abstract representation of scope assignment between prime and target. Further supporting this finding, Feiman and Snedeker also observed priming between different verbs (at least if the prime and target sentences contained the same quantifiers). This suggests that logical representations are abstract representations of a sentence's combinatorial semantic structure, which do not specify conceptual content of the content words in a sentence (such as the event type denoted by the verb; see Dwivedi, 2013; Fodor, 1982).

Summing up, existing studies on the organisation of mental logical representations indicate that logical representations abstract away from the syntactic structure and the conceptual meaning content of a sentence, but not from quantifier-specific combinatorial properties (Feiman & Snedeker, 2016; Raffray & Pickering, 2010). This suggests that logical representations are partly represented at a lexical level and are therefore language-dependent, supporting a linguistic view of logical representations. Does this also mean that logical representations are language-specific? This latter question has not been addressed by previous research before. In this dissertation, this question will be assessed by studying bilingual logical representations.

1.5 Between-language priming

The structural priming paradigm is also a fruitful tool to uncover bilingual linguistic representations. So far, structural priming studies with bilinguals have predominantly focused on bilingual syntactic representations. In this body of research, the prime and target sentences are presented in different languages (*between-language* priming) to bilingual participants. Recall that the facilitating effect of priming emerges because prime and target share representational overlap. Therefore, between-language priming indicates that bilinguals rely on the same representation in the processing of both languages they know (see Van Gompel & Arai, 2018, for review). In early research on syntactic representations, Hartsuiker et al. (2004) observed that bilinguals are more likely to produce a passive sentence in their L2 (their second language, which was English) if they just heard a passive sentence in their L1 (their first language, which was Spanish) compared to if they just heard an active sentence in their L1. This finding, which has been replicated numerous times in multiple languages and syntactic constructions (e.g., Bernolet et al., 2007, 2009, 2013; Cai et al., 2011; Hartsuiker et al., 2016; Hartsuiker et al., 2004; Kantola &

van Gompel, 2011; Loebell & Bock, 2003; Schoonbaert et al., 2007), has led to the *shared-syntax* account: Bilingual syntactic representations are shared if both languages allow the syntactic structure that is represented.

In addition, priming paradigms have also been used to test bilingual lexical representations. Studies on bilingual lexical representation do not rely on the structural priming paradigm, but on *semantic priming* paradigms. In these paradigms, the activation of the semantic representation of a word (like *dog*) is measured in terms of the time needed to recognise a different word that is semantically related (like *kat*, 'cat' in Dutch) or a translation equivalent in another language (like *hond*, 'dog' in Dutch). These studies have shown both translation priming and cross-linguistic semantic priming: Bilingual participants are faster in recognising a word (*dog*) after exposure to a translation equivalent (*hond*) or a semantically related word in their other language (*kat*; 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 (De Bot, 1992; Dijkstra & Van Heuven, 2002; Francis, 2005).

However, less is known about bilingual logical representations. As described in the previous subsections, logical representations are assumed to be separate from the syntactic realisation of a sentence and from the conceptual meaning content of the lexical items involved. Given that logical representations seem to be language-dependent because they specify the combinatorial properties instantiated by the quantifier words (Feiman & Snedeker, 2016), the question of whether logical representations are shared in bilinguals becomes relevant. Studying this question will not only give us insight in bilingual language processing, but also in the nature of logical representations.

1.6 A birds-eye view of this dissertation

This dissertation contains four chapters that report experimental work on the mental organisation of logical representations, focusing both on bilingual and monolingual logical representations. The studies that focus on bilingual logical representations (Chapters 2-3) test the question of whether logical representations are language-specific or whether they abstract away from language-specific properties and quantifier words in the assignment of scope. The studies that focus on monolingual logical representations (Chapters 4-5) focus on specific research questions of whether logical representations specify quantifier-specific lexical content (Chapter 4) or conceptual properties of the event type denoted by the verb (Chapter 5).

Chapter 2 presents a study in which between-language priming of doubly-quantified sentences (e.g., *All kids are climbing a tree*) is tested in Dutch-French bilinguals. A baseline experiment revealed that these sentences are interpreted alike in both Dutch and French. In three further experiments, we observed logical representation priming within the L1 (in both Dutch and French), from the L1 (Dutch) onto the L2 (French), and within the L2 (French), with no difference in the strength of priming across these experiments. A separate control experiment, finally, ruled out that these effects were caused by visual priming. These findings suggests that bilinguals use shared logical representations in both languages they know (at least if the scopal biases of the associated quantifier words in both languages under consideration is alike).

Chapter 3 reports a study that tested priming of logical representations in the comprehension *all...not* structures in Estonian-English bilinguals. In English, these sentences are typically given a universal-wide reading, whereas in Estonian, these sentences are usually given an negation-wide reading. Across four experiments, this study revealed logical representation priming within the L1 (in both Estonian and English), from the L1 (Estonian) onto the L2 (English), from the L2 (English) onto the L1 (Estonian), and within the L2 (English)[3]. Moreover, the magnitude of priming was similar across these experiments, and a control experiment ruled out an explanation in terms of visual priming. This suggests that bilinguals do not compute language-specific logical representations, even in cases where the preference patterns in the assignment of scope differ across languages. In addition, the study in Chapter 3 also showed that (highly) proficient Estonian-English develop sensitivity to language-specific preferences in the assignment of scope in the L2.

In **Chapter 4**, we conducted three experiments that tested priming within and between quantifiers in Dutch monolinguals. The prime sentences of these experiments contained the universal quantifier *elke* ('every/each'), *iedere* ('every/each') or *alle* ('all') vis-à-vis the existential quantifier *een* ('a'). The target sentences, on the other hand, always contained *elke* and *een*. In Experiment 1, the prime quantifier was manipulated between subjects (following Feiman & Snedeker, 2016). This experiment revealed priming within *elke*, but also from *alle* to *elke*. In Experiments 2-3, we further tested this inconclusive result by manipulated prime quantifier within participants. These experiments showed priming within the same quantifier and between different quantifiers, with no differences in the strength of the effect. These findings suggest that, although priming between different quantifiers is fragile, logical representations do not specify

[3]We also tested logical representation priming within L1 Dutch and from L1 Dutch onto L2 English in Chapter 3. These experiments did not show priming, but showed a large ceiling effect: The strong preference for the universal-wide interpretation in Dutch seemed to hinder any effects from priming. Please see Chapter 3 for more discussion on this unexpected finding.

lexical features of the quantifier words (contradicting the findings from Feiman & Snedeker, 2016).

Chapter 5 presents a study in which we studied the role of verb overlap in logical representation priming in Dutch monolinguals. Across two experiments, we observed that priming is stronger if the verb is repeated in the prime and the target. Since this enhancing effect of priming does not seem to be driven on repetition of the lexical item (see the bilingual studies in Chapters 2-3), this finding suggests that conceptual meaning of the event type denoted in the sentence is represented in logical representations (but cf. Feiman & Snedeker, 2016).

Finally, **Chapter 6** reports the General Discussion of this dissertation. This chapter reports a summary of the findings, and a discussion of these findings in relation to our understanding of the organisation of mental logical representations

2 Monolingual and bilingual logical representations of quantificational scope

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 compute 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 computed 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.*

Note. The research presented in this chapter is published (Slim, M. S., Lauwers, P., & Hartsuiker, R. J. (2021). Monolingual and bilingual logical representations of quantificational scope: Evidence from priming in language comprehension. *Journal of Memory and Language, 116*, 104184.). There are some minor differences between the published paper and this chapter, which were made to make the text presented in this chapter more consistent with the other chapters in this dissertation. We thank Marting Pickering for sharing the materials from Raffray and Pickering (2010) and Justine Métairy for her help in developing the French stimuli. All data and analysis scripts are available at https://osf.io/ysgx4/.

2.1 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 (Basnight-Brown & Altarriba, 2007; Grainger et al., 2010; Hartsuiker et al., 2016; Hartsuiker et al., 2004; 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.

2.1.1 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):

(3) 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) $\forall x[\textsf{HIKER}(x) \rightarrow \exists y[\textsf{HILL}(y) \wedge \textsf{CLIMB}(x,y)]]$
For all *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), represented as follows:

(1b) $\exists y[\mathsf{HILL}(y) \wedge \forall x[\mathsf{HIKER}(x) \rightarrow \mathsf{CLIMB}(x, y)]]$
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. Since the surface structure in (1) is not ambiguous, it has been proposed that semantic scope configurations are captured at a separate level of linguistic representations: the level of *logical representations* (Chomsky, 1995; Hornstein, 1995; May, 1985), although 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), whereas psycholinguists only recently started to investigate the architecture of mental logical representations (Feiman & Snedeker, 2016; Maldonado et al., 2017a; Raffray & Pickering, 2010). These studies focused on the mental organisation and computation 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 (e.g., Bock, 1986; Branigan et al., 2005; for reviews, see Branigan & Pickering, 2017; Pickering & Ferreira, 2008; for meta-analysis, see Mahowald et al., 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 compute 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 descriptive priming effect of 8%). This finding indicates that people compute logical representations in language comprehension, which influences 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 the syntactic representations of a sentence's surface structure. 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 trees*). 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 (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, using 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* or *four*. 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 the magnitude of the numeral (see also Maldonado et al., 2017a).

Finally, the verb in the prime-target sets in the above-described experiments from Raffray and Pickering (2010) and 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 et al., 2005; 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 (2010) and Feiman and Snedeker (2016) studies indicate that abstract logical representations are not merely a theoretical construct, but real mental representations that are computed 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 computation 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 computation 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.

(4) All the students are not in class.

(2a) $\forall x[\text{STUDENT}(x) \rightarrow \neg\text{IN-CLASS}(x)]$
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) $\neg\forall x[\text{STUDENT}(x) \rightarrow \text{IN-CLASS}(x)]$
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 computation 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 computation of logical representations is (at least) language-dependent.

2.1.2 Bilingual linguistic representations and between-language priming

Given our assumption that the computation 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 (their L2) to describe a picture on a card, after they had heard a similar passive description in Spanish (their L1) 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 et al., 2013; Cai et al., 2011; Hartsuiker et al., 2016; Hartsuiker et al., 2004; Kantola & van Gompel, 2011; Loebell & Bock, 2003; Schoonbaert et al., 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 et al., 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* ('boy') 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., 2007; Smith et al., 2019; Wen & van Heuven, 2017), which suggests 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, among other dimensions (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. Based on evidence from structural priming, 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 (see also 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., 2013; 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 et al., 2008; Duyck & Brysbaert, 2004). 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 computation 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 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 consideration or whether there is full meaning overlap for a word form between both languages).

2.1.3 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 computation of logical representations involves a language-specific mapping of form to meaning, it is an important question whether logical representations are shared among languages or separately computed 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 life (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 2.1). 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

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

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.

2.2 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 to include baseline trials in our priming experiments (e.g, Maldonado et al., 2017a), in order to reduce effects of priming on our baseline measures (Hartsuiker & Westenberg, 2000)

2.2.1 Method

Participants

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 years)[2]. 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

[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 has influenced the results.

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).

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 2.1; 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.

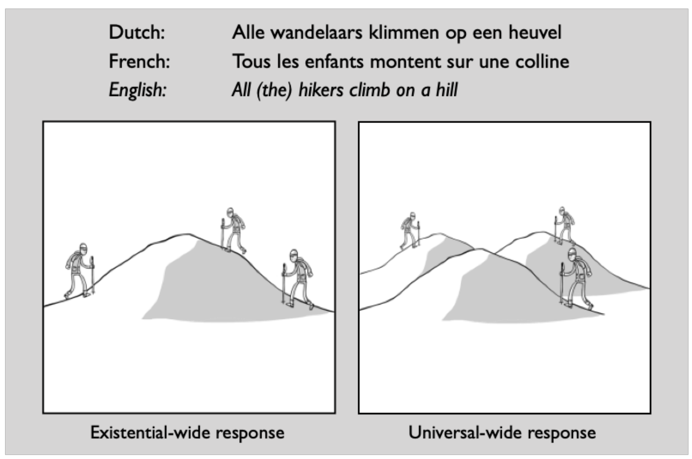


Figure 2.1: Sample target trial from Experiment 1. For the ease of illustration, we included the target sentence in both Dutch and French, together with an English translation, in this figure. *Note.* We added the labels 'existential-wide response' and 'universal-wide response' for the same reason. In the experiment, these labels were not presented to the participants and the sentence was only shown in one language.

We chose the quantifier *all* (unlike Raffray & Pickering, 2010, who used *every* in their stimuli) because we needed quantifiers that are close translation equivalents and 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.

Table 2.1 provides an example of a target sentence in both Dutch and French. A list of the sentences used in all experiments is given in Appendix 2 (and on 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. The French 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*.

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

Table 2.1: Example of the test sentences and their glosses in both Dutch and French.

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.

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 pseudorandomly organised: The target items were 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 were 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.

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 2.1). 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.

2.2.2 Analyses and results

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 (sum 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 χ-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., 2014) 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/.

Results and discussion

Figure 2.2 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 (χ^2(1) = 0.36, p = 0.547).

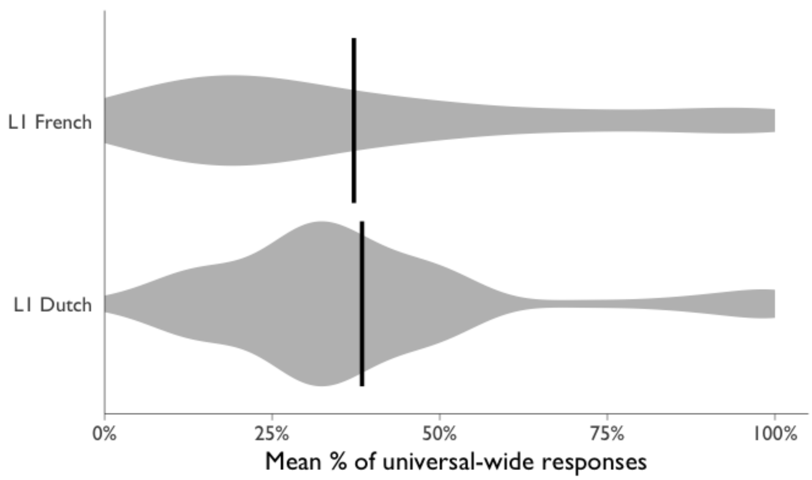


Figure 2.2: The participants' mean percentage of universal-wide responses on the target trials in Experiment 1. The black vertical lines represent the overall mean response rate and the shape of the violin plots indicates the distribution of the data: The width of the outlined area represents the proportion 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 similar combinatorial patterns.

2.3 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. 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) finding that people compute logical representations in the comprehension of doubly-quantified sentences replicate in Dutch and French L1 comprehension.

In all priming experiments reported in this chapter (Experiments 2-4), we repeated the verb in each prime and target pair (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.

2.3.1 Method

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; 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 (mean age: 27 years, SD: 8 years, range: 18–56 years[4]). Of all participants, 49 reported to speak

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

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.

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. Recall that 12 of our 54 prime-target sets were constructed by Raffray and Pickering (2010). For these trials, we used the same sentences in the prime trials as Raffray and Pickering. For the other 42 prime-target sets, we randomly selected which of the trials would serve as prime trials, although 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 2.3.

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). Prime-target sets were intervened by two to five filler trials (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.

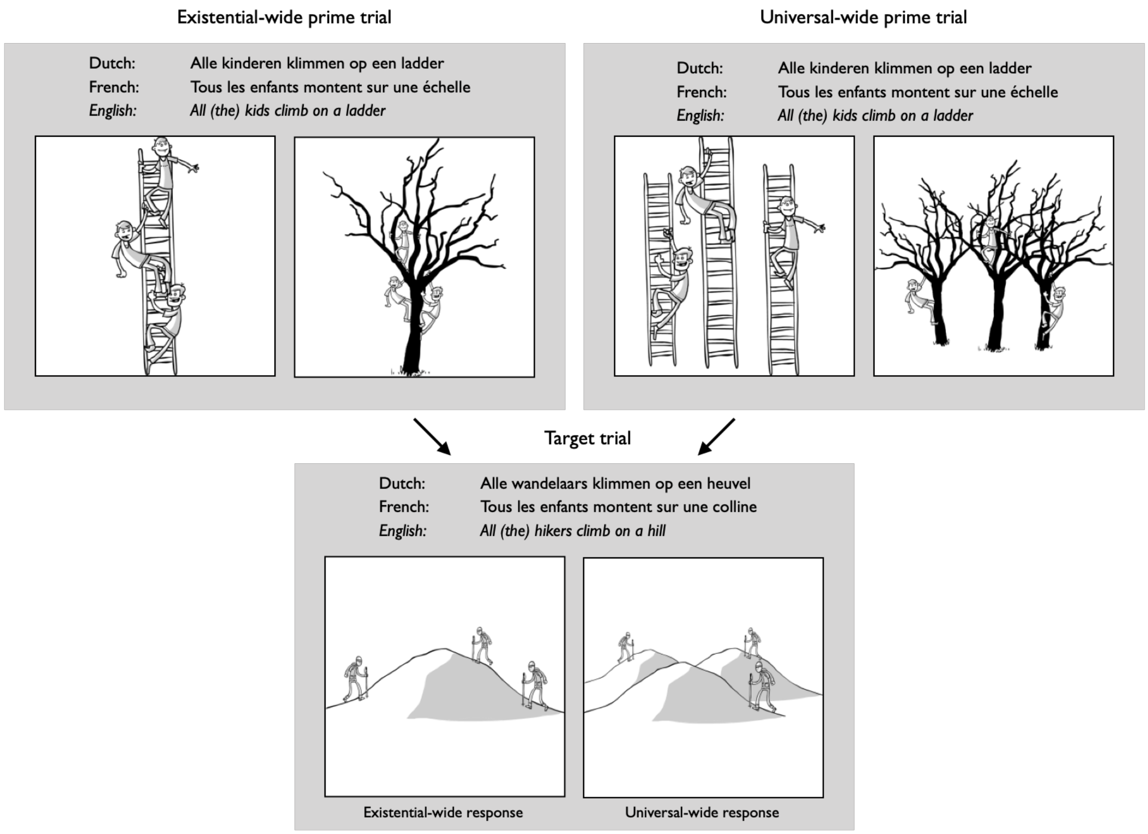


Figure 2.3: The prime-target procedure in Experiments 2–4. The target trials were always immediately preceded by prime trials.

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 we tested the influence from the preceding trial on the target trials.

2.3.2 Analyses and results

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 (sum 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.

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 2.4 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 (χ^2(1) = 31.04, $p < 0.001$) and Language (χ^2(1) = 7.93, $p < 0.001$), but no significant interaction

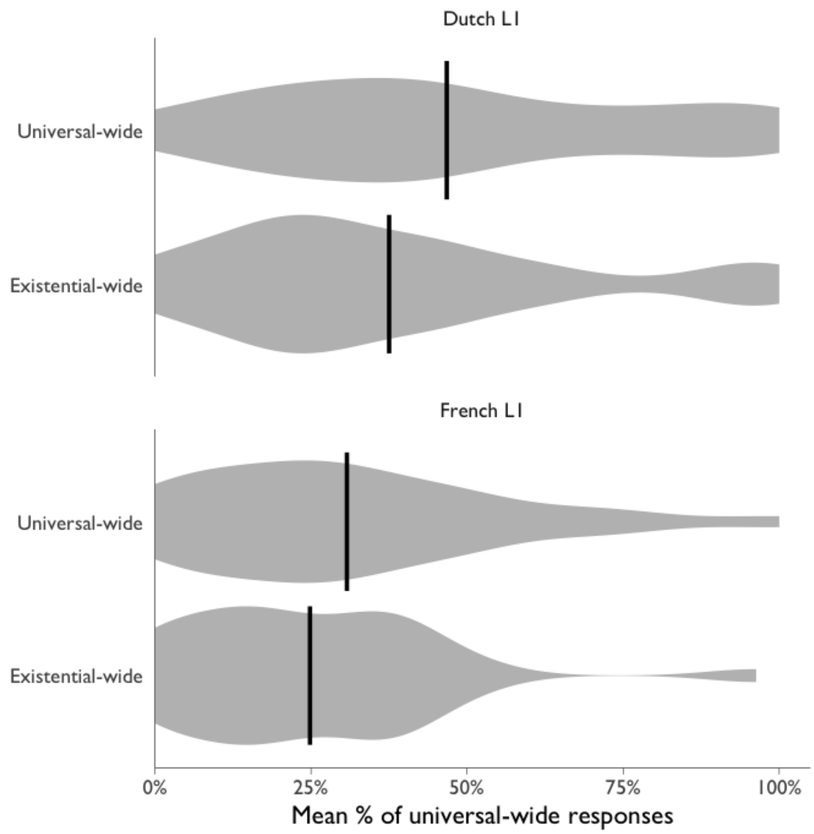


Figure 2.4: The participants' mean rate of universal-wide responses on the target trials in Experiment 2. The black vertical lines represent the overall mean response rate and the shape of the violin plots represent the proportion of the data located at that point.

between Prime Condition and Language (χ^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 (χ^2(1) = 28.02, $p < 0.001$) and in the French version (χ^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 2.2). We will return to this unexpected result in the General Discussion of this chapter.

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 compute 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.

2.4 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 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.

2.4.1 Method

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 2.2 provides information about the participant characteristics. More detailed information about the 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.

	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% (10%)	14% (17%)

Table 2.2: 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 to 10.

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.

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 after completing the sentence-picture matching task and before the language background questionnaire (the *LexTale-FR* test; Brysbaert, 2013). 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 2.2 and the individual participant characteristics available at https://osf.io/ysgx4/).

2.4.2 Analyses and results

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[5]. These LexTale-FR scores were centred around the mean (following Bernolet et al.,

[5] 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 (τ = 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, 2012)), we decided to only include LexTale-FR in the analyses.

2013).

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. 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 significant (χ^2(1) = 21.99, $p < 0.001$).

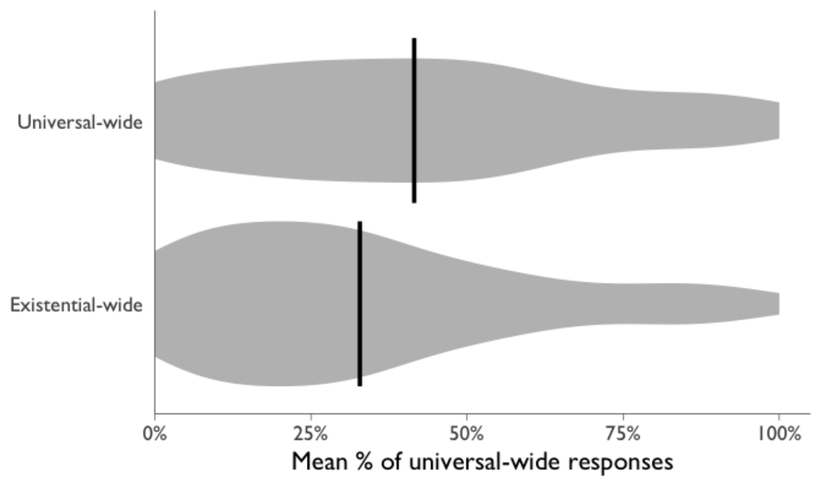


Figure 2.5: The participants' mean rate of universal-wide responses on the target trials in Experiment 3. The black vertical lines represent the overall mean response rate and the shape of the violin plots represent the proportion of the data located at that point.

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 2.2, 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 (χ^2(1) = 3.43, p = 0.064), although we note that the p-value of this test is close to the conventional alpha level of 0.05. This result is plotted in the left panel of Figure 2.6. 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 (χ^2(1) = 0.12, p = 0.718). These results are plotted in the right panel of Figure 2.6, where we visualised the proportion of *primed* responses (i.e., a universal-wide responses following a universal-wide prime and an existential-wide response following an existential-wide prime) as a function of LexTale-FR scores. This finding suggests that there was no observable influence from L2 proficiency on the strength of the priming effects.

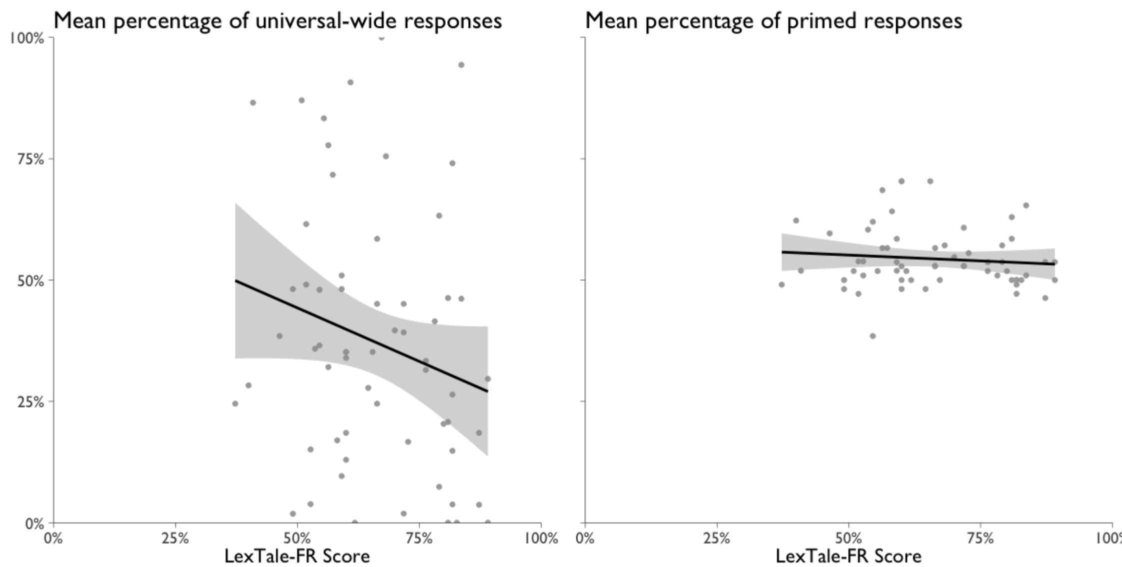


Figure 2.6: The participants' mean rate of universal-wide target responses (left panel) and of primed target responses (universal-wide in the universal-wide prime condition and existential-wide in the existential-wide prime condition; right panel) in function of LexTale-FR scores in Experiment 3.

Thus, the results of Experiment 3 showed that priming of logical representations persists from the L1 onto the L2. This indicates that bilinguals use shared logical representations if the logical representation is computed 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.

2.5 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 computed in the L1 are comparable to those computed in the L2. We addressed this question in Experiment 4, where we investigated priming within the L2.

2.5.1 Method

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 2.2 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 the participant characteristics data available at https://osf.io/ysgx4/).

Materials

The materials were identical to those of Experiment 2b.

2.5.2 Analyses and results

Data treatment and analyses procedure

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

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 2.7 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 (χ^2(1) = 18.88, $p < 0.001$).

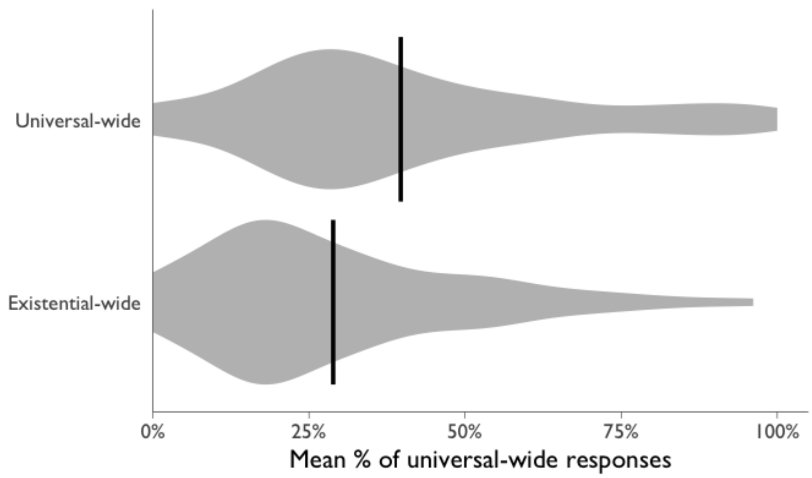


Figure 2.7: The participants' mean rate of universal-wide responses on the target trials in Experiment 4. The black vertical lines represent the overall mean response rate and the shape of the violin plots represent the proportion of the data located at that point.

Regarding L2 proficiency, Table 2.2 shows that the mean score on the LexTale-FR test was 56% of the stimuli correct (SD: 9.81%, range: 18% 75%)[6]. 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 (χ^2(1) = 961.1, $p < 0.001$) and in terms of self-ratings (χ^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

[6]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 (τ = 0.252, $p < 0.001$).

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 (χ^2(1) = 0.262, p = 0.609). This result is plotted in the left panel of Figure 2.8. Moreover, there was no significant interaction between LexTale-FR scores and Prime Condition (χ^2(1) = 0.452, p = 0.501), which is visualised in the right panel of Figure 2.8.

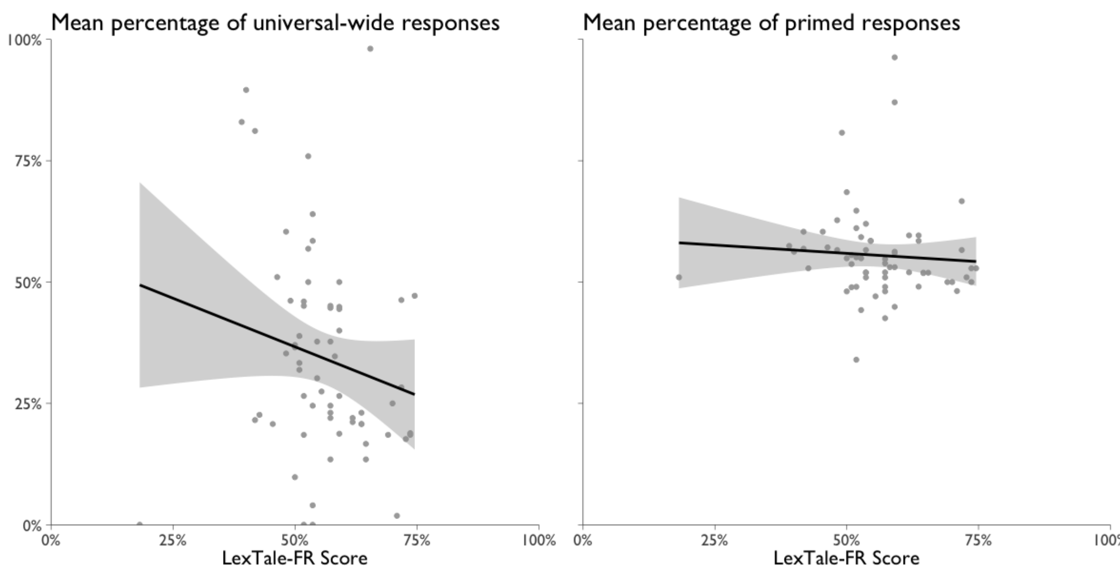


Figure 2.8: The participants' mean rate of universal-wide target responses (left panel) and of primed target responses (universal-wide in the universal-wide prime condition and existential-wide in the existential-wide prime condition; right panel) in function of LexTale-FR scores in Experiment 4.

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 is the observation that there is priming of logical representations in L2 comprehension. This finding indicates that logical representations computed 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).

2.6 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 chapter, the random effects structure was maximal following Barr et al. (2013) and the two categorical predictor variables were sum coded. Subsequent post-hoc pairwise comparisons to contrast the different levels of Prime Direction were carried out using the `phia` package in `R` (De Rosario-Martinez, 2015).

A Type III Wald χ^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, which indicates 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 (see Kantola & van Gompel, 2011, for a similar hypothesis on 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.

2.7 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 (Tulving & Schacter, 1990), so 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.

2.7.1 Method

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 compared to Experiments 2-4. 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.

Materials

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 2.9). 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, so 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.

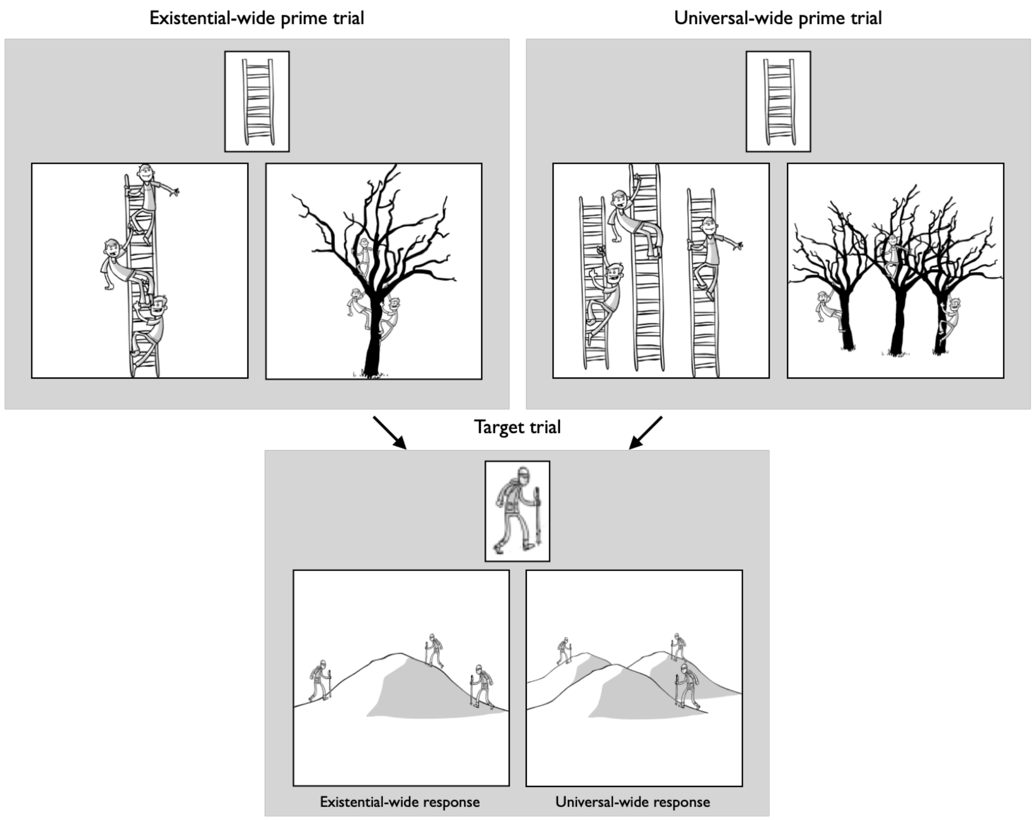


Figure 2.9: Sample prime and target trials in the two prime conditions of Experiment 5. The participant needed to search the small visual item in the two response pictures and select the response picture that contained this item. *Note.* The labels 'Universal-wide response' and 'Existential-wide response' were not shown to the participants but were added to this figure for the ease of illustration.

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 condition, 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. Note that this experiment was non-linguistic, but we still refer to the two prime conditions as universal-wide and existential-wide for clearer comparison with the previous experiments.

The task in the filler trials was similar. The participants searched for a visual figure in two response pictures and selected 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

2.7.2 Analyses and results

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.

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 2.10. 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 (χ^2(1) = 0.12, p = 0.733), so participants were not (or at least not considerably) guided by visual similarities between prime and target pictures in their target response choice.

To test whether the strength of logical representation priming observed in Experiment 2-4 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 (χ^2(1) = 35.40, $p < 0.001$), Prime Direction (χ^2(1) = 11.71, $p < 0.01$) and a significant interaction between Prime Condition and Prime Direction (χ^2(3) = 31.38, $p < 0.001$). Planned post-hoc pairwise comparisons using the `testInteractions` command from the `phia` package (De Rosario-Martinez, 2015) showed

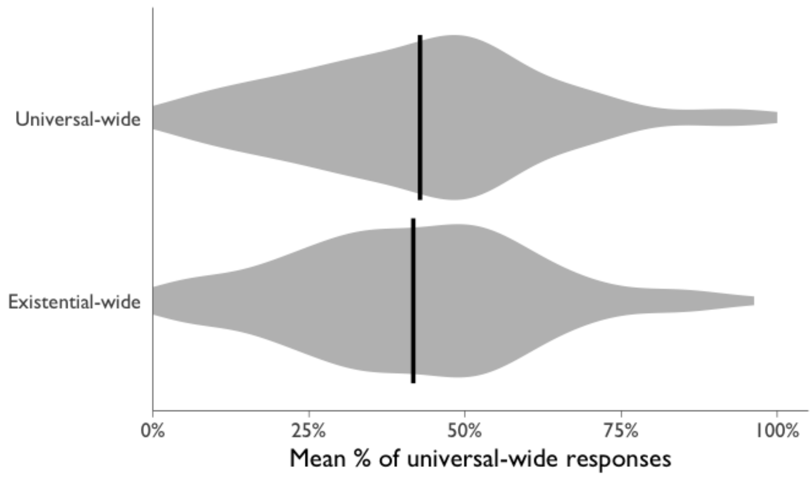


Figure 2.10: The participants' mean percentage of universal-wide responses on the target trials in Experiment 5. The black vertical lines represent the overall mean response rate and the shape of the violin plots indicates the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. For ease of interpretation, we chose to display these results in percentages rather than in logit space.

that priming was greater in L1-L1 priming than in visual priming (χ^2(1) = 18.20, $p < 0.001$), in L1-L2 priming than in visual priming (χ^2(1) = 13.60,$p < 0.001$), and finally also in L2-L2 priming than in visual priming $\chi^2$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.

2.8 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 indicates that people compute 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 computed in the L2 are comparable to those computed 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., Kantola & van Gompel, 2011; 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 (replicating Maldonado et al., 2017a; Raffray & Pickering, 2010).

Thus, the findings listed above firstly indicate 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. Second, our results are ambiguous in whether French and Dutch exhibit cross-linguistic differences in interpreting *all...a* sentences in Cross-linguistic differences in interpreting *all...a* in Dutch and French. 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).

2.8.1 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. This shared nature of bilingual linguistic representation demostrates *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. Following 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 computed 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 et al., 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 *all* 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. (2013) 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 effectively lead 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 (Ferreira, 2003; Segaert et al., 2013; Tooley & Bock, 2014). 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.

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

As noted in the Introduction, the computation 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 are 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 [eːn]). 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.

2.8.3 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 assign a predicate to the individual members 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. 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 across languages. 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 et al., 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* ('Each/Every student of the class') (Kleiber, 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 (e.g., 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 2.1), 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., A*ll boys ride an elephant*; see Appendix 2 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 et al., 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* (see Appendix 2). 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., 2017a). Thus, our main finding that bilingual logical representations are shared still holds under the alternative explanation in terms of quantifier distributivity.

2.8.4 Logical representation as part of wider semantic or conceptual representations?

The previous subsection described 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 debated whether these logical representations are linguistic levels of representations (Fodor, 1982; Khemlani et al., 2012).

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 (Dwivedi, 2013; Ziegler et al., 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.

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 (see e.g., 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 organisation of bilingual logical representations.

However, we argued in the Introduction that the computation of logical representations is (at least) language-dependent because the computation 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 computation 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 computation 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 computation of logical representation may arise due to cross-linguistic lexical differences. Feiman and Snedeker (2016) observed that logical representations computed 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 the computation of logical representations. Alternatively, they may experience L1 transfer in the computation of logical representations if there are lexical differences between quantifiers in their L1 and L2 (Grüter et al., 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.

Second, cross-linguistic differences in the computation 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 the syntactic representation of a sentence's surface structure (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 computation 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, as shown in this chapter, studying the organisation of bilingual logical representations can elucidate the (language-specific) computation of logical representations, which enriches our understanding of logical representations in general.

2.9 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.

3 Are bilingual logical representations shared? Priming *all...not* in Estonian-English bilinguals

Do bilinguals use the same logical representations in processing both languages they know, even if those languages diverge on the preferred interpretation of a scopally ambiguous sentence? We investigated this question by studying effects of cross-linguistic influence and priming in the comprehension of scopally ambiguous all...not sentences. *We focused on Estonian-English bilinguals because* all...not *sentences are interpreted differently in English and Estonian. Across four sentence-picture matching experiments, we firstly observed that bilingual logical representations can be primed within languages (both from L1-to-L1 and from L2-to-L2) and between languages (both from L1-to-L2 and from L2-to-L1). This finding indicates that bilinguals use shared logical representations in the processing of both their languages, and that logical representations do not specify language-specific biases in the assignment of scope. Secondly, we observed that Estonian bilinguals learn English-specific biases in the assignment of scope, which rules out an interpretation of the above-mentioned effects in terms of L1 transfer. Finally, our results tentatively revealed bidirectional cross-linguistic influence in the construction of logical representations, which suggests that bilinguals use integrated representations of implicit knowledge about scopal preferences.*

Note. This chapter presents joint work with Napoleon Katsos. Earlier versions of Experiments 1 and 2 described in this chapter were previously reported in my master's dissertation (Slim, M.S. (2018). *Bilingual Representations of the Logical Form* [Unpublished Master's dissertation, University of Cambridge, Cambridge, United Kingdom].) Since then, this work has been expanded considerably (by collecting more data and adding three additional experiments). All data and analysis scripts are available at https://osf.io/59ezt/.

3.1 Introduction

Languages differ from each other in many ways. Some of these differences are obvious, like differences in sounds, words, or the way in which words are combined to form a sentence. Other differences are more subtle, like the interpretation of semantically ambiguous sentences. Consider the sentence in (1a).

(1a) All the sheep are not in the boxes.

Does this sentence mean that none of the sheep are in the boxes, or that not all (but some) of the sheep are in the boxes? Most speakers of English will interpret this sentence as meaning that none of the sheep are in the boxes. This contrasts with Estonian. Consider the Estonian sentence in (1b).

(1b) Kõik lambad ei ole kastides
all.NOM sheep-NOM.PL neg be.CNG box-PL.INE
"All the sheep are not in the boxes"

Like its English counterpart in (1a), this Estonian sentence is also ambiguous between a reading in which none of the sheep are in the boxes and a reading in which not all (but some) sheep are in the boxed. However, speakers of Estonian typically interpret this sentence as meaning that not all sheep are in the boxes.

Such cross-linguistic differences in the preference patterns in sentence interpretation pose some important questions about how bilinguals assign meaning to sentences: If a bilingual[1] knows two languages that differ in the typical assigned of scope in sentence interpretation, do they assign meaning using integrated linguistic representations that are shared in both languages? And do they encounter influence from one language in the interpretation of such sentences in the other language they know? In the present study, we will test these questions by studying the organisation of bilingual semantic representations in Estonian-English bilinguals. To gain insight in these questions, we used structural priming paradigm and looked at cross-linguistic influence in the assignment of scope.

[1]Like in Chapter 2, we define a bilingual as anyone who uses two languages at a daily basis (following Grosjean, 1989). Thus, we do not distinguish between balanced vs unbalanced bilinguals or simultaneous bilinguals vs late L2 learners.

3.1.1 Scope ambiguity and logical representations

The ambiguity in an *all...not* construction like in (1) emerges because it contains the universal quantifier *all* and the negator *not*. These two operators both assign *semantic scope* over other elements in the sentence. If there are two of such scope-bearing operators in one clause, like in (1), there are two ways in which the scope-bearing operators can be assigned scope with respect to each other.

Consider (1a-b) again. Firstly, *all* can be assigned wide scope over *not* (the *universal-wide* interpretation). In this interpretation, every thing that is a 'sheep' is also a thing that is 'not in the boxes' (i.e., none of the sheep are in the boxes). In (1c), this interpretation is captured using first-order logic.

(1c) *Universal-wide*: $\forall x[\text{SHEEP}(x) \rightarrow \neg\text{IN-BOXES}(x)]$
It is the case that for all *x*, if *x* is a sheep, *x* is not in the boxes

Secondly, *not* can be assigned wide scope over *all* (the *negation-wide* interpretation). In this interpretation, not everything that is a 'sheep' is also a thing that is 'in the boxes' (i.e., not all, but possibly some, sheep are in the boxes). This interpretation is captured in (1d).

(1d) *Negation-wide*: $\neg\forall x[\text{SHEEP}(x) \rightarrow \text{IN-BOXES}(x)]$
It is the case that for not all *x*, if *x* is a sheep, *x* is in the boxes

The logical representations in (1c) and (1d) show that the ambiguity in an *all...not* sentence is caused by the two possible orders in which the scope-bearing operators (*all* and *not*) take scope vis-à-vis each other. The disambiguated messages that capture these two scopal orders are assumed to be represented at a level of semantic representation known as *logical representation* (e.g., Horn & Wansing, 2020; Ruys & Winter, 2011). A scopally ambiguous sentence, like an *all...not* sentence, is thus ambiguous because it corresponds to two possible logical representations.

The mental architecture of logical representations can be tested using a structural priming paradigm (e.g., Feiman & Snedeker, 2016; Raffray & Pickering, 2010). *Structural priming* refers to the effect that the processing of a sentence influences subsequent processing of another sentence that involves a similar underlying structure. This effect is assumed to emerge because the two related sentences share similarities in their representational structure, which makes it easier to re-use these representations (e.g., Bock, 1986; Branigan et al., 2005; see Branigan & Pickering, 2017; Pickering & Ferreira, 2008, for reviews, and Mahowald et al., 2016, for meta-analysis). Therefore, priming can elucidate the underlying representations between two related, but different, structures.

Priming of logical representations was first observed by Raffray and Pickering (2010), who used a (monolingual) sentence-picture matching task. In this task, the critical test sentences were doubly-quantified sentences like (2).

(2) Every hiker climbed a hill.

These sentences are scopally ambiguous: The universal *every* can be assigned wide scope over *a* (the *universal-wide* interpretation; (2a)), but the existential quantifier *a* can also be assigned wide scope over *every* (the *existential-wide interpretation*; (2b)).

(2a) $\forall x[\text{HIKER}(x) \rightarrow \exists y[\text{HILL}(y) \wedge \text{CLIMB}(x, y)]]$
For all *x*, if *x* is a hiker, there exists a *y* such that *y* is a hill, and *x* climbs *y*
"Every hiker climbed a (potentially) different hill"

(2b) $\exists y[\text{HILL}(y) \wedge \forall x[\text{HIKER}(x) \rightarrow \text{CLIMB}(x, y)]]$
There exists a *y*, such that *y* is a hill, and for all *x*, if *x* is a hiker, then *x* climbs *y*
"Every hiker climbed the same hill"

On each trial in Raffray and Pickering's (2010) task, the participants matched a sentence with one out of two pictures. In the prime trials of this task, the sentence was a doubly-quantified construction (e.g., *Every kid climbed a tree*). One of the two response pictures was a foil picture that was no match for either interpretation, whereas the other picture depicted one of the two possible readings of the sentence (either the universal-wide or the existential-wide picture). Each prime trial was directly followed by a target trial. On these trials, participants read a similar doubly-quantified sentence (e.g., *Every hiker climbed a hill*) and were presented with pictures that depicted the two possible interpretations of the sentence. Using such prime-target sets, the participants were thus forced to assign one of the two possible interpretations on the prime trials but they could freely choose between the two interpretations in the target trials. The results showed that the participants tended to perseverate in their interpretation: They were more likely to assign the universal-wide interpretation to the target sentences after a universal-wide prime trial than after an existential-wide prime trial. This effect of priming suggests that comprehenders compute logical representations that specify the assignment of scope in language comprehension.

But how abstract are such logical representations? Do they specify linguistic properties of scope assignment? A study from Feiman and Snedeker (2016) showed that priming of logical representations depends on the lexically-specified combinatorial properties of the quantifiers in the prime and in the target sentence. Using a similar sentence-picture matching task as Raffray and Pickering (2010), this study revealed that priming is enhanced if the prime and the target shared the same quantifier words (e.g., *Every kid climbed a tree* to *Every hiker climbed a hill*) compared to if the quantifier differed between prime and target (e.g., from *Each kid climbed a tree* to *Every hiker climbed a hill*). Quantifier words are known to differ in their tendency to take wide scope: The English quantifier *each*, for instance, is more often assigned wide scope over other sentence constituents than the English quantifier *every* (e.g., Beghelli & Stowell, 1997; Ioup, 1975). Feiman and Snedeker's results show that logical representations capture these quantifier-specific combinatorial properties. This suggests that the computation of logical representations is language-dependent: Logical representations are differentiated according to the combinatorial properties of the specific quantifier words involved.

3.1.2 Bilingual logical representations

Structural priming is also a useful technique to study the nature of bilingual linguistic representations. Recall that structural priming arises because the prime and target share parts of their representational content. Therefore, if priming persists from one language onto another language in bilingual language processing, features of the primed representation are shared between languages (e.g., Bernolet et al., 2007; Hartsuiker & Westenberg, 2000; Kantola & van Gompel, 2011; Schoonbaert et al., 2007; see Van Gompel & Arai, 2018, for review).

To our knowledge, a study from Slim et al. (2021, reported in Chapter 2) is the only study so far that tested whether logical representations are prone to priming between languages. Using a similar sentence-picture matching task as Raffray and Pickering (2010), this study showed priming of logical representations in the interpretation of doubly quantified sentences like *All hikers are climbing a hill* in Dutch-French monolingual and bilingual language comprehension. In one of their experiments, the prime trials were presented in Dutch (the participants' L1) and the target sentences in French (the participants' L2). The results of this experiment revealed an effect of priming: The participants were more likely to assign the universal-wide interpretation to the (French) target sentence after exposure to the universal-wide interpretation of the (Dutch) prime sentence than after exposure to the existential-wide interpretation of the (Dutch) prime sentence. Therefore, this finding indicates that the Dutch-French bilinguals that participated in Slim et al.'s study rely on shared logical representations in the processing of both their L1 and their L2.

The *all...a* sentences investigated in the study reported in Chapter 2 are similarly interpreted in Dutch and French (which was assessed in a baseline experiment). Recall that Feiman and Snedeker's (2016) study revealed that different combinatorial properties across quantifiers reflect different scope-taking mechanisms, which prevented sharing logical representations across different quantifier words. Given that Estonian and English differ in preference patterns in interpreting *all...not* constructions, a relevant question is whether bilingual logical representations are differentiated according to language-specific combinatorial tendencies in the assignment of scope. In case they are, bilinguals do not rely on shared logical representations in the interpretation of sentences that display cross-linguistic variation in the assignment of scope.

Moreover, note that the bilingual participants in the study reported in Chapter 2 could in principle rely on transfer from the L1 to achieve native-like competence in the assignment of scope in the L2 because this study was concerned with scopally ambiguous sentences that are interpreted similarly in both languages that they tested. If this were the case, the bilingual participants may not have relied on abstract integrated logical representations that specify both features for the L1 and the L2 but solely rely on their L1-specific knowledge. Under this explanation, the effects of priming are not at the level of shared representations, but at the level of L1 representations (see also Hartsuiker & Bernolet, 2017, for a similar account on bilingual syntactic representations). The present study will therefore follow-up on the study in Chapter 2, by testing bilinguals who speak two languages (i.e., Estonian and English) with combinatorial tendencies in the assignment of scope.

3.1.3 Cross-linguistic influence

Bilinguals who speak two languages with different preferences in the assignment of scope may also encounter cross-linguistic influence in the interpretation of scopally ambiguous sentences. *Cross-linguistic influence*, which can be defined as "the influence of the non-selected language on the selected language in language use by bilinguals" (De Groot, 2011, p.449), is an important phenomenon in bilingual language processing. Here, we can make a distinction between (i) transfer from the L1 in processing of the L2 due to incomplete L2 acquisition (as previously mentioned) and (ii) cross-linguistic influence as the result of integrated knowledge about the preferences, rules, and structures of both languages a bilingual knows (e.g., Macken et al., 2014; Merema & Speelman, 2015; see also Van Gompel & Arai, 2018). In case cross-linguistic influence is due to incomplete acquisition of the L2, bilinguals rely on L1-specific knowledge because their L2-specific knowledge is not sufficiently developed (Hohenstein et al., 2006; Montero-Melis & Jaeger, 2020). If cross-linguistic influence is caused by incomplete L2 acquisition, then

L1 knowledge is expected to affect L2 processing but not the reverse. If, on the other hand, cross-linguistic influence is due to integrated implicit knowledge about the dependencies of both languages a bilingual knows, then L1-specific knowledge is expected to influence processing in the L2, but L2-specific knowledge is also expected to affect procesing in the L1 (Brown & Gullberg, 2011; Hohenstein et al., 2006; Pavlenko & Jarvis, 2002).

To our knowledge, cross-linguistic influence in the assignment of scope has not received much attention. Nevertheless, it is an important phenomenon with regard to our research goals: Like between-language priming, cross-linguistic influence indicates that the two languages a bilingual knows are not two separate entities in the mind of a bilingual, but that they are highly integrated (e.g., Jarvis & Pavlenko, 2008; Marian & Kaushanskaya, 2007). Therefore, cross-linguistic influence indicates the representations of the implicit knowledge about preferences and structures in one language can influence the representations of the other language through adaptation (e.g., Montero-Melis & Jaeger, 2020; Van Gompel & Arai, 2018). In fact, priming and cross-linguistic influence seem to have a shared underlying mechanism, namely that language processing affects subsequent language processing in an adaptive manner (Serratrice, 2013). However, between-language priming and cross-linguistic influence offer insights at slightly different levels of linguistic priming: Structural priming shows that language processing can influence subsequent language processing in the short-term (e.g., on a trial-by-trial basis; Bock, 1986; Chang et al., 2006; Pickering & Branigan, 1998) and therefore indicates that short-term representations (i.e., representations that are computed on each instance of language processing) are shared between languages (Hartsuiker et al., 2004; Schoonbaert et al., 2007; Van Gompel & Arai, 2018). Cross-linguistic influence, on the other hand, indicates that long-term representations, which is pre-existing knowledge about the biases and structures of a language, are also integrated in the mind of a bilingual (e.g., Macken et al., 2014; Merema & Speelman, 2015; see also Van Gompel & Arai, 2018).

3.1.4 The present study

The present study investigates whether bilingual logical representations are shared across languages if those two languages diverge on the preferred interpretation of a scopally ambiguous sentence. We studied this question by testing effects of (between-language) priming and cross-linguistic influence in the interpretation of scopally ambiguous sentences in the interpretation of *all...not* sentences by (highly proficient) Estonian-English bilinguals (who speak Estonian as their L1 and English as their L2). In addition, we tested cross-linguistic priming and influence in the interpretation of *all...not* sentences by Dutch-English bilinguals. *All...not* sentences are interpreted similarly in Dutch and English. Comparing Estonian-English and Dutch-English bilinguals will therefore elucidate the role of cross-linguistic influence in the construction and organisation of logical representations: Estonian-English bilinguals are expected to encounter such cross-linguistic influence, whereas Dutch-English bilinguals are not. Cross-linguistic influence should result in a difference between Estonian-English and Dutch-English participants in the interpretation of *all...not* sentences, independent from the trial-by-trial priming effects.

We conducted five sentence-picture matching experiments that were designed to elicit priming effects on the level of logical representations in the comprehension of *all...not* sentences (Feiman & Snedeker, 2016; Raffray & Pickering, 2010; see also Branigan et al., 2005). In Experiment 1, we tested L1-L1 priming in the interpretation of *all...not* in English, Estonian, and Dutch. In Experiment 2, we tested priming of logical representation from the L1 onto the L2. In Experiment 3, we tested priming from the L2 onto the L1. In Experiment 4, we studied L2-L2 in English (again, with Estonian-English participants). Finally, testing effects of priming within a sentence-picture matching task has the risk of eliciting effects of visual priming. Priming does not only emerge at linguistic levels of representation: Visual information is also processed with more ease after repeated exposure (e.g., Tulving & Schacter, 1990). Therefore, participants may not only perseverate in their interpretation of the test sentences because of priming at a linguistic level, but because they tend to select the target picture that resembles the pictures of the preceding prime. In Experiment 5, we tested (and ruled out) possible confounding effects of visual priming in the sentence-picture matching tasks used in Experiments 1-4.

3.2 Experiment 1: L1-L1 priming

Experiment 1 consisted of three web-based sentence picture matching tasks that were designed to elicit within-language priming effects on the level of logical representations in L1 language comprehension (Feiman & Snedeker, 2016; Raffray & Pickering, 2010). This experiment tested whether logical representations of *all...not* sentences are susceptible to priming in a native language. Experiment 1a measured within-L1 priming effects in English, Experiment 1b in Estonian, and Experiment 1c in Dutch.

3.2.1 Method

Participants

Experiment 1a: English. In this experiment, a total of 113 native speakers of English participated (80 were recruited on Prolific, the others online via social media; mean age: 29 years old, sd: 10 years; range: 18 – 59 years). Following Raffray and Pickering (2010), we excluded participants if they gave incorrect responses on more than 10% of all filler trials (i.e., those who made more than 5 mistakes on the filler trials). However, none of the participants needed to be excluded from the analyses. Of the 113 participants, 103 reported to only use English daily.

Experiment 1b: Estonian. In this experiment, a total of 153 native speakers of Estonian participated (who were recruited via online social media and via the University of Tartu; mean age: 27.48 years old; sd: 7.40; range: 18 – 60). None of the participants needed to be excluded from the analyses. Of the 146 participants who used Estonian daily, some indicated to only use Estonian (n = 14) while others reported to use multiple languages daily (mostly Estonian and English, n = 136).

Experiment 1c: Dutch. In this experiment, a total of 136 native speakers of Dutch participated (who were recruited via social media; mean age: 37.07 years old; sd: 13.99; range: 19 – 73). None of the participants needed to be excluded from the analyses. Of all participants, 133 reported to use Dutch daily, the other 3 participants only used English daily.

Materials

The experiment involved three different versions of the same sentence-picture matching task: In Experiment 1a, all sentences were presented in English, in Experiment 1b in Estonian, and in Experiment 1c in Dutch.

On all trials, a sentence was presented together with two pictures[2]. In the prime and target trials, the sentences were *all...not* sentences of the form *All the* [plural noun] *are not in the squares* (See Appendix 3 for a list of all target sentences). There are some cross-linguistic differences in the structure of *all...not* sentences between English, Estonian and Dutch (Table 3.1). Most notably, the negator directly follows the finite verb in English in Dutch, whereas it

[2]The materials used in this experiment and all subsequent experiments are available online at https://osf.io/59ezt/.

precedes the finite verb in Estonian (Tamm, 2015). The surface order of the scope-bearing operators with respect to each other, however, is alike in all three languages.

Language	**Sentence and gloss**
English	All the apples are not in the boxes
Estonian	Kõik õun-ad ei ole kasti-des
	all.NOM apple-NOM.PL NEG be.CNG box-PL.INE
Dutch	Alle appel-s zijn niet in de vierkant-en
	all apple-PL be.3.PL NEG in the square-PL

Table 3.1: Example of a prime/target sentence in English, Estonian, and Dutch

In the prime trials, an *all...not* sentence was presented with one matching picture and one foil picture. The matching picture corresponded to one of the two possible interpretations of the sentence, whereas the foil picture matched neither interpretation of the sentence. The foil pictures always displayed all objects named in the subject noun in the squares. This way, the participants were forced to assign a specific interpretation in the sentence. Prime trials were presented in two prime conditions: The *universal-wide* condition and the *negation-wide* condition. In the universal-wide condition, the compatible picture corresponded to the interpretation in which the universal quantifier takes wide scope over the negator. In the negation-wide condition, the compatible picture corresponded to the interpretation in which the negator takes wide scope over the universal quantifier (Figure 3.1). The pictures in the target trials displayed both possible interpretations of the test sentence: One picture corresponded to the universal-wide interpretation of the test sentence, and the other picture corresponded to the negation-wide interpretation of the test sentence. In the target trials, the participants thus had a choice between two pictures that both displayed situations that matched the test sentences semantically. Prime and target trials were organised in triplets: Each target trial was preceded by two prime trials of the same prime condition (Figure 3.2). We used two prime trials instead of one to boost the priming effect (following Maldonado et al., 2017a).

In addition, the experiment included unambiguous filler trials. Filler trials contained an unambiguous sentence (either a universally-quantified affirmative transitive sentence like *All the* [plural noun] *are in the boxes* or affirmative sentences like *The* [plural noun] *are in the boxes*) and two pictures. One of those pictures matched the sentences, whereas the other picture mismatched the sentence. The foil picture mismatched the sentence either because none or some of the referents denoted in the filler sentence were in the boxes, or because those referents mismatched the sentence.

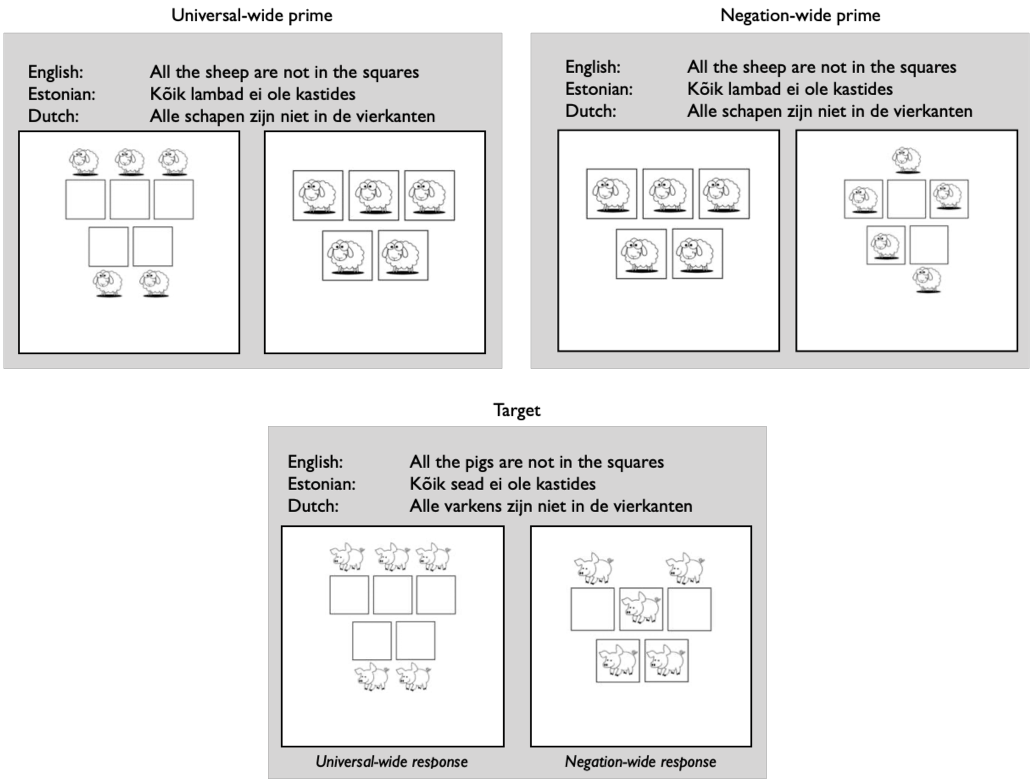


Figure 3.1: Examples of a prime (in both prime conditions) and a target trial. In the prime trials, one picture matched (one possible interpretation of) the sentence, whereas the other picture did not match either interpretation of the sentence. In the target trials, on the other hand, both pictures matched both possible interpretations of the sentence. In the experiment, only one language was shown to the participants. Similarly, the labels 'Universal-wide response' and 'Negation-wide response' are added to the target trial in this figure for ease of illustration.

We made two lists that contained 18 prime-target triplets as well as 54 filler trials. In each list, the 18 prime-target triplets and 54 fillers trials were organised in a pseudorandomised order. The restrictions on the randomisation of the order were that (i) the prime and target trials were organised in triplets, so that two prime trials immediately preceded a target trial, and that (ii) a minimum of two and a maximum of four fillers intervened the prime-target triplets (following Raffray & Pickering, 2010). Prime Condition was counterbalanced between both lists (with nine prime-target triplets in each prime condition).

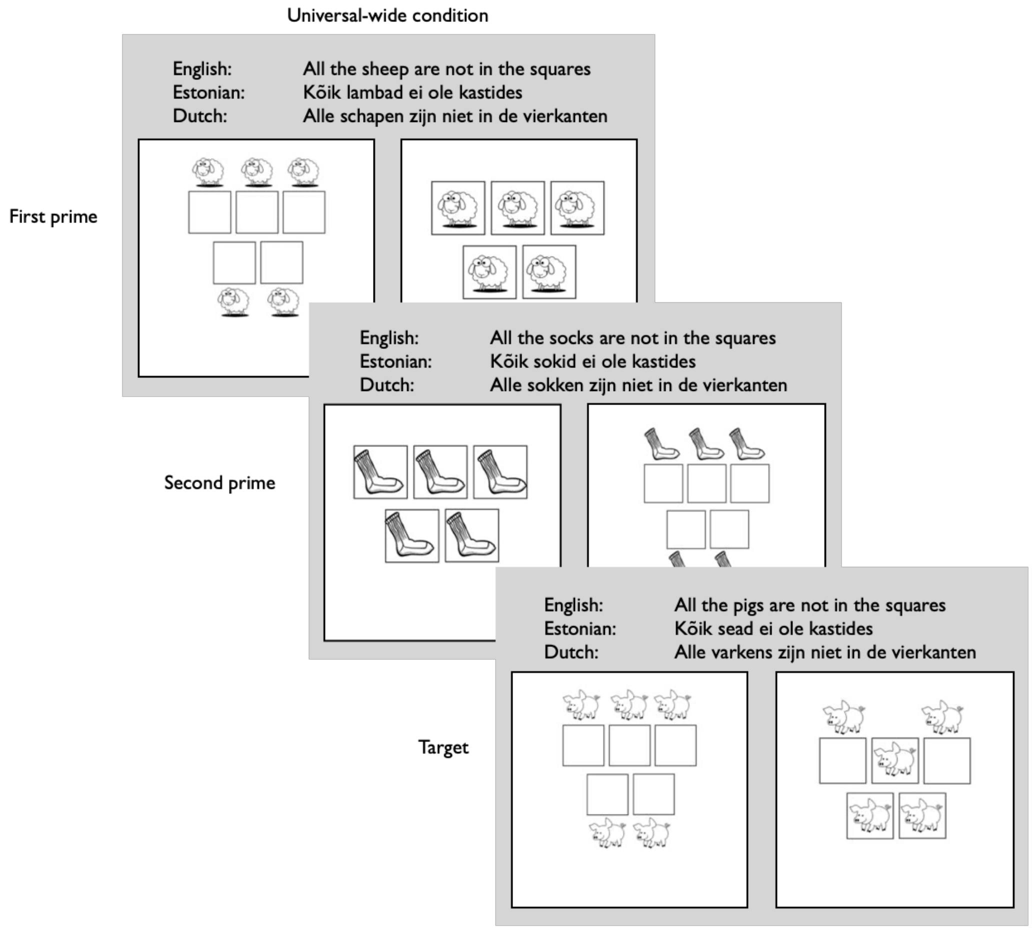


Figure 3.2: The triplet procedure used in our experiments: Each target trial was preceded by two prime trials (in the same prime condition). The example shows a universal-wide prime condition, but the procedure was the same for both prime conditions. Note that the example trials show the sentences in all three languages, this is only for illustration. The participants saw each sentence in only one language.

Procedure

The experiment was carried out online using Qualtrics (https://www.qualtrics.com). In all trials, the sentence and the two pictures were shown simultaneously on the screen. The participants were instructed to select the picture that matched the sentence and select their spontaneous preference if they thought that both pictures matched the sentence. Once the participant selected a picture, the next trial started automatically. After completing the task, the participants filled in a short demographic questionnaire.

3.2.2 Analyses and results

Data treatment and analysis procedure

A target trial response was excluded from further analyses if the participant responded incorrectly on one of the two preceding prime trials, following Raffray and Pickering (2010). The remaining target responses were coded `TRUE` if the universal-wide interpretation was selected and `FALSE` if the negation-wide interpretation was selected. We analysed the data using logit mixed-effect models (Jaeger, 2008). These models included Target Response Type as the binomial dependent variable, and Prime Condition and Language (i.e., sub-experiment) as fixed effects. In all models, the categorial fixed effects were sum coded. These models were constructed using the `lme4` package for mixed-effect models (Bates et al., 2014) in `R` (version 4.0.0; R Core Team, 2019).

The random-effects structure was selected by model comparisons. To avoid overfitting (Bates et al., 2015), we compared the model with the maximal random-effects structure that converged with models in which the random slopes were removed one-by-one. These model comparisons were performed by means of χ^2-tests on the log-likelihood values of the models. Following Matuschek et al. (2017), we used the model with the simpler random effects structure instead of the maximal model if the model comparisons showed a p-value higher than 0.2. Once we selected our full model, we calculated the p-values of the fixed effects by running χ^2-tests on the log-likelihood values. Subsequently, we conducted post-hoc comparisons between the different levels of the Language predictor using the `testInteractions` command from the `phia` package in `R` (De Rosario-Martinez, 2015).

In addition to the above-described frequentist statistics, we also calculated Bayes Factors. Bayes Factors are indicators for the likelihood of the data under the null hypothesis: A Bayes Factor of 1 indicates no evidence towards either the null hypothesis or the alternative hypothesis. A Bayes Factor that is greater than 1 indicates evidence in favour of the null hypothesis (with higher values providing stronger evidence), and a Bayes Factor below 1 provides evidence in favour of the alternative hypothesis (with lower values indicating stronger evidence) (Dienes, 2014)[3]. The Bayes Factors were calculated using the *Bayesian Information Criteria* (BIC) values

[3] We interpret Bayes Factors using Raftery's (1995) classification: A Bayes Factor indicates weak evidence for the null hypothesis if it lies between 1-3, positive evidence for the null hypothesis if it lies between 3-20, strong evidence for the null hypothesis if it lies between 20-150, and very strong evidence if it is a value above 150. Conversely, a Bayes Factor indicates weak evidence for the alternative hypothesis if it lies between 0.33-1, positive evidence for the alternative hypothesis if it lies between 0.05-0.33, strong evidence for the alternative hypothesis if it lies between 0.0067 and 0.05, and very strong evidence for the alternative hypothesis if it lies below 0.0067.

extracted from the above-described model comparisons. Bayes Factors were then calculated by measuring the difference between two BIC values (one for the full model, which characterises the alternative hypothesis, and one for the reduced model, which characterises the null hypothesis) in the following way: ΔBIC_{10} = BIC_{H1} - BIC_{H0}. This value can then be transformed into a Bayes Factor using the following formula: BF = $e^{\Delta BIC_{10}/2}$ (Wagenmakers, 2007).

Finally, we conducted logit mixed-effect models for the separate datasets of each Language condition to obtain Bayes Factors for the prime effect in each level of the Language variable. Here, the model comparisons involved a full model that contained a predictor for Prime Condition, and a null model in which the predictor was removed.

Results and discussion

In Experiment 1a (English), 24 target responses were excluded in the universal-wide condition (2.36% of all responses in the universal-wide condition), and 19 target responses were excluded in the negation-wide condition (1.87% of all responses in the negation-wide condition). In Experiment 1b (Estonian), 31 responses were excluded in the universal-wide condition (2.25% of all responses in the universal-wide condition), and 13 in the negation-wide condition (0.94% of all responses in the negation-wide condition). In Experiment 1c (Dutch), 25 responses were removed from the universal-wide condition (2.04% of all responses in the universal-wide condition) and 29 responses were removed from the negation-wide condition (2.37% of all responses in the negation-wide condition), due to incorrect responses in the preceding primes.

In Experiment 1a, the universal-wide response was selected in 94.78% of all target trials following a universal-wide prime, and in 92.40% of all target trials following a negation-wide prime (a difference of 2.38%). In Experiment 1b, the universal-wide response was selected in 30.10% of the targets in the universal-wide prime condition, and in 26.51% of all the targets in the negation-wide prime condition (a difference of 3.50%). In Experiment 1c, finally, this universal-wide response was selected in 98.16% of the targets following a universal-wide prime, and in 97.07% of the targets following a negation-wide prime (a difference of 1.09%). Thus, these results show a small descriptive priming effect (Figure 3.3): The participants chose the universal-wide response more often in the universal-wide condition compared to the negation-wide condition.

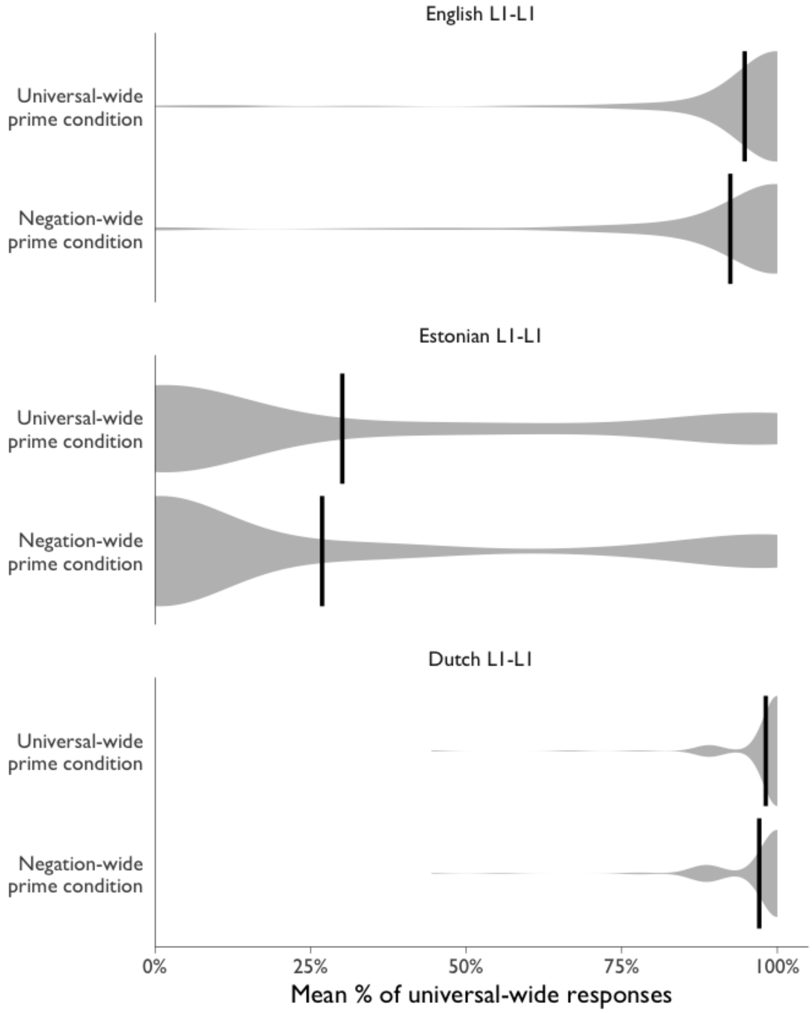


Figure 3.3: The participants' mean percentage of universal-wide responses on the target trials in all conditions in Experiment 1. The vertical lines represent the mean response rates and the outline of the blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. The mean percentage of universal-wide responses is higher in the universal-wide than in the existential-wide prime condition, which descriptively suggests effect of priming.

The logit mixed-effect models used in the analyses included random intercepts per Subject and Item in the random effects structure, since a more complex model failed to converge. Model comparisons revealed a significant effect of Prime Condition (χ^2(1) = 20.07, $p < 0.001$) and Language (χ^2(2) = 311.96, $p < 0.001$) but no interaction between Prime Condition and Language (χ^2(2) = 4.26, p = 0.119). This overall pattern was replicated in our Bayes Factor analyses:

The Bayes Factor representing the interaction term was > 150 (meaning that the data is > 150 times more likely under the null hypothesis than under the alternative hypothesis, which is very strong evidence for the null hypothesis). The Bayes Factor representing the Language predictor was < 0.001 (very strong evidence in favour of the alternative hypothesis, i.e., an effect of Prime Condition) and the Bayes Factor indicating the effect of Prime Condition was 0.004 (very strong evidence for the alternative hypothesis).

The planned post-hoc pairwise comparisons on the full model indicated that the effect of Prime Condition was significant in Experiment 1a (English; $\chi^2(1) = 8.34$, $p = 0.008$) and in Experiment 1b (Estonian; $\chi^2(1) = 10.99$, $p = 0.027$), but not significant in Experiment 1c (Dutch; $\chi^2(1) = 3.47$, $p = 0.062$; although this p-value could be interpreted as a trend). Separate models for each dataset per language showed a significant effect of Prime Condition in English (Bayes Factor: 0.51; i.e., weak support for the alternative hypothesis) and in Estonian (Bayes Factor: 0.12; i.e., positive evidence for the alternative hypothesis), but not in Dutch ($\chi^2(1) = 2.84$, $p = 0.092$; Bayes Factor: 11.93; i.e., positive evidence for the null hypothesis).

Summing up, the omnibus analyses of Experiment 1 revealed that logical representations can be primed in L1 language comprehension. Moreover, the analyses also revealed that native speakers of Estonian indeed assign a negation-wide interpretation more often to an *all...not* sentence in their native language than English or Dutch speakers. The lack of an interaction between Prime Condition and Language furthermore suggested that the strength of priming is not dependent on the language of the experiment (English, Estonian, on Dutch). Zooming in on the separate datasets of each Language condition, however, the analyses provided evidence for within-language logical representation priming in Estonian and English, but the evidence is not as strong in Dutch. Note that we found a very strong ceiling effect in Dutch: Even in the negation-wide prime condition, the universal-wide response is selected 97% of the time. This ceiling effect in Dutch might have blocked possible priming effects in this experiment.

3.3 Experiment 2: L1-L2 Priming

In Experiment 2, we tested between-language priming effects from the L1 onto the L2. This experiment therefore elucidated the possible sharedness of bilingual logical representations. In Experiment 2a, the prime trials were presented in Estonian (the participant's L1), and the target trials in English (the participant's L2). In Experiment 2b, the prime trials were presented in Dutch (the participant's L1), and the target trials in English (the participant's L2). By comparing Estonian-English and Dutch-English bilingual language processing, we will also gain insight in the possible influence of cross-linguistic interference on the level of logical representations. Given that Estonian and English differ in the interpretation of the scopally ambiguous *all...not* sentences, we may find cross-linguistic influence in Estonian-English bilingual processing. On the other hand, we expected no differences in interpretation of *all...not* sentences between Dutch and English.

3.3.1 Method

Participants

Experiment 2a: Estonian-English. A total of 124 native speakers of Estonian who are proficient L2 speakers of English participated in this version of the experiments (who were recruited via social media and via the University of Tartu). One participant was removed because they reported that Estonian was not their L1. The remaining 123 participants self-rated their proficiency in (L2) English as highly proficient.[4] See Table 3.2 for more demographic information about the participants.

Experiment 2b: Dutch-English. In this experiment, a total of 103 native speakers of Dutch who are proficient L2 speakers of English participated (who were recruited via social media). We removed 5 participants who reported that Dutch was not their (sole) L1. Information about the remaining 98 participants can be found in Table 3.2.

Materials

The materials used in Experiment 2 were the same as in Experiment 1, but the language of the prime and target trials differed in Experiment 2. In Experiment 2a, the prime sentences were presented in Estonian (the participants' L1), and the target sentences in English (the participants' L2). In Experiment 2b, the prime sentences were in Dutch (the participants' L1), and the target

[4]We gained some additional insight in the proficiency in L2 English of the participants through a brief C-test. A C-test consist of short texts, in which the second half of each other word is missing (apart from in the first and final sentence). The participant's task is to fill in these missing parts. Previous research has shown that C-tests are valid and efficient predictors of general language proficiency because the results of these tests tend to have high correlations with other tests measuring listening, reading, speaking, and writing abilities and vocabulary knowledge (Harsch & Hartig, 2016). We used a short C-text that consists of one short text with 21 gaps Sarapuu and Alas (originally constructed by 2016). This brief test only served as a quick indicator of whether the bilingual is indeed highly proficient in English. The mean number of mistakes on this test was 1.4 (sd: 1.7; range 0-9) in Experiment 1a and 1.0 (sd: 1.3; range 0-6) in Experiment 1b.

	Experiment 2a: Estonian-English	Experiment 2b: Dutch-English
Age	28 years (8.4)	41.0 years (14.3)
Age of onset of L2 English	9 years (4.3)	11 years (2.4)
Residency in an English-speaking country?	n = 60 (mean length: 5.5 years, range: 3 months - 26 years)	n = 97 (mean length: 12.5 years; range: 4.5 months - 50 years)
Self-rating English (L2)		
Speaking	8.2 (1.2;4 - 10)	8.8 (1.0;5 – 10)
Listening	8.9 (0.9;7 - 10)	9.2 (0.8;7 – 10)
Reading	8.9 (0.9;6 - 10)	9.3 (0.8;7 – 10)
Overall	8.7 (0.9; 6 - 10)	9.1 (0.8;7 – 10)

Table 3.2: Mean self-ratings of L2 English proficiency from the included participants of Experiment 2. Standard deviations and ranges are given between parentheses.

sentences in English (the participants' L2). In addition, half of the filler trials were presented in the participant's L1, and the other half were presented in the participant's L2.

Procedure

The procedure was identical to Experiment 1, with the exception that the demographic survey now also included a short C-test (see footnote 3).

3.3.2 Analyses and results

The data treatment and analysis procedure were the same as in Experiment 1.

Results and discussion

In Experiment 2a, 22 responses were excluded from the universal-wide condition (2.37% of all universal-wide responses), and 15 responses were excluded from the negation-wide condition (1.62% of all negation-wide responses) due to incorrect responses on the preceding prime trials. In Experiment 2b, 33 target responses were excluded in the universal-wide condition due to errors made on the preceding prime trials (3.74% of all universal-wide responses). In the negation-wide condition, 31 target responses were excluded due to errors made on the preceding prime trials (3.51% of all negation-wide responses).

In Experiment 2a, the Estonian-English bilinguals selected the universal-wide response in 46.15% of all target trials in the universal-wide condition, and in 42.93% of all target trials in the negation-wide condition (a difference of 3.22%). In Experiment 2b, the Dutch-English bilinguals selected the universal-wide response in 99.21% of the target trials following a universal-wide prime, and in 98.41% of the target trials following a negation-wide prime (a difference of 0.80%; Figure 3.4).

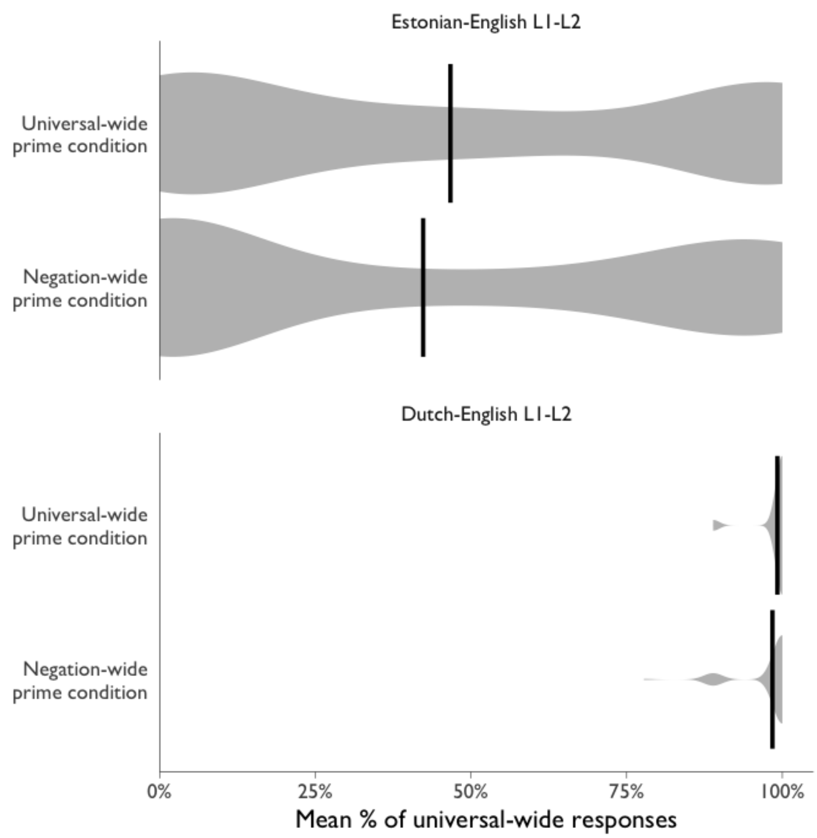


Figure 3.4: The participants' mean percentage of universal-wide responses on the target trials in all conditions in Experiment 2. The vertical lines represent the mean response rates and the outline of the blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. The mean percentage of universal-wide responses is higher in the universal-wide than in the existential-wide prime condition, which suggests (at least a) descriptive effect of priming.

Our statistical analyses were conducted using the model that only contained random intercepts per Item and Subject in the random effects structure, since a more complex random-effects structure did not converge. Model comparisons revealed a significant effect of Language (χ^2(1) = 157.41, $p < 0.001$) and of Prime Condition (χ^2(1) =12.77, $p < 0.001$), but no interaction between Language and Prime Condition (χ^2(1) = 0.18, p = 0.674). The Bayes Factor analysis showed a similar pattern: The Bayes Factor for the interaction term was 57 (strong evidence for the null hypothesis), the Bayes Factor for Language was < 0.001 (very strong evidence in favour of the alternative hypothesis) and the Bayes Factor for Prime Condition was 0.21 (positive evidence in favour of the alternative hypothesis).

Planned post-hoc pairwise comparisons revealed that the effect of Prime Condition was significant in Experiment 2a (Estonian-English; χ^2(1) = 12.23, $p < 0.001$), but not in Experiment 2b (Dutch-English; χ^2(1) = 2.29, p = 0.130). The analyses on the separate datasets of Experiment 2a and 2b also showed that the effect of Prime Condition was significant in Experiment 2a (χ^2(1) = 10.49, p = 0.0012; Bayes Factor = 0.25, which indicates positive evidence in favour of the alternative hypothesis), but not in Experiment 2b (χ^2(1) = 1.42, p = 0.234; Bayes Factor = 20, which indicates strong evidence in favour of the null hypothesis).

The analyses thus revealed that logical representations of *all...not* sentences can be primed between languages: We observe these effects from L1 Estonian onto L2 English, although the effects are not as clear from L1 Dutch onto L2 English. However, note that we observed a strong ceiling effect in the Dutch-English Experiment 2b (as in Experiment 1c; which was monolingual Dutch): Roughly 99% of all responses, regardless of prime condition, were universal-wide (see Figure 3.4). This ceiling effect may have weakened, or blocked, the effects of priming. We will return to the strong preference for the universal-wide interpretation in interpreting *all...not* sentences in Dutch in the General Discussion of this chapter.

More important for our purposes is that the results show that logical representation priming emerged from Estonian onto English. In addition, the Estonian-English bilinguals less often selected the universal-wide responses than the Dutch-English bilinguals. The target trials in both Language conditions were presented in English, and this result thus indicates that the prime language (which was the native language of the participants) influenced the responses on the English target trials. This effect emerged independent from trial-by-trial priming effects, since the universal-wide and existential-wide were presented an equal number of times in the prime trials in both versions of the experiment.

3.4 Experiment 3: L2-L1 priming

In Experiment 3, we primed logical representations from the L2 onto the L1. In case bilingual logical representations are indeed shared between languages, we would also expect effects of priming in this direction. Since both Experiment 1 and Experiment 2 showed that priming of logical representations of *all...not* sentences was weakened or blocked if the participants were native speakers of Dutch, we decided to only test Estonian-English bilinguals in Experiment 3.

3.4.1 Method

Participants

A total of 98 native speakers of Estonian who reported to speak English as an L2 participated in Experiment 2. Of all participants, 3 participants were excluded from further analyses because they indicated that Estonian was not their (sole) L1. Information about the remaining 95 participants is presented in Table 3.3.[5]

Age	27 years (6.8; 18-51)
Residency in an English-speaking country?	n = 14
Self-rating English (L2)	
Speaking	8.7 (1.4; 2 - 10)
Listening	7.8 (1.5; 2 - 10)
Reading	8.7 (1.4; 2 - 10)
Overall	8.3 (1.3; 2 - 10)

Table 3.3: Mean self-ratings of L2 English proficiency from the included participants of Experiment 3. Standard deviations and ranges are given between parentheses.

[5] The mean number of mistakes on the short C-test was 3.3 (sd: 3.3; range: 0-8).

Materials

The materials were similar to those of the previous to experiments. The prime sentences were presented in the participants' L2 (English), and the target sentences in the participants' L1 (Estonian).

Procedure

A minor change in Experiment 3 compared to the previous experiments is that the experiment was implemented in `javascript` using `PennController for Ibex` (`PCIbex`; Zehr & Schwarz, 2018), whereas the previous experiments were administered over Qualtrics. This minor change was purely practical: `PCIbex` is freely available software, whereas Qualtrics is not. The look and procedure of the experiment, however, did not differ much compared to the previous experiments, and therefore we do not expect that this difference in implementation caused any differences in the results.

3.4.2 Analyses and results

Data treatment and analyses procedure

The data treatment and analyses procedure were like those in Experiment 1 and Experiment 2, with the difference that Language was not included as a predictor variable in any of the models.

Results and discussion

We removed 21 target responses from in the universal-wide prime condition (2.45% of all targets in the universal-wide prime condition), and 19 target responses from the negation-wide prime condition (2.22% all targets in the negation-wide prime condition) due to incorrect responses on the preceding prime trials.

The universal-wide response was selected in 51.93% of all targets in the universal-wide prime condition, and in 42.74% of all targets in the negation-wide prime condition (Figure 3.5; a difference of 9.19%). The random-effects structure of the full model was maximal (random intercepts and slopes for Subject and Item). The analysis revealed a significant main effect of Prime Condition (χ^2(1) = 12.74, $p < 0.001$; Bayes Factor: 0.07, i.e., strong support in favour for the alternative hypothesis).

The results of Experiment 3 show that logical representations can be primed between languages in bilingual language comprehension. In Experiment 2, we already observed that

Figure 3.5: The participants' mean percentage of universal-wide responses on the target trials in all conditions in Experiment 3. The vertical lines represent the mean response rates and the outline of the blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. The mean percentage of universal-wide responses is higher in the universal-wide than in the existential-wide prime condition, which suggests (at least a) descriptive effect of priming.

logical representations can be primed from the L1 onto the L2; the results of Experiment 3 indicate that the reverse is also possible. This finding further demonstrates that bilingual logical representations are shared between the L1 and the L2 in language comprehension. Moreover, this finding suggests that logical representations that are computed in the L2 are strong enough to trigger effects of priming, a finding we will further test in Experiment 4.

3.5 Experiment 4: L2-L2 priming

In Experiment 4, we tested priming of logical representations from the L2 onto the L2 in Estonian-English bilinguals. Because priming emerged from the L2 to the L1 (Experiment 3), it is expected that priming will also emerge within the L2. Moreover, Experiment 4 will further elucidate the role of cross-linguistic influence in the construction of logical representations in language processing. The results of Experiment 2 (L1-L2 priming) suggested that knowledge about the preference patterns in interpreting Estonian *all...not* sentences affected the interpretation of *all...not* sentences in English in Estonian-English bilinguals. This role of cross-linguistic influence may have been induced in Experiment 2, however, because the prime trials were presented in Estonian. In Experiment 4, all trials were presented in English. Therefore, possible cross-linguistic influence from the L1 (Estonian) is not due to recent exposure to Estonian in the experiment.

3.5.1 Method

Participants

We recruited 100 further native speakers of Estonian who speak English as a second language to participate in this experiment via Prolific. One participant was removed from further analysis because they reported that they were raised bilingually. Table 3.4 reports a summary of the language background of the participants. Due to a programming error, the age of English acquisition of each participant was unfortunately not saved, though none of the participants indicated to have acquired English from birth[6].

Age	27 years (6.8; 18-51)
Residency in an English-speaking country?	n = 12
Self-rating English (L2)	
Speaking	7.7 (1.2; 4 - 10)
Listening	8.6 (1.0; 6 - 10)
Reading	8.7 (1.0; 6 - 10)
Overall	8.3 (0.9; 6 - 10)

Table 3.4: Mean self-ratings of L2 English proficiency from the included participants of Experiment 4. Standard deviations and ranges are given between parentheses.

Materials

As the experiment was completely in English, the materials and procedure were identical to Experiment 1a (where we primed logical representations within L1 English comprehension).

Procedure

The procedure of Experiment 4 was identical to Experiment 3.

[6]The mean number of mistakes on the short C-test was 3.2 (sd: 3.0; range: 0-13); The responses on the C-test were not saved for one participant.

3.5.2 Analyses and results

Data treatment and analyses procedure

The data treatment and analyses procedure of Experiment 4 was identical to Experiment 3.

Results and discussion

In Experiment 4, 21 responses were excluded from the universal-wide condition (2.36% of all targets in the universal-wide prime condition), and 17 responses were excluded from the negation-wide condition (1.91% all targets in the negation-wide prime condition) due to incorrect responses on the preceding prime trials. The universal-wide response was selected in 77.89% of the target trials preceding a universal-wide prime, and in 71.94% of the target trials preceding a negation-wide prime (Figure 3.6; a difference of 5.95%).

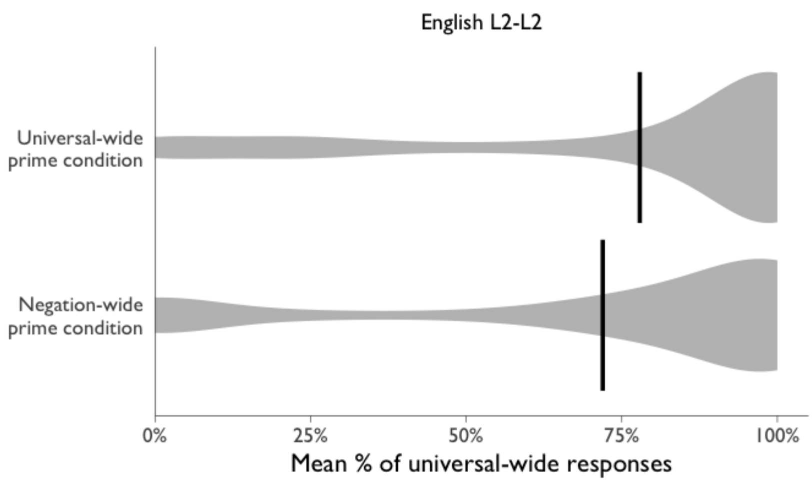


Figure 3.6: The participants' mean percentage of universal-wide responses on the target trials in all conditions in Experiment 4. The vertical lines represent the mean response rates and the outline of the blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. The mean percentage of universal-wide responses is higher in the universal-wide than in the existential-wide prime condition, which suggests (at least a) descriptive effect of priming.

The model selection procedure revealed that only random intercepts for Subject and Item were sufficient. Model comparisons revealed a significant effect of Prime Condition (χ^2(1) = 22.27, $p < 0.001$). The Bayes Factor representing this effect was $<$0.001 (i.e., very strong evidence for the alternative hypothesis).

Priming of logical representations thus emerges within an L2 (as previously observed in

Chapter 2). This result is not unexpected, because Experiment 3 already showed priming from an L2 onto an L1 and thus that logical representations computed in the L2 are stable enough to elicit priming. More importantly, we conducted Experiment 4 to further test whether Estonian-English bilinguals encounter cross-linguistic influence from Estonian in interpreting English *all...not* sentences, even in the absence of exposure to Estonian *all...not* sentences. We tested this in cross-experimental analyses, which are reported in the next section.

3.6 Combined analyses

We conducted cross-experimental analyses to test two broad questions: (i) Do bilinguals learn L2-specific biases in the assignment of scope and/or do they encounter (bidirectional) cross-linguistic influence in interpreting *all...not* sentences? And (ii) is the strength of priming influenced by prime direction (L1-L2, L1-L2, L2-L1, and L2-L2)?

3.6.1 Influences on overall preferences

In our first cross-experimental analyses, we tested for differences in the overall target response choices in Experiments 1-4 independent from priming. First, we tested whether Estonian-English bilinguals develop sensitivity to L2-specific biases in the assignment of scope, by combining the data of Experiment 1b (L1-L1 priming in Estonian) and Experiment 4 (L2-L2 priming in English).

Descriptively, the trend is clear: The Estonian-English participants selected the universal-wide response in 28.58% of the trials in Experiment 1b (which was conducted in their L1, Estonian) and in 74.92% of the trials in Experiment 4 (which was conducted in their L2, English; Figure 3.7). Analysis of this dataset, using mixed-effect models (see Experiments 1-4) revealed that the effect of Experiment was significant (χ^2(1) = 31.15, $p < 0.001$), which was also supported by the Bayes Factor calculated by using the BIC values of the models (< 0.001; i.e., very strong evidence in favour of the alternative hypothesis). Thus, participants selected the universal-wide response more often if the experiment was conducted in English (their L2) than if it was conducted in Estonian (their L1). This indicates that Estonian-English bilinguals learn L2-specific biases in the assignment of scope, and thus that processing of scopally ambiguous sentences in the L2 does not solely depend on L1 knowledge.

Second, we tested the role of cross-linguistic influence in the assignment of scope. The first comparison in these analyses involved the responses in Experiment 1a (L1-L1 priming in English), Experiment 2a (L1-L2 priming in Estonian-English bilinguals), and Experiment 4 (L2-

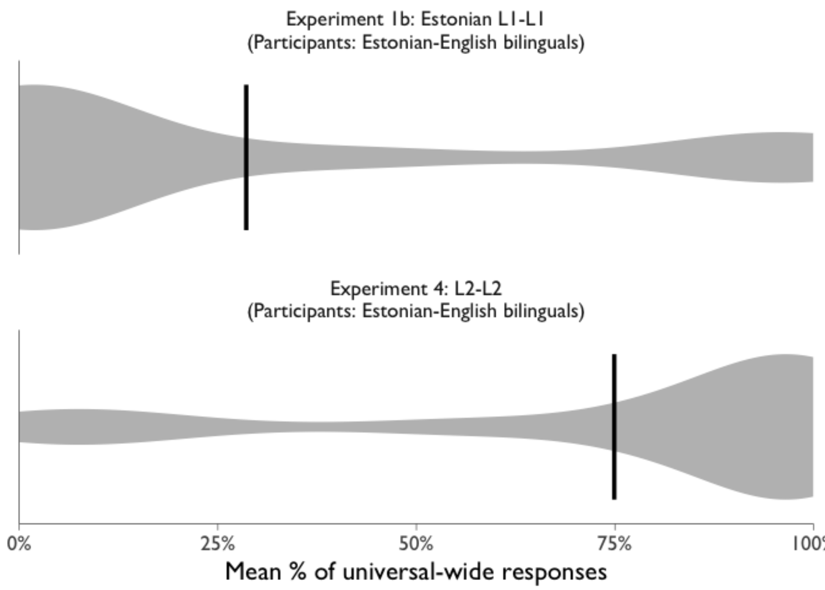


Figure 3.7: Overall percentage of universal-wide responses in Experiment 1b (Estonian L1-L1 priming) and Experiment 4 (English L2-L2 priming). The vertical lines represent the mean response rates, and the outline of the blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. The participants in Experiment 1b and 4 are Estonian-English bilinguals, and thus, these results suggest that that these bilinguals learn L2-specific biases in the interpretation of *all...not* sentences: They assign the universal-wide interpretation more often in English than in Estonian.

L2 priming in Estonian-English bilinguals). This dataset only contains English target trials, but the experiments differed in the participants (native speakers of English vs Estonian-English bilinguals) or the prime trials (English prime trials vs Estonian prime trials).

In Experiment 1a, the universal-wide response was selected in 93.95% of all target trials; in Experiment 2a, this was 48.72%, and in Experiment 4, this was 75.17% (Figure 3.8). The statistical analysis (again conducted using logit mixed-effect models) revealed a significant effect of Experiment (χ^2(2) = 128.21, $p < 0.001$), which was supported by the Bayes Factor estimation (< 0.001, i.e., very strong evidence for the alternative hypothesis). Moreover, planned post-hoc pairwise comparisons (using the `testInteractions()` function of the `phia` package in `R` (De Rosario-Martinez, 2015) revealed that the difference in the response rates on the target trials across the experiments are significant across all levels of the Experiment variable (Experiment 1a vs Experiment 4: χ^2(1) = 30.26, $p < 0.001$; Experiment 1a vs Experiment 2a: χ^2(1) = 116.44, $p < 0.001$; Experiment 2a vs Experiment 4: χ^2(1) = 31.29, $p < 0.001$). These analyses thus show that native speakers of Estonian assign the universal-wide response less often to English *all...not* sen-

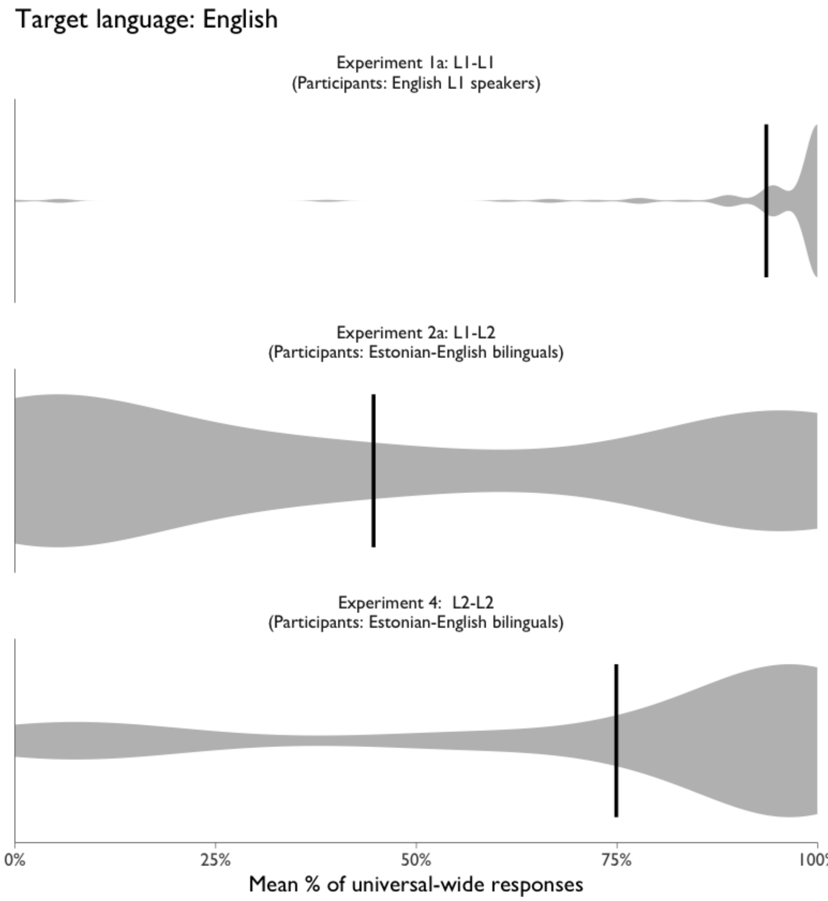


Figure 3.8: Overall percentage of universal-wide responses (independent of prime condition) in the (sub)experiments that contained English target trials (1a, 2a, and 4). The vertical lines represent the mean response rates and the outline of the blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. The mean percentage of universal-wide responses seems to differ across the conditions, which suggests that bilinguals experience cross-linguistic influence from the L1 onto the L2 in the construction of logical representations.

tences than native speakers of English, indicating that the bilinguals experience cross-linguistic influence from their L1. This cross-linguistic influence is enhanced by the presence of Estonian prime trials.

Finally, we tested whether Estonian-English bilinguals encounter cross-linguistic influence from the L2 onto the L1, by combining the data of Experiment 1b (L1-L1 priming in Estonian) and Experiment 3 (L2-L1 priming in Estonian-English bilinguals). These two (sub-)experiments both involved Estonian target trials and Estonian-English bilingual participants, but they differed in

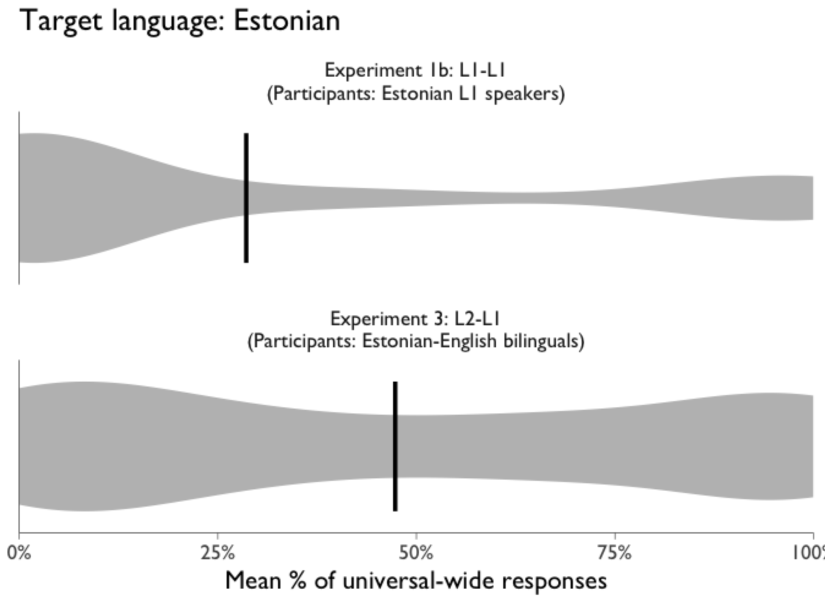


Figure 3.9: Overall percentage of universal-wide responses (independent of prime condition) in the (sub)experiments that contained Estonian target trials (1b and 3) The vertical lines represent the mean response rates and the outline of the blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. The mean percentage of universal-wide responses seems to differ across the conditions, which suggests that bilinguals experience cross-linguistic influence from the L2 onto the L1 in the construction of logical representations.

prime language.

In Experiment 1b, the universal-wide response was selected in 28.37% of all target trials. In Experiment 3, the universal-wide response was selected in 47.34% of all target trials (Figure 3.9). Logit mixed-effect model analyses showed that this difference was significant (i.e., a main effect of Experiment, $\chi^2(1) = 32.20$, $p < 0.001$). A Bayes Factor estimation also supported this finding (< 0.001; i.e., very strong evidence for the alternative hypothesis). These results show that the presence of prime trials in English (L2) also induces (at least short-term) cross-linguistic influence in interpreting *all...not* sentences in L1 Estonian. This again shows that bilinguals can learn L2-specific biases in the assignment of scope, since knowledge on L2-specific scope-taking biases is even stable enough to trigger (at least short-term) influence on the L1.

Summing up, these cross-experimental analyses revealed that (i) bilinguals learn L2-specific biases in the assignment of scope and (ii) bilinguals encounter cross-linguistic influence in interpreting *all...not* sentences. This cross-linguistic influence is induced if the bilingual is exposed to *all...not* sentences in the non-target language in the prime trials. Finally, this cross-linguistic influence is bidirectional: both from the L1 onto the L2, and from the L2 onto the L1 (at least when the bilingual is recently exposed to English *all...not* sentences prior to being exposed to Estonian *all...not* sentences). These findings suggest that (at least highly proficient) bilinguals do not solely rely on L1 knowledge in the assignment of scope.

3.6.2 The sharedness of bilingual logical representations

We also conducted cross-experimental analyses to address the question of whether the size of priming is modulated by prime direction (L1-L1, L1-L2, L2-L1, or L2-L2). In this analysis, we combined all data from Experiments 1-4 and tested for an interaction between Prime Condition and Experiment. We conducted this analysis by constructing a logit mixed-effect model to model Response Type likelihood, with Prime Condition, Experiment, and their interaction term as fixed effects. The random effect structure only involved a random intercept per Item and Subject, because a more complex random effects structure failed to converge. Model comparisons on this model revealed no significant interaction (χ^2(6) = 4.17, p = 0.654), a main effect of Experiment (χ^2(6) = 576.72, $p <$ 0.001) and a main effect of Prime Condition (χ^2(1) = 80.70, $p <$ 0.001). This pattern was also observed in the Bayes Factors: The Bayes Factor representing the interaction was $>$150 (very strong evidence for the null hypothesis), whereas those representing the main effects were both $<$0.001 (very strong evidence for the alternative hypothesis).

These analyses revealed that the priming of logical representations are comparable across all conditions in Experiments 1-4. Even though there seemed to be some numerical differences in the results of these experiments, priming within the L1, from the L1 onto the L2, from the L2 onto the L1, and within the L2 is comparable. This finding indicates that bilingual logical representations are shared, and that they are therefore comparable when they are constructed in the L1 or in the L2.

Having reached the main conclusions of this paper, it must be noted the effects of priming we observed can also be interpreted in terms of visual priming. On this account, the participants are more likely to select a particular response picture in the target trials because it visually resembled the response pictures selected in the preceding prime trials. We tested this alternative explanation of the results in a control experiment, which is reported below.

3.7 Experiment 5: Visual priming

Not only linguistic representations are susceptible to effects of priming. Visual information is also facilitated by prior exposure to similar visual information (e.g., Tulving & Schacter, 1990). Therefore, we need to test whether the results of Experiments 1-4 can be explained by visual priming. This explanation of the findings postulates that the universal-wide response is selected more often after a universal-wide prime than following a negation-wide prime because the response picture corresponding to this universal-wide response resembles the pictures shown in the previous prime trials. In Experiment 5, we tested whether this alternative explanation could also account for the findings, by replacing the prime sentences with generic existential sentences (Maldonado et al., 2017b; Raffray & Pickering, 2010).

3.7.1 Method

Participants

We recruited 151 native speakers of English to participate in Experiment 5, via social media or Prolific. None of these participants needed to be excluded from further analyses.

Materials

The stimuli and procedure are like those of Experiment 1a, in which we primed the interpretation of *all...not* sentences in native speakers of English. The main difference, however, is that the prime trials did not involve scopally ambiguous *all...not* sentences. The prime sentences were instead replaced by unambiguous sentences of the form *There are empty squares* (Figure 3.10). The filler and target items were identical to Experiment 1a.

Crucially, the response pictures were the same as those used in Experiments 1-4. Therefore, this experiment also contained two prime conditions, which we will still refer to as universal-wide and negation-wide (even though these prime trials did not involve scopally ambiguous sentences). As in the previous experiments, the matching picture in the universal-wide primes displayed a situation in which five items of the same type were shown outside five empty squares. The matching picture in the negation-wide prime portrayed three of these five items inside three of the five squares, and two items outside of these five squares (and therefore, two of the five squares were empty). In the non-matching picture, all five items were shown inside the five boxes. Therefore, the unambiguous prime sentence *There are empty* squares still only matched one of the two pictures in the prime trials, which was the same response picture in

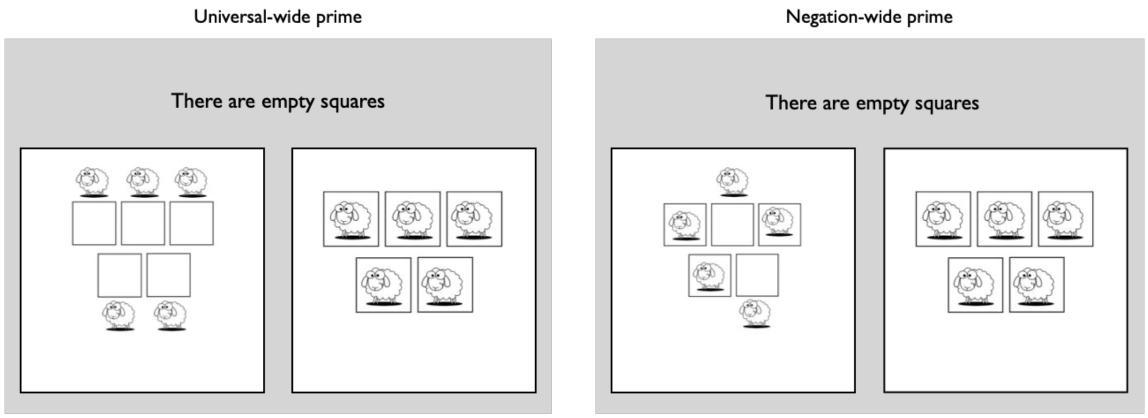


Figure 3.10: Example of a prime trial of Experiment 5 in both prime conditions. The target trials are the same as in the previous experiments, and contain an English *all...not* sentence. As in the previous experiments, two prime trials were presented directly before each target trial.

the prime trials as in Experiments 1-4. However, unlike Experiments 1-4, the participants were not forced to assign one of the possible readings of a scopally ambiguous *all...not* sentence in the prime trials of this experiment. Therefore, possible effects of priming cannot be attributed to persistence on the level of logical representations but have to be attributed to visual resemblances between the response pictures in prime and target trials.

Procedure

The procedure was identical to Experiment 3 and 4, with the exception that the participants did not fill in a C-test after the sentence-picture matching task.

3.7.2 Analyses and results

Data treatment and analyses procedure

The data treatment and analyses procedure were similar to those in Experiment 3 and 4.

Results and discussion

In Experiment 5, 8 from the target trials in the universal-wide prime condition (0.59% of all targets in the universal-wide prime condition), and 11 responses were removed from the target trials in the negation-wide prime condition (0.81% of all targets in the negation-wide prime condition). In the remaining target trials, the universal-wide response was selected in 83.44%

of all targets following a universal-wide prime trial, and in 84.47% of all targets following a negation-wide prime trial (Figure 3.11).

Descriptively, the results already show that the prime trials do not influence the responses in the target trials through visual priming: The universal-wide response was selected more often following negation-wide prime trials than following universal-wide prime trials, whereas priming would result in the reverse pattern. The statistical analyses (conducted using a model that contained a random intercept per Item and Subject and a random slope per Item) showed no effect of Prime Condition (χ^2(1) = 0.53, p= 0.468), which was supported by the Bayes Factor calculation (40, which indicates strong evidence for the null hypothesis).

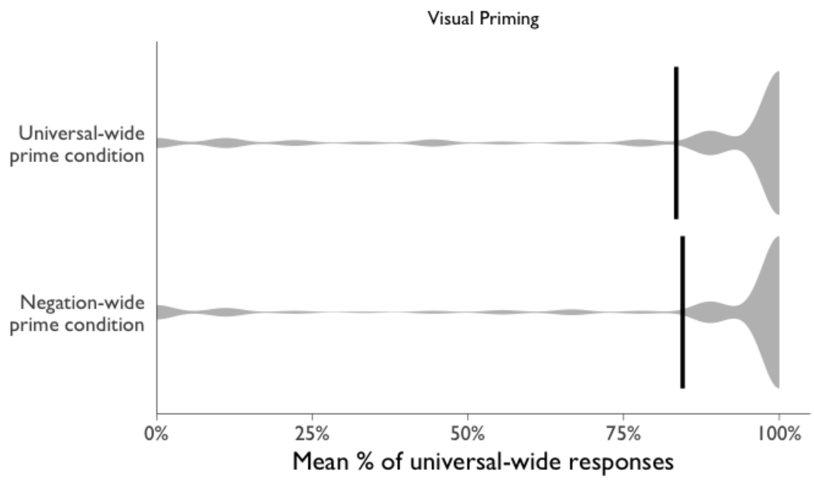


Figure 3.11: The participants' mean percentage of universal-wide responses on the target trials in all conditions in Experiment 5. The vertical lines represent the mean response rates and the outline of the blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point. The mean percentage of universal-wide responses is higher in the existential-wide than in the universal-wide prime condition, which suggests that there is no effect of visual priming (as the reverse pattern would be expected in case of priming).

Thus, these results suggest that there did not seem to be any effects of visual priming in the materials that we used in the experiments reported in this paper. To rule out that visual priming is not the explanation of the effects observed in Experiments 1-4, we conducted a cross-experimental analysis on the data of all five experiments. As in the previous cross-experimental analyses, this analysis was performed by using logit mixed-effects models. This analyses showed a significant interaction between Experiment and Prime Condition (χ^2(7) = 30.22, $p < 0.001$), a main effect of Experiment (χ^2(7) = 601.68, $p < 0.001$) and a main effect of Prime Condition (χ^2(1) = 63.59, $p < 0.001$). Bayes Factors calculations revealed a Bayes Factor of $>$150 for the interaction, which is considered very strong evidence for the null hypothesis. The Bayes Factor calculated for the main effects of Prime Condition and Experiment were both $<$0.001, which indicates very strong evidence for the alternative hypothesis. Thus, the Bayes Factor analysis revealed strong evidence for the main effects of Prime Condition and Experiment but not for the existence of an interaction between Prime Condition and Experiment.

Planned post-hoc pairwise comparisons using the `testInteractions` function of `R`'s `phia` package (De Rosario-Martinez, 2015) showed that the effect of priming was significantly larger in Experiment 1a (English L1-L1 priming) compared to Experiment 5 (χ^2(1) = 13.33, p= 0.007), in Experiment 1b (Estonian L1-L1 priming) compared to Experiment 5 (χ^2(1) = 11.56, p= 0.016), in Experiment 2a (Estonian-English L1-L2 priming) compared to Experiment 5 (χ^2(1) = 12.52, p= 0.010), in Experiment 3 (Estonian-English L2-L1 priming) compared to Experiment 5 (χ^2(1) = 27.98, $p <$ 0.001), and in Experiment 4 (English L2-L2 priming) compared to Experiment 5 (χ^2(1) = 23.50, $p <$ 0.001). On the other hand, the effect of Prime Condition was not stronger in Experiment 1b (Dutch L1-L1 priming) than in Experiment 5 (χ^2(1) = 8.89, p= 0.092) or in Experiment 2b (Dutch-English L1-L2 priming) than in Experiment 5 (χ^2(1) = 4.74, p= 0.647). Therefore, the interaction between Prime Condition and Experiment was driven by a subset of all levels, which may explain the dichotomy between the results of our frequentist and Bayesian analysis of the interaction.

Moreover,the effect of Prime Condition observed in the experiments that involved native speakers of Dutch do not seem to be stronger than the effect of Prime Condition in Experiment 5. Do note however, that the previous analyses of the separate experiments also revealed that there is no strong evidence for the existence of prime effects in these two experiments. Therefore, it is more important that our cross-experimental analyses reveal that the effects of priming observed in Experiments 1a, 1b, 2a, 3 and 4 (i.e., the effects of priming that were supported by our previous analyses) were stronger than the possible visual priming effect in Experiment 5.

3.8 General discussion

We studied the organisation of bilingual logical representations by focusing on the interpretation of ambiguous *all...not* sentences by Estonian-English bilinguals. The preferred interpretation of these sentences differs in Estonian and English. Therefore, this study gained insight in whether logical representations are differentiated according to language-specific combinatorial biases and in whether bilinguals experience cross-linguistic influence in the assignment of scope. Experiment 1 revealed priming within the L1 in the interpretation of *all...not* in Estonian and in

English (but not in Dutch, more below). Experiment 2 showed that such effects of priming also persisted from the L1 onto the L2 in Estonian-English bilinguals (but not in Dutch-English bilinguals; again, more below). In Experiment 3, we observed that such between-language priming also persisted from the L2 onto the L1 in Estonian-English bilinguals. Experiment 4 revealed priming of logical representations within the L2 in Estonian-English bilinguals. Finally, Experiment 5 ruled out an interpretation of these effects in terms of visual priming.

The results of Experiment 2 and 3 reveal that Estonian-English bilinguals use shared logical representations in the processing of *all...not* sentences in both their L1 (Estonian) and their L2 (English), even though both languages diverge on the preferred interpretation of *all...not* constructions. Moreover, the results of Experiment 4 showed that Estonian-English bilinguals learn L2-specific biases in the interpretation of *all...not*: They mostly assigned the universal-wide reading to the English *all...not* target sentences in this experiment, which is the preferred interpretation in English but not in Estonian. Therefore, we can rule out an interpretation of the observed priming effects between languages in terms of L1 transfer.

Finally, our results also suggest that knowledge of language-specific biases in the interpretation of *all...not* in both languages a bilingual knows influence each other in an adaptive manner: The Estonian-English bilinguals that participated in this study were more likely to assign the preferred scopal reading of *all...not* of the non-selected language in interpreting *all...not* in the selected language (regardless of whether this is the L1 or the L2) in case the primes and targets were given in different languages. This effect emerged independently from the trial-per-trial prime effects, so it seems that pre-existing implicit knowledge about language-specific preferences in the assignment of scope is integrated in bilingual representation, leading to transfer effects (Macken et al., 2014; Merema & Speelman, 2015; Van Gompel & Arai, 2018).

We will discuss the theoretical implications of these findings below. Before, however, it is important to note here that bilinguals form a heterogeneous group. Factors such as L2 proficiency (Hartsuiker & Bernolet, 2017; Hohenstein et al., 2006; Montero-Melis & Jaeger, 2020), age of L2 acquisition, amount of L2 exposure and language dominance (Cai et al., 2011; see also Green, 1998; Kootstra & Doedens, 2016), are sources of variation in bilingual language processing (to name just a few, see De Groot, 2011, for overview). Taking all such possible factors that influence the bilingual experience falls outside the scope of the present study. Nevertheless, it is important to bear in mind that generalisations on the nature of bilingual representations must be made with care.

3.8.1 Bilingual logical representations are shared in processing

We observed priming from the L1 onto the L1 (Experiment 1), from the L1 onto the L2 (Experiment 2), from the L2 onto the L1 (Experiment 3) and from the L2 onto the L2 (Experiment 4) in Estonian-English bilinguals. Recall that priming emerges because (parts of) the underlying representations are shared by both the prime and the target (e.g., Basnight-Brown & Altarriba, 2007; Hartsuiker et al., 2004; Smith et al., 2019; for review, see Van Gompel & Arai, 2018) and therefore, our findings indicate that bilinguals rely on shared logical representations in the processing of both languages they know even if both languages the bilingual knows diverge on the preferred interpretation of a scopally ambiguous construction. This replicates the earlier findings from Slim et al. (2021, reported in Chapter 2), although this latter study did not test priming from the L2 onto the L1.

Moreover, our findings add new insights regarding the role of language-specific scope-taking patterns in the organisation of bilingual logical representations. On a study on monolingual logical representations, Feiman and Snedeker (2016) observed that logical representations are differentiated according to quantifier-specific biases in the assignment of scope. They attributed this finding to quantifier-specific mechanisms in the assignment of scope, which are in turn mapped into logical representations (see also Beghelli & Stowell, 1997). Our results suggest that logical representations are not differentiated according to language-specific biases in the assignment of scope: The logical representations underlying both the universal-wide and the negation-wide interpretation are the same in English and Estonian and *all...not* sentences.

To understand this finding, we need to speculate on the possible source of cross-linguistic variation in the interpretation of *all...not* in Estonian and in English. Our findings above suggest that the difference between Estonian and English in interpreting *all...not* are not caused by differences in lexically specified scope-taking mechanisms that are mapped into the operators *all* and *not* in both languages (cf. Feiman & Snedeker, 2016). Rather, the cross-linguistic differences seem to emerge in the processes involved in deciding which interpretation should be assigned to *all...not* sentences. A possible explanation for this cross-linguistic difference is in terms of the availability of alternative constructions.

In Estonian, there is no alternative construction available to express the negation-wide interpretation of an *all...not* sentence. Negation *ei* ('not') always precedes the finite verb in

Estonian (Tamm, 2015), which makes a construction with *not all* (e.g., *Not all of the sheep are in the boxes* in English) ungrammatical. Therefore, the negation-wide interpretation of Estonian *all...not* sentences seems to be the best way to convey the meaning that not all entities have a certain property (see also Amiraz, 2021; Hemforth & Konieczny, 2019, for similar observations across languages).

In English, however, both the universal-wide and the negation-wide reading of *all...not* sentences can be expressed by alternative constructions (i.e., *None of the sheep are in the boxes* and *Not all of the sheep are in the boxes*). The preference for the universal-wide interpretation in English *all...not* sentences is typically attributed to the general preference for assigning scope in the same order as the surface order of the operators in the sentence, for which there are multiple explanations (discussing these possible explanations goes beyond the scope of this paper, but see e.g., Fodor, 1982; Kurtzman & MacDonald, 1993; Lidz, 2018; Lidz & Musolino, 2002; May, 1985).

The availability of alternative constructions is known to play a role in ambiguity resolution in a variety of constructions, such as the interpretation of syntactically ambiguous sentences (e.g., Gilboy et al., 1995) or ambiguity in the interpretation of pronouns (e.g., Carminati, 2002; Hemforth et al., 2010). The role of alternatives in ambiguity resolution is typically explained in terms of the pragmatic principle that it is assumed that a speaker is as clear (and thus unambiguous) as they can be (Grice's *Maxim of Manner*; Grice, 1975). Such pragmatic principles are not assumed to be represented at the same level of the combinatorial rules of compositional semantics (i.e., of logical representations). Logical representations thus specify how the parts of a sentence combine in the construction of sentence meaning (which may be sensitive to lexicalised combinatorial properties of the logical operators involved; Feiman & Snedeker, 2016), but not the higher-order (pragmatic) mechanisms that are involved in deciding upon a specific interpretation (like the availability of alternatives or contextual constraints; e.g., Gillon, 2008).

Summing up, Estonian-English bilinguals construct the same logical representations in the processing of both English and Estonian *all...not* constructions, which replicates Slim et al.'s (2021) earlier findings constructions and novel language pairs (reported in Chapter 2). Sharing of bilingual representation can be explained in terms of *cognitive economy*: Shared bilingual representations only need to be represented once (Cai et al., 2011; Hartsuiker et al., 2004). Estonian-English can successfully aim for such economy in the representation of scopal configurations in the interpretation of *all...not*, because the cross-linguistic differences in interpretation are not caused by grammatical or lexicalised combinatorial properties, but by pragmatic mechanisms involved in the resolution of scope ambiguity.

3.8.2 Cross-linguistic influence in bilingual logical representations

Our results also provided insight in the role of cross-linguistic influence in the interpretation of *all...not* sentences by Estonian-English bilinguals. Firstly, we observed that Estonian-English bilinguals encounter cross-linguistic influence from L1 Estonian onto L2 English: These bilinguals assigned the negation-wide interpretation, which is preferred in Estonian but not in English, more often to English *all...not* sentences than native speakers of English. Secondly, our results indicate that these bilinguals encounter cross-linguistic influence from the L2 onto the L1: The English-Estonian bilinguals who participated in Experiment 3, in which the prime trials were presented in English and the target trials in Estonian, assigned the universal-wide interpretation more often to the Estonian *all...not* sentences in the target than the English-Estonian bilinguals who participated in Experiment 1b, in which both prime and targets were presented in Estonian. Recall that the universal-wide interpretation is preferred in English but not in Estonian, which suggests that they encounter influence from English in interpreting Estonian *all...not* sentences.

Importantly, these effects emerged independently from the trial-by-trial effects of priming. Across all experiments, the participants were presented with the universal-wide and the negation-wide interpretation an equal number of times in the prime trials. Therefore, the influence of the non-selected language must be triggered by pre-existing implicit knowledge about language-specific scopal preferences. This suggests that implicit knowledge about the assignment of scope is shared between languages. These integrated representations lead to transfer effects from one language onto the other: The frequency of a certain interpretation of an *all...not* sentence in one language affects the likelihood of assigning that interpretation of an *all...not* sentence in another language. This cross-linguistic influence indicate that not only short-term representations constructed in processing are shared (as indicated by the effect of priming), but pre-existing implicit knowledge about the assignment of scope is shared between languages as well (see Kootstra & Doedens, 2016; Salamoura & Williams, 2006; Serratrice, 2013; Van Gompel & Arai, 2018, for similar findings in bilingual syntactic representations).

However, we find the evidence for the existence of cross-linguistic influence from the L2 onto the L1 in Experiment 3, which involved prime trials in the L2 (English) and target trials in the L1 (Estonian). Therefore, cross-linguistic influence from the L2 onto the L1 may have been induced because the participants were exposed to *all...not* sentences in the L2 in the primes. Our results on priming from the L1 onto the L2 suggest that there is such an enhancing effect: The Estonian-English bilingual participants that participated in Experiment 2, which involved Estonian primes and English targets, assigned the negation-wide more often to the English targets than the Estonian-English bilingual participants of Experiment 4, who were presented both English primes and English targets. Unfortunately, our data does not allow us to do a comparison between Estonian monolinguals and Estonian-English bilinguals in interpreting *all...not* sentences in a complete L1 Estonian experiment. Most of the participants in Experiment 1b, which tested L1-L1 priming in Estonian, reported to be bilingual (of the 146 participants that were included in the analyses, 132 reported to use both Estonian and another language daily). Therefore, future research is required to contrast bilingual and monolingual speakers. Nevertheless, we emphasise again that the effect of prime language on the overall response patterns in interpreting the target sentence emerged independently from the short-term effects of scope configuration priming. Therefore, the shift in overall response rate must triggered by pre-existing knowledge about the preference patterns in the prime language.

The finding that these cross-linguistic transfer effects were found both from the L1 onto the L2 and from the L2 onto the L1 indicates again that we can rule out an explanation in terms of incomplete acquisition of the L2 (which would only predict cross-linguistic influence from the L1 onto the L2, e.g. Hartsuiker & Bernolet, 2017). Rather, our results indicate that (i) bilinguals develop implicit knowledge on L2-specific biases in the assignment of scope and (ii) this knowledge is stable enough to trigger effects of cross-linguistic influence from the L2 onto the L1 (see Hohenstein et al., 2006, for similar findings regarding the bilingual lexicon; and Pavlenko & Jarvis, 2002, for similar findings in the organisation of bilingual syntactic representations).

3.8.3 *All...not* in Dutch

We have only discussed the implications for the organisation of bilingual logical representations based on the results of the experiments that involved Estonian-English bilinguals. However, we also tested effects of priming within L1 Dutch (Experiment 1c) and from L1 Dutch onto L2 English (Experiment 2b). We did not find strong evidence for effects of logical representation priming in these sub-experiments. Rather, the results of these sub-experiment showed a ceiling effect: The preference for the universal-wide reading of the *all...not* sentences seemed to neutralise effects of priming, because the participants did not alternate sufficiently between a universal-wide and a negation-wide interpretation. We did not expect this result, because we initially predicted that Dutch would pattern with English.

Possibly, the strong preference for the universal-wide interpretation of *all...not* sentences in Dutch can be explained in terms of information structure. Information structure has been argued to play a role in the assignment of semantic scope. For instance, topics are more likely to be assigned wide scope over other sentence parts (Goldberg, 2006; Ioup, 1975). Information-structural constraints differ between languages (e.g., Bernolet et al., 2009; Lambrecht, 1996). Therefore, biases in assignment of scope may differ cross-linguistically as well, as shown in previous work on German (Filippova & Strube, 2007). Like Dutch, German has a strong preference for the universal-wide interpretation of *all...not* sentences (at least stronger than in English; Hemforth & Konieczny, 2019).

In both English and German, the constituent in the preverbal position of a sentence is more likely to be the sentence topic, and thus more likely to be assigned wide scope, but this tendency seems to be stronger in German than in English. German is a verb-second language, meaning that the finite verb is fixed to the second position of the sentence. Any other constituent could in principle fill the preverbal slot. This relative freedom in German word order may strenghten information-structural constraints on the assignment of scope (Filippova & Strube, 2007; Hemforth & Konieczny, 2019). Important for our purposes, is that Dutch is also a verb-second language that allows similar word orders as German. Therefore, like German, information-structural properties of a sentence may put (relatively strong) constraints on the assignment of scope in Dutch. However, it must be noted that we did not do a thorough theoretical or empirical investigation into whether the informational-structural constraints observed in German also hold for Dutch, and thus whether this hypothesis also holds for the difference between Dutch and English observed in the present study.

3.9 Conclusion

We reported five experiments that reveal that Estonian-English bilinguals have shared logical representations of *all...not* sentences. The preferred interpretation of these sentences differs in the two languages they know. Despite this cross-linguistic difference, however, we observed priming of logical representations between these languages, which was similar in magnitude compared to within-language priming. This finding firstly indicates that bilingual logical representations computed in processing of scopally ambiguous sentences are shared between languages. Secondly, this finding suggests that the language-specific scope-taking biases in *all...not* are not specified in logical representations (cf. Feiman & Snedeker, 2016). We hypothesised that these scope-taking biases are governed by pragmatic principles not represented in logical representations. In addition, we observed that Estonian-English bilinguals develop sensitivity to L2-specific biases in the assignment of scope, which rules out an explanation of the above-findings in terms of reliance on L1-knowledge. Finally, our results showed that Estonian-English bilinguals experience bidirectional cross-linguistic influence in the construction of logical representations. This finding indicates that the pre-existing implicit knowledge about scopal preferences in the construction of logical representations is also not separately represented in the mind of a bilingual but integrated in shared representations.

4 Revisiting the logic in language: Each and every universal quantifier is alike after all

A doubly-quantified sentence like Every bear approached a tent *is ambiguous: Did every bear approach a different tent, or did they approach the same single tent? These interpretations are assumed to be mentally represented as logical representations, which specify how the different quantifiers are assigned scope with respect to each other. Based on evidence from structural priming in language comprehension, Feiman and Snedeker (2016) concluded that logical representations are differentiated according to quantifier-specific mechanisms in the assignment of scope. We re-examined this conclusion by testing logical representation priming in Dutch. Across three experiments and a small meta-analysis, we observed that priming of logical representations emerged if the same quantifiers are repeated in prime and target, but also if the prime and target contained different quantifiers. However, logical representation priming between quantifiers is fragile: It only emerged when the participants were exposed to multiple quantifier conditions in the prime trials. This finding suggests that people generalise in the representation of scope across different quantifiers if they are exposed to the scope-taking behaviour of multiple quantifiers. Therefore, we conclude that logical representations do not specify quantifier-specific biases in the assignment of scope, which supports a distinction between* lexical representations *of the quantifier words and conceptual* logical representations *of the compositional structure of sentence meaning.*

Note. This chapter presents collaborative work with Robert J. Hartsuiker and Peter Lauwers. We thank Roman Feiman for sharing the data from Feiman and Snedeker (2016) and Jesse Snedeker for her input on structure mapping. All data and analysis scripts are available at https://osf.io/s84bv/.

4.1 Introduction

Sentence comprehension involves the construction of a complex meaning by combining the meaning of the words that make up a sentence. This skill is far from trivial. Consider the interpretation of quantifier words, such as *all*, *each*, or *some*. These abstract words do not refer to a clear referent or event in the world but specify the cardinality of a set of referents and the relation between these sets and their predicates. Due to the abstract nature of quantifier words, ambiguity can emerge if multiple quantifiers are present within the same sentence. Consider sentence (1), containing the quantifiers *each* and *a*.

(1) Each bear approached a tent.

This sentence allows two interpretations: It can be understood as meaning that each bear approached a different tent but also as meaning that each bear approached the same tent. How do comprehenders disambiguate between these different interpretations? One of the cues that guide ambiguity resolution is the lexical content of the quantifier words. Consider sentence (2), containing the quantifiers *all* and *a*.

(2) All bears approached a tent.

This sentence displays the same ambiguity as (1): Again, both an interpretation in which all bears approached a different tent and an interpretation in which all bears approach the same tent is allowed. However, people typically interpret the sentences in (1) and (2) differently: The preferred interpretation of (1) is that each bear approached a different tent, whereas (2) is usually understood as meaning that all bears approached the same tent (Feiman & Snedeker, 2016; Ioup, 1975).

Given these lexical differences across quantifiers, the question arises whether semantic interpretation relies on the same mechanisms in the interpretation of different quantifier words (e.g., May, 1985; Szabolcsi, 2015) or on quantifier-specific mechanisms that account for the biases in interpretation (Beghelli & Stowell, 1997; Champollion, 2017). Feiman and Snedeker (2016) previously tested this question using a structural priming paradigm. *Structural priming* refers to the tendency to repeat the structure of a previously processed related sentence. This effect is assumed to emerge because it is easier to reuse a representation if it is recently used. Therefore processing of a sentence facilitates the processing of a subsequent similar sentence (e.g., Bock, 1986; Branigan et al., 2005; for reviews, see Branigan & Pickering, 2017; Pickering & Ferreira, 2008; for meta-analysis, see Mahowald et al., 2016). Feiman and Snedeker observed that the interpretations of doubly-quantified sentences can be primed in language comprehension, but only if the prime and the target sentence contained the same quantifiers. This finding suggests that the interpretation of doubly-quantified sentences relies on quantifier-specific mechanisms. Thus, the logical representations constructed in interpreting the sentences (1) and (2) differ, even though these sentences refer to similar events. In the present study, we re-examined Feiman and Snedeker's hypothesis that quantifier representations are quantifier-specific.

4.1.1 Quantifiers and logical representations

Quantifier words specify an abstract relation between the different concepts denoted in a sentence (e.g., Champollion, 2017; Szabolcsi, 2010, 2015). Consider the sentence *Every bear is hungry*, which describes that all things that are a 'bear' are also things that are 'hungry'. To define the order of such relations, quantifiers are assigned *semantic scope*. This causes ambiguity if multiple quantifiers co-occur within one sentential clause. In such cases, there are multiple ways in which quantifiers can take scope vis-à-vis each other.

Consider the sentences presented in (1) and (2). In one possible reading, the universal quantifier (*each* in (1) and *all* in (2)) is assigned wide scope over the existential quantifier (*a* in both sentences). This interpretation, referred to as the *universal-wide* interpretation, denotes the situation in which each bear approached a different tent (i.e., the property 'is approaching a tent' is asserted to each individual bear). Using the formal machinery of first-order logic, we can represent this interpretation as follows:

(1a) *Universal-wide*: $\forall x[\text{BEAR}(x) \rightarrow \exists y[\text{TENT}(y) \wedge \text{APPROACHED}(x,y)]]$
For all *x*, if *x* is a bear, there exists a *y* such that *y* is a tent, and *x* approached *y*

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

(1b) *Existential-wide*: $\exists y[\text{TENT}(y) \wedge \forall x[\text{BEAR}(x) \rightarrow \text{APPROACHED}(x,y)]]$
There exists a *y*, such that *y* is a tent, and for all *x*, if *x* is a bear, then *x* approached *y*

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

We know relatively little about the exact information that is specified in mental logical representations. A pertinent question is which mechanisms are involved in the assignment of scope and how scope is specified in logical representations. Theorists have postulated a variety of approaches to explain how listeners derive unambiguous meanings from scopally ambiguous structures. In one prominent class of theories, it has been argued that the construction of a logical representation predominantly relies on the syntactic ordering of the quantifiers. This hypothesis is based on the observation that people tend to prefer the interpretation in which the highest quantifier in the syntactic structure is assigned wide scope over the quantifier that is lower in the syntactic tree structure (e.g., Conroy et al., 2009; Fox, 2000; Jackendoff, 1972; Lidz & Musolino, 2002; May, 1985). In case the lowest quantifier in the grammatical structure is assigned wide scope over the highest quantifier, an additional operation is needed to reverse the order of the scope assignment. Theorists differ in the exact nature of this operation (e.g., Hendriks, 1988; May, 1985; see also Ruys & Winter, 2011), but they share the hypothesis that this 'scope reversal' operation is cognitively costly and therefore does not emerge in the default reading of the scopally ambiguous sentence.

However, as already demonstrated, the ordering of the quantifiers in the sentence is not the sole determiner of the final interpretation of a scopally ambiguous structure: The assignment of scope is also guided by the lexical content of the quantifier words.[1] Quantifier words differ from each other in scope-taking behaviour. The universal quantifier *each*, for instance, is more likely to be assigned wide scope than the universal quantifier *all* (which explains the contrast between (1) and (2)). Ioup (1975) observed that quantifier words can be placed in a hierarchy, depending on their inherent lexical tendency to be assigned wide scope. This *Quantifier Hierarchy* is presented in (3).

(3) EACH $\succ$ EVERY $\succ$ ALL $\succ$ MOST $\succ$ MANY $\succ$ SEVERAL $\succ$ SOME $\succ$ A FEW

Ioup constructed the Quantifier Hierarchy based on judgement data from a variety of languages and syntactic constructions (see also Feiman & Snedeker, 2016, Experiment 1). The existential quantifier *a* was not placed in the original hierarchy, although it is assumed that it is positioned between *every* and *all* in this hierarchy (Filik et al., 2004; Kurtzman & MacDonald, 1993).

In order to account for these quantifier-specific biases in the construction of logical representations, some theorists have posited that distinct scope-taking mechanisms are mapped

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

into the lexical representation of each quantifier (e.g., Beghelli & Stowell, 1997; Champollion, 2017). This goes against the prevalent hypothesis that quantifiers assign scope following a shared uniform scope taking mechanism (May, 1985; Montague, 1974). This distinction in scope-taking mechanisms across quantifiers has an important consequence for our understanding of the construction of mental logical representations: In case scope is assigned following quantifier-specific mechanisms, the representation of scope in logical representations is not uniform across different quantifier words. Instead, these theories predict that logical representations are differentiated according to quantifier-specific properties.

4.1.2 Structural priming of logical representations

The mental architecture of logical representations can be studied using the structural priming paradigm (Chemla & Bott, 2015; Feiman & Snedeker, 2016; Maldonado et al., 2017a; Raffray & Pickering, 2010). Recall that structural priming refers to the observation that people tend to repeat previously processed structures, because the use of a representation is facilitated by previous use. Therefore, structural priming indicates that (parts) of the representations used in sentence processing are shared between related sentences (Bock, 1986; Branigan et al., 2005, e.g., for reviews, see Branigan & Pickering, 2017; Pickering & Ferreira, 2008; for meta-analysis, see Mahowald et al., 2016).

The first to use the structural priming paradigm to study logical representations in language comprehension were Raffray and Pickering (2010). They implemented the structural priming paradigm in a sentence-picture matching task in which the participants matched a doubly quantified sentence like *Every kid climbed a tree* with one out of two pictures. These sentences are ambiguous between a universal-wide (as in 1a) and an existential-wide interpretation (as in 1b), similar to the sentences in (1) and (2). In the prime trials of their experiment, one picture corresponded to one possible interpretation of the sentence, whereas the other picture was a foil picture that was no match for either interpretation of the sentence. Each prime trial was immediately followed by a target trial, in which the two response pictures corresponded to both possible interpretations of the sentence. Thus, in the prime trials, the participants were forced to assign one specific interpretation to the prime sentence, whereas in the subsequent target trials, the participants could freely assign either interpretation. Raffray and Pickering observed that participants were more likely to assign the universal-wide interpretation to targets following a universal-wide prime than to targets following an existential-wide prime, showing that participants perseverate in their interpretation of doubly-quantified sentences.

Using the same sentence-picture matching paradigm as Raffray and Pickering (2010), Feiman and Snedeker (2016, Experiment 2) tested whether logical representations are differentiated according to quantifier-specific scope-taking properties or whether the representation of semantic scope is more abstract and non-quantifier-specific. They used a similar sentence-picture matching task as Raffray and Pickering in which the stimuli were active transitive sentences with a universal quantifier in the subject phrase and the existential quantifier *a* in the object phrase. The quantifier in the subject phrase was manipulated in both prime and target sentences: The quantifiers varied across the universal quantifiers *each*, *every*, *all* and numeral quantifiers such as *three* or *four*. Because the quantifier in the subject position was manipulated in both prime and target trials, Feiman and Snedeker's experiment involved sixteen different prime-target configurations (of which four were within-quantifier conditions: *each*-*each*, *every*-*every*, *all*-*all*, numeral-numeral, and the other twelve between-quantifier conditions, such as *each*-*every*, *every*-*all*, etc.). The prime-target quantifier configuration was manipulated between subjects, so each participant was repeatedly presented with similar primes and targets throughout the experiment.

Feiman and Snedeker's (2016) study showed priming effects for all quantifiers, but only if the prime and the target sentence contained the same quantifiers. For instance, there were effects of logical representation priming from an *each...a* sentence to a subsequent *each...a* sentence, but not to an *all...a* or *every...a* sentence. Feiman and Snedeker concluded that logical representations are differentiated according to quantifier-specific scope-taking properties. This finding thus supports theoretical accounts that postulate that there is no universal scope-assigning mechanism that is shared by all quantifiers, but that scope is assigned to quantifiers following quantifier-specific mechanisms (e.g., Beghelli & Stowell, 1997).

Moreover, Feiman and Snedeker (2016) conducted a follow-up experiment in which they tested effects of logical representation priming between different numeral quantifiers (e.g., from *three...a* to *four...a*). Importantly, numeral quantifiers are assumed to have identical scope-taking properties even though they are not synonymous (the cardinality of the specified set differs across different numbers). This experiment showed priming between different quantifiers, and the magnitude of this priming effect was similar to priming within the same number. Therefore, Feiman and Snedeker concluded that logical representation priming is not dependent on phonological or lexical repetition between prime and target (see also Slim et al., 2021, reported in Chapter 2, who observed priming from the Dutch quantifier *alle* ('all') onto its French translation equivalent *tous les* ('all'), which can also not be due to repetition of phonology or lexical items). Rather, priming of logical representations depends on the repetition of the abstract combinatorial properties of the quantifiers involved.

4.1.3 The present study

Feiman and Snedeker (2016) claimed that logical representations specify quantifier-specific scope-taking properties. In this paper, we present three structural priming experiments in Dutch, along with a small meta-analysis of the present and Feiman and Snedeker's data, that evaluate that claim. An important reason for reassessing this claim is the result of an experiment that we originally conducted for a different purpose (and even preregistered, see https://osf.io/s84bv/registrations), reported below as Experiment 1. This experiment was intended as a monolingual control experiment for a cross-language priming experiment involving the Dutch distributive quantifiers *iedere* and *elke*, and their approximate English translation equivalents *each* and *every*. However, *iedere* and *elke* seem to be closer in meaning than the English quantifiers *each* and *every* (Dik, 1975; Haeseryn et al., 1997). Most important for our present purposes, this experiment demonstrated priming between different quantifiers within a language (in contrast to the quantifier-specific account described by Feiman and Snedeker (2016)), which necessitated a reconsideration of monolingual logical representations.

The three experiments all used a similar sentence-picture matching task to the one used by Feiman and Snedeker (2016). In all experiments, the prime and target sentences were doubly-quantified active transitive sentences that contained a universal quantifier in the subject position and an existential quantifier in the object position. Prime sentences either had the form *elke...een* ('every...a'), *iedere...een* ('every ...a')[2], or *alle...een* ('all...a'). Target sentences always had the form *elke...een*. In all three experiments, we tested whether priming emerged within- and between-quantifiers in Dutch. We predicted that priming would emerge between *elke* and *elke* (within-quantifier condition) and possibly between *iedere* and *elke* (which, as near-synonyms, may have similar scope-taking properties), but not between *alle* and *elke* (which we assumed to have different scope-taking properties, similar to, say, *every* and *all* in English).

In Experiment 1, we manipulated the quantifiers in the prime sentences between-participants (following Feiman & Snedeker, 2016). To anticipate the results, Experiment 1 revealed a small but significant effect of priming from *alle* to *elke*, which contrasts Feiman and Snedeker's earlier findings. With the aim of providing a further and more sensitive test of within- and between-quantifier priming, we next conducted an experiment with a full within-subjects design (Ex-

[2]Because *iedere* and *elke* are assumed to be close meaning equivalents (Haeseryn et al., 1997), we translated both *iedere* and *elke* as 'every'.

periment 2). To again anticipate the results: We now observed clear priming both within and between quantifiers, with no difference in magnitude of priming.

Experiments 1 and 2 seemed to suggest that logical representations are not quantifier-specific. Rather, the extent of priming, at least in the absence of quantifier overlap, seemed to vary with other factors, such as the design (between- or within-participant). In a within-participant design, participants are exposed to both within-quantifier and between-quantifier trials. One possibility is that the presence of within-quantifier trials in the experimental session boosts priming of between-quantifier trials (see Muylle et al., 2021, for an analogous effect in syntactic priming). A mechanism for such a boost may be that participants adapt their initial bias towards one specific reading of the target sentence in the prime trials of a within-quantifier condition, in which they are explicitly exposed to both possible interpretations of the target sentence.

Due to this bias adaptation, the threshold for assigning the non-preferred reading is lowered, which may facilitate priming between quantifiers. We tested this hypothesis in Experiment 3. Here, the presence of within-quantifier trials was manipulated between blocks. For half of the participants, the within-quantifier condition appeared in the first block (in addition to two between-quantifier conditions). For the other half of the participants, the within-quantifier trials only appeared in the second block. If our hypothesis is correct, there should always be priming in the block with the within-quantifier condition trials, regardless of block order, as the bias for the preferred interpretation is adapted quickly. But in the block without the within-quantifier condition, priming depends on block order: No priming if it is the first block, priming if it is the second block. However, this experiment revealed priming across all conditions, regardless of block and block order.

Finally, we conducted a mini meta-analysis that included the data of all experiments conducted in this study and the data of Feiman and Snedeker's (2016) within- and between-quantifier priming experiment (Experiment 2). This meta-analysis tested the role of quantifier overlap between prime and target in logical representation priming, and thus further assessed the question of whether logical representations are quantifier-specific.

4.2 Experiment 1: Prime quantifier manipulated between subjects

4.2.1 Method

Participants

The participants were 218 native speakers of Dutch. They were first-year psychology students at Ghent University, and received course credit for their participation. Thirty participants were removed, either because they selected the wrong response in more than 10% of the filler trials (3 participants), suggesting insufficient attention to sentence meaning, or because they guessed the goal of the experiment in a post-experimental debriefing (27 participants). The final analysis therefore included 188 participants.

Materials

The stimuli were adapted from Slim et al. (2021, reported in Chapter 2) who in turn adapted some of their stimuli from Raffray and Pickering (2010, which were also used in Feiman & Snedeker, 2016). A list of the critical test sentences is provided in Appendix 4. A full list of sentences and the visual materials are available at https://osf.io/s84bv/. The experiment contained 54 prime trials, 54 target trials, and 162 filler trials. All trials consisted of a Dutch sentence and two pictures. In the prime trials, this sentence was a doubly quantified scopally ambiguous sentence (e.g., *Alle beren naderden een tent*, 'All bears approached a tent'). One of the two response pictures in the prime trials corresponded to one of the possible interpretations of the sentence, whereas the other response picture was a foil picture that matched neither interpretation of the sentence (either because the subject or the object noun mismatched that picture). This way, the participants were forced to assign one interpretation to the prime sentence.

The prime trials were presented in two prime conditions, which 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 (in which all bears approached different tents) of the sentence. In the existential-wide condition, the matching picture corresponded to the existential-wide interpretation of the sentence (in which all bears approached the same tent). The prime sentences contained the universal quantifier *alle* ('all'), *elke* ('every'), or *iedere* ('every') in the subject position. The subject quantifier in the prime

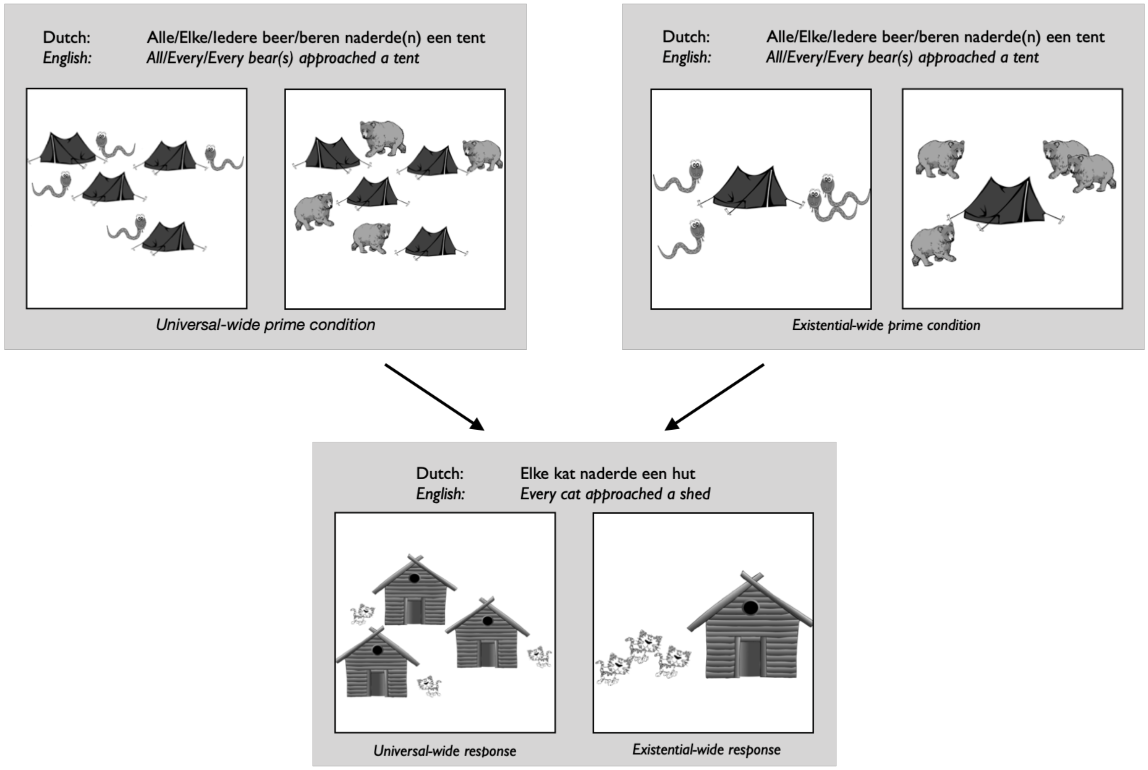


Figure 4.1: Example of the prime-target procedure in the experiment. The target trials were always immediately preceded by prime trials. The labels *Universal-wide/Existential-wide* prime condition, and *Universal-wide/Existential-wide response* are added for ease of illustration and were not shown to the participants. We added English translations to the figure for the sake of illustration.

sentences was manipulated between-subjects (following Feiman & Snedeker, 2016). Analyses included 63, 64, and 61 participants in the *elke*, *iedere*, and *alle* conditions respectively.

Similar to the prime trials, the target trials contained a scopally ambiguous doubly quantified sentence (e.g., *Elke kat naderde een hut*, 'Every cat approached a shed'). However, here the quantifier in subject position was the same in all trials: *elke* ('every'). The two response pictures in the targets displayed the two possible interpretations of the sentence: One picture corresponded to the universal-wide interpretation, whereas the other picture corresponded to the existential-wide interpretation of the sentences. Thus, in the target sentences, the participants had a choice between the two interpretations. The prime and target trials were organised in sets: Each target trial was directly preceded by a prime trial (Figure 4.1).

Filler trials all contained unambiguous sentences. Half of these filler sentences was transitive (e.g., *The cowboy punched the burglar*), and the other half was intransitive (e.g., *All witches* *slept*). One of the response pictures corresponded to the sentence, whereas the other response picture mismatched the sentence. In the transitive filler trials, the foil picture always showed the same event as denoted in the sentence, but the character or object that denoted the subject or object noun mismatched the sentence. In the intransitive filler trials, the foil picture either described the same agent doing the wrong action, or the right action but with the wrong agent. The intransitive filler sentences always contained a quantifier in the subject phrase. The quantifier always matched the Quantifier condition: Participants who saw the target sentences in the *alle* condition, for instance, were presented the intransitive filler sentences with *alle* in the subject phrase.

Prime and target trials were organised in sets: Target trials immediately followed prime trials. The verb in the prime-target sets was held constant. Verb repetition has been shown to increase effects of priming in research on structural priming in language production (Pickering & Branigan, 1998). Even though Feiman and Snedeker (2016) showed that logical priming emerged in the absence of verb overlap between prime and target, priming was (descriptively) larger when prime and target involved the same verb. We therefore repeated the verb in prime and target, in order to maximise our chances of finding effects of priming (following Raffray & Pickering, 2010; and Feiman & Snedeker, 2016, Experiment 2). Prime-target sets were intervened by two to five filler trials (also following Raffray & Pickering, 2010). In all Prime Quantifier conditions, we created two lists of trials in the pseudo-randomised order as described above. Moreover, we counterbalanced the position of the pictures across the trials within participants, and the prime trials were counterbalanced between prime conditions between participants.

Procedure

The experiment was implemented and conducted online using `PennController for Ibex`, which is a `javascript`-based library to program web-based experiments (Zehr & Schwarz, 2018). In all trials, the sentence and two pictures were shown simultaneously on a screen. The participants were instructed to select the picture that best fitted the sentence and to select their spontaneous preference if they thought that both pictures corresponded to the sentence. After selecting one of the two pictures with their computer mouse, the next trial began automatically. Once the sentence-picture matching task was completed, the participants filled in a short questionnaire regarding their language background. A final question 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 described the pattern of the trials (prime-target), and/or guessed that the experiment examined the possible influence from the preceding trial on the target trials.

4.2.2 Analyses and results

Data treatment and analyses procedure

Target responses were discarded if the participant selected the incorrect picture in the preceding prime trial (following Raffray & Pickering, 2010). These targets were removed from further analysis because participants that selected the incorrect pictures in the prime trials may not have constructed the logical representation that the prime was meant to elicit. The remaining responses were coded as `TRUE` if the universal-wide response was selected, and `FALSE` if the existential-wide response was selected.

The data were analysed by modelling response-type likelihood using logit mixed-effect models (Jaeger, 2008). The model included the binary target response type as the dependent variable and Prime Condition (*universal-wide* and *existential-wide*) and Prime Quantifier (*elke*, *iedere*, and *alle*) as predictor variables. Both predictors were sum coded. Finally, the model included a random slope and intercept of item and a random intercept of Prime Condition per Subject, and a random intercept of subject per Prime Quantifier. The model did not include a random slope per Prime Quantifier for subject, as Prime Quantifier was a between-subject manipulation (Barr et al., 2013). However, in case the maximal random effect structure did not converge, we omitted random effects until we reached convergence (Bates et al., 2015).

All analyses were carried out in `R` (Version 3.6.0; R Core Team, 2019). First, we constructed an omnibus full model using the `glmer` function of the `lme4` package (Bates et al., 2014). We obtained p-values by conducting Type I Wald χ^2 likelihood ratio tests to compare the full model with models in which the relevant predictor terms were removed (using the `Anova` function of the `car` package; Fox & Weisberg, 2019). Post-hoc interaction analyses were carried out to test for differences in the effect of Prime Condition between the multiple levels of the Prime Quantifier variable. These pairwise comparisons were χ^2 tests conducted using the testInteractions function from the `phia` package (De Rosario-Martinez, 2015). The data and analysis scripts are available on https://osf.io/s84bv.

Results

We removed 163 target responses in the universal-wide prime condition because the participants selected the foil picture in the preceding prime trial. Of those 163 responses, 51 were in the *elke-elke* condition (1.00% of responses in the universal-wide prime condition in the *elke-elke* condition), 55 in the *iedere-elke* condition (1.08% of responses in the universal-wide prime condition in the *iedere-elke* condition), and 57 in the *alle-elke* condition (1.13% of responses in the universal-wide prime condition in the *alle-elke* condition). For the same reason, we discarded 177 target responses in the existential-wide prime condition. Of these removed responses, 64 were in the *elke-elke* condition (1.26% of the responses following an existential-wide prime in this condition), 58 in the *iedere-elke* condition (1.14% of the responses in the existential-wide prime condition in the *iedere-elke* condition) and 58 were in the *alle-elke* condition (1.08% of responses in the existential-wide condition in the *alle-elke* condition).

As expected based on the inherent biases of *elke*, the results show a strong bias toward the universal-wide reading of the target sentences: 78.07% of all target responses are universal-wide. In addition, there is a descriptive effect of logical representation priming: In the *elke-elke* condition, the universal-wide response was selected in 83.77% of the targets in the universal-wide condition and in 75.52% of the targets in the existential-wide condition. In the *iedere-elke* condition, the universal-wide response was selected in 71.99% of the targets in the universal-wide condition and in 69.11% of the targets in the existential-wide condition. Finally, in the *alle-elke* condition, the universal-wide response was selected in 86.55% of the targets in the universal-wide condition and in 84.27% of the targets in the existential-wide condition. Numerically, there thus seems to be a priming effect of 8.25% in the *elke-elke* condition, of 2.88% in the *iedere-elke* condition, and of 2.28% in the *alle-elke* condition (Figure 4.2).

First, we fitted a full model in which we included predictor terms for Prime Condition, Prime Quantifier, and an interaction term for Prime Condition and Prime Quantifier. This model included the full maximal random effects structure. The Wald χ^2-test conducted on this model revealed a significant main effect of Prime Condition (χ^2(1) = 14.10, $p < 0.001$) and of Prime Quantifier (χ^2(2) = 9.53, p = 0.009). Moreover, the interaction between Prime Condition and Prime Quantifier was significant (χ^2(2) = 8.71, p = 0.013).

We tested the interaction between Prime Condition and Prime Quantifier further by conducting planned post-hoc pairwise comparisons. These comparisons revealed that the effect of Prime Condition was significant in the *elke-elke* condition (χ^2(1) = 20.96, $p < 0.001$) and in the *alle-elke* condition (χ^2(1) = 7.25, p = 0.014), but the effect in the *iedere-elke* condition did

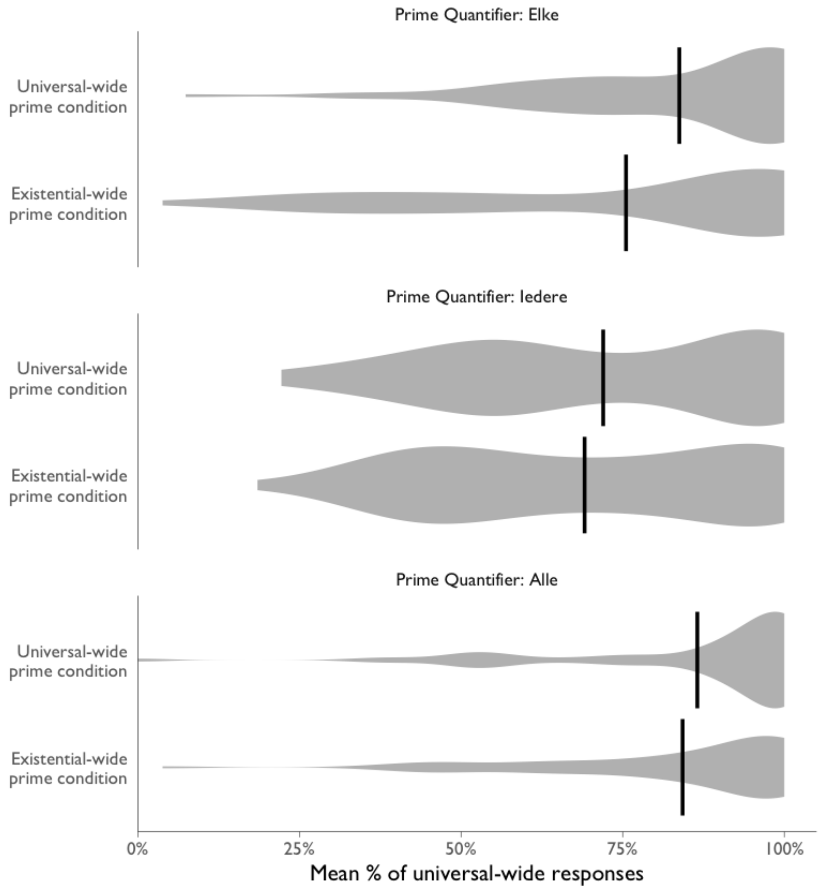


Figure 4.2: . The participants' mean percentage of universal-wide responses on the target trials in the Experiment 1. Note that the target sentences all contained *elke*. The black vertical lines represent the overall mean response rate, and the width of the outlined area represents the proportion of the data located at that point.

not reach the conventional level of significance (χ^2(1) = 3.47, p = 0.063). Additional pairwise comparisons that tested the difference in the strength of the effect of Prime Condition across all Prime Quantifier conditions revealed that this effect was stronger in the *elke-elke* condition compared to the *iedere-elke* condition (χ^2(1) = 8.40, p = 0.011), but not in the *elke-elke* condition compared to the *alle-elke* condition (χ^2(1) = 0.60, p = 0.127) or in the *iedere-elke* condition compared to the *alle-elke* condition (χ^2(1) = 0.48, p = 0.488). Thus, these analyses only revealed that priming was stronger in the *elke-elke* condition compared to the *iedere-elke* condition and no differences in strength of priming in the other conditions.

Descriptively, however, priming in the *elke-elke* condition seemed stronger than priming in the *iedere-elke* and *alle-elke* conditions. We therefore conducted an additional exploratory analysis, in which we tested the strength of this pattern. We fitted the full model again, but Prime Quantifier was now coded with Helmert contrasts (*elke*: 1, *iedere*: -0.5, and *alle*: -0.5). This allowed us to compare the mean strength of priming in the *elke-elke* condition to the mean strength of priming in the *iedere-elke* and *alle-elke* conditions. A Wald χ^2-test on this model revealed a significant effect of Prime Condition (χ^2(1) = 17.96, p < 0.001), but not of Prime Quantifier (χ^2(1) = 0.03, p = 0.863). Importantly, the interaction between Prime Condition and Prime Quantifier was significant (χ^2(1) = 9.05, p = 0.003), which suggests that priming in the *elke-elke* condition was stronger than the average of the *iedere-elke* and the *alle-elke* conditions.

4.2.3 Discussion

Descriptively, the results of Experiment 1 mirrored the results from Feiman and Snedeker (2016, Experiment 2): The size of priming was stronger in the within-quantifier *elke-elke* condition (8.25%) compared to the between-quantifier *iedere-elke* (2.88%) and *alle-elke* (2.28%) conditions. This descriptive pattern does not suggest considerable priming from *iedere* to *elke*, in contrast to our expectations, which were based on the semantic similarities between these two quantifiers. Possibly, there is a larger difference in the scope-taking properties of *elke* and *iedere* than we initially assumed. Although our analysis revealed that priming in the *elke-elke* condition was stronger than in the *iedere-elke* and *alle-elke* condition combined (which corroborates the descriptive pattern of findings), post-hoc comparisons also revealed significant priming in the *alle-elke* condition (which was not stronger than the priming in the *elke-elke* condition). This was unexpected, because *elke* and *alle* have different combinatorial properties. Moreover, this finding does not seem fully conclusive: Descriptively, the significant priming effect in the *alle* condition was very small and similar to the non-significant effect of *iedere*.

Finally, note that we did not describe any predictions regarding a main effect of Prime Quantifier, but there was such an effect, suggesting that the quantifiers in the prime trials influenced the overall target response choices (independent of the scope assignment in the preceding prime trial). Specifically, participants in the *alle* condition selected most universal-wide responses, followed by the participants in the *elke* and *iedere* conditions. Note that *elke* and *iedere* are both biased to the universal-wide interpretation. In the prime sentences, however, they are forced to alternate between the universal-wide and the existential-wide interpretations. This exposure to the non-preferred interpretation of the prime sentences may have weakened the universal-wide bias of the prime sentences because people adapt their expectations (Jaeger

& Snider, 2013; Myslín & Levy, 2016; Yildirim et al., 2016). This weakening of the bias, in turn, could then have affected the responses on the targets (independent from the trial-by-trial priming effects). In the case of *iedere*, this effect might generalise to the interpretation of *elke* (again, independent from priming; see the supplement materials from Feiman & Snedeker, 2016, for similar findings in the interpretation of *each* and *every* in English). The quantifier *alle*, however, is not as strongly biased towards the universal-wide or existential-wide reading (cf. Slim et al., 2021, reported in Chapter 2). Therefore, people do not have any strong biases to adjust in the prime sentences of the *alle* conditions, which is why the overall responses on the targets are closer to baseline.

Most important for our present purposes is that the results regarding priming between quantifiers of Experiment 1 are somewhat inconclusive. Therefore, we conducted a further experiment using the same manipulations of Prime Condition and Prime Quantifier but now manipulated both variables within participants. We expected this design to allow a more accurate comparison of the priming effects exerted by each quantifier type, as it reduces possible distortions caused by individual variation between participants (as all participants are now presented with the same conditions).

4.3 Experiment 2: Prime quantifier manipulated within subjects

4.3.1 Method

Participants

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

Materials

The materials were similar to those of Experiment 1. Now, however, both Prime Condition and Prime Quantifier were manipulated within participants. In order to counterbalance Prime

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

Procedure

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

4.3.2 Analyses and results

Data treatment and analysis procedure

The data treatment and analysis procedure were identical to those in Experiment 1.

Results

We removed 244 target responses in the universal-wide prime condition from further analysis, due to incorrect responses in the preceding prime trials. Of these discarded responses, 79 were in the *elke-elke* condition (4.88% of targets in the universal-wide prime condition in the *elke-elke* condition), 75 in the *iedere-elke* condition (4.63% of the targets in the universal-wide prime condition in the *iedere-elke* condition), and 90 in the *alle-elke* condition (5.56% of targets in the universal-wide prime condition in the *alle-elke* condition). We also discarded 233 target responses in the existential-wide prime condition for the same reason. Here, 77 of the removed responses were in the *elke-elke* condition (4.75% of targets in the existential-wide prime condition in the *elke-elke* condition), 82 in the *iedere-elke* condition (5.06% of the existential-wide prime condition in the *iedere-elke* condition), and 74 in the *alle-elke* condition (4.57% of the targets in the universal-wide prime condition in the *alle-elke* condition).

As in Experiment 1, there was a bias for the universal-wide reading of the target sentences: 75.62% of the targets responses were universal-wide. Moreover, the responses seem to be influenced by logical representation priming. In the *elke-elke* condition, the universal-wide

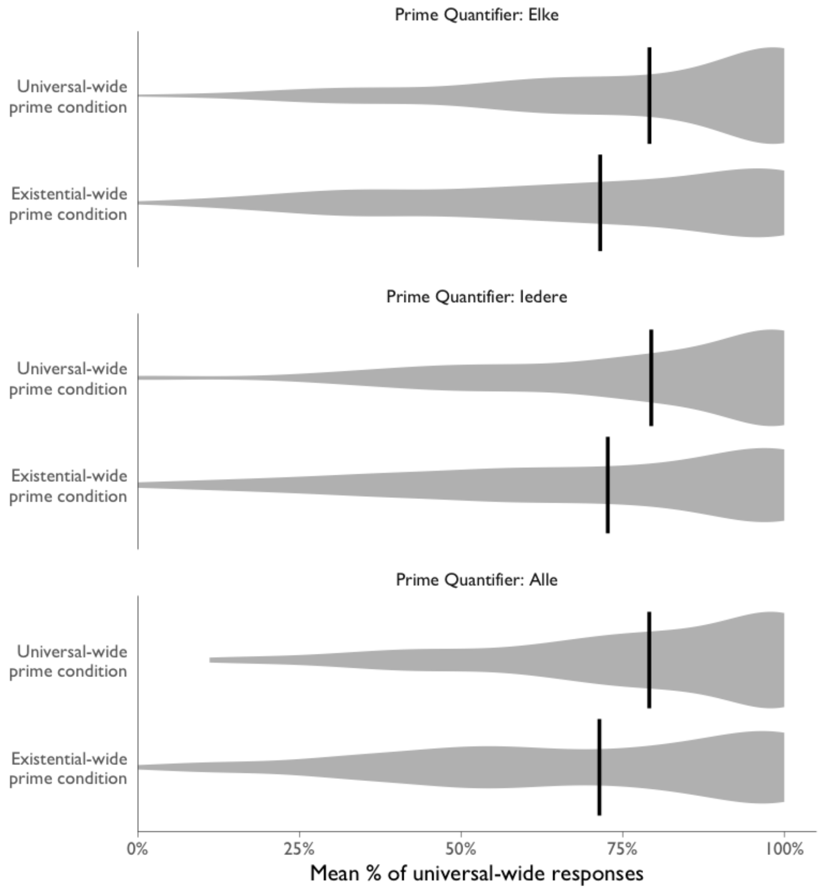


Figure 4.3: The participants' mean percentage of universal-wide responses on the target trials in Experiment 2. The black vertical lines represent the overall mean response rate, and the width of the outlined area represents the proportion of the data located at that point.

response was selected in 79.15% of the targets in the universal-wide prime condition and in 71.53% of the targets in the existential-wide prime condition. In the *iedere-elke* conditions, the universal-wide response was selected in 79.15% of the targets in the universal-wide prime condition and in 72.20% of the targets in the existential-wide prime condition. Finally, in the *alle-elke* condition, the universal-wide response was chosen in 79.12% of the targets in the universal-wide prime condition and in 71.40% of the targets in the existential-wide prime condition (Figure 4.3). Thus, across the three Prime Quantifier conditions, the universal-wide response was selected more often following a universal-wide prime trial than following an existential-wide prime trial (the difference was 7.63% in the *elke-elke* condition, 6.72% in the *iedere-elke* condition, and

7.71% in the *alle-elke* condition).

The full model contained predictor terms for Prime Condition, Prime Quantifier, and an interaction term for Prime Condition and Prime Quantifier. In addition, this model contained a random intercept and a random slope for Prime Condition per Subject and a random intercept and random slopes of Prime Condition and Prime Quantifier per Item, because the maximal random effect structure did not converge. The χ^2-test conducted on this model revealed a significant main effect of Prime Condition (χ^2(1) = 39.18, $p < 0.001$) but not of Prime Quantifier (χ^2(2) = 0.11, p = 0.945). There was no interaction (χ^2(2) = 0.13, p = 0.935). The planned post-hoc analyses revealed that this main effect of Prime Condition was significant in all three Prime Quantifier conditions (*elke-elke*: χ^2(1) = 16.52, $p < 0.001$, *iedere-elke*: χ^2(1) = 23.90, $p < 0.001$, *alle-elke*: χ^2(1) = 12.98, $p < 0.001$), and that the effect of Prime Condition was comparable in all three Prime Quantifier conditions (*elke* vs *iedere*: χ^2(1) = 0.03, p = 0.999, *elke* v.s *alle*: χ^2(1) = 052, p = 0.999, *iedere* vs. *alle*: χ^2(1) = 0.51, p = 0.999).

4.3.3 Discussion

Experiment 2 revealed priming in the *elke-elke*, *iedere-elke*, and in the *alle-elke* condition, with no significant difference in the size of priming across these three conditions. Importantly, the results of Experiment 2 show that priming within the same quantifier is comparable to priming within quantifiers. This result does therefore not support the hypothesis that logical representations are quantifier-specific. If logical representations specify quantifier-specific features, it would be expected that priming within quantifiers is stronger than priming between quantifiers, since there is larger representational overlap in the first case.

In addition, the results of Experiment 2 differed from those of Experiment 1, as Experiment 1 did show differences in priming across the three Prime Quantifier conditions. Note that Experiments 1 and 2 only differed from each other in design: Both Prime Quantifier and Prime Condition were manipulated within subjects in Experiment 2, whereas Prime Quantifier was manipulated between subjects in Experiment 1 (like Feiman & Snedeker, 2016). The question arises how such differences in experimental design influence the strength of priming between quantifiers. One possibility is that between-quantifier priming emerged in Experiment 2 because the participants saw both the within-quantifier and the between-quantifier conditions. One scenario according to which the presence of both between- and within-quantifier conditions might influence between-quantifier priming is the following: In the within-participants experiment, all participants were explicitly exposed to both possible interpretations of the target sentence in the prime trials with the same quantifiers as the target trials (i.e., in the *elke-elke* condition). Therefore, the participants may learn that both possible interpretations are acceptable in these prime trials, which lowers the threshold to compute the dispreferred interpretation of the target sentences. Once this bias for a particular interpretation of the target sentence is lowered sufficiently, priming may emerge both within and between quantifiers (as previously hypothesised in research on syntactic priming, Muylle et al., 2021).

This hypothesis explains the discrepancy between Experiment 1 and Experiment 2. In the between-subjects design of Experiment 1, only a third of the participants were explicitly exposed to the dispreferred interpretation of the target sentence (viz. those in the *elke-elke* condition). In Experiment 2, however, all participants were explicitly exposed to the dispreferred interpretation of the target sentences in some of the prime trials (in the *elke-elke* trials), which we hypothesise weakens the bias for the preferred interpretations in the target sentences. Thus, this hypothesis postulates that priming between quantifiers only emerges in case the participants are exposed to a within-quantifier condition. We tested this hypothesis in Experiment 3, by manipulating the presence of a within-quantifier condition (*elke-elke*) between experimental blocks.

4.4 Experiment 3: Prime Quantifier manipulated between blocks

4.4.1 Method

Participants

We recruited 279 further native speakers of Dutch via Prolific. All participants were paid £4.50 for their participation. As in the previous experiments, we removed participants from further analyses if they answered more than 10% of the filler trials incorrectly, or if they guessed the goal of the experiment in a post-experimental debriefing question. We removed 5 participants from further analyses for the first reason and 14 for the second reason. Thus, the data of 260 participants were included in the analyses. This was our pre-defined sample size, so that each cell in our design would have a similar number of observations as in Experiments 1 and 2.

Materials

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

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

We constructed 10 lists in which Prime Condition, Prime Quantifier, and Block were counterbalanced across trials. Thus, each trial was presented in all possible Prime Condition, Prime Quantifier, and Block configurations across these ten lists. Similar to the previous experiments, the trials were organised in a pseudo-randomised fashion: Prime-target pairs were intervened by two to five filler trials, and each list started with four filler trials. The trials were pseudo-randomised for each list, so the trials were arranged in ten different orders. Prime Quantifier, Prime Condition, and Block were manipulated within subjects. The order of the two blocks, however, was manipulated between subjects, leading to *inclusive-elke first* and *inclusive-elke second* conditions. There were 130 participants in each Block Order configuration.

Procedure

The procedure was identical to Experiments 1-2. There was no pause or any other type of obvious transition from the first block onto the second block. The rest of the procedure of Experiment 3 was similar to that of Experiments 1-2.

4.4.2 Analyses and results

Data treatment and analyses procedure

As in Experiments 1-2, the analyses modelled response-type likelihood using logit mixed-effect models. Again, the dependent variable was the binomial target response choice (universal-wide, coded as TRUE, vs. existential-wide, coded as FALSE). Now, however, we were not only interested in effects of Prime Condition and the interaction between Prime Condition and Prime Quantifier, but also in effects and interactions of the Block (*exclusive-elke* and *inclusive-elke*) and Block Order (*exclusive-elke* first or *exclusive-elke* second) variables. This led to two potential issues. First, the levels of the Prime Quantifier variable were not the same between the two levels of the Block variable (the *inclusive-elke* block contained three Prime Quantifier levels, whereas the *exclusive-elke* block only contained two Prime Quantifier levels). Second, we were interested in interactions among four predictor variables (Prime Condition, Prime Quantifier, Block, and Block Order), but this makes the omnibus model that includes all these variables very complex.

To tackle these obstacles, we created two logit mixed-effect models. First, we analysed whether the effect of Prime Condition was modulated by Block and an interaction between Block and Block Order. We therefore constructed a model with Prime Condition, Block, and Block Order as predictor variables. In this analysis, we excluded the data from the *elke-elke* condition, in order to have a balanced design between the two blocks. Second, we tested whether Prime Quantifier and Block Order modulated the effect of Prime Condition. We therefore constructed a further model that contained Prime Condition, Prime Quantifier, and Block Order as the predictor variables. This model was run on the data of each Block separately.

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

Results

Similar to Experiments 1-2, we removed target responses from further analyses if the participant selected the incorrect response on the preceding prime trials (Table 4.1).

Prime Quantifier	Block	Block Order	Removed trials: u-wide condition (% of total)	Removed trials: e-wide condition (% of total)
Iedere	Exclusive-elke	Exclusive-elke-first	40 (3.08%)	32 (2.46%)
Alle	Exclusive-elke	Exclusive-elke-first	37 (2.85%)	25 (1.92%)
Iedere	Exclusive-elke	Exclusive-elke-second	29 (2.23%)	25 (1.92%)
Alle	Exclusive-elke	Exclusive-elke-second	41 (3.15%)	22 (1.69%)
Iedere	Inclusive-elke	Exclusive-elke-first	30 (2.31%)	22 (1.69%)
Elke	Inclusive-elke	Exclusive-elke-first	22 (1.69%)	19 (1.46%)
Alle	Inclusive-elke	Exclusive-elke-first	24 (1.85%)	20 (1.54%)
Iedere	Inclusive-elke	Exclusive-elke-second	34 (2.62%)	29 (2.23%)
Elke	Inclusive-elke	Exclusive-elke-second	24 (1.85%)	22 (1.69%)
Alle	Inclusive-elke	Exclusive-elke-second	42 (3.23%)	22 (1.69%)

Table 4.1: Overview of the removed trials across all conditions in Experiment 3.

Numerically, there seems to be priming in all conditions (Figure 4.4; Table 4.2): The universal-wide response was selected more often after a universal-wide prime than after an existential-wide prime in all Prime Quantifier, Block, and Block Order configurations.

The full model of our first analysis included Prime Condition, Block, and Block Order as predictor variables and a three-way interaction term of these three predictors. The random effects structure contained a random intercept for Subject, a random intercept for Item, and a random slope of Prime Condition, Block, and Block Order per Item and Prime Condition and Block per Subject. We did not include a random slope for Block Order per Subject, because Block Order was a between-subject variable. The Wald χ^2-test revealed that the three-way interaction term of Prime Condition, Block, and Block Order did not significantly improve the model (χ^2(1) = 0.10, p = 0.747). The two-way interaction between Prime Condition and Block Order also did not significantly improve the model (χ^2(1) = 0.85, p = 0.358) and neither did the two-way interaction between Prime Condition and Block (χ^2(1) = 0.73, p = 0.393). The two-way interaction between Block and Block Order was significant (χ^2(1) = 23.42, $p < 0.001$). Finally, the model comparisons revealed that there was no significant main effect of Block Order (χ^2(1)

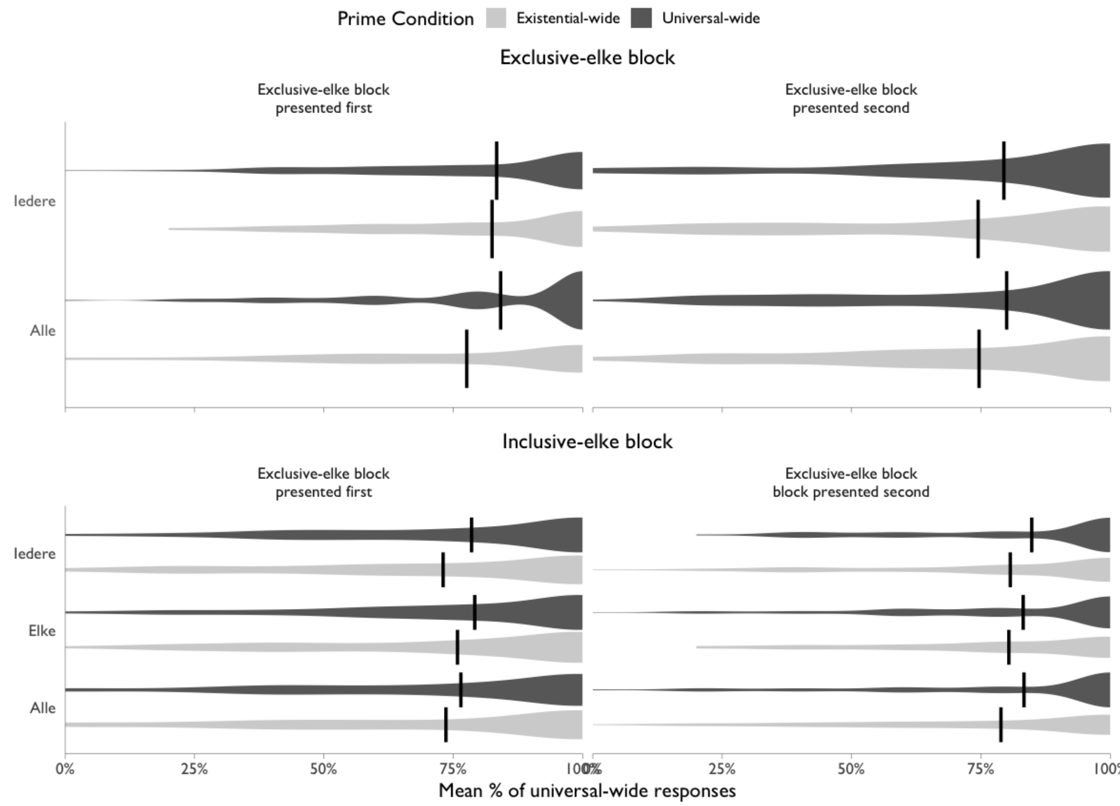


Figure 4.4: The participants' mean percentage of universal-wide responses on the target trials in all conditions of Experiment 3. The black vertical lines represent the overall mean response rate. The width of the outlined area represents the proportion of the data located at that point.

= 0.85, p = 0.358) and Block (χ^2(1) = 0.68, p = 0.411), but there was a main effect of Prime Condition (χ^2(1) = 24.15, $p < 0.001$).

The second analysis tested, separately for each block, whether the effect of Prime Condition is modulated by Prime Quantifier and Block Order. For each block, we conducted a full model that included three predictors (Prime Condition, Prime Quantifier, Block Order) and a three-way interaction term of these three predictors. In the *inclusive-elke* block, the Wald χ^2-test showed that none of the possible interactions between Prime Condition, Prime Quantifier, and Block Order were significant (three-way: χ^2(2) = 0.37, p = 0.833; two-way Prime Quantifier x Block Order: χ^2(2) = 2.73, p = 0.255; two-way Prime Condition x Block Order: χ^2(1) = 0.27, p = 0.604; two-way Prime Condition x Prime Quantifier: χ^2(2) = 0.03, p = 0.988). Moreover, the model comparison showed no significant main effects of Block Order (χ^2(1) = 2.08, p =

Prime Quantifier	Block	Block Order	% u-wide responses in u-wide condition (SD)	% u-wide responses in e-wide condition (SD)	Difference
Iedere	Exclusive-elke	Exclusive-elke-first	79.42% (29.68%)	74.45% (31.38%)	4.97%
Alle	Exclusive-elke	Exclusive-elke-first	79.96% (28.09%)	74.63% (29.64%)	5.33%
Iedere	Exclusive-elke	Exclusive-elke-second	83.37% (23.27%)	82.49% (22.66%)	0.88%
Alle	Exclusive-elke	Exclusive-elke-second	84.14% (23.27%)	77.59% (28.39%)	6.55%
Iedere	Inclusive-elke	Exclusive-elke-first	84.81% (22.73%)	80.67% (26.22%)	4.14%
Elke	Inclusive-elke	Exclusive-elke-first	79.14% (27.32%)	75.81% (29.45%)	3.33%
Alle	Inclusive-elke	Exclusive-elke-first	83.31% (26.48%)	78.86% (21.17%)	4.45%
Iedere	Inclusive-elke	Exclusive-elke-second	78.53% (27.72%)	73.03% (31.28%)	5.50%
Elke	Inclusive-elke	Exclusive-elke-second	83.15% (24.15%)	80.38% (24.19%)	2.77%
Alle	Inclusive-elke	Exclusive-elke-second	76.46% (30.05%)	73.57% (32.43%)	2.89%

Table 4.2: Summary of the responses across all conditions in Experiment 3. Numerically, the participants provided more universal-wide target responses in the universal-wide condition than in the existential-wide condition, although the descriptive size of this effect varies somewhat.

0.149) or Prime Quantifier (χ^2(2) = 0.91, p = 0.634). The comparison did reveal a significant main effect of Prime Condition (χ^2(1) = 26.61, $p <$ 0.001). Similarly, in the *exclusive-elke* block, none of the possible interactions between Prime Condition, Prime Quantifier, or Block Order significantly improved the model (three-way: χ^2(1) = 1.88, p = 0.170; two-way Prime Quantifier x Block Order: χ^2(1) = 0.40, p = 0.528; two-way Prime Condition x Block Order: χ^2(1) = 0.16, p = 0.693; two-way Prime Condition x Prime Quantifier: χ^2(1) = 1.79, p = 0.180). Additionally, the Wald χ^2-test revealed no significant main effects of Block Order (χ^2(1) = 0.21, p = 0.649) or Prime Quantifier (χ^2(1) = 0.11, p = 0.735). There was, however, a main effect of Prime Condition (χ^2(1) = 11.50, $p <$ 0.001).

4.4.3 Discussion

Experiment 3 revealed an effect of Prime Condition, both between-quantifiers and within-quantifier, thus replicating the results of Experiment 2. An initial analysis showed that between-quantifier priming was not modulated by the Block or Block order variables. These null effects show that priming between quantifiers emerged regardless of whether the participant had been exposed to a within-quantifier condition. Furthermore, this analysis revealed an interaction between Block and Block Order: The participant selected the universal-wide response more often in the *exclusive-elke* block if the *exclusive-elke* block was presented first and in the *inclusive-elke* block if the *exclusive-elke* block was presented second. Thus, participants selected the universal-wide response more often in the beginning than in the end of the experiment. This latter finding can be explained in terms of adaptive learning, as also mentioned in the Discussion of Experiment 1: Throughout the experiment, the participants are exposed to both the universal-wide and the existential-wide interpretations in the prime sentences. This may weaken the bias for the universal-wide reading of the target sentences as well, leading to more alternations in the target responses in the second half than in the first half of the experiment (e.g., Jaeger & Snider, 2013; see also Feiman & Snedeker, 2016, supplement materials).

The second part of our analysis of the results of Experiment 3 indicated that the effect of Prime Condition was also not modulated by Prime Quantifier or Block Order. Taken together, Experiment 3 thus showed priming of logical representations across the board: Both within- and between quantifiers, regardless of whether the participant was also exposed to a within-quantifier condition. These results suggest that priming of logical representations emerges independently from quantifier overlap. However, in light of the full set of experiments reported here, it seems to be a prerequisite for between-quantifier priming that participants are exposed to multiple quantifiers in the prime trials (even if those are multiple between-quantifier conditions, like in the *exclusive-elke* block of this experiment). If that is the case, participants may generalise over quantifiers in the construction of logical representations. Otherwise, priming of logical representations seems stronger within quantifiers than between quantifiers (as previously observed in Experiment 1 and in Feiman & Snedeker, 2016). We will return to this finding in the General Discussion.

Altogether, the three experiments that we conducted showed that logical representations do not specify scope assignment in a quantifier-specific way. However, the design of the experiment influences the strength of priming between quantifiers. In order to further evaluate possible differences in priming within and between quantifier priming in Experiments 1-3 we conducted a cross-experimental analysis in the form of a small meta-analysis.

4.5 Meta-analysis

Experiments 1-3 suggest that priming of logical representations between quantifiers depends on the experimental design: Priming does not (robustly) emerge between quantifiers in case the participants are only shown one prime quantifier condition but does emerge between quantifiers if participants are exposed to multiple prime quantifier conditions. In order to statistically test this possible interaction between priming between quantifiers and diversity in the prime quantifier conditions presented to the participants, we conducted a meta-analysis on all data from Experiments 1-3 as well as the data from Feiman and Snedeker's (2016) Experiment 2, which tested priming of logical representations within and between quantifiers in English, using a similar sentence-picture matching task as Experiments 1-3 of the present study. The design of that experiment was similar to our Experiment 1: Prime quantifier (*all*, *every*, or *each*) was manipulated between participants. However, Feiman and Snedeker did not only manipulate the quantifier in the prime trials, but also in the target sentence (*all*, *every*, or *each*)[3]. The target quantifier was also manipulated between participants, so each participant only saw one prime target condition and one target quantifier condition.

In this meta-analysis, we aimed to answer two questions: (i) Does quantifier overlap between prime and target sentence amplify effects of logical representation priming? And (ii) is the possible modulating effect of quantifier overlap on prime condition dependent on the diversity in the prime quantifier conditions presented to the participants?

4.5.1 Meta-analysis procedure

The procedure of this meta-analysis is based on Mahowald et al.'s (2016) meta-analysis on syntactic priming. The first step of our meta-analysis was to express the effects observed in each experiment in a uniform way, which we did by calculating the effect size observed in each experimental condition. However, each experimental condition should not be given the same weight, because the number of observations varied across conditions. The second step of our meta-analysis was therefore to determine the weight of each condition by calculating the standard error and confidence intervals of each effect size.

[3]Feiman and Snedeker's (2016) study also included a prime/target quantifier condition with numeral quantifiers (e.g., *three* or *four*) in the subject phrase. We omitted the data from these conditions, in order to make the data from Feiman and Snedeker's experiment and our experiments more similar.

We measured the effect size by calculating the log odds ratio of the proportion of universal-wide responses in the universal-wide prime condition (i.e., the primed condition) compared to the proportion of universal-wide responses in existential-wide condition (i.e., the non-primed condition). This calculation is shown in equation (4.1).

$$LogOddsRatio = \log(\frac{p(X|universal - wide)}{1 - p(X|universal - wide)}) - \frac{p(X|existential - wide)}{1 - p(X|existential - wide)}) \quad (4.1)$$

In this equation, $p(X|universal - wide)$ denotes the proportion of universal-wide responses in the universal-wide prime condition and $p(X|existential - wide)$ the proportion of universal-wide responses in the existential-wide prime condition. We then calculated the standard error on the log odds ratio by calculating the square root of the sum of the reciprocals of the number of both types of target responses (*universal-wide* or *existential-wide*) in each prime condition (*universal-wide* and *existential-wide*). This calculation is given in equation (4.2).

$$StandardError = \sqrt{\frac{1}{n_{UwideUwide}} + \frac{1}{n_{EwideUwide}} + \frac{1}{n_{UwideEwide}} + \frac{1}{n_{EwideEwide}}} \quad (4.2)$$

In this equation, $n_{UwideUwide}$ specifies the number of observations in which the universal-wide response was given in the targets following a universal-wide prime, $n_{EwideUwide}$ the number of observations in which the existential-wide response was given in the targets following a universal-wide prime, $n_{UwideEwide}$ the number of observations in which the universal-wide response was given in the targets following an existential wide prime, and $n_{EwideEwide}$ the number of observations in which the existential-wide response was given in the targets following an existential wide prime. The 95% confidence interval, which denotes that the probability that the true effect size lies in that range is 95%, is then calculated by multiplying the standard error by 1.96. The range is then specified by subtracting this value from the log odds ratio to calculate the lower bound and adding it to the log odds ratio to calculate the upper bound.

The next step was to fit meta-analysis models to these data. With these models, we tested whether the effect of logical representation priming was significant in this complete sample of data, and whether quantifier overlap affects the strength logical representation priming. We first fitted a random effect meta-analysis model that only included intercepts to all the effect size data. This model was implemented using the `rma` command of the `metafor` package in `R` (Viechtbauwer, 2010). We used a random effects model, rather than a fixed effects model, because a random effects model assumes that the size of logical representation priming can differ depending on the experimental design used (e.g, Brysbaert, 2019). The outcome of this model will inform us whether the effect of logical representation priming is significant across all the data considered here.

In a second model, we tested whether quantifier overlap between prime and target (i.e., a within-quantifier condition) amplifies effects of logical representation priming. Therefore, we fitted another mixed-effect meta-analysis model on the data (following Mahowald et al., 2016). In this model, which was fitted using the `rma.mv` command of the `metafor` package, Quantifier Overlap (*yes* vs *no*) was included as a fixed effect. This model included random effects of Experiment and Condition. This model can reveal whether quantifier overlap between prime and target is a significant moderator of logical representation priming, but note that this model did not assess the possible interaction between Quantifier Overlap and Design (*within-subjects* vs *between-subjects*). The results of the studies reported in this chapter, however, suggest that a possible boost of quantifier overlap only emerges if the quantifier pairings in prime and target are manipulated between subjects. Therefore, we fitted a final mixed-effects meta-analysis model that included an interaction term of Quantifier Overlap and Design. This model again contained random effects for Experiment and Condition.

4.5.2 Results

Figure 4.5 displays the effect sizes, measured in terms of log odd ratios, observed in all the experimental conditions taken into consideration in this meta-analysis. The random effects model that was fitted on the data first revealed a significant intercept (estimated effect size: 0.25, z = 7.79, se: 0.03, 95% CI: 0.19 – 0.32, $p < 0.001$). Converted into Cohen's d, the effect size is d = 0.14, which is considered a small effect. This finding indicates that the effect of logical representation priming was small but significant in the combined data of all experimental conditions. However, this model also revealed significant heterogeneity in the estimated effect of logical representations (Q(24) = 51.51, $p < 0.001$). This means that this meta-analysis model cannot explain most of the variability in the effect sizes, even though all experiments used the same paradigm and similar prime-target sentences.

The mixed-effects meta-analysis model that tested whether quantifier overlap between prime and target boosts effects of logical representation priming showed a significant intercept (0.21, se = 0.05, z = 4.29, 95% CI = 0.12 – 0.31, $p < 0.001$, d = 0.12) and a significant effect of Quantifier Overlap (0.18, se = 0.05, z = 3.82, 95% CI = 0.09 – 0.28, p = 0.001, d = 0.19).

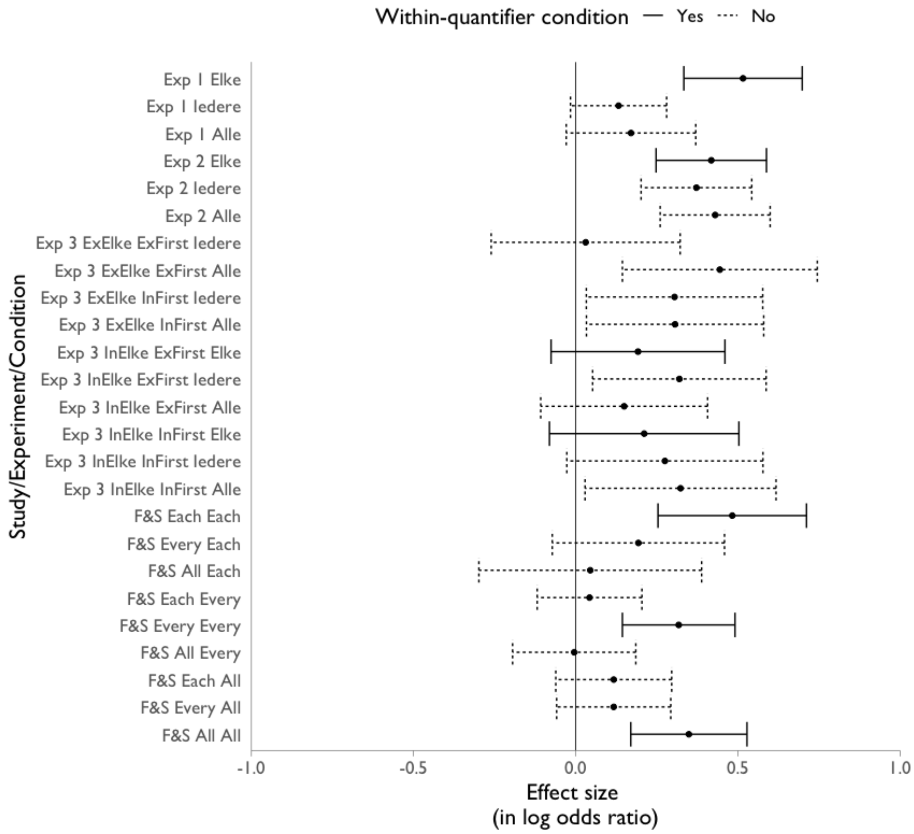


Figure 4.5: Effect sizes of all experimental conditions considered in the meta-analysis. The points denote the effect size, expressed in log odds ratio, and the error bars the 95% Confidence Interval. The dashed and solid error bar specify whether the condition was a within-quantifier or a between-quantifier condition. In the labels of the conditions, "FS" denotes a condition from Feiman and Snedeker's (2016) Experiment 2. The two quantifiers behind 'FS' specify the quantifier mapping in the prime and target trial: The first quantifier is the quantifier that was used in the prime sentence and the second quantifier the quantifier that was used in the target sentence. All other data comes from the present study. Here, 'Exp 1' to 'Exp3' refers to the Experiment, and the quantifier (*elke, iedere, alle*) to the prime quantifier condition. Finally, the block and block order in Experiment 3 is specified as well.

The significant intercept indicates a significant effect of logical representation priming. The significant effect of Quantifier Overlap indicates that repetition of the quantifiers in prime and target indeed enhanced the effect of logical representation priming (Figure 4.6). However, the test for residual heterogeneity included in the output of this model suggested that there is still considerable variability in the effect sizes that is not accounted for by the moderating effect of Quantifier Overlap on logical representation priming (QE(23) = 36.11, p = 0.040).

To test whether the effect of quantifier overlap depended on the experimental design

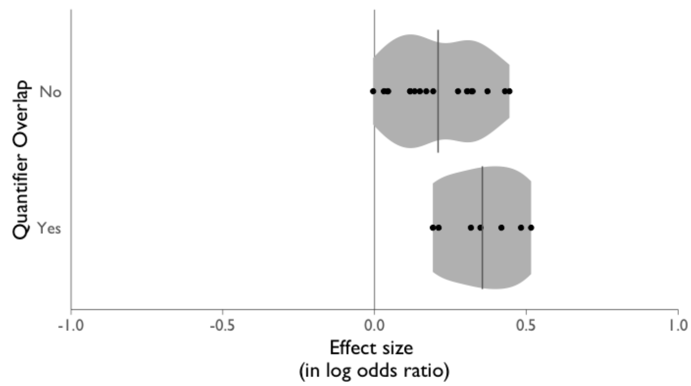


Figure 4.6: Effect size estimates by Quantifier Overlap. The black dots denote the effect size of each data point (i.e., the observed effect in each experiment/condition), the vertical black lines represent the mean effect size. The blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point.

(between- vs within-subjects; Figure 4.7), we fitted a second mixed effects meta-analysis model in which we included an interaction term of Quantifier Overlap and Design. This model showed a significant intercept (0.33, se = 0.07, z = 4.92, 95% CI = -0.01 – 0.24, $p < 0.0001$, d = 0.18), no significant effect of Quantifier Overlap (-0.01, se = 0.08 z = -0.19, 95% CI = -0.17 – 0.14, p = 0.851, d = 0.01), a significant effect of Design (-0.21, se = 0.09, z = -2.33, 95% CI = -0.40 – -0.03, p = 0.020, d = 0.12) and a significant interaction between Quantifier Overlap and Design (0.32, se = 0.10, z = 3.34, 95% CI = 0.13 - 0.51, p = 0.0008, d = 0.18). Moreover, the test for residual heterogeneity revealed that most of the variability in the effect sizes is explained by the moderators included in the model (QE(21) = 17, p = 0.708). This model output should be interpreted as follows: The reference level was the within-subject between-quantifier condition. Quantifier Overlap did not cause any considerable changes in logical representation priming compared to this reference level (i.e., there was no boost of quantifier overlap in case of a within-subject design). The significant effect of Design indicates that logical representation priming - in the absence of quantifier overlap - is weaker in a between-subjects design than in a within-subjects design. Finally, the significant interaction between Quantifier Overlap and Design indicates that the effect of quantifier overlap is larger in a between-subjects design than a within-subjects design (Figure 4.7).

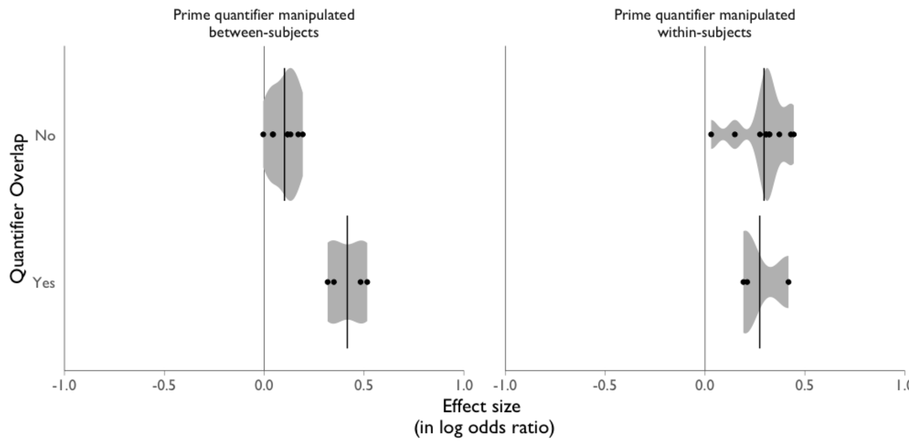


Figure 4.7: Effect size estimates by Quantifier Overlap, broken down per experimental design. The effect sizes are given in log odds space. The black dots denote the effect size of each data point (i.e., each experiment/condition), the vertical black lines represent the mean effect size. The blobs indicate the distribution of the data: The width of the outlined area represents the proportion of the data located at that point.

4.5.3 Discussion

This meta-analysis suggests that there is a moderating effect of quantifier overlap (priming of logical representations is stronger in case of quantifier repetition between prime and target), but only if the quantifier pairing in prime and subject is manipulated between subjects. Moreover, in the absence of quantifier overlap, priming is stronger if the quantifier pairing between prime and target is manipulated within subjects than between subjects.

Importantly, this meta-analysis further confirmed that logical representation priming emerges both within- and between-quantifiers. This indicates that scope assignment is not represented in a quantifier-specific way in mental logical representations. Moreover, priming of logical representations can be boosted by quantifier overlap, but only in a between-subjects design. There is no enhancing effect of quantifier overlap if the quantifier pairing in prime and target is manipulated within subjects.

4.6 General discussion

This study centred around the question of whether logical representations specify inherent combinatorial properties of quantifier words, by testing effects of logical representation priming within and between quantifiers in the comprehension of doubly-quantified sentences in

Dutch. In Experiment 1, the participants were presented with one of three universal quantifiers (*elke*, *iedere*, or *alle*) in the prime trials. In the target trials, all participants were presented with sentences that contained *elke*. There was stronger priming when the prime and the target sentences contained the same quantifier (i.e., *elke-elke*) than when the prime and target sentences contained different quantifiers (i.e., *iedere-elke* or *alle-elke*). This pattern replicates earlier findings from Feiman and Snedeker (2016) in English, but our statistical analyses also revealed priming between *alle* and *elke*. In Experiment 2, all participants were presented with all three universal quantifiers under consideration in the prime trials. Here, we observed comparable priming within and between quantifiers. In Experiment 3, we manipulated the presence of a within-quantifier condition (in addition to between-quantifier conditions) in blocks of the experiment. Like in Experiment 2, the results of Experiment 3 showed that logical representations can be primed both within and between quantifiers and priming of logical representations between quantifiers did not require the presence of a within-quantifier condition. Finally, we performed a meta-analysis to further test the effect of quantifier overlap between prime and target. This meta-analysis confirmed that priming of logical representations emerges both within and between quantifiers. Overlap in quantifier in the prime and target can enhance priming of logical representations, but only if the participants are only presented with one quantifier in the prime trials. This enhancing effect does not emerge if participants are presented with multiple quantifiers in the prime trials.

Taken together, these results suggest that (i) logical representations do not specify the inherent combinatorial tendencies of the quantifier words under consideration, and (ii) priming of logical representations between quantifiers is more fragile than priming within the same quantifier. We will discuss the implications of these findings below.

4.6.1 Logical representations are not quantifier-specific

Feiman and Snedeker (2016) argued that logical representations are quantifier-specific, based on their findings that priming of logical representations only emerges if the prime and target sentences contain the same quantifiers, and not if the prime and target sentences contain different quantifiers. They sketched an account of logical representation in which quantifiers instantiate different mechanisms that are responsible for the assignment of scope (e.g., Beghelli & Stowell, 1997; Champollion, 2017), which are specified in logical representations.

Our results do not corroborate this account, which predicts that priming is at least stronger within than between quantifiers, whereas we observed logical representation priming between quantifiers that is comparable to priming within the same quantifier. Our results therefore indicate that scope assignment is represented alike for universal quantifiers. These findings are in line with a view in which quantifiers assign scope with a general scope-taking mechanism but differ in their tendency to call upon this mechanism. Multiple formalisations of such a general mechanism have been proposed (e.g., Fodor, 1982; Hendriks, 1988; May, 1985). Note that our data do not allow us to differentiate between these different proposed operations, but our interpretation of the results is also not committed to any specific formalisation of scope-taking.

Our findings suggest a distinction in the lexical representations of quantifiers and logical representations underlying complex sentence meaning. This distinction fits theoretical accounts that posit that logical representation is not a linguistic, but a conceptual, level of representation. Such theories posit that logical representations specify the relation between different concepts in the conceptual structure of a sentence's meaning (e.g., Fodor, 1982; Jackendoff, 1992), but not any language-specific dependencies in the establishment of these relations, like lexically defined mechanisms in the assignment of scope (see also the studies reported in Chapters 2-3). Here, it is relevant to note that lexical features of quantifier words are not the only determiners of scope preferences. Structural properties, like the position of a quantifier in the syntactic tree structure, also play a role: Quantifiers that are higher in the syntactic tree structure are more likely to take wide scope than quantifiers that are lower in the syntactic tree structure. For instance, *every* is less likely to take wide scope in *A hiker climbed every hill* than in *Every hiker climbed a hill* (e.g., Fodor, 1982; Ioup, 1975; Kurtzman & MacDonald, 1993). Raffray and Pickering (2010) observed that logical representations can be primed from passive sentences like *A tree was climbed by every kid* onto *Every hiker climbed a hill*: Participants were more likely to assign the universal-wide reading to an active target sentence if the previous passive prime sentence required a universal-wide than an existential-wide reading. Moreover, the strength of this priming was comparable to priming within the same syntactic structure.

The proposed distinction between linguistic and conceptual levels of representations described above predicts this pattern of results: Linguistic features, like lexical or grammatical properties of the sentence, facilitate the online construction of a logical representation, but they are not specified in the same level or representation as these logical representations. It is worth emphasising, however, that our results only indicate that the representation of scope is alike for universal quantifiers, and that care is required in generalising these findings to other quantifiers. Importantly, universal quantifiers can all be roughly paraphrased as "for all" in logical representation, making the abstract relation that they specify between concepts in semantic interpretation similar. Other quantifiers, such as scalar terms like *some* or *most*, specify different relations between sets (e.g., Katsos et al., 2016; Szabolcsi, 2010). This may lead to a differentiation in the representation of these quantifiers at the level of logical representations.

4.6.2 Lexical differences across universal quantifiers

In the previous subsection, we described that universal quantifiers rely on the same scope-taking mechanisms in the construction of logical representations. If this is the case, we still need explain the different biases in scope-taking behaviour across different quantifiers. Again, this can be explained if we assume a distinction between lexical representations of the quantifiers and conceptual logical representations underlying complex sentence meaning.

The scope-taking biases of quantifier words are specified in their lexical representations. An important semantic difference between (universal) quantifier words is *quantifier distributivity*, which is a semantic feature that is inherently specified in some universal quantifiers (e.g., Gil, 1995). The quantifiers *each* and *every* (or *elke* and *iedere* in Dutch) bear this feature: They invoke a distributive interpretation of the predicate, meaning that this property is predicated to each individual member of the quantified set. This explains why *Each kid did the assignment individually* is grammatical, whereas **Each kid did the assignment together* is not. The quantifier *all* (or *alle* in Dutch), on the other hand is optionally distributive: It allows an interpretation in which predicate is asserted to each individual member of the quantified group, but also to the group as a whole. Therefore, *All kids did the assignment individually* and *All kids did the assignment together* are both acceptable sentences (e.g., Dowty, 1987; Gil, 1995; Link, 1987; Tunstall, 1998).

Distributivity affects scope-taking tendencies (as also noted by Ioup, 1975): A distributive quantifier like *each* instantiates a distributive reading of the predicate. Such a reading invokes a wide-scope reading of the quantifier. Collective readings of the predicate, however, require a narrow-scope reading of the universal quantifier. This explains why a non-distributive quantifier like *all* shows a weaker tendency to invoke a wide-scope reading (see also Goldberg, 2006). Given the correlation between distributivity and scope assignment, we should emphasise that our results require an interpretation in terms of scope assignment, and not in terms of the possible application of distributivity (cf. Maldonado et al., 2017a). First, our target sentences involved a distributive quantifier (*elke*, '*every*'), which does not allow a collective reading (**Elk kind maakte de opdracht gezamelijk*; *'*Each/Every kid did the assignment together*'). Therefore, the targets were not ambiguous between a collective or a distributive reading of the predicate but were ambiguous in the assignment of scope. Second, distributivity also affects the interpretation of the verb. Consider the collective reading of *All kids built a sandcastle* (i.e., all kids built one sandcastle together). In this reading, there is joint action involved in the 'building' event (e.g., Tunstall, 1998). Our materials (as previously noted by Feiman & Snedeker, 2016) do not invoke such a collective reading of the verbs: The verbs mostly describe individual actions (e.g., climbing, approaching) and the agents of these actions are not depicted as groups in the accompanying pictures (see Slim et al., 2021, reported in Chapter 2, see also Appendix 4).

Summing up, universal quantifiers rely on the same scope-taking mechanisms but differ in their tendency to invoke this mechanism. These differences across quantifiers are specified in the lexical representation of the quantifier words: Distributive quantifiers have a stronger tendency to invoke a wide-scope reading than non-distributive quantifiers. Importantly, our finding that logical representation priming is similar both within the same quantifier and between quantifiers indicates that these lexical properties of quantifier words are not represented in logical representations. This suggests a division of labour between lexical (i.e., linguistic) levels of representations that are involved in computing logical representations and logical representations that specify abstract relations in semantic interpretation. To gain a full understanding of sentence interpretation and the assignment of scope, future research is encouraged to test the interface between lexical and logical representations. How are the combinatorial properties of quantifier words represented, and how do they guide the computation of logical representations in language processing? The present work does not gain insight on these questions. However, by showing the distinction between lexical and logical representations, it has highlighted the relevance of these questions.

4.6.3 Priming as structure-mapping

A second finding of this study is that logical representation priming between different quantifiers is more fragile than priming within the same quantifier: We observed priming if participants are presented with prime sentences that involve different quantifiers (Experiment 2 and 3), but not if the participants are presented with the same quantifiers in the prime sentences throughout the experiment (Experiment 1, see also Feiman & Snedeker, 2016). This finding is difficult to reconcile with the prevalent accounts of structural priming (which originate from research on syntactic priming in production Chang et al., 2006; Jaeger, 2008; Pickering & Branigan, 1998; see also Branigan & Pickering, 2017; Pickering & Ferreira, 2008, for reviews). Although these prevalent accounts specify mechanisms to explain a possible enhancing effect of lexical repetition (i.e., the *lexical boost* effect often observed in syntactic priming), they do not predict that such an enhancing effect is dependent on experimental design.

However, there is a less-prevalent explanation that could explain for these results, namely in terms of *structure-mapping*. Structure-mapping is the observation that people tend to align different situations if they have a common relational structure (Gentner, 1983). For instance, Spellman et al. (2001) showed that people are faster in comprehending a word pair that form a relation (e.g., the relation *is in the center of* between 'planet' and 'core') if they were just presented with a word pair that involved a similar relation (e.g., 'fruit' and 'pit') than if they were presented with a word pair that did not involve this relation (e.g., 'stage' and 'pit'). This shows that people recognise the abstract relations between words, and map these onto subsequent word pairs by aligning the situations based on their common relational structure (an effect that can also occur unintentionally; see Popov & Hristova, 2015). This results in the transfer of the relational structure of one situation onto a second situation (e.g. Gentner & Smith, 2012; Holyoak, 2012).

Although the structure-mapping hypothesis originates in research on problem-solving and reasoning (e.g. Catrambone & Holyoak, 1989; Gentner, 1983; Holyoak, 2012), it has also been linked to structural priming and language learning (Fisher, 2000; Fisher et al., 2020; Popov & Hristova, 2015; Taylor et al., 2011). A study from Popov and Hristova (2014), for instance, found that language comprehenders perseverate in the assignment of thematic roles in the comprehension of sentences. In their experiment, participants were presented with an unambiguous prime sentence like *The doctor watched the patient by using glasses* or *The doctor watched the patient who wore glasses*. The thematic role of *glasses* differs in these two examples: They are an instrument of the action watching in the first example, and an attribute of the patient in the second example. After reading one of these unambiguous primes, the participants read an ambiguous sentence like *The hunter watched the alpinist with binoculars*. In this sentence, *binoculars* can receive an instrumental (i.e., the hunter used the binoculars to watch the alpinist) or an attributive role (i.e., the alpinist had the binoculars while the hunter watched them). The participants were asked to disambiguate this sentence by indicating whether the alpinist was watched by binoculars or whether the alpinist with the binoculars was watched. The results revealed that participants assigned the instrumental interpretation more often following an instrumental prime than following an attributive prime.

Thus, Popov and Hristova's (2014) study shows that people recognise the relational structure underlying a sentence (i.e., the assignment of thematic roles) and map this structure onto a subsequent sentence (even if those sentences do not share syntactic structure; cf. Branigan et al., 2005). Moreover, most participants indicated that they did not notice the connection between the two sentences, which shows that this effect of structure-mapping was automatic and unconscious. Our results can also be explained in terms of structure-mapping: People recognise the common quantificational relation underlying the primes and the targets (i.e., a relation that specifies that multiple agents act upon separate themes or a relation that specifies that multiple agents act upon the same theme) and align the two situations described in the prime and targets based on this common structure. Concretely, this results in an increased likelihood of assigning the logical structure of the prime sentence onto the target sentence.

Important for our purposes is that theories on structure mapping can explain the finding that logical representation priming is more robust within the same quantifier than between quantifiers. First, previous studies have shown that structure mapping is facilitated by overlap in the surface similarities of the two structures under consideration (e.g., Gentner & Smith, 2012; Holyoak, 2012). In this case, it is easier to detect the commonalities in the relational structures across the different instantiations of this structure, and transfer from the base structure onto the target structure. This explains why we consistently observe priming in prime-target pairs that share the same quantifiers: The repetition of the quantifiers facilitates the detection of the commonalities in the underlying logical representations in the prime and target, which affects the target responses.

Second, it has been argued that the deduction of an abstract relational structure across similar situations is facilitated by diversity in the input. Here, the hypothesis is that variation in the input highlights the abstract underlying structure, rather than the commonalities in superficial features (e.g., Braithwaite & Goldstone, 2015). Our study is not the first to show that a diversity in the primes facilitates abstract priming. In a study on production, Savage et al. (2006) observed that 4-year-old children showed more abstract syntactic priming in transitive structures (i.e., they were more likely to produce an active sentence following active primes than following passive primes) if they were presented with primes that contained different verbs than if they were presented with primes that all contained the same verb. This suggests that lexical variation in the input helps children to recognise the abstract structure underlying the primes, which in turn, will be transferred onto the target. The authors interpreted this finding in terms of schematisation: Diversity in the input enables a learner to detect the commonalities in the underlying structure of different lexical instantiations, and therefore, learners who receive a diverse input are more likely to deduct an abstract, schematic, representation of the shared underlying structure (e.g., Savage et al., 2003; Thothathiri & Snedeker, 2008). Our results indicate that such schematisation also facilitates the detection of abstract structures in adults (see Chang et al., 2006; Rowland et al., 2012). This explains why we observe logical representation priming between different quantifiers, but only consistently if the participants are presented with diversity in the primes (as in Experiment 2 and 3 of the present study).

It should be noted, however, that the explanation below is a post-hoc explanation to account for our unexpected findings, and therefore requires further investigation. For instance, what are the memory processes involved in structure mapping (Taylor et al., 2011)? And what are the cognitive mechanisms underlying schematisation? And does this account on priming (at least in comprehension) also explain structural priming at other levels of representations besides logical representations (e.g., Branigan & Pickering, 2017; Popov & Hristova, 2014; Taylor et al., 2011; Ziegler et al., 2019)? Such questions are important to gain understanding in the mechanisms driving structural priming in comprehension, at least at the level of logical representations.

4.7 Conclusion

Three experiments showed that priming of logical representations in the comprehension of doubly quantified sentences is not dependent on the overlap of the quantifier between the prime and the target (at least if the prime and the target sentences are both active transitive sentences with a universal quantifier in the subject position and an existential quantifier in the object position); a meta-analysis involving our data and those of Feiman and Snedeker (2016) supported this conclusion. These findings suggest that logical representations do not specify quantifier-specific scope-taking properties. We explain our findings in terms of a distinction between lexical representations that specify the scope-taking biases of each quantifier and conceptual logical representations that specify the relation between different sentence parts in complex sentence meaning. We speculate that the finding that logical representation priming between quantifiers is fragile fits within the theoretical framework of structure-mapping: Priming between quantifiers emerges once participants deduce the abstract underlying logical structure instantiated by different quantifier words, which can be facilitated by a diversity in the primes (cf., Savage et al., 2006). Once this abstract structure is recognised, the participants transfer it onto the target sentences, which results in priming (Popov & Hristova, 2014).

5 The role of verb meaning in logical representations

Language comprehension involves the derivation of the meaning of sentences by combining the meaning of their parts. The compositional structure of such sentence meanings is assumed to be represented in logical representations. *Using a structural priming paradigm, Feiman and Snedeker (2016) observed that the strength of logical representation priming is not dependent on overlap of the verb between prime and target. This indicates that comprehenders compute a representation of a sentence's logical form, which specifies the compositional structure of the sentence meaning but not any conceptual meaning content. However, in a similar experiment in Dutch, there was no abstract (verb-independent) priming. Comparison with a previous, within-verb priming experiment showed an interaction, suggesting stronger verb-specific than abstract priming. A power analysis on both Feiman and Snedeker's data and our Experiment 1 revealed that both experiments were underpowered. Therefore, we replicated our Experiment 1, using the sample size guidelines provided by our power analysis. This experiment again found no abstract logical representation priming and an interaction, with the earlier experiment, so that priming was stronger in verb-specific than abstract priming. Our experiments show that logical representation priming is enhanced if the prime and target sentence contain the same verb and that priming of logical representation priming between verbs is a fragile effect at best.*

Note. This chapter presents collaborative work with Robert J. Hartsuiker and Peter Lauwers. We thank Roman Feiman for sharing the data from Feiman and Snedeker (2016). All data and analyses script of this study are available online at https://osf.io/697wg/.

5.1 Introduction

To what extent do representations of complex sentence meanings abstract away from the conceptual content of a sentence? A prominent assumption in semantic theories is that the representations of sentence meaning involve a distinct abstract level of *logical form*, in which the compositional structure of a sentence is specified (i.e., the way in which the constituents of a sentence combine into complex sentence meaning) but not the conceptual meaning of the lexical items themselves (e.g., Heim & Kratzer, 1998; May, 1985). However, this assumption has been contested by theorists who posit that sentence meaning representations take the form of conceptual representations that specify both the compositional structure of a sentence and its conceptual meaning content (e.g., Fodor, 1982; Johnson-Laird et al., 1989). In this study, we investigated this question by testing the role of verb meaning in the computation of complex sentence meaning.

5.1.1 Logical forms or conceptual representations?

The representation of the compositional structure of sentence meaning is especially well-studied in doubly-quantified sentences, which are notorious for their ambiguity in the compositional semantic structure (see Brasoveanu & Dotlail, 2019; Ruys & Winter, 2011, for overview). Consider (1):

(4) Every man bit a dog.

This sentence can mean that every man bit a different dog, but it can also be understood as meaning that every man bit the same dog. Different theories have been put forward to describe the mental representations that capture the two interpretations of an ambiguous sentence like (1). A prevalent account within semantics posits that sentence interpretation involves an abstract level of mental representation known as the *logical form* (e.g., Heim & Kratzer, 1998; Hornstein, 1995; May, 1985). These logical forms can be captured in formulae like the ones in (1a) and (1b).

(1a) *Universal-wide*: $\forall x[\mathsf{MAN}(x) \rightarrow \exists y[\mathsf{DOG}(y) \wedge \mathsf{BIT}(x, y)]]$
For all *x*, if *x* is a man, there exists a *y* such that *y* is a dog, and *x* bit *y*

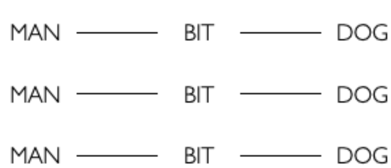
(1b) *Existential-wide*: $\exists y[\mathsf{DOG}(y) \wedge \forall x[\mathsf{MAN}(x) \rightarrow \mathsf{BIT}(x, y)]]$
There exists a *y*, such that *y* is a dog, and for all *x*, if *x* is a man, then *x* bit *y*

The logical form in (1a) corresponds to the interpretation in which every man bit a (potentially) different dog, and the one in (1b) corresponds to the interpretation in which the same dog was bitten by every man. The logical forms in (1a-b) show that the ambiguity emerges because there are two orders in which *every* and *a* combine with the other sentence constituents in the compositional structure of the sentence's interpretation. In (1a) *every* takes wide scope over the other elements in the sentence (this reading will therefore be called the *universal-wide* interpretation), whereas in (1b) *a* takes wide scope over the other elements in the sentence (henceforth the *existential-wide* interpretation).

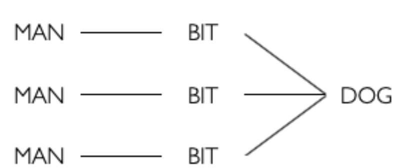
A logical-form-based account typically posits that logical forms specify the compositional relation between sentence constituents, but not the conceptual meaning of the content words in these constituents (e.g., Heim & Kratzer, 1998). This is illustrated in (1a) and (1b): The verb arguments are represented as variables (x and y), and the verb is represented as a relation between these variables (i.e., BIT(x, y)). The quantifiers *every* and *a* specify the relations between the content words of a sentence: The quantifier *every*, as exemplified in (1a) and (1b) specifies that all things (denoted by the variable x) that are 'men' are also things that are involved in 'biting'. Similarly, *a* specifies that there is at least one thing (denoted by the variable y) that is a 'dog' that is also involved in 'biting'. However, the logical forms only specify the relation between the concepts DOG, MAN, and BIT, and not the meaning content of these concepts: It captures that everything that is a 'man' is also a thing that is involved in 'biting' and that there exists something that is a 'dog' that is also a thing that is involved in 'biting', without specifying what it means to be a 'man', a 'dog', or 'biting' . Therefore, such accounts posit a distinction between the *combinatorial system* and the representations of *conceptual meaning* content in the computation of sentence meaning (see also Feiman & Snedeker, 2016).

An alternative account on complex sentence meaning was postulated by Fodor (1982). In this account, the compositional structure of sentence meaning is represented in conceptual representations that capture the event situation that is described in the sentence. Such conceptual structures can be captured in abstract mental models like the ones represented in (2a) and (2b).

(2a)



(2b)



The schema in (2a) represents the universal-wide reading. Here, multiple men act in a separate biting event on a separate dog (i.e., every man bit a separate dog). The schema in (2b), on the other hand, represents the existential-wide reading, in which multiple men act in a separate biting event on one single dog. In this account, scope behaves slightly different than in logical-form-based accounts. Quantifiers that specify a multitude of referents (like *every*, *all* or *several*) take scope over other sentence parts by instantiating a plural interpretation of these sentence parts. In (2a) the scope of *every* ranges over *a*, which instantiates a plural interpretation of '(a) dog'. In (2b), however, the scope of *every* is terminated before 'a dog' is represented: This instantiates that 'bit' receives a plural interpretation (as each man is involved in a separate biting event), but 'a dog' receives a singular one (Fodor, 1982; Kurtzman & MacDonald, 1993). Thus, scope ambiguity is analysed as the range over which universal quantifiers induce a plural interpretation over other sentence constituents, instead of the order in which quantifiers take scope with respect to each other in the sentence's logical form.

Such a theory does not make a strict distinction between the representation of the logical form and the representation of the meaning content of the lexical items in a sentence. Thus, conceptual meaning content of a sentence is specified at the same level as its compositional structure (and not in the form of abstract variables or predicates; e.g., Goodwin & Johnson-Laird, 2011; Johnson-Laird et al., 1989; Khemlani et al., 2012).

5.1.2 Priming of sentence meaning

The nature of logical representations (a term we will use in a theory-neutral way, without any commitment to logical-form-based theories) can be studied using the structural priming paradigm in language comprehension (Feiman & Snedeker, 2016; Raffray & Pickering, 2010, and the previous chapters in this dissertation). *Structural priming* is the tendency to re-use the structure of a prior linguistic stimulus, which indicates that exposure to a certain structure facilitates the future processing of that structure. This effect is assumed to arise because it is easier to re-use a representation if it was used in the processing of a previous, related, sentence. Structural priming is therefore a suitable method to gain insight into (linguistic) representation, because priming effects indicate that two sentences share underlying representations (e.g., Bock, 1986; Raffray & Pickering, 2010; for review, see Branigan & Pickering, 2017).

Logical representation priming is typically tested using a sentence-picture matching task. In this task, originally designed by Raffray and Pickering (2010), participants read sentences and match each sentence with one out of two pictures. The primes contain a doubly-quantified sentence (e.g., *Every boy climbed a tree*), a matching picture, and a non-matching picture. Primes are presented in two conditions: the *universal-wide* condition, in which the matching picture depicts the universal-wide interpretation of the sentence, and the *existential-wide* condition, in which the matching picture depicts the existential-wide interpretation of the sentence. In the targets, which directly follow the primes, the participants read a similar doubly-quantified sentence. Now, however, the two pictures display both possible readings of the sentence. Using this paradigm, Raffray and Pickering observed that participants selected the universal-wide reading more often in targets that followed a universal-wide prime than in targets that followed an existential-wide prime, which demonstrates that logical representations can be primed.

Since then, priming of logical representations has been replicated several times in language comprehension (Feiman & Snedeker, 2016; Maldonado et al., 2017a; Raffray & Pickering, 2010, and the previous chapters in this dissertation). Note, however, that Raffray and Pickering (2010) always repeated the verb between the prime and the target. This means that the prime and target sentences do not only share an abstract logical form, but also have overlap in the conceptual meaning of the content words. Therefore, Raffray and Pickering's results do not allow us to discriminate between a logical-form-based account and a conceptual-structure-based account of representation of compositional structure. Important for our purposes is a study from Feiman and Snedeker (2016, Experiment 3), which does provide insight in this question. Using the same paradigm as Raffray and Pickering (2010), they observed that logical representations can be primed between doubly-quantified sentences that contained different verbs: For instance, after exposure to the existential-wide reading of the sentence *Every beggar hit a reporter*, people were more likely to assign that same existential-wide reading to the sentence *Every hiker climbed a hill* (compared to if they were exposed to the universal-wide reading of the sentence *Every beggar hit a reporter*). Moreover, their analyses showed that the priming effect was not modulated by verb overlap between the prime and target (although there was a numerical difference: Priming within the same verb showed a descriptive effect of 6.47%, whereas priming between verbs showed a descriptive effect of 4.98%). If logical representations are sensitive to conceptual meaning content, one would expect priming to be stronger within the same verb than between different verbs, as there would be more representational overlap in the first case. Therefore, Feiman and Snedeker's experiment supports an abstract logical-form-based account of compositional sentence meaning, which specifies the relations between sentence parts in interpretation, without specifying the conceptual meaning content of these sentence parts.

5.1.3 The present study

Below, we first report a close replication experiment of Feiman and Snedeker's (2016) Experiment 3 in Dutch. Our initial motivation for this experiment was not necessarily to re-evaluate the strength of logical representation priming between verbs (see https://osf.io/e3mkb for the preregistration) but, to foreshadow the results, Experiment 1 did not find logical representation priming in the absence of verb overlap. This finding required us to replace our initial goals with the goal of testing whether Feiman and Snedeker's finding of abstract logical representation priming is generalisable and whether such priming is enhanced by (or even conditional on) verb overlap. To gain more insight into the reliability of the between-verb priming effect, we next performed a power analysis on Feiman and Snedeker's data and on our Experiment 1 (inspired by Harrington Stack et al., 2018). This power analysis revealed that Feiman and Snedeker's original experiment and our replication were both underpowered. A new close replication of Feiman and Snedeker's experiment, which followed the sample size guidelines provided by the power analyses (reported below as Experiment 2), again showed that logical representation priming is stronger within the same verbs than priming between different verbs. These findings suggest that logical representation priming between verbs is not robust, and that the conceptual meaning of verbs play a role in processing and representing the compositional structure of a sentence's interpretation.

5.2 Experiment 1

Experiment 1 was our first replication of Feiman and Snedeker's (2016) Experiment 3. We used the same task as Feiman and Snedeker with similar materials. However, we presented our stimuli in Dutch (to native speakers of Dutch), whereas Feiman and Snedeker's original task was in English (and tested native speaker of English). Nevertheless, Experiment 1 measured the same dependent variable as Feiman and Snedeker and implemented the independent variable in the same way as in Feiman and Snedeker's experiment, which makes it a close replication following the taxonomy of replications defined by LeBel et al. (2017).

Like Feiman and Snedeker (2016), we gained further insight into the role of verb repetition in logical representation priming by comparing the data of Experiment 1 to the data of a similar experiment that tested logical representation priming within verbs (in Dutch) in the analyses. This latter experiment is not reported here but in Chapter 4.

5.2.1 Method

Participants

We recruited 69 Dutch-speaking participants. They were first-year psychology students at Ghent University and received course credit for their participation. We excluded two participants from the analyses because they guessed the aim of the experiment in a post-experimental questionnaire, and three further participants because they responded incorrectly on more than 10% of the filler trials (see below). Thus, 64 participants were included in the analysis.

Materials

Experiment 1 was a sentence-picture matching task, like the one used in Feiman and Snedeker (2016). The stimuli were adapted from the study reported in Chapter 1, and were partly borrowed from Raffray and Pickering (2010). The materials from Raffray and Pickering were also used in Feiman and Snedeker's original experiment.

Each trial consisted of a sentence and two response pictures. In the prime and target trials, the sentence was a doubly-quantified scopally ambiguous sentence with the universal quantifier *elke* ('every') in the subject position and the existential quantifier *een* ('a') in the direct object position (e.g., *Elke beer naderde een tent*; 'Every bear approached a tent'). Prime trials were presented in two prime conditions: the *universal-wide* and the *existential-wide* condition. In the *universal-wide* condition, the matching picture displayed the universal-wide reading of the prime sentence and in the existential-wide condition, the matching picture depicted the existential-wide reading.

Each prime trial directly preceded a target trial. In the target trials, the participants read another *elke... een* sentence, which always contained a different verb than the preceding prime sentence (see Appendix 5 for a list of the prime-target pairs). The two response pictures in the target trials displayed both possible readings of the target sentence (Figure 5.1). Thus, the participants were forced to assign one of the two possible readings to the prime sentence but had a free choice between either interpretation in the target trials.

Finally, the filler trials contained unambiguous sentences, one matching picture, and one non-matching picture. Half of the filler trials contained unambiguous transitive sentences (e.g.,

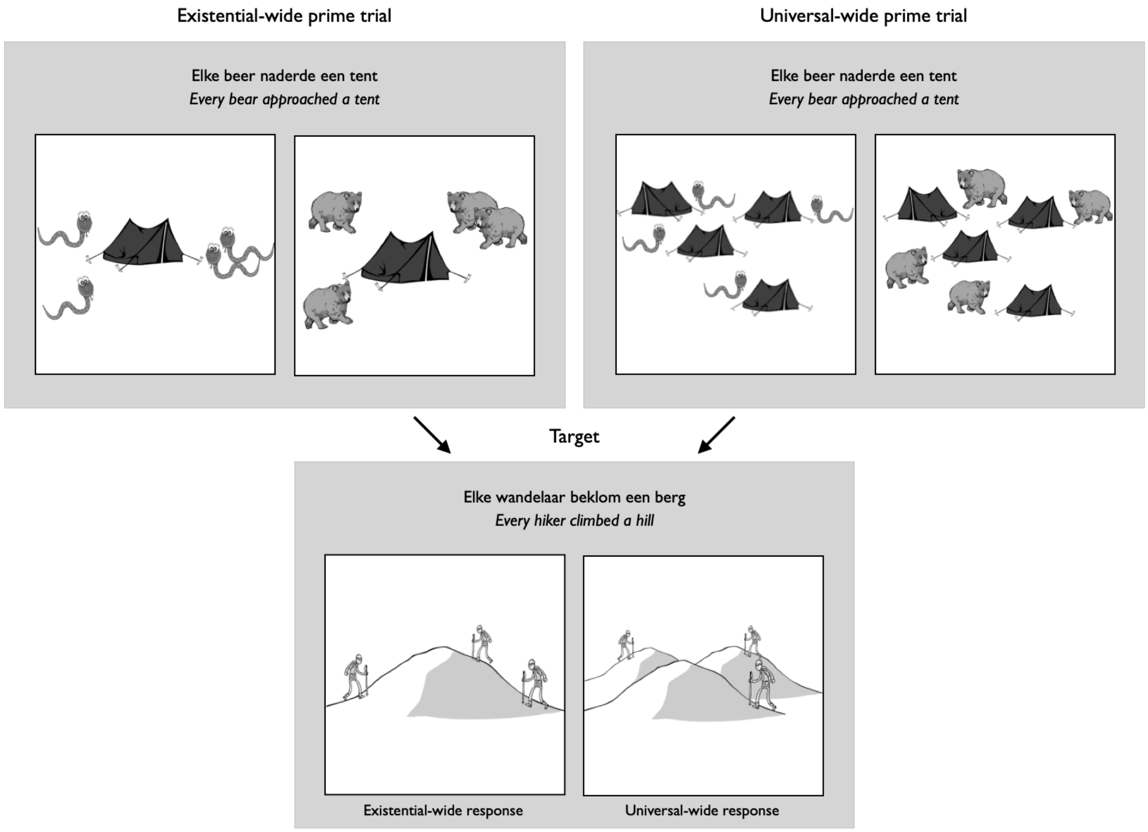


Figure 5.1: Example of a prime-target pair in Experiment 1. The English translation of the sentences and the labels 'Universal/Existential-wide prime condition/response' are added to this figure for the sake of illustration.

De cowboy sloeg de boef; 'The cowboy punched the burglar') and the other half involved intransitive sentences with *elke* in subject position (e.g., *Elke heks sliep*; 'Every witch slept'). The aim of adding these additional fillers was to further mask the prime-target pattern in the trials, because a previous study showed that a considerable number of participants guessed the aim of the experiment (reported in Chapter 2).

The experiment contained 54 prime trials, 54 target trials, and 162 filler trials. Trial order was organised pseudo-randomly: Primes and targets appeared in pairs, and prime-target sets were intervened by two to five filler trials (following Raffray & Pickering, 2010). We created two lists in which the prime condition was counterbalanced across trials. Our materials differed in three aspects from Feiman and Snedeker's (2016) original experiment: (i) We presented our stimuli in Dutch, (ii) Feiman and Snedeker's experiment only contained transitive fillers, whereas we constructed additional intransitive fillers, and (iii) our experiment contained 54 prime-target sets, whereas Feiman and Snedeker's experiment contained 24 prime-target sets. We therefore added additional fillers to our task, so that the ratio of fillers to primes/targets was the same. Note further that Feiman and Snedeker recruited more participants than us (107 compared to 64) but fewer critical trials; we therefore had a larger total number of observations (3456 observations in the present experiment vs. 2568 in Feiman and Snedeker's experiment).

Procedure

The experiment was implemented using `PennController for Ibex` and carried out online via the `PCIbex Farm` (Zehr & Schwarz, 2018). The experiment started with an informed consent form. In all trials, the sentence and two pictures were shown simultaneously on a screen. The participants were instructed to click on the picture that best fitted the sentence. The instructions also said that participants needed to select their spontaneous preference if they thought that both pictures matched the sentence.

After completing the sentence-picture matching task, the participants filled in a short questionnaire about their language background. A final question asked whether the participant had any ideas about the research aims of the experiment. Those who guessed the pattern of the trials (prime-target), and/or guessed that the experiment examined the possible influence from the preceding trial on the target trials were excluded from the analyses (following the study reported in Chapter 2).

5.2.2 Analyses and results

Data treatment and analysis procedure

A target response was discarded if the non-matching picture in the preceding prime was selected (following Raffray & Pickering, 2010). Moreover, all responses of a participant were removed if they responded incorrectly on more than 10% of the filler trials. The remaining responses were coded as `TRUE` if the universal-wide response was selected, and `FALSE` if the existential-wide response was selected.

The data were analysed by modelling the response-type likelihood with logit mixed-effect models (Jaeger, 2008). The full model contained the target response as a binomial dependent variable and Prime Condition as a (sum-coded) fixed effect. The random effects structure was maximal (both random slopes and intercepts by Item and Subject; Barr et al., 2013), unless this maximal random-effect structure did not converge. In that case, we omitted random effects until we reached convergence (Bates et al., 2015). We calculated p-values by running χ^2-tests on the log-likelihood values of the full model compared to models in which the predictor values were removed one-by-one. We then compared the data of Experiment 1 to the data from the *elke-elke* condition of Experiment 1 reported in Chapter 4. The materials, procedure, and number of participants (n = 63) of this experiment was similar to Experiment 1 reported here, with the exception that the verb was repeated in each prime-target pair. Therefore, this comparison elucidates a possible difference in the size of within-verb vs. between-verb priming. These analyses were again carried out with logit mixed-effect modelling. The model contained Prime Condition, Verb Overlap, and the interaction term as (sum-coded) fixed effects. The rest of the analysis procedure was similar to the one described above. All analyses were carried out in `R` (R Core Team, 2019) using the `lme4` package (Bates et al., 2014).

Results and discussion

We discarded 171 target responses because the participants responded incorrectly on the preceding prime (4.95% of the total numbers of prime-target pairs, 88 of these responses were from the *universal-wide* and the other 83 were from the *existential-wide* condition).

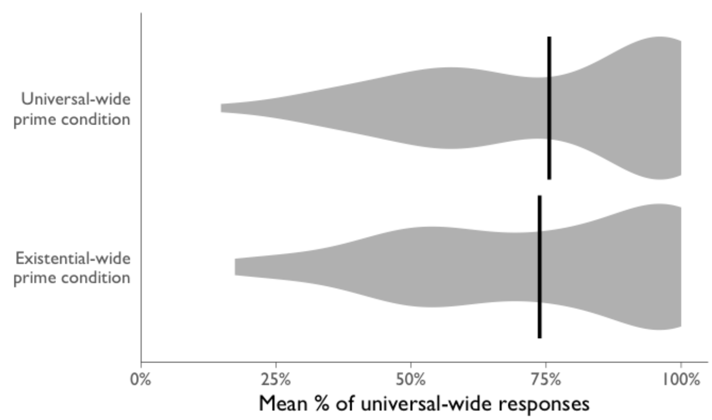


Figure 5.2: The participants' mean percentage of universal-wide responses on the target trials in Experiment 1, as a function of prime condition, compared to the participants' mean percentage of universal-wide responses on the target trials in the within-verb dataset. The black vertical lines represent the overall mean response rate, and the width of the outlined area represents the proportion of the data located at that point.

The remaining responses and reveal that the percentage of universal-wide responses was similar in both prime conditions (a difference of only 1.78%; Figure 5.2). The mixed-effect model that contained the maximal random-effects structure converged, so we used this model in the rest of our analyses. This is a deviation from Feiman and Snedeker's (2016) analysis procedure, who removed the correlation between the random slopes and random intercepts from their model. We, however, decided to retain this parameter, since a log-likelihood comparison test between the full model and a model that did not include the correlation parameter indicated that the maximal effect structure significantly improved model fit ($\chi^2(2) = 6.99$, $p = 0.03$).

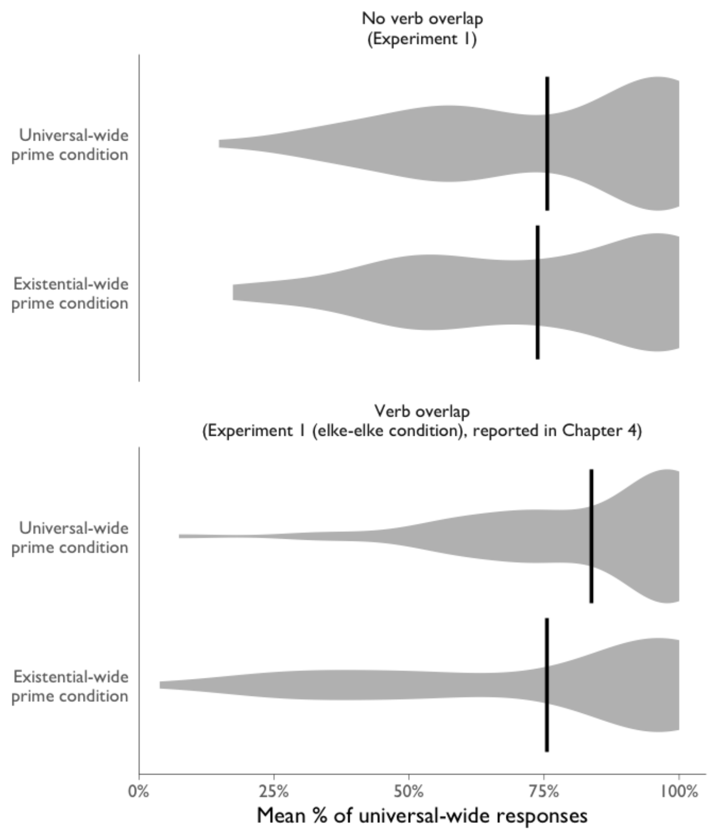


Figure 5.3: The participants' mean percentage of universal-wide responses on the target trials in Experiment 1, as a function of prime condition. The black vertical lines represent the overall mean response rate, and the width of the outlined area represents the proportion of the data located at that point.

Log-likelihood tests on the full model revealed no main effect of Prime Condition ($\chi^2(1) = 0.96$, $p = 0.328$). The analyses on the combined dataset of Experiment 1 and the within-verbs data of the *elke-elke* condition of Experiment 1 reported in Chapter 3 (Figure 5.2) revealed a significant interaction between Prime Condition and Experiment ($\chi^2(1) = 5.74$, $p = 0.017$), no main effect of Experiment (χ^2(1) = 3.26, p = 0.071) or Prime Condition (χ^2(1) = 2.47, p = 0.116).

These results do not replicate Feiman and Snedeker's (2016) findings that logical representation priming is independent of verb repetition. Logical representation priming between verbs is therefore, at the least, not a robust effect. It is unclear, however, whether Feiman and Snedeker or the present Experiment 1 were sufficiently powered to detect effects of between-verb logical representation priming. Therefore, we ran a power analysis on the original data of Feiman and Snedeker's Experiment 3, which is reported in the section below.

5.3 Power analysis

To gain insight in the reliability of logical representation priming between verbs, we conducted power simulations on the original data of Feiman and Snedeker's (2016) Experiment 3. First, we estimated the effect size observed in Feiman and Snedeker's data, by retracting the coefficient of interest from a logit mixed-effect model constructed to analyse the effect of priming in Feiman and Snedeker's Experiment 3 (following Harrington Stack et al., 2018).

As described in Section 2, Feiman and Snedeker's (2016) Experiment 3 used similar materials, procedure, and design as the present Experiment 1. Moreover, both experiments were carried out remotely over the internet (albeit with different populations: We recruited Dutch-speaking first-year psychology students, whereas Feiman and Snedeker recruited a more diverse group of English-speaking participants on Amazon MTurk). Feiman and Snedeker's test sentences were English doubly-quantified sentences that contained *every* and *a* (e.g., *Every hiker climbed a hill*) and the verb differed between prime and target. Feiman and Snedeker tested 107 English-speaking participants. Each participant was presented with 12 universal-wide prime-target pairs and 12 existential-wide prime-target pairs. Based on a re-analysis of Feiman and Snedeker's data, we extracted the effect size of the prime effect. Then, we ran power simulations to estimate the number of observations required to obtain 80% and 95% power. We aimed for 95% power, rather than commit to the usual 80% power threshold, to further reduce the risk of a false negative.

5.3.1 Re-analysing Feiman and Snedeker's (2016) Experiment 3

Feiman and Snedeker's (2016) Experiment 3 revealed a numerical priming effect of 4.98% of logical representation priming between verbs (Figure 5.4). Feiman and Snedeker analysed the data using logit mixed-effect models (as did we in our Experiment 1). We re-analysed their original data by modelling the response-type likelihood using logit mixed-effect models as well. The model constructed in this analysis was subsequently used in our power simulations. The model was similar to the one constructed in the analyses of Experiment 1 above: It contained the binomial target selection (TRUE if universal-wide and FALSE if existential-wide) as the dependent variable and Prime Condition as a (sum-coded) predictor variable. The random-effects structure contained random slopes and intercepts for Item and Subject. See Table 5.1 for the output of the full model.

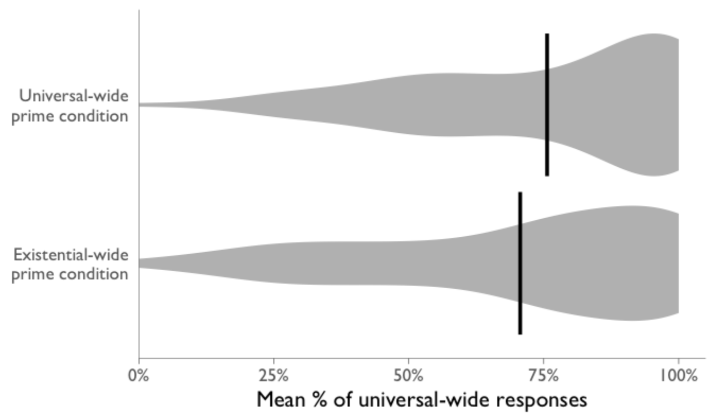


Figure 5.4: The participants' mean percentage of universal-wide responses on the target trials in Feiman and Snedeker's (2016) Experiment 3. The responses are broken down per prime condition. The black vertical lines represent the overall mean response rate, and the width of the outlined area represents the proportion of the data located at that point. The results show a priming effect of 4.98%.

Note that Feiman and Snedeker (2016) used a slightly reduced random effects structure in their original analyses, since they removed the parameter of correlation between the random slope and intercept. We followed the analysis procedure of Experiment 1 and Barr et al. (2013) recommendations, especially since the results of Experiment 1 revealed that the maximal random-effects structure significantly improved model fit (see Section 5.2.2).

	β	se	z-value	p-value
Prime Condition	-0.208	0.089	-2.345	0.019

Table 5.1: Model output of the logit mixed-effect model constructed to re-analyse Feiman and Snedeker's (2016) Experiment 3.

The significant effect of Prime Condition indicates that significantly more universal-wide responses were given in the universal-wide condition compared to the existential-wide condition. In our power analysis, we estimated the power to find an effect of the size observed in this analysis (as expressed by the β-coefficient of -0.208).

5.3.2 Power simulation and analysis

At the core of simulation-based power analysis is the simulation of new datasets based on the existing dataset. Then, all the simulated datasets are analysed for significance using the same model and procedure as described in the previous subsection. Power is defined as the proportion of significant outcomes in the complete set of simulations.

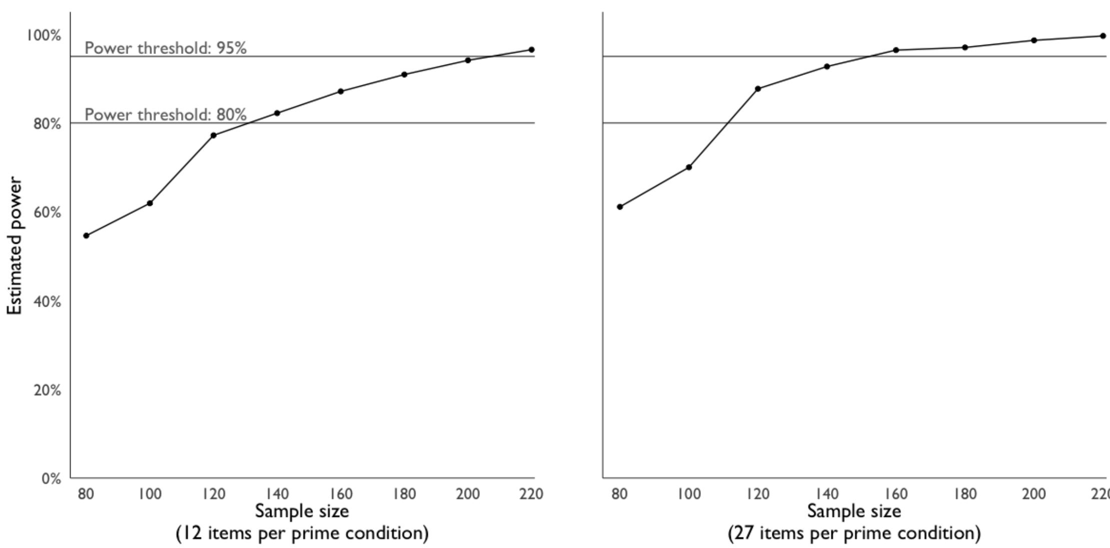


Figure 5.5: The required sample size to obtain power levels. The left panel shows that 140 participants are needed to obtain 80% power and 220 participants would be needed to obtain 95% if the experiment contained 12 items per prime condition. In the right panel, you can see that 120 participants are needed to reach the 80% power threshold and 160 participants are needed to reach the 95% power threshold if the experiment involved 27 items per prime condition.

We conducted this power analysis using the `mixedpower` package in `R` (Kumle et al., 2021). First, we estimated the required sample size to obtain 95% power if we take the design of Feiman and Snedeker's (2016) original experiment (with 12 items in each prime condition). We estimated the power based on 1000 simulations for a sample size of 80, 100, 120, 140, 160, 180, 200, and 220 participants. To reach 80% power with 12 items in each prime condition, 140 participants would be needed. To reach 95% power with 12 items in each prime condition, 220 participants would be required (Figure 5.5, left panel). This is almost double the number of participants that Feiman and Snedeker originally tested.

Second, we repeated this power analysis, but now simulated the data as if there were 27 items in each prime condition (as in Experiment 1). This power analysis revealed that 120 participants are needed to obtain 80% power and 160 participants are needed to obtain 95% power (Figure 5.5, right panel). This is roughly 100 participants more than we tested in Experiment 1. Thus, the power analyses revealed that both Feiman and Snedeker's (2016) experiment and our Dutch replication were underpowered.

5.4 Experiment 2

In Experiment 2[1], we replicated Experiment 1, but now determined the sample size based on the guidelines from our power analyses described in Section 2.

5.4.1 Method

Participants

We recruited 172 native speakers of Dutch. These participants were all recruited via Prolific and were paid £3.75 for their participation. Of the 172 participants, 9 were removed because they guessed the aim of the experiment and 3 participants were removed because they responded incorrectly on more than 10% of the filler items. Thus, 160 participants were included in the analyses (which follows the guidelines to obtain 95% power, as calculated in our power analysis).

Materials and procedure

The materials and procedure were identical to Experiment 1.

5.4.2 Analyses and results

Data treatment and analyses procedure

The data treatment and analyses procedure were similar to those in Experiment 1. However, we added one extra analysis in the comparison between the data of Experiment 2 and the within-

[1]Experiment 2 is pre-registered on https://osf.io/697wg/

verb data: The within-verbs experiment only contained 63 participants, which is considerably less than the 160 participants recruited in Experiment 2. Therefore, we randomly selected data of 63 participants of Experiment 2 and re-ran the analysis that tested the interaction between Prime Condition and Experiment on this dataset.

Results and discussion

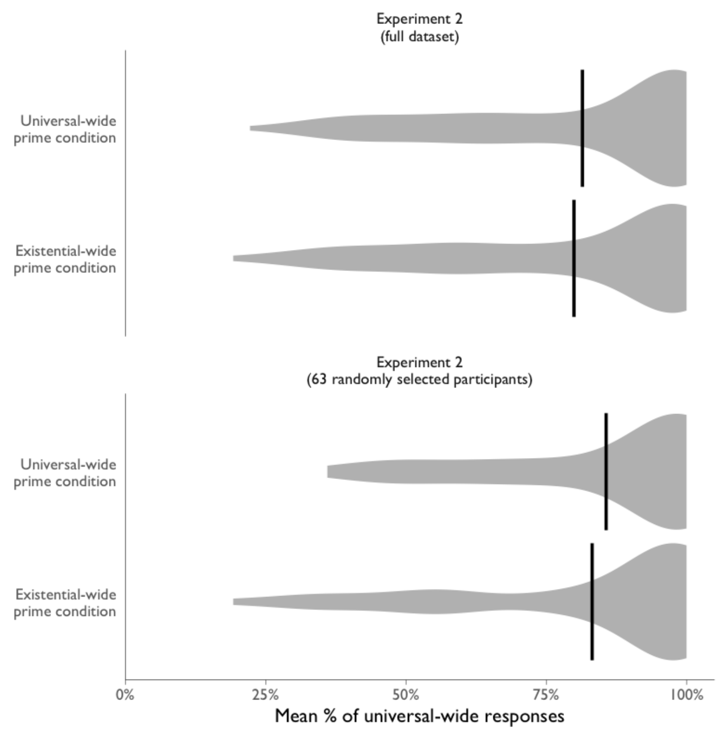


Figure 5.6: The participants' mean percentage of universal-wide responses on the target trials in Experiment 2, divided between the two prime conditions. The left panel shows the data of all participants in Experiment 2, and the right panel shows the data of 63 randomly selected participants of Experiment 2. The black vertical lines represent the overall mean response rate, and the width of the outlined area represents the proportion of the data located at that point.

Due to an error in the counterbalancing, list A contained 28 universal-wide items and 26 existential-wide items, while list B contained 27 items in both prime conditions. We removed 186 target responses in the universal-wide prime condition (4.28%) and 132 target responses in the existential-wide prime condition (3.11%) due to incorrect responses to the preceding prime trial. The remaining responses are plotted in Figure 5.6 and indicate that the percentage of universal-wide target responses was similar between both prime conditions (with a difference of 1.5%).

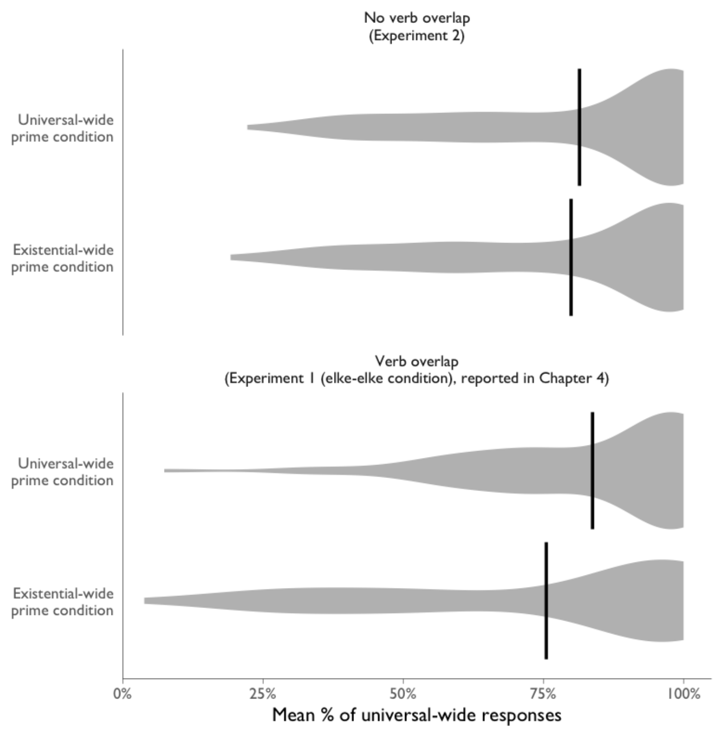


Figure 5.7: The participants' mean percentage of universal-wide responses on the target trials in Experiment 2, as a function of prime condition, compared to the participants' mean percentage of universal-wide responses on the target trials in the within-verb dataset. The black vertical lines represent the overall mean response rate, and the width of the outlined area represents the proportion of the data located at that point.

Like the model constructed in the analysis of Experiment 1, the random-effects structure of the model constructed in the analysis of Experiment 2 was maximal. The log-likelihood test showed no main effect of Prime Condition (χ^2(1) = 1.98, p = 0.159). This suggests that Experiment 2 also failed to detect a reliable effect of logical representation priming between verbs.

Additionally, the comparison of Experiment 2 and the within-verb data (Figure 5.7) revealed a significant interaction between Prime Condition and Experiment (χ^2(1) = 8.11 p = 0.004), a significant main effect of Prime Condition (χ^2(1) = 4.46, p = 0.035), and no main effect of Experiment (χ^2(1) = 0.13, p = 0.715). This demonstrates stronger logical representation priming within than between verbs.

Finally, we randomly took the data of 63 participants in the between-verbs condition and repeated the analysis using this dataset (Figure 5.6; bottom panel). There was a significant interaction between Prime Condition and Experiment (χ^2(1) = 7.09, p = 0.008), but no main effect of Prime Condition (χ^2(1) = 3.59, p = 0.058) or Experiment (χ^2(1) = 0.76, p = 0.385). Thus, this analysis replicates the finding from Experiment 1 that logical representation priming is stronger within than between verbs.

5.5 General discussion

Feiman and Snedeker (2016; Experiment 3) observed that the strength of logical representation priming is not modulated by verb repetition between prime and target, which suggests that logical representations do not specify the conceptual meaning content of verbs. This finding corroborates logical-form-based accounts of sentence meaning representation that pose a distinction between the combinatorial system and the representations of conceptual meaning content in semantic interpretation. However, our close replication in Dutch (Experiment 1), did not replicate this result. We therefore ran a power analysis on Feiman and Snedeker's data, which revealed that neither Feiman and Snedeker's experiment nor our Experiment 1 had adequate statistical power to reliably detect an effect of priming of logical representations between verbs. Therefore, we conducted a further, preregistered replication (Experiment 2), but now determined the sample size based on the power analysis (threshold set at 95% power). This experiment again failed to provide evidence that logical representation priming is comparable within and between verbs. Instead, the analyses of both Experiment 1 and Experiment 2 revealed that logical representation priming between verbs was weaker than logical representation priming within the same verb.

These findings suggest that priming of logical representations between verbs is not a robust effect, and that sentence meaning representations are less abstract than proposed by Feiman and Snedeker (2016). Below, we will discuss the implications of these findings for our understanding of logical representations and the processing of quantificational scope.

5.5.1 Methodological differences: Feiman and Snedeker (2016) and this study

The first question that we should ask is whether we can attribute the differences in findings to methodological differences between our experiments and Feiman and Snedeker's (2016) original experiment. There are good reasons to assume that this is not the case. First, although there was overlap between the sets of stimulus materials in our and Feiman and Snedeker's experiments (namely those borrowed from Raffray & Pickering, 2010), we constructed additional materials. Thereby, we increased the number of trials in each experimental condition (27 prime-target pairs per prime condition instead of 12). However, this increase of prime trials does not seem to influence the strength of priming: Previous studies that involved the same materials and contained the same number of items did reveal effects of logical representation priming (reported in Chapters 2 & 4). In these studies, however, the verb in the prime and target sentence was repeated (replicating Raffray & Pickering, 2010; and Feiman & Snedeker, 2016, Experiment 2, Experiment 4).

Second, the experiments reported here were in Dutch, whereas Feiman and Snedeker's (2016) experiments were administered in English. It is unlikely however that the lack of between-verb priming is due to a difference between Dutch and English. First, the Dutch and English stimuli were close translation equivalents (see Appendix 5). And second, the studies reported in Chapters 2 & 4 have shown that logical representations can be primed in Dutch language comprehension if the verb is repeated between prime and target. Therefore, we see no reason to suspect that the processing of verb meaning is different in English and Dutch language comprehension.

A final difference that is worth mentioning is that we recruited participants amongst first-year psychology students (Experiment 1) or via Prolific (Experiment 2), whereas Feiman and Snedeker (2016) recruited their participants via Amazon MTurk. Here, it is worth noting that the results of Experiment 1 and 2 reported in the present study are similar, even though there are differences in the demographic characteristics between the undergraduate population tested in Experiment 1 and the more diverse population tested in Experiment 2. Moreover, the participants from Experiment 2 were also paid participants recruited online, like the population tested by Feiman and Snedeker. Therefore, we see no reason to assume that demographic differences affect logical representation priming and caused the discrepancy between the present and Feiman and Snedeker's results.

The most likely explanation for the difference between our experiments and Feiman and Snedeker's (2016) Experiment 3 is the difference in power. Our power analysis revealed that Feiman and Snedeker's experiment was underpowered. Our well-powered Experiment 2 again showed a null effect of logical representation priming between verbs, and an interaction suggesting that logical representation priming is stronger if the verb is repeated in the prime and target.

5.5.2 Verb repetition and the lexical boost

Research on syntactic priming has shown that effects of priming increase if the prime and the target share the same verb (the *lexical boost*, e.g., Branigan & Pickering, 2017; Hartsuiker et al., 2008; Pickering & Branigan, 1998; see also Mahowald et al., 2016, for meta-analysis). Therefore, the dependence on verb repetition demonstrated here may be considered as an analogue of the lexical boost. However, care is required in drawing this comparison, since it does not seem to bear out completely. Firstly, the role of the lexical boost is predominantly studied in syntactic priming in production (Branigan & Pickering, 2017; Pickering & Branigan, 1998; Pickering & Ferreira, 2008; see also Mahowald et al., 2016, for meta-analysis). These studies consistently show that the effect of priming is enhanced by repetition of the verb in the prime and the target sentences. However, studies on syntactic priming in comprehension reveal mixed evidence about the occurrence of a lexical boost: Some studies have shown syntactic priming that is comparable with and without verb overlap (Ziegler & Snedeker, 2019), whereas other studies fail to find syntactic priming without verb overlap altogether (e.g., Arai et al., 2007). Therefore, these studies cast doubt on whether the presumed mechanisms underlying the lexical boost are generalisable to language comprehension (see also Segaert et al., 2013).

Secondly, even if we presume that the lexical boost emerges in both priming in production and in comprehension, further care is required in interpreting our results in terms of a lexical boost. The lexical boost is typically studied in priming of syntactic representations, whereas we focused on logical representations. Although there are multiple mechanisms proposed to explain the lexical boost in syntactic priming (Bock & Griffin, 2000; Chang et al., 2006; Pickering & Branigan, 1998), they share the assumption that the lexical boost emerges because a the lexical item, and not necessarily its conceptual meaning content, is repeated. However, evidence from bilingual priming suggests that the role of verb repetition does not behave similarly in logical representation priming in comprehension. In syntactic priming, the effect of verb repetition is typically stronger if the prime and target are presented in the same language than if the prime and target are presented in different languages (in which case not the same lexical item, but a translation equivalent is repeated, e.g., Schoonbaert et al., 2007). This suggests that the lexical boost in syntactic priming is caused by repetition of the same lexical item, and not necessarily by repetition of the meaning representations of these items (which are assumed to be shared across translation equivalents, e.g., De Bot, 1992, 2004). In the study on priming of logical representations between languages reported in Chapter 2, however, we found that the size of priming is similar within the same verb in one language and between translation equivalents in

Dutch and French (e.g., Dutch: *achtervolgen* – French: *poursuivre* 'to chase'). This indicates that logical representation priming involves semantic processing of the conceptual meaning of the sentence beyond mere formal repetition of the same lexical items. This finding suggests that logical representation priming is sensitive to overlap in the conceptual meaning content in the prime and target after all.

5.5.3 Why logical representation priming between verbs is fragile

So, why is the computation of logical representations dependent on conceptual processing of the verb, and is priming of logical representations between verbs not a robust effect? One explanation may be that the computation of complex sentence meaning in language comprehension is often driven by real-world (pragmatic) knowledge of the event type described in a sentence (Dwivedi, 2013; Dwivedi et al., 2010; Ferreira, 2003). Regarding quantifier scope ambiguity, this pragmatic knowledge causes a bias for the universal-wide reading of a sentence like *Every pilgrim rode a donkey* whereas no such bias occurs in the interpretation of *Every jeweller praised a diamond* (as shown by data reported in Chapter 2 and in Dwivedi et al., 2010). Given the importance of such pragmatic biases in scope ambiguity resolution, Dwivedi (2013) sketched an account of quantifier scope ambiguity resolution that involves two processing routes: (i) a heuristic route in which comprehenders rely on shallow processing of pragmatic number biases associated with event type, and (ii) an 'algorithmic' route in which comprehenders rely on deep processing of the abstract compositional semantic structure. These two processing mechanisms are independent, and do not interact in parallel: Comprehenders assign a first 'good enough' interpretation to a scopally ambiguous sentence based on heuristic processing of the event type, and only engage in more abstract compositional mechanisms if needed (for instance, by task demands).

Both these processing routes may serve as a locus of priming (as previously suggested by Dwivedi, 2013): Priming of the heuristic route causes an adjustment in the pragmatic bias regarding number of a specific event type (e.g., *climbing*) in the prime trials. This type of priming is only expected to affect the interpretation of target trials that contain the same verb as the preceding prime. Priming of the abstract compositional route, however, primes the combinatorial mechanisms involved in the computation of abstract compositional meaning structure. This type of priming is expected to emerge both if the prime and target contain different verbs and if the prime and target contain the same verbs. However, priming of deep combinatorial computation is predicted to emerge only if a participant engages in deep structural processing of the test sentence (making it a less robust locus for priming).

What does this hypothesis processing route tell us about the logical representations computed in sentence comprehension? It posits that people often bypass the computation of an abstract and content-free 'logical form' representation (e.g., Feiman & Snedeker, 2016; Heim & Kratzer, 1998; May, 1985) and rely on shallow processing of the conceptual meaning of a sentence instead. Therefore, abstract, content-free representations of compositional structures are only a possible locus of priming for participants that rely on algorithmic processing in interpreting the sentences, making it a weak locus of priming. The representation of the conceptual meaning of the event type denoted of a sentence, which also specifies the number of participants involved in that event (see (2a) and (2b) Fodor, 1982; Jackendoff, 1992), is a stronger locus of priming. This makes logical representation priming within verbs more robust than priming between verbs.

Altogether, the finding that logical representation priming between verbs is not a robust effect suggests that there is no strict distinction in the system that is responsible for the processes involved in combining concepts and the system that stores the meaning content of these concepts. We hypothesised that comprehenders can compute abstract and content-free logical-form-like representations, but they often bypass this stage of processing, and compute conceptual structures that specify the number of participants involved in a specific event instead. Therefore, abstract logical representations are a weak locus of priming (and may be overridden by pragmatic biases in sentence interpretation, see also Chemla & Bott, 2015; Feiman et al., 2020; Maldonado et al., 2017b).

This post-hoc hypothesis to explain the fragility of between-verb priming of logical representations raises some important further questions about the processing and representation of quantifier scope ambiguity. Firstly, we made a distinction between abstract ('deep') and pragmatic ('shallow') processing of sentence meaning, but our results do not allow us to characterise the possible processing mechanisms involved in the computation of abstract sentence meaning (see for instance Fodor, 1982; Hendriks, 1988; May, 1985, for proposed mechanisms), or possible factors that lead to deeper processing of scope assignment (Dwivedi, 2013). Moreover, this study has only considered the biases and representation of the verb, whereas it is entirely possible that such biases are also partly elicited by noun content in the predicate (e.g., *Every tourist rode a donkey* is possibly more universal-wide biased than *Every tourist rode an elephant*, based on our real-world knowledge of the predicate). Secondly, it may be that the priming of verb-specific biases causes an adjustment in the pragmatic number-related biases of related verbs that share conceptual features (e.g., *chase-follow* or *hit-slap*; e.g., Jackendoff, 1992), suggesting that conceptual logical representations do abstract away from specific verbs to some extent. For now, however, we conclude that the findings reported in this chapter suggest that the processing and representation of quantifier scope relies on processing of the conceptual meaning of the lexical items in a sentence, which is not predicted by theories that assume a strict division between the combinatorial system and the conceptual meaning representations of lexical items in sentence interpretations.

5.6 Conclusion

Feiman and Snedeker (2016, Experiment 3) observed that logical representation priming is not sensitive to any effects of verb overlap between prime and target. Two experiments in Dutch, however, showed a different pattern of results. Unlike Feiman and Snedeker, we found that logical representation priming is enhanced if prime and target contain the same verb than if prime and target involve different verbs. This indicates that logical representation priming between verbs is, at the very least, not a robust effect. This finding suggests that a sentence's logical representation is sensitive to properties of the conceptual meaning of the content words in a sentence.

6 General Discussion

Quantifiers (e.g., *all*, *each*, *a*) are abstract functional words that specify the relation between sets of referents, by instantiating rules about how the content words must be combined in the interpretation of sentences (e.g., Szabolcsi, 2010). These relations are mentally represented in *logical representations*, which capture the structure of semantic composition (e.g., Heim & Kratzer, 1998). This dissertation was concerned with the nature of these logical representations, focusing on the representation of quantifiers in language comprehension. An important question throughout the chapters of this dissertation was how abstract such logical representations are: Are they language-specific (Chapter 2 and 3)? Do they specify quantifier-specific scope-taking properties (Chapter 4)? And do they only specify compositional structure, or also conceptual meaning content of the message underlying a sentence (Chapter 5)?

Below, the critical findings reported in this dissertation are summarised and the implications of these findings for our understanding of semantic representation are discussed. The first two subsections of this General Discussion focus on the question of whether logical representations capture linguistic features (Section 6.1), and how this question relates to our understanding of bilingual logical representations (Section 6.2). In the subsequent subsections, the relations between logical representations and lexical representations of quantifiers (Section 6.3) and between logical representations and conceptual event representations (Section 6.4) are discussed. Then, the contribution of the work presented in this dissertation with respect to the possible mechanisms underlying structural priming will be elaborated (Section 6.4). Finally, the General Discussion concludes with an outlook for future research (Section 6.5).

6.1 Logical representations as conceptual structures

An first question that this dissertation addressed was whether logical representations capture *linguistic* properties on how the content words of a sentence combine in sentence interpretation, or whether they specify *conceptual* properties of the underlying meaning of a sentence. Hornstein (1995), for instance, identified logical representations (or *logical form* in his terminology) as "the level of linguistic representation at which all grammatical structure relevant to semantic interpretation is provided" (see also Chomsky, 1995). In other words, logical representations provide the linguistic mechanisms that are needed to combine the lexical items in a semantic interpretation of a sentence. Other theorists, however, posit that the combinatorial mechanisms of semantic interpretation are not specified in linguistic representations, but in non-linguistic combinatorial thought (e.g., Fodor, 1982; Jackendoff, 1992, 2002; Johnson-Laird et al., 1989). In this view, semantic composition is not a linguistic process, and therefore not dependent on linguistic mechanisms (see also Frankland & Greene, 2015, 2020).

The results presented in this dissertation fit the assumptions of this second class of theories. Chapter 2 and 3 revealed that bilinguals rely on the same logical representations in the comprehension of both languages they know. Moreover, the organisation of bilingual logical representations was, at least descriptively, not influenced by L2 proficiency (Chapter 2) or by cross-linguistic differences in scope-taking preferences (Chapter 3). The implications of these findings with respect to our understanding of bilingual language processing will be elaborated in Section 6.3, but for now, it is worth noting that these findings automatically follow from the assumption that logical representations are non-linguistic: Non-linguistic representations are not expected to be influenced by linguistic factors such as L2 proficiency or language-specific preference patterns in the mapping between form and meaning.

In addition, the findings reported in Chapter 4 revealed that logical representations do not capture quantifier-specific lexical biases in the assignment of scope. Quantifiers differ in their inherent tendencies to take wide scope: The English quantifier *each*, for instance, is more likely to take wide scope than the English quantifiers *every* or *all* (Ioup, 1975). This observation has led some theorists to posit quantifier-specific scope-taking mechanisms (Beghelli & Stowell, 1997): Quantifier words differ in their inherent (lexically-specified) scope-taking mechanisms, which leads to a quantifier-specific representation of scope in logical representations (Feiman & Snedeker, 2016).

However, the studies presented in Chapter 4 do not corroborate such an account. These studies tested priming of logical representations in transitive doubly-quantified sentences in Dutch. These sentences contained a universal quantifier in the subject position (*elke*, 'every'; *iedere*, 'every'; and *alle*, 'all') and an existential quantifier (*een*, 'a') in the object position. These three sentence types are all ambiguous between a universal-wide and an existential-wide reading, but the preferred reading differs: *elke* and *iedere* are more likely to take wide scope than *alle* (e.g., Dik, 1975; Ioup, 1975). Nevertheless, the results of Chapter 4 showed priming if the prime and target shared the same universal quantifier (*elke* to *elke*) but also if the prime and target contained different quantifiers (*alle* to *elke* or *iedere* to *elke*; cf. Feiman & Snedeker, 2016). Moreover, although priming between quantifiers is more fragile (more in Section 6.5), if it emerged, it was comparable to priming within the same quantifier. This indicates that the representation of the three tested universal quantifiers (*elke*, *iedere* and *alle*) is alike at the level of logical representations, despite their lexical and combinatorial differences.

Altogether, the results of Chapter 2-4 revealed that abstract relations between concepts are not lexically specified at the logical representation level. Although (universal) quantifier words are associated with different scopal preferences (both within a language and across different languages), the relation that they instantiate is represented alike in logical representations. This fits a non-lexicalised view of logical representation, at which the abstract conceptual relations between concepts are specified (Fodor, 1982; Goodwin & Johnson-Laird, 2011; Johnson-Laird, 1983). As already briefly mentioned, this conclusion has implications for our understanding of bilingual logical representations, which will be elaborated in the next subsection.

6.2 Bilingual logical representations

Chapters 2 and 3 presented research on bilingual logical representations. These results gave insight in whether logical representations are language-specific, but also in semantic processing in bilinguals: Do bilinguals use the same logical representations in the comprehension of both languages they speak? The results reported in Chapters 2-3 revealed that this is indeed the case: Priming of logical representations emerges both within one language and between two languages, with no difference in the magnitude of this effect. As discussed in the previous section, these findings are predicted if we assume that logical representations are non-linguistic representations of a sentence's semantic structure (Fodor, 1982; Jackendoff, 1992).

These findings show that bilinguals can map these underlying logical representations onto linguistic structures in both languages they know. Chapter 2 showed that Dutch-French bilinguals can compute both logical representations that are associated with doubly-quantified *all...a* sentences in Dutch (*alle...een*) and in French (*tou(te)s les...un(e)*). Note that both Dutch and French allow the same two readings of these sentences. Therefore, it is not unlikely that Dutch-French bilinguals learn the ambiguity in such doubly-quantified sentences early on in L2 development, based on transfer from their L1 (see also Grüter et al., 2010). If this is the case, it is predicted that these bilinguals can map both logical representations onto doubly-quantified structures in their L2 as soon as they learn the relevant quantifier words in their L2. Moreover, given the meaning overlap in the quantifier words tested in Chapter 2 (i.e., translations of *all* and *a*; Gil, 1995), bilinguals may learn these words early on in L2 development (e.g., Brysbaert & Duyck, 2010; Duyck & Brysbaert, 2004; cf. Brooks & Braine, 1996, for early development of *all* in L1 development).

Chapter 3 followed up on these findings by testing the organisation of bilingual logical representations underlying *all...not* structures in Estonian-English bilinguals (*kõik...ei* in Estonian). These sentences are ambiguous between the same two interpretations in both English and Estonian, but the preferred interpretation differs: In English the universal-wide interpretation in which *all* takes wide scope is preferred, whereas the negation-wide interpretation in which *not* takes wide scope is preferred in Estonian (see also Amiraz, 2021). Nevertheless, Chapter 3 showed that this difference in preference does not hinder the sharing of logical representations: Estonian-English bilinguals map the same logical representations onto both English and Estonian *all...not* sentences.

The developmental trajectory of these logical representations may be similar as the one sketched out above for *all...a* in Dutch-French bilingual development. Since both English and Estonian are ambiguous between the same two interpretations of *all...not*, Estonian-English bilinguals may learn the ambiguity present in *all...not* structures in their L2 early on in L2 development (i.e., as soon as they learn the meaning of *all* and *not* in their L2). This would mean that Estonian-English can rapidly map both possible logical representations onto *all...not* structures in their L2, although it may be the case that these bilinguals do not have native-like preference patterns in the interpretation of *all...not*, especially early in L2 development (cf., Grüter et al., 2010; Marsden, 2009). To gain a full understanding of bilingual logical representations, however, studies that test these development patterns are required. Are bilinguals rapidly able to map both logical representations onto scopally ambiguous sentences in their L2, or do they go through a stage in which the assignment of scope is lexical- and language-specific when they first learn a new scope-bearing operators (e.g., quantifiers or negators) in the L2?

Interesting with respect to this question is that Chapter 3 showed that bilinguals develop sensitivity to language-specific preference patterns in the interpretation of scopally ambiguous sentences: The Estonian-English bilinguals we tested in Chapter 3 assigned the universal-wide interpretation (which is the preferred interpretation in English) more often to English *all...not* sentences than to Estonian *kõik...ei* sentences. Unfortunately, our results do not offer insight in the developmental trajectory of such L2-specific preferences in scope assignment, because we only tested highly-proficient bilinguals.

Here, we should once again emphasise an important aspect of bilingualism: Bilinguals form a very heterogenous group, with differences in proficiency, language dominance, age of second language acquisition, and so on (see De Groot, 2011, for overview). However, it is expected that these individual differences between bilinguals affect linguistic representations (e.g., Hartsuiker & Bernolet, 2017; Kootstra & Doedens, 2016), but not non-linguistic representations like logical representations. This prediction was descriptively supported by exploratory analyses in Chapter 2: These analyses revealed that the sharing of logical representations is not affected by L2 proficiency (even though such a relation has been observed in syntactic representation; Bernolet et al., 2013; Hartsuiker & Bernolet, 2017). Although this finding needs to be interpreted with care given its exploratory nature, it is worth noting that this null relationship is expected under the hypothesis that logical representations are non-linguistic. Further studies are required to test whether language-specific factors in bilinguals indeed do not affect the organisation of logical representation, and how L2-specific preference patters in the assignment of scope develop over the course of L2 learning.

Altogether, the work presented in this dissertation reveals that logical representations do not specify language-specific or quantifier-specific mechanisms involved in the assignment of scope, which allows for shared bilingual logical representations. This means that quantifier-specific scope-taking tendencies need to be specified elsewhere. This question will be elaborated in the following subsection.

6.3 Distributivity and scope

Chapter 4 showed that the (Dutch) universal quantifiers *elke* ('every'), *iedere* ('every'), and *alle* ('all') specify the same abstract relation between concepts in logical representations, even though these quantifiers differ in their scope-taking biases (Feiman & Snedeker, 2016; Ioup, 1975). To account for the different scope-taking biases of quantifier words, we posited a distinction in Chapter 4 between *lexical* representations of quantifier words and *logical* representations of the conceptual relations specified by these quantifier words.

The lexical representation of a quantifier specifies the distributivity features of that quantifier (Gil, 1995). Distributive quantifiers, like *each* and *every* in English[1] (and *elke* and *iedere* in Dutch), force the assignment of a predicate to the individual members of the quantified set. On the other hand, non-distributive quantifiers, like English *all* and Dutch *alle*, allow both a

[1]In English, *each* is understood as being stronger distributive than *every*, since *every* also allows partial distributivity (Tunstall, 1998)

collective reading of the predicate in which the predicate is assigned to the quantified set as a whole as well as a distributive reading. Therefore, predicates that require a collective reading, such as *to gather*, cannot be linked to distributive quantifiers (e.g., **Each protester gathered on the square* vs *All protesters gathered on the square*; Dowty, 1987; Link, 1987; Tunstall, 1998).

A quantifier's distributive properties patterns with its scope-taking biases: Distributive quantifiers are more likely to take wide scope (Feiman & Snedeker, 2016; Ioup, 1975). However, this link between distributivity and scope is not well understood. This is partly because semantic theories predominantly seek to explain *possible* scopal configurations, rather than *preferred* ones (cf., AnderBois et al., 2012; Feiman & Snedeker, 2016; Ioup, 1975). Possibly, the explanation is in terms of *individualisation*: Distributivity singles out individual members of a quantified set, by predicating distinct events onto each member. This individualisation could increase the likelihood that a distributive universal quantifier takes wide scope over other sentence parts, since such a universal-wide reading entails a relation between the existentially-quantified noun and each individual member of the universally-quantified set (e.g., the universal-wide reading of our much-used example *Each man bit a dog* specifies that the property 'bit a dog' is assigned to each individual man; see also Dolinina, 2004; Goldberg, 2006; Ioup, 1975).

Here, it is worth noting that distributivity and scopal preferences may pattern together, but there is no one-to-one relation between these two notions. Consider the sentence in (1).

(1) All men lifted a rock.

In the collective reading of (1), all men lift a rock in the same lifting event, which requires joint action from the group of men. In the distributive reading of (1), all men individually lifted a rock. The collective reading automatically entails an existential-wide reading in which a specific rock is lifted by all men. However, the reverse does not hold: An existential-wide reading of (1) does not automatically entail a collective reading. It may be the case that all men lifted a specific rock, but in separate lifting events (for instance, each man may individually lift the same rock in subsequent lifting events). This asymmetric relation between distributivity and scope has led theorists to describe different combinatorial mechanisms underlying distributivity and scope assignment (Champollion, 2017; Dowty, 1987; Link, 1987; Maldonado et al., 2017a; but cf. Fodor, 1982, who proposes that distributivity and scope relates to the same mechanisms in combinatorial thought).

The interface between lexical quantifier representations and conceptual logical representations, and presumably between the mechanisms underlying distributivity and scope assignment, warrants future investigation. How are quantifier-specific scope-taking biases represented in lexical representation and what mechanisms are responsible for such scopal preferences? This question is pivotal to our understanding of how people map complex thought onto linguistic expressions. For now, however, we conclude that quantifier words, with different distributivity and scope-taking properties, affect the preference of a certain scopal configuration, but not the underlying representation of that configuration. Again, this conclusion suggest that logical representations are abstract conceptual representations of the relation between concepts in sentence interpretation. But do these representations only specify these relations, or also any meaning content of these concepts? This question will be addressed in the next subsection.

6.4 Logical representations as event representations

A prevalent assumption in semantic literature is that the semantic interpretation of sentences depends on two distinct systems: The *combinatorial* system that specifies how different content words in a sentence must be put together in sentence interpretation, and the *conceptual* system that specifies the conceptual meaning of these content words (e.g., Heim & Kratzer, 1998; see also Feiman & Snedeker, 2016). In this dissertation, this assumption was tested by priming logical representations between different verbs. In semantic theory, verbs are typically modelled as an abstract relation between the verb and its arguments (e.g., Champollion, 2017; Davidson, 1967, 1969; Parsons, 1995). Consider the – by now familiar – sentence in (2), together with its corresponding logical representations (2a-b):

(2) Every man bit a dog.

(2a) *Universal-wide interpretation:* $\forall x[\text{MAN}(x) \rightarrow \exists y[\text{DOG}(y) \wedge \text{BIT}(x, y)]]$

(2b) *Existential-wide interpretation:* $\exists y[\text{DOG}(y) \wedge \forall x[\text{MEN}(x) \rightarrow \text{BIT}(x, y)]]$

In the logical representation, the verb *bit* is represented as an abstract relation between *x* (the *biter*) and *y* (the *bitee*). Although logical representations may specify thematic roles (Champollion, 2017; Davidson, 1967, 1969; and empirically shown by Raffray & Pickering, 2010), it is typically assumed that logical representations do not specify what it means to be 'biting' or to be 'bitten'.

If people compute such abstract (content-free) logical representations in language processing, and if this level of representation is the locus of priming, then priming is expected to emerge both within the same verb and between different verbs. A priming study from Feiman and Snedeker (2016) corroborated this prediction: They observed priming within the same verb and priming between different verbs. Moreover, their statistical analyses revealed no difference in the strength of this priming (although there was a numeric difference of roughly 1.5%: Numerically, the effect of priming was 6.47% within the same verb, and 4.98% between different verbs). They interpreted this finding as support for a distinction between the combinatorial and conceptual system in semantic interpretation.

However, the studies reported in Chapter 4 did not replicate Feiman and Snedeker's (2016) findings. Across two experiments, we consistently observed that logical representation priming is stronger if the prime and the target contained the same verb than if the prime and the target contained different verbs. This suggests that conceptual meaning content of the verb is captured at logical representation, and therefore priming is larger (or at least more robust) when prime and target share the same verb than when prime and target contain different verbs. This finding therefore indicates that the distinction between the combinatorial and the conceptual systems in semantic interpretation is not as strict as argued in semantic theory (e.g, Heim & Kratzer, 1998) and by Feiman and Snedeker (2016).

Here, we should elaborate our use of the term *verb repetition*. In studies on syntactic priming, it is often observed that priming is enhanced if the prime and target share the same verb (the *lexical boost*; Mahowald et al., 2016; Pickering & Branigan, 1998, *inter alia*). However, this effect is attributed to repetition of the same lexical item (Pickering & Branigan, 1998), and not necessarily to semantic overlap between prime and target. Therefore, this lexical boost is typically weaker if the prime and targets are given in the same language (where the same verb form is repeated), than if the primes and targets are given in different languages (where translation equivalents are presented in the prime and their target; Schoonbaert et al., 2007). This contrasts with the findings presented in this dissertation: The between-language priming studies reported in Chapters 2-3 revealed no difference in priming within the same verb form (e.g., *klimmen* – *klimmen* in Dutch; 'climb' – 'climb') and priming between translation equivalents (e.g., *klimmen* in Dutch to *montent* in French; 'climb' – 'climb'). Thus, verb repetition enhances logical representation priming due to semantic, and not lexical, overlap.

In Chapter 4, we related this enhancing role of verb overlap to Dwivedi's (2013) dual-route account of scope ambiguity resolution. In this account, the resolution of (quantifier) scope ambiguity relies on two independent processing mechanisms: 'shallow' heuristic processing of the pragmatic number biases associated with the event type specified in the verb, and 'deep' abstract processing of the abstract quantifier scope configurations. These routes are processed in serial: In comprehension, people first rely on heuristic processing of the number biases associated with each event denoted in the verb. For instance, people are more likely to assign a universal-wide reading to *Every pilgrim rode a donkey* because they know, based on real-world ('encyclopaedic') knowledge, that it is more likely that people ride different donkeys than that they share one donkey (see also Dwivedi et al., 2010). Typically, such heuristic processing of the pragmatic number biases associated with each event type is sufficient and 'good enough' (cf. Ferreira, 2003). If needed, however, a comprehender can subsequently engage in abstract processing of quantifier scope configurations (for instance, if required by task-specific demands).

Dwivedi (2013) hypothesised that both heuristic and abstract processing of quantifier scope ambiguity can be primed. Heuristic processing can be primed by the updating of the pragmatic number biases associated to each event type in the prime trials. This priming is therefore expected to be associated to specific verbs. Priming of abstract processing, on the other hand, is characterised as priming of the combinatorial processing involved in the construction of an abstract and content-free logical representation. This priming is not verb-specific. Since these two processing mechanisms underlying priming exist in tandem, it naturally follows that priming within the same verb is stronger (and more robust) than priming between verbs. If comprehenders only rely on heuristic processing, priming is predicted to emerge within the same verb but not between verbs. On the other hand, if comprehenders process the prime and target in an abstract manner, then priming is predicted to emerge both within the same verb and between different verbs. However, it is expected that the prime and target sentences are not necessarily processed in such an abstract manner. In addition, Dwivedi's account postulates that abstract processing always follows heuristic processing: A participant who processed the logical representation of a sentence in an abstract manner has previously processed that sentence heuristically. Therefore, these participants may show priming at both independent routes of processing, which then enhances the overall observed effect of logical representation priming within the same verb (see also Ziegler & Snedeker, 2018). At the same time, we should emphasise that this explanation of our findings presented in Chapter 4 is post-hoc, and the experiments presented in Chapter 4 were not designed to specifically test the predictions of Dwivedi's dual-route account of scope assignment.

Altogether, our results, in conjugation with Feiman and Snedeker's (2016) finding who did find priming of logical representations between verbs, suggest that logical representations are (in most cases) computed using the conceptual meaning of the event type denoted by the verb: They specify the number of participants involved in a specific event. This description of logical representation raises questions about the representation of noun content in logical representations. Chapters 2-5 all showed that priming of logical representations persists in the absence of noun overlap (also also shown by Feiman & Snedeker, 2016; Raffray & Pickering, 2010), but no study so far has sought to test a possible enhancing effect of noun overlap in logical representation priming. Given the assumption that logical representations specify conceptual features of the event type denoted by the sentence, it is not unlikely that features of the noun content are also captured in logical representations. Nouns can affect the conceptual representation of an event (possibly, the 'climbing' event in *climbing a hill* differs from *climbing a ladder*, for instance in the required body movements from the agent; Frankland & Greene, 2015, 2020). Future work is encouraged to test this prediction, which will further elucidate the abstractness of logical representation.

Summing up, our results indicate that comprehenders can compute logical representations at varying degrees of abstraction. We hypothesised that people can compute abstract and content-free logical representations, but the comprehension typically relies on shallow processing of the event type denoted by the verb. Such processing does not lead to the computation of abstract logical representations, but to a less abstract conceptualisation of the event type denoted by the sentence. This conceptualisation also specifies the number of participants involved in that event (as previously put forward by Fodor, 1982). This finding makes it difficult to maintain a strict distinction between combinatorial and conceptual processing in semantic interpretation.

6.5 Mechanisms of priming

A final important implication of the work presented in this dissertation concerns the mechanisms underlying the structural priming observed in Chapters 2-5. The usage of structural priming finds its origin in studies on syntactic representation in production (Bock, 1986; Bock & Griffin, 2000; Hartsuiker & Westenberg, 2000; Pickering & Branigan, 1998; for meta-analysis and review, see Mahowald et al., 2016). An important deviation from this work on syntactic representation in production and the findings reported in this dissertation is that syntactic priming in production shows a robust *lexical boost* effect. As described in the previous subsection, the lexical boost refers to the effect that priming is enhanced if the prime and the target share the same verb (Bock & Griffin, 2000; Pickering & Branigan, 1998). Our results do not indicate any effect that is reminiscent of the lexical boost. Repetition of any lexical item (whether it is the quantifiers, the verb, or the nouns) did not consistently enhance priming. It is true that verb repetition boosted priming in Chapter 5, but we argued that this is unlike the lexical boost in syntactic priming, especially if we consider the results in conjunction with those of the between-language priming studies reported in Chapters 2 and 3.

The prevalent theories on structural priming predominantly seek to explain syntactic priming in production, and therefore specify mechanisms that explain the lexical boost (e.g., Chang et al., 2006; Pickering Branigan, 1998; see also Hartsuiker et al., 2008). Although these theories have been applied to studies on syntactic priming in comprehension as well (albeit with mixed success; Arai et al., 2007; Segaert et al., 2013; Ziegler & Snedeker, 2019), our results indicate that the mechanisms described for priming of syntactic structure cannot explain the patters of priming in Chapters 2-5. We therefore put forward an account of priming in terms of *structure-mapping* in Chapter 4 (Gentner & Smith, 2012; Gentner, 1983; Taylor et al., 2011). This account postulates that people align situations or events that share commonalities in their relational structure. This requires the (implicit) detection of a common relational structure of both situations. The conceptual representation of this structure, in turn, is then mapped onto both situations, which facilitates processing (Gentner & Smith, 2012; Gentner, 1983). Focusing on priming of logical representations, this conceptual representation underlying prime and target specifies how many agents acted upon how many themes in an event. Upon encountering a prime-target set, participants align the prime structure with the target structure, which facilitates the processing of the logical representation that was presented in the prime trial (see also Popov & Hristova, 2014; Taylor et al., 2011).

The work presented in this dissertation revealed that priming of logical representations is not dependent on repetition of the quantifiers in the primes and targets. Priming within the same quantifier was more robust than priming between different quantifiers, but once priming between quantifiers emerged, it was comparable to priming within the same quantifier. The observation that priming within the same quantifier is more robust than priming between quantifiers fits the assumptions of structure-mapping: The alignment of relational structures is facilitated by an overlap in surface form (Holyoak, 2012), as this facilitates the detection of a common relational structure. Moreover, theories on structure-mapping are also able to explain the finding that logical representation priming between quantifiers is more robust if the participants are presented with a diverse set of prime quantifiers. Here, the hypothesis is that variation in the prime structures facilitates the participants to recognise abstract quantificational relations and align these onto multiple structures (e.g., Braithwaite & Goldstone, 2015; Savage et al., 2006). This detection of the abstract common logical relations, in turn, leads to priming between and within quantifiers.

Note that priming across quantifiers and priming across verbs behaved differently: Priming between verbs was not facilitated by variation in the prime trials. The results reported in Chapter 4 reveal that priming between different quantifiers is more fragile, but its magnitude (once it emerges) it is comparable to priming within the same quantifier. However, the results reported in Chapter 5 showed that priming is consistently stronger if the verb is repeated (even though the participants were presented with a variation of verbs in the prime and target sentences). As also discussed in Section 6.4 in this General Discussion, the logical representation therefore specifies the quantificational relations in the prime and target sentences in a specific event: It captures how many agents and themes were involved in a specific event type (e.g., the number of 'climbers' and 'things that are being climbed' in a *climbing* event), rather than how many agents and themes were involved in a broad (abstract) event (how many agents acted upon how many themes?). Section 6.4 put forward that this manner of representation is related to processing: Although comprehenders can compute abstract (event-general) logical representations, they typically bypass this stage and rely on heuristic processing of the event denoted by the verb instead (Dwivedi, 2013; Dwivedi et al., 2010). Since participants do not necessarily compute abstract logical representations, they fail to detect the commonalities in the relational structure between primes and targets with different verbs (unless if they engaged in deep processing).

Summing up, the pattern of priming observed in Chapters 2-5 are not easily reconciled with the prevalent accounts on structural priming that find their origin in research on syntactic priming in production. However, a structure-mapping based account of priming can explain the patterns of our results: People detect the commonalities in the underlying quantificational structure underlying primes and targets, which leads them to align these structures. At the same time, it is worth emphasising that this dissertation did not initially aim to test theories structural priming, but our results – most notably our findings on between- and within-quantifier priming presented in Chapter 4 – led us to re-evaluate the possible mechanisms underlying structural priming. Therefore, the structure-mapping-based account described here is a post-hoc explanation of our results, and future work is required to further test the efficacy of this explanation.

6.6 Limitations and what lies ahead

The work presented in this dissertation was concerned with the nature of logical representations, which was tested using structural priming paradigms. We have already discussed specific pitfalls and limitations throughout the subsections reported in this General Discussion, but some more general limitations of this work – together with some pointers for future investigation – are reported below.

The first limitation relates to the structural priming paradigm. As shown by this dissertation, structural priming is a fruitful technique to uncover the organisation of logical representations (see also Feiman & Snedeker, 2016; Maldonado et al., 2017a; Raffray & Pickering, 2010). However, a full understanding of logical representation does not only require insight in the organisation of these representations, but also in the processes and mechanisms involved in the mapping of these logical representations onto linguistic forms. Structural priming is not ideal to gain insight in this latter question: It taps into the representation of the final interpretation, but it seems to be less suitable to uncover the processes involved in the disambiguation of scope ambiguity (see also Chemla & Bott, 2015; Maldonado et al., 2017b).

What are the processes involved in disambiguating scope, and when do these processes occur in comprehension? We know that the disambiguation of scope ambiguity relies on multiple sources of information, such as lexical (Ioup, 1975), structural (Ioup, 1975; Kurtzman & MacDonald, 1993; Lidz & Musolino, 2002), and real-word or contextual knowledge (Dwivedi, 2013; Dwivedi et al., 2010; see also Altmann & Steedman, 1988). In the processing of scope, these different sources of information interact, which leads to a final interpretation. Existing research does not reveal a clear picture of this interaction: Some studies have shown that scopal ambiguity is rapidly resolved in real-time comprehension (e.g., Anderson, 2004; Dotlail & Brasoveanu, 2015; Radó & Bott, 2012), whereas other studies have shown that the interpretation of scopally ambiguous sentences are often left unspecified unless disambiguation is required by contextual or task demands (e.g., Dwivedi, 2013; Filik et al., 2004). Moreover, these studies have been limited to studying the processing of a restricted set of quantifiers (typically *every* and *a*; Dotlail & Brasoveanu, 2015; Dwivedi, 2013; Dwivedi et al., 2010; Filik et al., 2004), even though quantifier-specific lexical features play an important role in the disambiguation of scope (Feiman & Snedeker, 2016; Ioup, 1975). Therefore, future work is required to study the processes and interactions of these processes involved in the computation of logical representations, using more online methods than the structural priming studies reported in this dissertation (e.g., Dotlail & Brasoveanu, 2015; Filik et al., 2004).

Another limitation of the work presented in this dissertation is that it only tested logical representations in language comprehension, whereas logical representations likely play an important role in production as well. This dissertation has shown that logical representation specify the perceived number of referents or events in the conceptualisation of an event. Existing work has indicated that the perceived number of referents or events do not only affect semantic interpretation, but also grammatical processing in both production and comprehension. A good example of such a grammatical process is the computation of agreement (e.g., Bock et al., 2004; Eberhard, 1997; Eberhard et al., 2005; Staub, 2009, 2010). *Agreement* refers to the morphosyntactic marking of sentence constituents that belong together, like the usage of the plural verb form *are*, rather than its singular equivalent *is*, in *The bears are hungry* (Sauerland, 2004). Importantly, the computation of agreement is influenced by the conceptual representation of the number of referents or events denoted by the intended message to be conveyed: If a referent or event is conceptualised as plural, people are more likely to compute plural agreement (Mirkovi & MacDonald, 2013), even in cases where plural agreement is ungrammatical (e.g., *Each key to the cabinet *are rusty*; Den Dikken, 2001; Eberhard, 1997; Staub, 2009, 2010; see also, e.g., Nicol et al., 1997, for experimental work on subject-verb agreement in comprehension). Therefore, the computation of logical representation may influence subject-verb agreement. Subject-verb agreement illustrates how the computation of logical representations could influence grammatical processes in production. Studying the interface between logical representation and grammatical processes would provide a rich insight in the interaction between non-linguistic and linguistic processing in the mapping of meaning onto linguistic structures, in production and comprehension.

Summing up, the work presented in this dissertation has given important insights in the organisation of logical representations, but less in the processes involved in the binding of these logical representations onto linguistic forms. Nevertheless, this work has put us in a better position to investigate such questions. This section described two possible avenue for further studies on this question: (i) by looking at more online measures to test the processing trajectory of scope assignment, and (ii) by testing how the computation of (non-linguistic) logical representations interact with (linguistic) grammatical processes in language production.

Nederlandse samenvatting

Kwantoren, woorden zoals *alle*, *elke* of *een*, hebben een abstracte betekenis. Deze woorden verwijzen namelijk niet naar iets in de wereld, maar specificeren een abstracte relatie tussen de verschillende inhoudswoorden in semantische interpretatie (bijv., Ruys & Winter, 2011; Szabolcsi, 2010). Deze abstracte aard van kwantoren kan leiden tot ambiguïteit, zoals te merken is in de zin in (1).

(5) Elke man beet een hond.

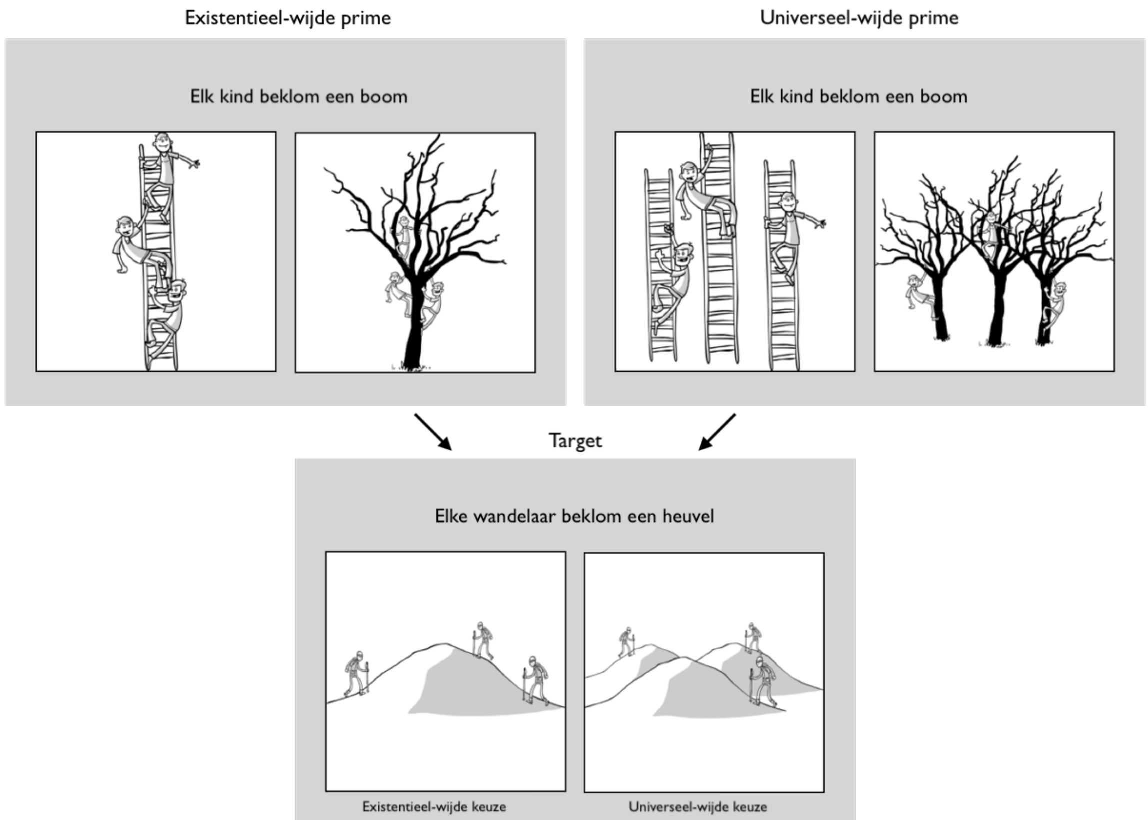
Betekent deze zin dat elke man een verschillende hond beet, of dat elke man dezelfde hond beet? Als er meerdere kwantoren in hetzelfde zinsdeel staan, zoals het geval is in (1), dan kunnen de relaties die gespecificeerd worden door de verschillende kwantoren op meerdere manieren met elkaar interageren. In de semantiek wordt dit verklaard aan in termen van *(semantisch) bereik*. In (1) kan *elke* wijd bereik krijgen (de *universeel-wijde* interpretatie, gegeven in (1a)), maar *een* kan ook wijd bereik krijgen (de *existentieel-wijde* interpretatie, gegeven in (1b)).

(1a) $\forall x[\textsf{MAN}(x) \rightarrow \exists y[\textsf{HOND}(y) \wedge \textsf{BEET}(x, y)]]$

(1b) $\exists y[\textsf{HOND}(y) \wedge \forall x[\textsf{MAN}(x) \rightarrow \textsf{BEET}(x, y)]]$

In de universeel-wijde interpretatie wordt het predicaat 'beet een hond' gekoppeld aan elke individuele 'man'. Dit betekent dat elke man een hond beet, maar dit hoeft niet noodzakelijkerwijs dezelfde hond te zijn. In de existentieel-wijde interpretatie daarentegen wordt het predicaat 'elke man beet *y*' gekoppeld aan een specifieke hond (namelijk *y*). Dus, er is één hond die gebeten werd door elke man.

Hoe worden deze niet-ambigue interpretaties mentaal gerepresenteerd? Het wordt aangenomen dat ons cognitieve systeem een niveau van representatie bevat waarin de relaties tussen de inhoudswoorden in semantische interpretatie gespecificeerd (zoals in de formules in (1a-b;) Heim & Kratzer, 1998; Hornstein, 1995; Jackendoff, 1972; Ruys & Winter, 2011; Szabolcsi, 2010). Deze representaties zijn bekend onder de naam *logische representaties*. Het onderzoek in dit proefschrift bestudeerde de aard van deze logische representaties. Specificeren logische representaties talige eigenschappen van de (talige) structuur waar ze aan verbonden zijn? Specificeren ze enkel de semantische relaties tussen de inhoudswoorden in een zin, of ook eigenschappen van de conceptuele betekenis van deze inhoudswoorden?



Figuur 1: Voorbeeld van een prime-targetpaar waarin de priming van logische representaties in het begrip van een dubbel-gekwantificeerde *elke...een* zin getest kan worden. Dit voorbeeld is een Nederlandse vertaling van een voorbeeld uit Raffray en Pickering's (2010) Experiment 1 (gebruikt in Hoofdstuk 3).

De verschillende studies in dit proefschrift onderzochten deze vragen door structurele priming te testen. *Structurele priming* is het effect dat mensen geneigd zijn om structuren te gebruiken die ze recentelijk hebben verwerkt in eerdere taalverwerking. Priming tussen twee zinnen laat daarom zien dat er sprake is van gedeelde representaties voor de structuur die gebruikt is in de verwerking van de prime- en targetzin (bijv., Branigan & Pickering, 2017; Pickering & Ferreira, 2008). Priming van logische representaties kan worden getest met een congruentietaak waarin proefpersonen een afbeelding kiezen die het beste bij een zin past (zoals eerder is gedaan door Chemla & Bott, 2015; Feiman & Snedeker, 2016; Maldonado e.a., 2017a; Raffray & Pickering, 2010; zie ook Branigan e.a., 2005). In elke trial leest de proefpersoon een zin en kiest welke van twee afbeeldingen het beste bij die zin past. In de primetrials lezen de proefpersonen een zin met twee kwantoren (bijv., *Elk kind beklom een boom*). Eén van beide afbeeldingen in de primetrials past niet bij de zin, en de andere afbeelding geeft slects één van de mogelijke interpretaties van de zin weer. Elke prime trial wordt onmiddelijk gevolgd door een targettrial. In deze trials lezen de proefpersonen een andere zin met twee kwantoren (bijv., *Elke wandelaar beklom een berg*). In de targettrials geven de twee afbeeldingen de twee mogelijke interpretaties van de zin weer. Op deze manier wordt de proefpersoon geforceerd om de primezinnen op een bepaalde manier te interpreteren, maar ze kunnen vrij kiezen tussen beide mogelijke interpretaties van de targetzinnen (Figuur 1). Eerder onderzoek heeft laten zien dat proefpersonen vaker de universeel-wijde interpretatie kiezen in de targettrials na een universeel-wijde prime, dan in de targettrials na een existentieel-wijde prime. Dit priming effect laat zien dat mensen logische representaties construeren in taalbegrip (Chemla & Bott, 2015; Feiman & Snedeker, 2016; Maldonado e.a., 2017a; Raffray & Pickering, 2010)

Maar welke informatie is precies gespecificeerd in logische representaties? De eerste vraag die we hierover stelden was of logische representaties talige eigenschappen van de zin specificeren. Dit hebben we eerst getoetst door logische representaties in tweetaligen te testen: Heeft een tweetalige logische representaties die gedeeld zijn in beide talen, of aparte, taalspecifieke logische representaties? In Hoofdstuk 2 onderzochten we deze vraag door effecten van priming in de interpretatie van ambigue zinnen met *alle* en *een* te toetsen in Nederlands-Frans tweetaligen. De Nederlandse en Franse equivalenten van *alle* en *een* lijken directe vertalingen van elkaar (zie ook Gil, 1995), waardoor we verwachtten dat *alle...een* zinnen soortgelijk worden geinterpreteerd in het Nederlands en het Frans. Deze aanname werd bevestigd in Experiment 1, waar we de standaardinterpretatie (dus zonder enige invloed van priming) van deze zinnen in moedertaalsprekers van het Nederlands en het Frans met elkaar vergeleken. De verdere experimenten bevatten een primingmanipulatie. In Experiment 2 vonden we effecten van priming als de primes en de targets in de moedertaal (de *T1*) van de proefpersonen werden gepresenteerd (in zowel Frans als Nederlands). Experiment 3 liet zien dat dit effect ook optreedt als de primes in de T1 (Nederlands) en de targets in de tweede taal (de *T2*, in dit geval het Frans) werden gepresenteerd. In Experiment 4 observeerden we dat dergelijke priming ook optrad als zowel de primes als de targets in de T2 (Frans) gepresenteerd werden. Onze analyses lieten zien dat de grootte van deze effecten vergelijkbaar was in al deze experimenten, en een controle-experiment (Experiment 5) toonde aan dat de resultaten niet te verklaren zijn in termen van visuele priming. Deze bevindingen laten zien dat tweetaligen gebruik maken van gedeelde logische representaties in allebei de talen die ze kennen, tenminste als de kwantoren dichte (of directe) vertaalequivalenten van elkaar zijn en de interpretatie van de zinnen hetzelfde is in beide talen.

In Hoofdstuk 3 onderzochten we of tweetaligen ook gedeelde logische representaties gebruiken als er verschillen zijn in de typische interpretatie van een semantisch ambigue zin in beide talen die ze kennen. We focusten op de interpretatie van *alle...niet* zinnen, zoals *Alle appels zitten niet in de dozen*, in Ests-Engels tweetaligen. Zulke zinnen worden in het Engels doorgaans met een universeel-wijde lezing geïnterpreteerd waarin *alle* wijd bereik heeft. In deze interpretatie hebben alle appels de eigenschap dat ze niet in de dozen zitten (dus geen van de appels zitten in de dozen). In het Ests daarentegen, wordt de negatie-wijde interpretatie waarin *niet* wijd bereik heeft geprefereerd. In deze interpretatie hebben niet alle appels de eigenschap dat ze in de dozen zitten (dus niet alle, maar misschien wel sommige, appels zitten in de dozen). Experiment 1 liet priming zien in de interpretatie van *alle...niet* zinnen in de T1 (zowel in het Ests als in het Engels). Experiment 2 toonde aan dat deze effecten ook optraden van de T1 (Ests) naar de T2 (Engels). In Experiment 3 observeerden we dat dit effect ook binnen de T2 (Engels) optrad. De grootte van deze effecten was bovendien vergelijkbaar. Tot slot demonstreerde Experiment 5 dat deze bevindingen niet te verklaren zijn door visuele priming. Alles welbeschouwd laten de resultaten in Hoofdstuk 3 zien dat het delen van tweetalige logische representaties niet beïnvloed wordt door het verschil tussen het Ests en het Engels in de interpretatie van *alle...niet* zinnen. Daarnaast lieten de resultaten zien dat vloeiende Ests-Engels tweetaligen de taalspecifieke patronen in de interpretatie van *alle...niet* in hun T2 (Engels) leren. Dit is een interessante vondst op zichzelf, maar deze vondst sluit ook een alternatieve verklaring van de effecten in termen van transfer vanuit T1 uit.

De studies in Hoofdstuk 2 en 3 demonstreren dat tweetaligen abstracte, niet-taal-specifieke, logische representaties construeren in de verwerking van beide talen die ze kennen (zie ook Jackendoff, 1992, 2002). In Hoofdstuk 4 onderzochten we of logische representaties ook worden geabstraheerd over de lexicale eigenschappen van kwantoren heen, door (eentalige) priming tussen verschillende (universele) kwantoren te testen in het Nederlands. Kwantoren verschillen van elkaar in hun interne neiging om wijd bereik te nemen. Distributieve kwantoren, zoals *elke* en *iedere*, hebben een sterkere neiging om wijd bereik te nemen dan niet-distributieve kwantoren zoals *alle* (bijv., Ioup, 1975). Om deze observatie te verklaren hebben semantici voorgesteld dat kwantoren van elkaar verschillen in de lexicaal-gespecificeerde mechanismen die nodig zijn om bereik toe te kennen (Beghelli & Stowell, 1997; Champollion, 2017). Deze hypothese werd gesteund door de bevinding van een eerdere priming studie van Feiman en Snedeker (2016) in het Engels. Deze studie toonde namelijk aan dat priming van logische representaties afhankelijk is van herhaling van de kwantor in de prime- en targetzinnen. Deze bevinding laat zien dat logische interpretaties inderdaad lexicaal-gespecificeerde combinatorische eigenschappen bevatten van de kwantoren.

Echter, de experimenten in Hoofdstuk 4 lieten een ander beeld zien. De experimenten in dit hoofdstuk testten priming in de interpretatie van ambigue zinnen met een universele en een existentiële kwantoren (bijv. *Elke wandelaar beklom een berg*). De universele kwantor in de primezinnen varieerde tussen *elke*, *iedere*, en *alle*, terwijl de targetzinnen altijd *elke* bevatten. Experiment 1, waarin de kwantor in de prime zin gemanipuleerd werd tussen proefpersonen, leverde onduidelijke resultaten op. Dit experiment toonde namelijk priming aan tussen *elke* en *elke* en tussen *alle* en *elke*, maar niet tussen *iedere* en *elke*. Om deze bevinding verder te testen manipuleerden we de kwantor in de primezinnen binnen proefpersonen in Experiment 2 en Experiment 3. Deze experimenten lieten beide duidelijk zien dat priming van *elke* naar *elke* vergelijkbaar was met priming van *alle* naar *elke* en van *iedere* naar *elke*. Dit toont aan dat priming tussen verschillende universele kwantoren fragieler is dan priming binnen dezelfde kwantor, maar zodra het optreedt is het vergelijkbaar met priming binnen dezelfde kwantor. Dit effect duidt aan dat de representatie van het bereik van universele kwantoren hetzelfde is voor de kwantoren *elke*, *iedere*, en *alle*, ook al zijn er verschillen in de lexicale en semantische eigenschappen van deze kwantoren.

De studies in Hoofdstukken 2 tot en met 4 laten zien dat logische representaties de conceptuele abstracte relaties tussen concepten in semantische interpretatie specificeren, en geen talige eigenschappen van de zin. In de (formele) semantiek wordt doorgaans aangenomen dat logische representaties enkel de relaties tussen concepten specificeren, en niet de betekenis van deze concepten (bijv., Heim & Kratzer, 1998; Parsons, 1995). In Hoofdstuk 5 toetsten we deze aanname door priming van logische representaties te testen tussen dubbel-gekwantificeerde zinnen met verschillende werkwoorden (de studies in Hoofdstuk 2 tot en met 4 bevatten namelijk altijd prime-targetparen met hetzelfde werkwoord). De twee experimenten in Hoofdstuk 5 lieten beide zien dat priming sterker is als de prime- en de targetzin hetzelfde werkwoord bevatte. Deze bevinding suggereert dat logische representaties conceptuele representaties zijn van de situatie of actie beschreven in de zin, en zowel informatie over die actie/situatie als het aantal participanten of objecten betrokken bij die actie specificeren (Fodor, 1982; maar zie ook Feiman & Snedeker, 2016).

Alles bij elkaar genomen laten de vier experimentele studies in dit proefschrift zien dat logische representaties geen taal-speficieke of lexicale eigenschappen van bereik specificeren. Daarnaast specificeren logische representaties niet enkel de relaties tussen concepten in semantische interpretatie, maar ook de betekenis van deze concepten. In Hoofdstuk 6, de discussie, bespreken we dat deze bevindingen passen binnen een theorie die beschrijft dat logische representaties conceptuele representaties zijn van het aantal participanten of object betrokken bij de actie of situatie beschreven in de zin (zoals bijv., Fodor, 1982).

English Summary

Quantifiers like *all*, *each* or *a* have an abstract meaning. Rather than referring to anything out there in the world, these words specify abstract relations between the content words in a sentence in semantic interpretation (e.g., Ruys & Winter, 2011; Szabolcsi, 2010). This abstract nature of quantifier words can give rise to ambiguity, which is illustrated in the sentence in (1).

(1) Every man bit a dog.

Does this sentence mean that every man bit a different dog, or did every man bit the same dog? This ambiguity emerges because the relations instantiated by *every* and *a* can interact in two ways in the interpretation of (1). In semantic literature, this interaction is explained in terms of *(semantic) scope*. In (1), *every* can take wide scope (the *universal-wide* interpretation; represented in (1a)), but *a* can also take wide scope (the *existential-wide* interpretation; represented in (1b)).

(1a) $\forall x[\mathsf{MAN}(x) \rightarrow \exists y[\mathsf{DOG}(y) \wedge \mathsf{BIT}(x,y)]]$

(1b) $\exists y[\mathsf{DOG}(y) \wedge \forall x[\mathsf{MAN}(x) \rightarrow \mathsf{BIT}(x,y)]]$

In the universal-wide interpretation, the property 'bit a dog' is predicated to each individual 'man'. This means that every man is such that he bit a dog, but this is not necessarily the same dog. In the existential-wide interpretation, on the other hand, the property 'every man bit *y*' is predicated to a single dog (that is, *y*). So, there exists a dog that is such that it was bitten by every man.

How are such disambiguated interpretations mentally represented? In semantic literature, it is typically assumed that our cognitive system contains a level of representation that is known as *logical representations*. Logical representations specify the relations between the content words of a sentence in semantic interpretation (like in the formulae given in (1a-b); Heim & Kratzer, 1998; Hornstein, 1995; Jackendoff, 1972; Ruys & Winter, 2011; Szabolcsi, 2010). This dissertation is concerned with the organization of these logical representations. Do logical representations specify linguistic properties of the (linguistic) structure that they are mapped onto? Do they only specify the abstract relations between the content words of a sentence, or do they also specify the conceptual meaning of these content words?

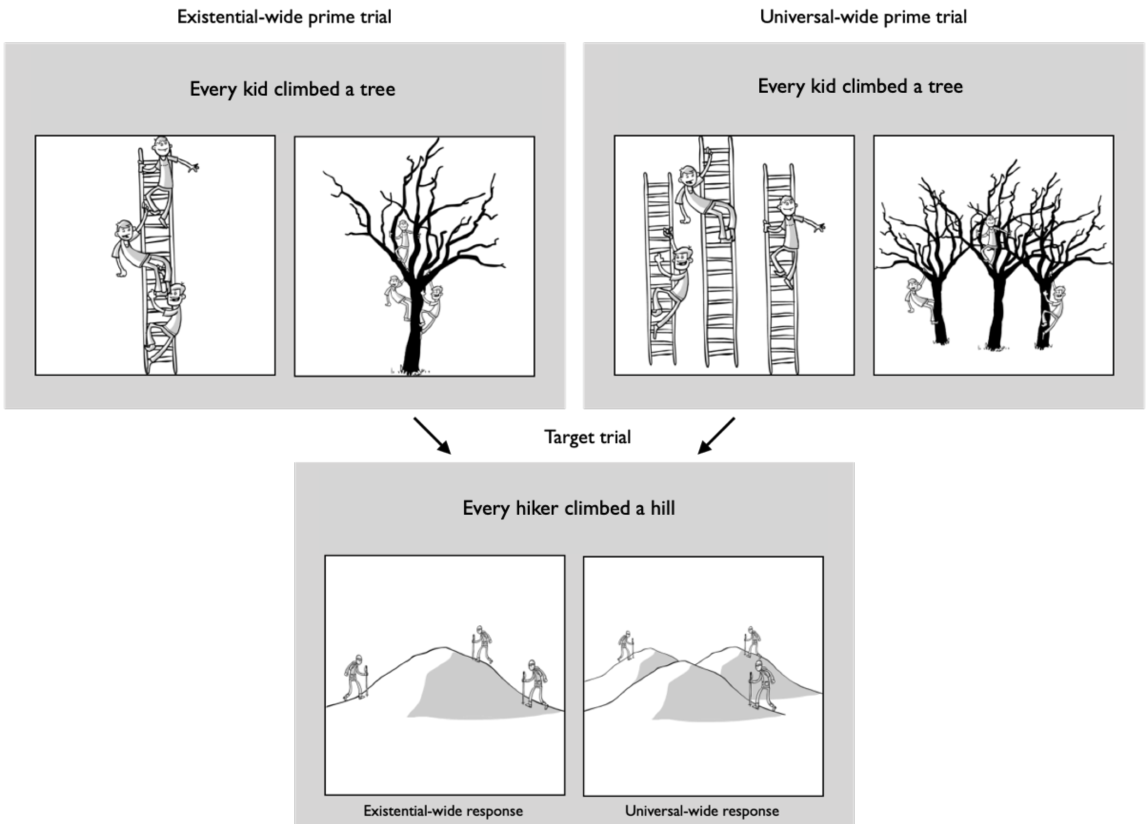


Figure 1: Example of a prime-target set in which the priming of logical representation in the comprehension of doubly-quantified sentences can be tested. This example is from Raffray and Pickering's (2010) Experiment 1.

The studies reported in this dissertation studied these questions by using the structural priming paradigm. *Structural priming* refers to the effect that people tend to repeat structures in linguistic processing that they recently processed in an earlier instance of language processing. Priming indicates that a prime and target pair share underlying representations of the shared structure (e.g., Branigan & Pickering, 2017; Pickering & Ferreira, 2008). Priming of logical representations can be tested in a sentence-picture matching task (following Chemla & Bott, 2015; Feiman & Snedeker, 2016; Maldonado et al., 2017a; Raffray & Pickering, 2010; see also Branigan et al., 2005). The participant is presented with a sentence and two pictures on each trial. The task is to read the sentence and select the picture that matches the sentence best. The prime trials involve a scopally ambiguous sentence (e.g., a doubly-quantified sentence like *Every kid climbed a tree*), a mismatching picture, and a picture that matches only one reading of the sentence. Each prime trial is immediately followed by a target trial. These target trials again involve a similar scopally ambiguous sentence (e.g., *Every hiker climbed a hill*), but the two pictures now depict both possible readings of this sentence. This way, the participants are forced to assign a certain interpretation to the prime trials, but they can freely choose between either interpretation in the target trials (Figure 1). Previous research has shown that participants assign the universal-wide interpretation more often to the targets following a universal-wide prime than to targets following an existential-wide prime. This effect of priming indicates that people compute logical representations in language comprehension (Chemla & Bott, 2015; Feiman & Snedeker, 2016; Maldonado et al., 2017a; Raffray & Pickering, 2010)

But which information is exactly specified in logical representations? The first question we asked is whether logical representations specify linguistic properties of the sentence. We investigated this question by testing effect of logical representations priming in bilinguals: Do bilinguals use shared or separate language-specific logical representations in the processing of both languages they know? In Chapter 2, we tested effects of logical representation priming in the interpretation of doubly-quantified sentences with *all* and *a* in Dutch-French bilinguals. The Dutch and French translations of *all* and *a* seem to be direct translation equivalents of each other (see Gil, 1995), which is why we expected that the typical interpretation of *all...a* sentences is similar in Dutch and French. This expectation was confirmed in Experiment 1, where we tested the canonical interpretation of these sentences in the absence of priming in native speakers of Dutch and French. All other experiments in Chapter 2 involved a priming manipulation. Experiment 2 showed priming within the native language (*L1*) in both Dutch and French speakers. Experiment 3 revealed that this effect also emerged if the primes are given in the L1 (Dutch) and the targets in a second language (*L2*; in this case French). In Experiment 4, we observed that these effects also emerge within the L2 (French). Our analyses revealed that the size of this effect was comparable across the experiments, and a control experiment (Experiment 5) ruled out an explanation of these findings in terms of visual priming. Altogether, these findings suggest that bilinguals use shared logical representations in both languages they know, at least if the quantifiers under consideration are close or direct translation equivalents and if the interpretation of the sentence under consideration is comparable in both languages they know.

In Chapter 3, we studied whether bilinguals also use shared logical representations if there are differences in the canonical interpretation of a scopally ambiguous sentence in both languages they know. We focused on the interpretations of *all...not* sentences (like *All apples are not in the boxes*) in Estonian-English bilinguals. In English, these sentences are typically interpreted with a universal-wide reading in which *all* takes wide scope. In this interpretation, the property "is not in the boxes" is predicated to each individual "apple" (i.e., none of the apples are in the boxes). In Estonian, on the other hand, the negation-wide interpretation in which *not* takes wide scope is preferred. In this reading, the property "is not in the boxes" is predicated to not all apples. So, not all, but possibly some, apples are in the boxes. Experiment 1 showed priming in the interpretation of *all...not* in the L1 (both in Estonian and in English). Experiment 2 revealed that these effects also emerged from the L1 (Estonian) onto the L2 (English), and Experiment 2 showed that these effects also occur from the L2 (English) onto the L1 (Estonian). In Experiment 4, we observed that this effect also emerges within the L2 (English). The magnitude of these effects was comparable across experiments. Finally, a control experiment in Experiment 5 revealed that these effects are not explained by visual priming. Altogether, the findings in Chapter 3 suggest that the sharing of bilingual logical representations is not influenced by the cross-linguistic difference between Estonian and English in the interpretation of *all...not*. In addition, the results showed that highly proficient Estonian-English bilinguals develop sensitivity to language-specific preference patterns in the assignment of scope. This is an interesting finding in its own right, but is also rules out an alternative interpretation of the findings in terms of L1 transfer.

Chapters 2-3 indicate that bilinguals compute abstract, non-language-specific, logical representations in the processing of both languages they know (see also Jackendoff, 1992, 2002). Chapter 4 investigated whether logical representations also abstract away from the lexical properties of quantifier words, by testing effects of logical representations between different (universal) quantifiers in Dutch. Quantifiers differ in their inherent tendency to take wide scope. Distributive quantifiers, like *each* and *every* in English have a stronger tendency to take wide scope than non-distributive quantifiers like English *all* (e.g., Ioup, 1975). Based on this observation, semantic theorists have proposed that quantifier words differ in their scope-taking mechanisms (Beghelli & Stowell, 1997; Champollion, 2017). The predictions of this class of theories were supported by the findings from a study from Feiman and Snedeker (2016). Using the structural priming paradigm discussed above, they observed that priming of logical representations depends on repetition of the quantifiers in the prime and the target sentences. This pattern of results suggest that logical representations indeed specify lexically-specified combinatorial properties of quantifier words. However, the experiments reported in Chapter 4 do not corroborate this hypothesis. These experiments tested priming in a doubly-quantified sentence with a universal and an existential quantifier (e.g., *Every hiker climbed a hill*) in Dutch. In the prime trials, the universal quantifier varied between *elke* ('every/each'), *iedere* ('every/each'), and *alle* ('all'). The target trials, on the other hand, always involved the quantifier *elke*. Experiment 1, in which the prime quantifier was manipulated between participants (following Feiman & Snedeker, 2016), yielded mixed results. This experiment revealed priming from *elke* to *elke* and from *alle* to *elke*, but not from *iedere* to *elke*. The results of Experiments 2 and 3, in which we manipulated the prime quantifier within participants, however, clearly showed that priming from *elke* to *elke*, from *alle* to *elke*, and from *iedere* to *elke* was comparable. This suggests that priming between quantifiers may be more fragile between quantifiers than within quantifiers, but once it emerges, the effect is similar to priming within quantifiers. This indicates that the representation of scope assignment is alike for the three universal quantifiers *elke*, *iedere*, and *alle*, despite their lexical and semantic differences.

The studies reported in Chapters 2-4 reveal that logical representations specify the conceptual abstract relations between concepts in semantic interpretation, and not any linguistic features of the sentence. In (formal) semantics, it is typically assumed that logical representations only specify these relations between concepts, and not any meaning content of these concepts (e.g., Heim & Kratzer, 1998; Parsons, 1995). In Chapter 5, we tested this assumption by measuring effects of priming in the interpretation of doubly-quantified sentences between verbs (since the experiments in Chapters 2-4 involved prime-target pairs in which the verb was repeated). Both Experiment 1 and Experiment 2 showed that logical representation priming is enhanced, or at least more robust, if the prime and target sentences contain the same verb. This finding indicates that logical representations are conceptual interpretations of the event denoted in the sentence that specify the number of participants or objects involved in this event (Dwivedi, 2013; Fodor, 1982; but cf., Feiman & Snedeker, 2016)

Altogether, the four experimental studies reported in this dissertation show that logical representations do not specify language-specific or lexical properties of scope assignment. Moreover, logical representations do not only capture the relations between concepts in semantic interpretation, but also the meaning content of the event type denote by the sentence. In Chapter 6, the General Discussion, we discuss that these findings fit within a theoretical approach to logical representations that posit that logical representations are conceptual event representations that specify the number of participants or objects that are involved in the event type denoted in the sentence (Fodor, 1982).

Appendix 2

The table below reports the sentences of all prime-target sets used in Experiments 1-4. In Experiment 1, the prime sets serves as additional target sets. The sentences are given in Dutch and French (in that order). Please see https://osf.io/v2w3a/ for the visual materials, a list of the filler trials, and English translations of these sentences.

Prime sentence	**Target sentence**
Alle dwergen achtervolgen een clown	Alle leeuwen achtervolgen een dierenverzorger
Tous les nains poursuivent un clown	Tous les lions poursuivent un gardien
Alle kunstenaars raken een ballerina aan	Alle feeën raken een zebra aan
Tous les artistes touchent une ballerine	Toutes les fées touchent un zèbre
Alle vossen zien een taart	Alle tuinmannen zien een schep
Tous les renards voient un gâteau	Tous les jardiniers voient une pelle
Alle toeristen zien een standbeeld	Alle gasten zien een taart
Tous les touristes voient une statue	Tous les invités voient un gâteau
Alle ballerina's herkennen een cake	Alle protesteerders herkennen een vlag
Toutes les ballerines reconnaissent un gâteau	Tous les manifestants reconnaissent un drapeau
Alle farao's knuppelen een slaaf	Alle cowboys knuppelen een zwemmer
Tous les pharaons matraquent un esclave	Tous les cow-boys matraquent un nageur
Alle nonnen kussen een clown	Alle professoren kussen een monnik
Toutes les nonnes embrassent un clown	Tous les professeurs embrassent un moine
Alle skiërs dalen een berg af	Alle meisjes dalen een glijbaan af
Tous les skieurs descendent une montagne	Toutes les filles descendent un toboggan
Alle politici ruiken een taart	Alle engelen ruiken een pizza
Tous les politiciens sentent un gâteau	Tous les anges sentent une pizza

Alle klusjesmannen verven een reclamebord Tous les bricoleurs peignent un panneau d'affichage	Alle jongens verven een muur Tous les garçons peignent un mur
Alle ballerina's dalen een trap af Toutes les ballerines descendent un escalier	Alle wielrenners dalen een weg af Tous les cyclistes descendent une route
Alle vampiers steken een saxofonist Tous les vampires poignardent un saxophoniste	Alle cowboys steken een dokter Tous les cow-boys poignardent un médecin
Alle bijen dragen een aardbei Toutes les abeilles portent une fraise	Alle koks dragen een koffer Tous les cuisiniers portent une valise
Alle kinderen klimmen op een ladder Tous les enfants montent sur une échelle	Alle wandelaars klimmen op een heuvel Tous les randonneurs montent sur une colline
Alle redders wijzen naar een heks Tous les sauveteurs pointent du doigt une sorcière	Alle dokters wijzen naar een serveerster Tous les médecins pointent du doigt une serveuse
Alle professoren slaan een tiener Tous les professeurs frappent un adolescent	Alle hippies slaan een reiziger Tous les hippies frappent un voyageur
Alle professoren bestraffen een matroos Tous les professeurs punissent un matelot	Alle wetenschappers bestraffen een student Tous les scientifiques punissent un étudiant
Alle portiers grijpen een koffer Tous les porteurs saisissent une valise	Alle koks grijpen een bord Tous les cuisiniers saisissent une assiette
Alle beren naderen een tent Tous les ours se rapprochent d'une tente	Alle katten naderen een hut Tous les chats se rapprochent d'une cabane
Alle schooljongens bereden een eenhoorn Tous les écoliers montent une licorne	Alle heksen rijden op een koe Toutes les sorcières montent une vache
Alle ridders volgen een monnik Tous les chevaliers suivent un moine	Alle apen volgen een kat Tous les singes suivent un chat
Alle matadors kietelen een detective Tous les matadors chatouillent un détective	Alle monniken kietelen een monteur Tous les moines chatouillent un mécanicien
Alle kunstenaars kussen een boxer Tous les artistes embrassent un boxeur	Alle serveersters kussen een soldaat Toutes les serveuses embrassent un soldat
Alle mieren dragen een brood Toutes les fourmis portent un pain	Alle verhuizers dragen een doos Tous les déménageurs portent un carton
Alle aristocraten ruiken een ijsje Tous les aristocrates sentent une glace	Alle detectives ruiken een muffin Tous les détectives sentent un muffin
Alle vissen volgen een orka Tous les poissons suivent une orque	Alle olifanten volgen een wasbeer Tous les éléphants suivent un raton-laveur

Alle dienstmeisjes meppen een loodgieter Toutes les servantes rossent un plombier	Alle voetballers meppen een politieman Tous les joueurs de football rossent un policier
Alle Mexicanen schieten op een kan Tous les Mexicains tirent sur une carafe	Alle jagers schieten op een bal Tous les chasseurs tirent sur un ballon
Alle nonnen steken een trol Toutes les nonnes poignardent un troll	Alle ridders steken een koningin Tous les chevaliers poignardent une reine
Alle zakenvrouwen duwen een trol Toutes les femmes d'affaires poussent un troll	Alle nonnen duwen een clown Toutes les nonnes poussent un clown
Alle koks duwen een zwemmer Tous les cuisiniers poussent un nageur	Alle zwemmers duwen een ballerina Tous les nageurs poussent une ballerine
Alle honden achtervolgen een eekhoorn Tous les chiens poursuivent un écureuil	Alle beveiligers achtervolgen een schoonmaker Tous les agents de sécurité poursuivent un agent de propreté
Alle jongens bekijken een golfer Tous les garçons regardent un golfeur	Alle serveersters bekijken een klant Toutes les serveuses regardent un client
Alle kunstenaars kietelen een matroos Tous les artistes chatouillent un matelot	Alle boeven kietelen een dokter Tous les voleurs chatouillent un médecin
Alle dieven grijpen een zak Tous les voleurs saisissent un sac	Alle ridders grijpen een zwaard Tous les chevaliers saisissent une épée
Alle bewakers bekijken een gevangene Tous les gardes regardent un prisonnier	Alle schoolmeisjes bekijken een vogel Toutes les écolières regardent un oiseau
Alle haaien vallen een surfer aan Tous les requins attaquent un surfeur	Alle studenten vallen een professor aan Tous les étudiants attaquent un professeur
Alle drugsdealers schieten op een beer Tous les trafiquants tirent sur un ours	Alle huurmoordenaars schieten op een zwemmer Tous les assassins tirent sur un nageur
Alle piraten vallen een schip aan Tous les pirates attaquent un navire	Alle gekken vallen een standbeeld aan Tous les fous attaquent une sculpture
Alle matrozen herkennen een vliegtuig Tous les matelots reconnaissent un avion	Alle zakenmannen herkennen een krant Tous les hommes d'affaires reconnaissent un journal
Alle koks knuppelen een boef Tous les cuisiniers matraquent un voleur	Alle nonnen knuppelen een ballerina Toutes les nonnes matraquent une ballerine
Alle boeven stelen een auto Tous les voleurs volent une voiture	Alle zwervers stelen een bed Tous les clochards volent un lit

Alle apen klimmen op een muur Tous les singes montent sur un mur	Alle bergbeklimmers klimmen op een klif Tous les alpinistes montent sur une falaise
Alle astronauten raken een microfoon aan Tous les astronautes touchent un microphone	Alle meisjes raken een drumstel aan Toutes les filles touchent une batterie
Alle politieagenten bestraffen een monnik Tous les policiers punissent un moine	Alle engelen bestraffen een monster Tous les anges punissent un monstre
Alle obers stelen een handtas Tous les serveurs volent un sac à main	Alle musici stelen een piano Tous les musiciens volent un piano
Toutes les infirmières effleurent un gitan Tous les mendiants frappent un journaliste	Alle acteurs slaan een cameraman Tous les acteurs frappent un caméraman
All beggars punch a journalist Alle verpleegsters tikken een zigeuner aan	Alle nonnen tikken een baby aan Toutes les nonnes effleurent un bébé
Alle varkens naderen een schuur Tous les cochons se rapprochent d'une grange	Alle honden naderen een kasteel Tous les chiens se rapprochent d'un château
Alle serveersters wijzen naar een klusjesman Toutes les serveuses pointent du doigt un bricoleur	Alle kabouters wijzen naar een brandweerman Tous les nains pointent du doigt un pompier
Alle konijnen verven een schilderij Tous les lapins peignent une peinture	Alle tovenaars verven een deur Tous les sorciers peignent une porte
Alle kinderen bereden een olifant Tous les enfants montent un éléphant	Alle pelgrims bereden een ezel Tous les pèlerins montent un âne
Alle cowboys meppen een boer Tous les cow-boys rossent un agriculteur	Alle lijfwachten meppen een fan Tous les gardes du corps rossent un fan
Alle kleuters tikken een predikant aan Tous les enfants effleurent un vicaire	Alle huisvrouwen tikken een verkoper aan Toutes les femmes au foyer effleurent un vendeur

Appendix 3

The table below reports the sentences of all prime-target sentences used in the experiments reported in Chapter 3. The sentences are given in English, Estonian, and Dutch (in that order). In all experiments in Chapter 3, the primes and the targets were arranged in triplets: Two primes preceded each target. A list of filler trials and the visual materials are available at https://osf.io/59ezt/

Prime/target sentences
All tennis rackets are not in the squares
Kõik tennisereketid ei ole kastides
Alle tennisrackets zijn niet in de vierkanten
All the balloons are not in the squares
Kõik õhupallid ei ole kastides
Alle ballonnen zijn niet in de vierkanten
All the balls are not in the squares
Kõik pallid ei ole kastides
Alle ballen zijn niet in de vierkanten
All the bananas are not in the squares
Kõik banaanid ei ole kastides
Alle bananen zijn niet in de vierkanten
All the bikes are not in the squares
Kõik jalgrattad ei ole kastides
Alle fietsen zijn niet in de vierkanten
All the boats are not in the squares
Kõik laevad ei ole kastides
Alle boten zijn niet in de vierkanten

All the books are not in the squares Kõik raamatud ei ole kastides Alle boeken zijn niet in de vierkanten
All the buses are not in the squares Kõik bussid ei ole kastide Alle bussen zijn niet in de vierkanten
All the cactuses are not in the squares Kõik kaktused ei ole kastides Alle cactussen zijn niet in de vierkanten
All the camels are not in the squares Kõik kaamelid ei ole kastides Alle kamelen zijn niet in de vierkanten
All the cameras are not in the squares Kõik kaamerad ei ole kastides Alle camera's zijn niet in de vierkanten
All the cars are not in the squares Kõik autod ei ole kastides Alle auto's zijn niet in de vierkanten
All the cats are not in the squares Kõik kassid ei ole kastides Alle katten zijn niet in de vierkanten
All the chairs are not in the squares Kõik toolid ei ole kastides Alle stoelen zijn niet in de vierkanten
All the chickens are not in the squares Kõik kanad ei ole kastides Alle kippen zijn niet in de vierkanten
All the cows are not in the squares Kõik lehmad ei ole kastides Alle koeien zijn niet in de vierkanten
All the crowns are not in the squares Kõik kroonid ei ole kastides Alle kroontjes zijn niet in de vierkanten

All the cups are not in the squares Kõik tassid ei ole kastides Alle kopjes zijn niet in de vierkanten
All the dogs are not in the squares Kõik koerad ei ole kastides Alle honden zijn niet in de vierkanten
All the fish are not in the squares Kõik kalad ei ole kastides Alle vissen zijn niet in de vierkanten
All the forks are not in the squares Kõik kahvlid ei ole kastides Alle vorken zijn niet in de vierkanten
All the giraffes are not in the squares Kõik kaelkirjakud ei ole kastides Alle giraffes zijn niet in de vierkanten
All the glasses are not in the squares Kõik prillid ei ole kastides Alle brillen zijn niet in de vierkanten
All the guitars are not in the squares Kõik kitarrid ei ole kastides Alle gitaren zijn niet in de vierkanten
All the hammers are not in the squares Kõik haamrid ei ole kastides Alle hamers zijn niet in de vierkanten
All the hedgehogs are not in the squares Kõik siilid ei ole kastides Alle egels zijn niet in de vierkanten
All the horses are not in the squares Kõik hobused ei ole kastides Alle paarden zijn niet in de vierkanten
All the ice creams are not in the squares Kõik jäätised ei ole kastides Alle ijsjes zijn niet in de vierkanten

All the keys are not in the squares Kõik võtmed ei ole kastides Alle sleutels zijn niet in de vierkanten
All the lions are not in the squares Kõik lõvid ei ole kastides Alle leeuwen zijn niet in de vierkanten
All the mice are not in the squares Kõik hiired ei ole kastides Alle muisjes zijn niet in de vierkanten
All the microphones are not in the squares Kõik mikrofonid ei ole kastides Alle microfoons zijn niet in de vierkanten
All the motorcycles are not in the squares Kõik mootorrattad ei ole kastides Alle motorfietsen zijn niet in de vierkanten
All the muffins are not in the squares Kõik muffinid ei ole kastides Alle muffins zijn niet in de vierkanten
All the mushrooms are not in the squares Kõik seened ei ole kastides Alle paddenstoelen zijn niet in de vierkanten
All the pandas are not in the squares Kõik pandad ei ole kastides Alle panda's zijn niet in de vierkanten
All the pears are not in the squares Kõik pirnid ei ole kastides Alle peren zijn niet in de vierkanten
All the pencils are not in the squares Kõik pliiatsid ei ole kastides Alle potloden zijn niet in de vierkanten
All the phones are not in the squares Kõik telefonid ei ole kastides Alle telefoons zijn niet in de vierkanten

All the pigs are not in the squares Kõik sead ei ole kastides Alle varkens zijn niet in de vierkanten
All the pineapples are not in the squares Kõik ananassid ei ole kastides Alle ananassen zijn niet in de vierkanten
All the screws are not in the squares Kõik kruvid ei ole kastides Alle schroeven zijn niet in de vierkanten
All the sheep are not in the squares Kõik lambad ei ole kastides Alle schapen zijn niet in de vierkanten
All the ships are not in the squares Kõik laevad ei ole kastides Alle schepen zijn niet in de vierkanten
All the shoes are not in the squares Kõik kingad ei ole kastides Alle schoenen zijn niet in de vierkanten
All the socks are not in the squares Kõik sokid ei ole kastides Alle sokken zijn niet in de vierkanten
All the spoons are not in the squares Kõik lusikad ei ole kastides Alle lepels zijn niet in de vierkanten
All the T-shirts are not in the squares Kõik t-särgid ei ole kastides Alle T-shirts zijn niet in de vierkanten
All the tigers are not in the squares Kõik tiigrid ei ole kastides Alle tijgers zijn niet in de vierkanten
All the trains are not in the squares Kõik rongid ei ole kastides Alle treinen zijn niet in de vierkanten

All the trees are not in the squares Kõik puud ei ole kastides Alle bomen zijn niet in de vierkanten
All the umbrellas are not in the squares Kõik vihmavarjud ei ole kastides Alle paraplu's zijn niet in de vierkanten
All the watermelons are not in the squares Kõik arbuusid ei ole kastides Alle watermeloenen zijn niet in de vierkanten
All the rockets are not in the squares Kõik raketid ei ole kastides Alle raketten zijn niet in de vierkanten

Appendix 4

The table below reports the sentences of all prime-target sets used in the experiments reported in Chapter 4. Note that *elke* and *iedere* select a singular NP and require singular agreement, whereas *alle* selects a plural noun and requires plural agreement. Please see https://osf.io/v2w3a/ for the visual materials, a list of the filler trials, and English translations of these sentences.

Prime sentence	**Target sentence**
{Elke/Iedere/Alle} dwerg(en) achtervolgde(n) een clown	Elke leeuw achtervolgde een dierenverzorger
{Elke/Iedere/Alle} kunstenaar(s) raakte(n) een ballerina aan	Elke fee raakte een zebra aan
{Elke/Iedere/Alle} vos(sen) zag(en) een taart	Elke tuinman zag een schep
{Elke/Iedere/Alle} toerist(en) zag(en) een standbeeld	Elke gast zag een taart
{Elke/Iedere/Alle} ballerina('s) herkende(n) een cake	Elke protesteerder herkende een vlag
{Elke/Iedere/Alle} farao('s) knuppelde(n) een slaaf	Elke couwboy knuppelde een zwemmer
{Elke/Iedere/Alle} non(nen) kuste(n) een clown	Elke professor kuste een monnik
{Elke/Iedere/Alle} skiër(s) daalde(n) een berg af	Elke meisje daalde een glijbaan af
{Elke/Iedere/Alle} politicus/politici rook/roken een taart	Elke engel rook een pizza
{Elke/Iedere/Alle} klusjesman(nen) verfte(n) een reclamebord	Elke jongen verfte een muur
{Elke/Iedere/Alle} ballerina('s) daalde(n) een trap af	Elke wielrenner daalde een weg af
{Elke/Iedere/Alle} vampier(s) stak(en) een saxofonist	Elke cowboy stak een dokter
{Elke/Iedere/Alle} bij(en) droeg(en) een aardbei	Elke kok droeg een koffer
{Elke/Iedere/Alle} kind(eren) klom(men) op een ladder	Elke wandelaar klom op een heuvel
{Elke/Iedere/Alle} redder(s) wees/wezen naar een heks	Elke dokter wees naar een serveerster
{Elke/Iedere/Alle} professor(en) sloeg(en) een tiener	Elke hippie sloeg een reiziger
{Elke/Iedere/Alle} professor(en) bestrafte(n) een matroos	Elke wetenschapper bestrafte een student
{Elke/Iedere/Alle} portiers greep/grepen een koffer	Elke kok greep een bord

{Elke/Iedere/Alle} beren naderde(n) een tent	Elke kat naderde een hut
{Elke/Iedere/Alle} schooljongens bereed/bereden een eenhoorn	Elke heks reed op een koe
{Elke/Iedere/Alle} ridders volgde(n) een monnik	Elke aap volgde een kat
{Elke/Iedere/Alle} matadors kietelde(n) een detective	Elke monnik kietelde een monteur
{Elke/Iedere/Alle} kunstenaars kuste(n) een boxer	Elke serveerster kuste een soldaat
{Elke/Iedere/Alle} mieren droeg(en) een brood	Elke verhuizer droeg een doos
{Elke/Iedere/Alle} aristocraten rook/roken een ijsje	Elke detective rook een muffin
{Elke/Iedere/Alle} vissen volgde(n) een orka	Elke olifant volgde een wasbeer
{Elke/Iedere/Alle} dienstmeisjes mepte(n) een loodgieter	Elke voetballer mepte een politieman
{Elke/Iedere/Alle} Mexicanen schoot/schoten op een kan	Elke jager schoot op een bal
{Elke/Iedere/Alle} nonnen stak(en) een trol	Elke ridder stak een koningin
{Elke/Iedere/Alle} zakenvrouwen duwde(n) een trol	Elke non duwde een clown
{Elke/Iedere/Alle} koks duwde(n) een zwemmer	Elke zwemmer duwde een ballerina
{Elke/Iedere/Alle} honden achtervolgde(n) een eekhoorn	Elke beveiliger achtervolgde een schoonmaker
{Elke/Iedere/Alle} jongens bekeek/bekeken een golfer	Elke serveerster bekeek een klant
{Elke/Iedere/Alle} kunstenaar(s) kietelde(n) een matroos	Elke boef kietelde een dokter
{Elke/Iedere/Alle} dief/dieven greep/grepen een zak	Elke ridder greep een zwaard
{Elke/Iedere/Alle} bewaker(s) bekeek/bekeken een gevangene	Elk schoolmeisje bekeek een vogel
{Elke/Iedere/Alle} haai(en) viel(en) een surfer aan	Elke student viel een professor aan
{Elke/Iedere/Alle} drugsdealer(s) schoot/schoten op een beer	Elke huurmoordenaar schoot op een zwemmer
{Elke/Iedere/Alle} piraat/piraten viel(en) een schip aan	Elke gek viel een standbeeld aan
{Elke/Iedere/Alle} matroos/matrozen herkende(n) een vliegtuig	Elke zakenman herkende een krant
{Elke/Iedere/Alle} kok(s) knuppelde(n) een boef	Elke non knuppelde een ballerina
{Elke/Iedere/Alle} boef/boeven stal(en) een auto	Elke zwerver stal een bed
{Elke/Iedere/Alle} aap/apen klom(men) op een muur	Elke bergbeklimmer klom op een klif
{Elke/Iedere/Alle} astronauten raakte(n) een microfoon aan	Elk meisje raakte een drumstel aan
{Elke/Iedere/Alle} politieagent(en) bestrafte(n) een monnik	Elke engel bestrafte een monster
{Elke/Iedere/Alle} ober(s) stal(en) een handtas	Elke musicus stal een piano
{Elke/Iedere/Alle} verpleegster(s) tikte(n) een zigeuner aan	Elke non tikte een baby aan
Elk/Iedere/Alle varken(s) naderde(n) een schuur	Elke hond naderde een kasteel

{Elke/Iedere/Alle} serveerster(s) wees/wezen naar een klusjesman	Elke kabouter wees naar een brandweerman
{Elke/Iedere/Alle} konijn(en) verfde(n) een schilderij	Elke tovenaar verfde een deur
{Elke/Iedere/Alle} kind(eren) bereed/bereden een olifant	Elke pelgrim bereden een ezel
{Elke/Iedere/Alle} cowboy(s) mepte(n) een boer	Elke lijfwacht mepte een fan
{Elke/Iedere/Alle} kleuter(s) tikte(n) een predikant aan	Elke huisvrouw tikte een verkoper aan
{Elke/Iedere/Alle} konijn(en) verfde(n) een schilderij	Elke tovenaar verfde een deur
{Elke/Iedere/Alle} kind(eren) bereed/bereden een olifant	Elke pelgrim bereden een ezel
{Elke/Iedere/Alle} cowboy(s) mepte(n) een boer	Elke lijfwacht mepte een fan
{Elke/Iedere/Alle} kleuter(s) tikte(n) een predikant aan	Elke huisvrouw tikte een verkoper aan

Appendix 5

The table below reports the sentences of all prime-target sets used in the experiments reported in Chapter 5. Please see https://osf.io/v2w3a/ for the visual materials, a list of the filler trials, and English translations of these sentences.

Prime	Target
Elke kok knuppelde een boef	Elke engel rook een pizza
Elke kunstenaar kuste een bokser	Elke hippie sloeg een reiziger
Elke beer naderde een tent	Elke student viel een professor aan
Elk varken naderde een schuur	Elke lijfwacht mepte een fan
Elke cowboy mepte een boer	Elke musicus stal een piano
Elke kunstenaar kietelde een matroos	Elke verhuizer droeg een doos
Elke mier droeg een brood	Elke professor kuste een monnik
Elke vis volgde een orka	Elke huurmoordenaar beschoot een zwemmer
Elke toerist zag een standbeeld	Elke voetballer mepte een politieman
Elk konijn verfde een schilderij	Elke aap volgde een kat
Elke aap beklom een muur	Elke zwerver stal een bed
Elke Mexicaan beschoot een kan	Elke cowboy stak een arts
Elke kunstenaar raakte een ballerina aan	Elke jongen verfde een muur
Elke piraat viel een schip aan	Elke huisvrouw tikte een verkoper aan
Elke aristocraat rook een ijsje	Elke ridder stak een koningin
Elke boef greep een zak	Elke acteur sloeg een cameraman
Elke bewaker bekeek een gevangene	Elke bergbeklimmer beklom een klif
Elke jongen bekeek een golfer	Elk meisje daalde een glijbaan af
Elk dienstmeisje mepte een loodgieter	Elke tuinman zag een schep
Elke bedelaar sloeg een journalist	Elke protesteerder herkende een vlag
Elke ballerina daalde een trap af	Elke jager beschoot een bal

Prime	Target
Elke politicus rook een taart	Elke cowboy knuppelde een zwemmer
Elke redder wees naar een heks	Elke wetenschapper bestrafte een student
Elke portier greep een koffer	Elke hond naderde een kasteel
Elke professor sloeg een tiener	Elke ridder greep een zwaard
Elke farao knuppelde een slaaf	Elke gast zag een taart
Elke drugsdealer beschoot een beer	Elke pelgrim bereed een ezel
Elke zakenvrouw duwde een trol	Elke serveerster bekeek een klant
Elke ballerina herkende een taart	Elke heks bereed een koe
Elke vos zag een taart	Elke monnik kietelde een monteur
Elke verpleegster tikte een zigeuner aan	Elke engel bestrafte een monster
Elke haai viel een surfer aan	Elke zwemmer duwde een ballerina
Elk kind bereed een olifant	Elke detective rook een muffin
Elke boef stal een auto	Elke kat naderde een hut
Elke non stak een trol	Elke boef kietelde een arts
Elke kok duwde een zwemmer	Elke wandelaar beklom een heuvel
Elke matador kietelde een detective	Elke kabouter wees naar een brandweerman
Elke astronaut raakte een microfoon aan	Elke serveerste kuste een soldaat
Elke ridder volgde een monnik	Elke kok greep een bord
Elke kleuter tikte een predikant aan	Elke tovenaar verfde een deur
Elke klusjesman verfde een reclamebord	Elk meisje raakte een drumstel aan
Elke ober stal een handtas	Elke arts wees naar een serveerster
Elke serveerster wees naar een klusjesman	Elke zakenman herkende een krant
Elke matroos herkende een vliegtuig	Elke olifant volgde een wasbeer
Elk kind beklom een ladder	Elke gek viel een standbeeld aan
Elke vampier stak een saxofonist	Elke non duwde een clown
Elke jongen bereed een eenhoorn	Elke leeuw achtervolgde een dierenverzorger
Elke dwerg achtervolgde een clown	Elke fee raakte een zebra aan
Elke hond achtervoglde een eekhoorn	Elke non knuppelde een ballerina
Elke ski&eumlr daalde een berg af	Elke non tikte een baby aan
Elke professor bestrafte een matroos	Elk schoolmeisje bekeek een vogel
Elke non kuste een clown	Elke kok droeg een koffer
Elke bij droeg een aardbei	Elke wielrenner daalde een weg af
Elke politieman bestrafte een monnik	Elke beveiliger achtervolgde een schoonmaker

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Chapter 2: Data storage fact sheet

% Data Storage Fact Sheet

% Chapter 2: Monolingual and bilingual logical representations of quantificational scope.
% Author: Mieke Slim
% Date: June 2021

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Chapter 3: Data storage fact sheet

% Data Storage Fact Sheet

% Chapter 3: Are bilingual logical representations shared? Priming *all...not* in Estonian-English bilinguals.

% Author: Mieke Slim

% Date: June 2021

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Slim, M. S. Katsos, N. (in preparation). The representation of scope assignment across languages. *Pre-print available at:* https://psyarxiv.com/tv2w8/

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Chapter 4: Data storage fact sheet

% Data Storage Fact Sheet

% Chapter 4: Revisiting the logic in language: Each and every universal quantifier is alike after all.
% Author: Mieke Slim
% Date: June 2021

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Chapter 5: Data storage fact sheet

% Data Storage Fact Sheet

% Chapter 5: The role of verb meaning in logical representations

% Author: Mieke Slim

% Date: June 2021

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